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Alliance for Global Sustainability Bookseries

Sustainability in Food and Water

An Asian Perspective

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Sustainability in Food and Water

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Preface

Food and water security issues are regarded as *sine qua non* if a society wants to promote health, peace and prosperity. People who are well fed are also people with the means to change their situation. However, this is still an immense challenge for Asia especially in the global environmental perspective in the 21st century. People around the globe will be facing a combination of problems concerning both environmental as well as social changes; therefore, the policy for future food and water security has to be upgraded in an integrated and holistic way. The need to put into perspective the ever-mounting body of new information on environmental security of food and water issues in Asia beyond the boundaries of separate disciplines provided the impetus for the development of this book. It is a compilation of selected articles from two international symposiums entitled "Food and Water Sustainability in China 2007" and "Food and Water Sustainability in Asia 2008" which were held in Macau, China. Eminent scientists/researchers from different parts of Asia spoke at the symposium on topics such as the challenges in sustainable water resource management, future projection of development strategies for fisheries, increased yield of food grains by rainwater management in arid lands, multi-functional role of rice paddy area for food and water sustainability, the impact of biofuel production on food security, reclaimed wastewater for sustainable urban water use, heavy metal removal from contaminated soil and water, and adaptation strategies to cope with the climate change issues for food and water.

Sustainability of food and water is closely related and cannot be discussed without understanding their interactions and trade-off. For instance, the increase in demand for food production increases the demand for irrigation water; on the other hand, flood and drought severely hamper agriculture. It is, therefore, important to untangle the interactions and to clarify the requirements for sustainable supply and utilization of food and water. It is heartening that there are already so many initiatives to address the sustainability issues of food and water separately, and these efforts have established a rich foundation of practical, implementable models. But the scale of action so far is disappointingly small and there are no major international initiatives to address the interrelated challenges on this topic. The pathways for sustainable development in food and water need to be innovative rather than narrow technical solutions as they must work for those who are underprivileged, in areas where modern facilities may not be available, and where the climate is always unpredictable. Accordingly, this book is intended to promote synergistic ideas and pathways for the sustainable development of food and water in Asia. Solely new ideas, leading to specific new results, seem difficult for multidisciplinary-discussion. In this regard, the articles in the book were peer reviewed in a broad spectrum to stimulate a lively interdisciplinary discussion on food and water. Although not all papers represent innovative ideas readers of this book can surely benefit from some integrated fresh ideas on tackling the security concerns of food and water in the Asian perspective. The sustainability in food and water is not only regarded as a scientific exercise but also has political and socioeconomic aspects. Thus, to make a sound decision in food and water policy responding to changing political and socioeconomic needs and demands under conditions of climate change, a holistic approach is imperative.

A substantial portion of the funds used to support travel and other expenses of symposium participants and to developing this book was provided by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) Japan through Integrated Research System for Sustainability Science (IR3S), The University of Tokyo. The IR3S's mission for "Sustainability Science" is a newly emerging academic field that seeks to understand the relations among global, social, and human systems, and concomitant risks to human well-being and security. It is a problem-oriented discipline methods and visions for repairing these complex systems. We hope that this book, having a transdisciplinary wide-ranging view, will benefit both governmental and nongovernmental agencies related to the environmental management for food and water sustainability in Asian countries.

K. Fukushi, K.M. Hassan, R. Honda and A. Sumi
Editors

PART 1

Water Resources Management

Sustainable Water Resource Management in China: A Great Challenge

Z.X. Xu and J.Y. Li

Abstract With the rapid growth of population and socio-economics, progressive urbanization, and the development of agriculture and industry, the increased demand on water resources has been and will continue to be a serious problem for the sustainable development of economics in China. Available water resource is not enough in China. Overexploitation of groundwater resources, mostly to meet the irrigation demands and domestic uses, has already affected the aquifer's productivity. Water quality continues to deteriorate from south to north, from downstream to upstream. This paper gives an overview on the hydrological features, water resources availabilities, water uses, and projected future water demands in China. Adaptation of an efficient and integrated policy for water utilization and relevant conservation techniques in various water consumption sectors are suggested. Recycling of water and artificial recharge of groundwater by surface water and treated wastewater should be adapted at a larger scale. The South-North Water Transfer project is one of the suitable ways to solve the problem of the water shortage in China. Scarcity of freshwater will lead to China introducing demand-oriented water management strategy to complement or replace the existing supply-oriented water management practice in the future.

Key words: China, groundwater, surface water, sustainability, water resources

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Introduction

During the past several decades, there has been an increasing global concern on sustainable water resource management, and it is widely recognized as a major challenge to the world (Johnson and Handmer, 2002; Al-Salihi and Himmo, 2003). With the rapid development of economics and the speedy growth of population, sustainable water resource management for the increasing industrial, agricultural, and domestic purposes is becoming a critical issue in China (Liu and He, 2000). From the 1960s onward, the demand for water has increased tremendously. Of the major 600 cities in China, nearly 400 suffer from water shortage, and more than 100 cities were in a critical state of water shortage (Jiang, 2000).

With unbridled development and over-exploitation on both surface and groundwater resources, a lot of springs and wells dried up, many previous perennial rivers and streams have become intermittent or dried up, and hundreds of lakes disappeared over the past several decades. The Yellow, Huai, and Hai/Luan rivers, as well as the Baiyang marshes, which sustained Chinese civilization over 5,000 years, are under the threat of flow cessation. The streamflow in Yellow River, the second-longest river in China, has being declining due to excessive water use. The downstream dried up more than 700 km from the sea over 226 days in 1997. Besides the impact from anthropogenic activities, global warming has also put great pressure on the water supply in China. In part of the Northern China Plain, over-extraction of groundwater has even resulted in inundation by saltwater, leading to contamination of remaining freshwater supplies. It is estimated that the groundwater is being extracted several times faster than its replenishment rate. The use of water resources is approaching an unsustainable level because of increased consumption as a result of population growth, industrial development, expansion of irrigated land and the escalating uncontrolled exploitation for groundwater. In recent years, the problem associated with the increased demand for water has been further compounded by a drastic decrease in water quality, resulting from contamination by untreated industrial wastes, domestic sewage water, and agricultural fertilizers and pesticides.

This continuing shortage of water resources has become and will continue to be an important factor restricting the sustainable economic and social development in China. Based on a number of scientific papers and books related with different aspects of water resources in China, this study provides an overall overview on the water resources: the demand, possible supplies, and the assessment of available water resources in China for the future. On the basis of the examination, some sustainable measures and strategies on the possible water shortage are proposed at the end of the paper.

Study Area Description

China has an area of 9.6 million km^2, of which 33.3% is mountains, 26% plateau, 9.9% hilly areas, 18.8% basin and desert, and 12% plains. Only about 11% of the

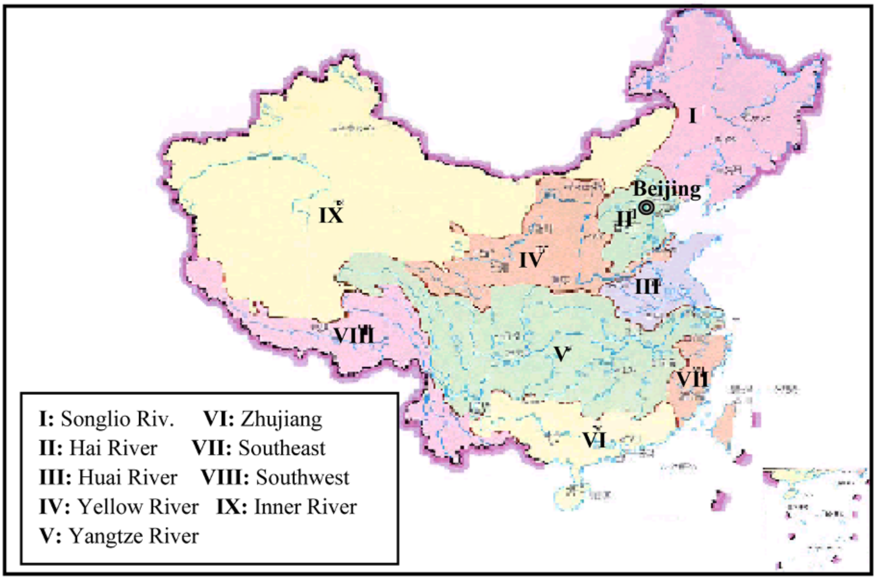

Fig. 1 Map of China showing nine basins/regions.

land area is suitable for agricultural production. According to the study made by the Ministry of Water Resources (MWR, 1999), China is divided into nine major basins/regions: Songhua/Liao River, Hai/Luan River, Huai River, Yellow River, Yangtze River, Zhujiang (Pearl) River, Southeast Region, Southwest Region, and Inland River basin, as shown in Figure 1.

The territory of China stretches over 62 longitudes from east to west, and extends over 50 latitudes from south to north across the equatorial belt, the tropics, the subtropics, the moderate temperate and the cold temperate zones. It therefore shows a diverse climate from humid tropics in the south to continental temperate climate with extreme cold winter in the north and vast desert in the west. Precipitation decreases as the monsoon releases its moisture when it moves inland, and decreases from more than 2000 mm in the southeast to less than 100 mm in the northwest annually. Northwest China is the most arid area with an annual precipitation less than 50 mm, while the Tianshan mountains region constitutes an exception with annual precipitation reaching up to 600 mm. The North China Plain and Northeast China receive annual precipitation ranging from 400 to 800 mm, with exception of the southeast coast of Liaoning Province, where annual precipitation exceeds 1000 mm. The southeastern China is dominated by the sub-humid and humid climates with evergreen broadleaf forest and locally sub-tropical rainforest. Annual precipitation is over 1000 mm and locally exceeds 2000 mm along the southern coast of Guangdong Province and the eastern coast of Hainan Island. Not only does the precipitation in China show high geographical variation, but also the precipitation greatly fluctuates from season to season, and from year to year.

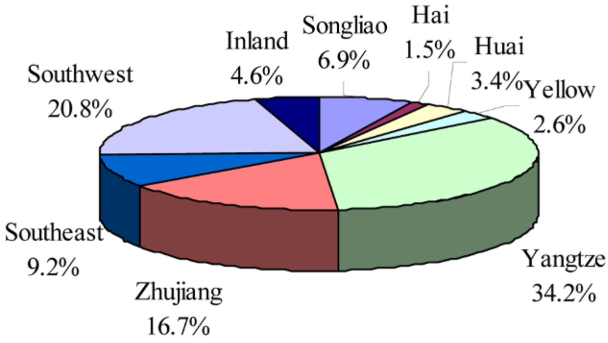

Fig. 2 Shares of water resources by different basins/regions.

Water Resource Availability

The mean value of available water resources in China is estimated at 2812.4 km^3 per year. It varies greatly in space and time, as shown in Figure 2. In terms of absolute amount, the largest water resources are located in the Yangtze River basin (961.3 km^3), and the smallest volume is found in the Hai River basin (42.1 km^3). Both account for 34.2% and 1.5% of the total amount in China, respectively. Because of the rapid population growth between the 1950s and the 1990s, especially after the 1980s, the water resources availability per capita in China has decreased over the past several decades. The average available water resource per capita is 2,220 m^3 in 1997, being less than 1.3% of that in Canada, which holds the amount of 170,000–180,000 m^3. Even in the densely populated Asia, the current water availability is within 1,200–5,000 m^3 per capita, and most of the area is richer than China. Because the water resources in China are very much uneven, even in 1993 several basins/regions such as Yellow River, Hai River, Huai River were catastrophically low, holding only 707, 343 and 487 m^3 of water resources per capita (Chen, 2000). Besides the spatial distribution of water resources, the possibilities to use water for economic developments still depend on their intra- and inter-annual variability. The temporal distribution of the river runoff in China is very uneven. For individual years, the amount of water resources may vary in a range of approximately 10–30% of their average values. During a specified year, about 50–80% of the runoff usually occurs in the period of flooding. The amounts of available water resources vary noticeably in both spatial and temporal scales. This fact further adds to difficulties for the management and use of limited water resources in China.

Due to the severe shortage of freshwater resources and despite the higher cost of the desalinated water compared with other conventional water resources, several coastal cities in China have constructed desalination plants. These facilities were constructed mainly for domestic water supply. In some developed cities, treatment plants were also constructed for wastewater treatment and this treated wastewater is then used for irrigation. Compared with other countries, especially the Middle East,

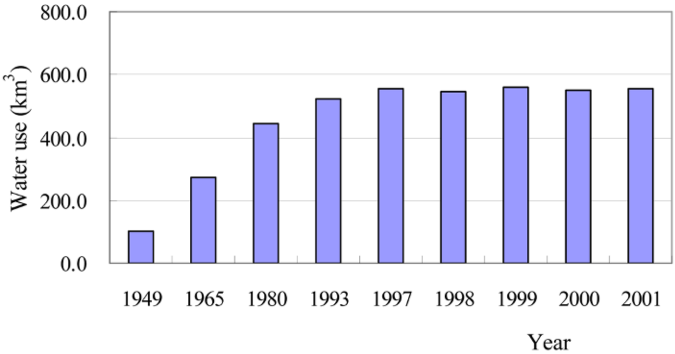

Fig. 3 The changes of water consumption in China during the past several decades.

this amount is quite small. In 1993, the total volume of produced desalinated water and treated wastewater was only 0.7 km^3, accounting for 0.1% of the total water supply. Even in 2001 this amount only reached 2.22 km^3, accounting for 0.4% of the total withdrawal.

Water Consumption

With the development of economics during the past fifty years, the amount of water consumption in China has increased drastically. Figure 3 shows the changes of water consumption in China during the past several decades. It can be seen that the amount of water use experienced a significant increase from the 1950s to the 1990s. The tendency of increase was low during the past two decades. For example, the water use in 1949 was 103 km^3, it drastically increased to 519.8 km^3 in 1993, showing an annual increase of 9%. In 2001, the amount of water withdrawal was 556.7 km^3, showing a smaller annual increase of 7.1%. In China, most of the water withdrawal – approximately 381.7 km^3 or 73.4% – was used by the agricultural sector, mainly for irrigation (66.2%) in 1993. With 90.6 km^3 (or 17.4%), industry was the second largest water user. Domestic water supply used only 47.5 km^3, approximately 9.1% of the total water consumption. In 2001, the total water consumption increased to 556.7 km^3, in which the shares by agricultural, industrial and domestic sectors changed to 68.7%, 20.5%, and 10.8%. It is noted that the share of agriculture water decreased, but both shares of industrial and domestic uses increased. In China, a relatively high percentage of the agricultural water use went to the forestry, pastures, and fishery sector (7.2% of all water use in 1993 and 6.1% in 2001).

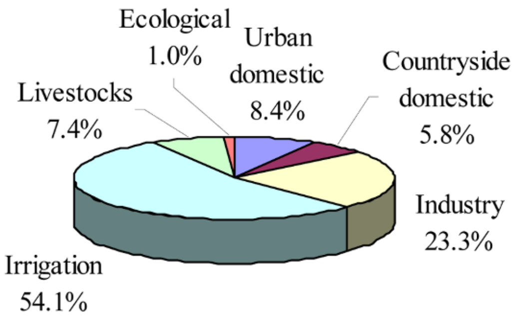

Fig. 4 Shares of water demand for different sectors in 2010.

Projected Future Water Demand

In China, most of the basins/regions have experienced a 2–10% annual increase in the domestic and industrial water demands over the last 20 years. The total water consumption in China was 556.7 km^3 in 2001 of which 382.5 km^3 were devoted for the agricultural practices including irrigation and livestock uses and 174.3 km^3 were utilized by domestic and industrial sectors. The domestic and industrial demands in China are expected to reach 251.3 km^3 by the year 2010, while the agricultural demand is expected to reach 412 km^3, bringing the total demand to 663.3 km^3 including 7.0 km^3 water for ecological uses. Figure 4 shows the projected water demand for different basins/regions, and the shares of different sectors. It is interesting to note that the share of irrigation water further decreased to 54.1% in 2010 from 62.6% in 2001.

Sustainable Water Resource Management and Strategies

The water scarcity issue will be one of the factors affecting the development of economics in China. A rational response to the possible water shortage in the future, including both strategic and tactical measures, must be made. The long-range strategic measures mainly include the development of reservoir and irrigation systems, and water conservation measures. The short-term tactical measures include emergency conservation measures, drought relief activities, and supply reallocation (Karavitis, 1998). Considering the conditions in China, the most efficient and realistic measures may include: (1) protection of water resources by a drastic decrease in water consumption, especially in irrigation use, (2) reduction or full cessation of untreated wastewater into the rivers and reservoirs, (3) efficient utilization of local water resources through seasonal and long-term streamflow regulation, (4) the use of salt and brackish waters, (5) the exploitation and use of secular water storage in lakes and deep underground aquifers, and (6) the redistribution of water resources across watersheds. In terms of the fact that the development of new reservoirs will become more difficult due to the limitations of hydrology, topography, and geology, an efficient demand-oriented water resources management strategy for the limited water resources will become more and more important.

Water conservation techniques should be implemented in various water consumption sectors with specific focus on the agriculture sector. Irrigation should increase the practices to use both drip and sprinkler systems step by step (Jin and Young, 2001). Cultivation of crops with low water demand should be encouraged. Water price reform to increase the tariff with the increase of consumption rate will be beneficial to the water conservation practice. The major challenge in water resources management in the future will not be merely to increase the water supplies, but improve the water resources management so that the factors of production including land and water are optimal and sustainable. Land use has to be considered integrally with water availability in the future. Improving the water use efficiency by cutting down losses of conveyance, evaporation and over-use and improving the agricultural yield per unit volume of water and unit area of land will be a great challenge for the water authorities in China. Water-saving should be regarded as a basic national policy. A feasible solution to the future water demand may be only through optimal utilization of the limited water resources. Protection of water resources against environmental degradation is another challenge in China. The demand-reduction, recycling and reuse measures instead of supply-augmentation measures should be paid much attention in the future.

The distribution of water resources in China is highly disproportionate throughout the country, both vast intertemporal variation and tremendous interspatial variability are significant in the distribution of water resources. The Yangtze River basin and those river basins situated in southern China yield a runoff accounting for more than 80% of the total water resources, while only less than 35% of arable area is irrigated there; on the contrary, the northern China especially the Yellow River, Huai and Hai River basins have available water resources of approximately 7.5%, while having to irrigate an area of arable land at a larger share of 39.3%. The feasible and immediate solution to this challenge may only be through inter-basin water transfer. The successful implementation of the South-North Water Transfer (SNWT) project will efficiently improve the water resources management in China. The SNWT project is under implementation and expected to be completed in nearly 20 years. Presently the SNWT project is the optimum solution to mitigate the increasing crisis of water resources in North China.

Conclusions

The amount of available water resources is not enough in China and some basins/regions have already shown water shortage. An integrated and comprehensive policy for both surface and groundwater exploitation is needed for the sustainability of the water resource development. Although there has been considerable controversy on the development of dams for decades, it seems not the case in China. Considering the local hydrological features, multipurpose dams are still necessary. Multipurpose reservoirs will be beneficial for mitigating losses resulting from both floods and droughts in the future. The conventional water planning methodology that seeks to alleviate water shortages by increasing water supplies through the development of water supply infrastructure projects should be complemented or replaced with the demand-oriented strategy through water resources allocation and the improvements on water efficiency, and alternative water uses such as wastewater reclamation and desalination. The establishment of a clear and well-defined national water policy for alleviating potential impact from water shortage will be imperative. Water price reform is necessary, in which water should be viewed as an economic commodity instead of a public good. Public awareness relating to water scarcity issues is also very important. While there are still many hurdles towards sustainable development and management of water resources in China, these can be overcome by suitable planning and policy implementation and this will be a forthcoming opportunity and a great challenge to the hydrologists and water resources managers in China.

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Affecting Factors of Salinity Intrusion in Pearl River Estuary and Sustainable Utilization of Water Resources in Pearl River Delta

Zhang Xinfeng and Deng Jiaquan

Abstract The rivers in the Pearl River Delta were seriously affected by the strong salinity intrusion and the drinking water of residents in this area was continuously threatened in recent years. To solve the salinity intrusion problem, the Pearl River Water Resources Commission (PRWRC) has organized fresh water transfers from upstream several times since 2005. Noticing the fact that the salinity intrusion in recent years is getting more active, the duration is getting longer, the affected scope is getting larger, the intensity is getting stronger, and etc, this paper analyzes the factors that affect the salinity intrusion in the Pearl River Estuary from the following aspects: the variation of upstream runoff, the change of river topography, the variation of sea level, wind and its direction, and etc. Based on the analysis, this paper proposes some measures for preventing the salinity intrusion to ensure the safety of water supply and the sustainable development of water resources.

Key words: Pearl River, salinity intrusion, sustainable water resources

Introduction

The Pearl River Delta has a large population, developed industry and high-level urbanization. With the growth of population, the quick industrialization and urbanization, the water supply demand is continuously expanding. However, due to the weak adjusting ability of local water resources, the salinity intrusion has had a serious effect on the water supply in the Pearl River Delta area in recent years. In addition, since the global warming causes the rise of sea level, the water demand in the middle and upper stream of the river basin increases, the river-bed sand dredging for construction material and the navigable channels dredging in the estuary rivers, the salinity intrusion in recent years is getting more active, the duration is getting

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longer, the affected scope is getting larger, the intensity is getting stronger. Since the autumn of 2003, the strong salinity intrusion seriously threatens the safety of the water supply in the Pearl River Delta, especially Macau and Zhuhai cities. The salinity intrusion results in serious economic loss and negative social effect to the Pearl River Delta. In order to solve the salinity intrusion problem, and protect the safety of drinking water, PRWRC organized and executed the emergent fresh water transfer project in the Pearl River Basin by transferring the upstream fresh water to the Delta to repel salt water intrusion in early 2005 and early 2006. And PRWRC implemented fresh water transfer from the upstream major reservoirs in the river basin during the dry periods of the years 2006–2007 and 2007–2008.

With the rise of global temperature and sea level, the salinity intrusion has a more serious effect on the water supply in the Pearl River Delta. So, studying the factors affecting the salinity intrusion in Pearl River Estuary and exploring the effective measures for utilizing the water resources of the whole river basin have a very important significance to ensure the sustainable development of water resources and the social stability in the Pearl River Delta.

Analysis of Factors Affecting Salinity Intrusion

In the Pearl River estuary, there are many waterways forming a rivers network. The behavior of the salt tide is mainly controlled by the upstream runoff and the downstream tidal current. When the high saline tidal water mass in the continental shelf flows into the estuary during the flood tidal period, the salt water diffuses and mixes with the fresh water coming from upstream, which makes the water in upstream rivers salty. This causes a salinity intrusion (or called salinity invasion) (Chen and Zong, 1999). When the chlorine content in the water exceeds 250 mg/l, the water quality will not meet the drinking water standard. The factors influencing the salinity intrusion in the Pearl River estuary are as follows: the river mouth shape, the rivers topography, the sea level variation, the wind and its direction, etc., in which the effect of the astronomic tide is relatively stable and periodic. The tidal current in the Pearl River estuary is irregular and semidiurnal, with two flood tides and low tides a day. Usually, on the first day and the fifteenth day of each lunar month, the water level during the flood tide period reaches maximum, and the effect of the salinity intrusion is also relatively large.

The Decrease of the Runoff from Upstream in Dry Period

The upstream runoff is an important factor influencing the salinity intrusion. The larger the fresh water amount coming from upstream is, the shorter the distance of the salinity intrusion will be and the less the effect of the salinity intrusion will be. The salinity intrusion often occurs in dry seasons. The observed data show that when the upstream runoff decreases, the salinity observed in the rivers increases, and vice versa. In recent years, the upstream runoff (the data obtained at Makou Station + Sanshui Station represents the upstream runoff of the West River and the North River, corresponding to Wuzhou Station + Shijiao Station in the upper stream, respectively) is less than 2000 m^3/s during the salinity intrusion period. Especially, the most serious salinity intrusion all happened in the spring, particularly in 1993, 1999 and 2004. The corresponding discharge was between 1500–1600 m^3/s. But in the dry period of 2002–2003, the salinity intrusion was relatively weak, the corresponding monthly upstream water amount at the Wuzhou Station and Shijiao Station were ample or partially ample.

The Topography Change of Estuary and Rivers

Since 1990s, there are more and more such human activities as dredging sand from rivers, navigation channel dredging, and so on, which leads to the riverbed level getting down in the Pearl River Estuary area and hence, makes the major tidal channels deep. According to statistics (Chen, 2005), the annual average sand amount from upstream is about 50,000,000 m^3, but in recent 15 years, the annual dredged sand amount is about 120,000,000 m^3, which means that the annual over-dredged sand amount is about 70,000,000 m^3. Due to the over-dredging year after year, the sand amount from the upstream of the Pearl River cannot supplement the dredged sand amount, which causes the riverbed to recede seriously and leads to the salinity intrusion.

The Rise of Sea Level Resulting from Global Warming

Global warming leads to the melting of polar ice, consequently, the rise of sea level. According to a study finished cooperatively by 13 organizations in Chinese Academy of Sciences in July 2003, the coastal sea level of Pearl River Delta may rise by 30 cm to 2030. If there are no prevention measures, Pearl River Delta will be intruded by more serious flood, storm tide, water logging disaster and salinity intrusion (Jiamakou Yellow River Diversion Administration Bureau, 2005). The rise of sea level accelerates the salinity intrusion to the Pearl River Estuary. By calculating the change of the distance of salinity intrusion in the estuaries of Lingdingyang Bay, Modaomen Mouth, Jitimen Mouth and Huangmao Sea under the condition that seal level rises by 0.4–1.0 m, Li Suqiong et al. reached the conclusion that when the high tide occurs in a dry period, the intrusion distance in Humen Waterway increases by 1–3 km, and the maximum is about 4 km; the maximum intrusion distance in Modaomen Waterway increases by about 3 km; the maximum intrusion distance in Huangmao Sea increases by about 5 km (Li and Da-guang, 2000).

The Effect of Wind Direction on Salinity Intrusion (Pan, 2007)

From topography, most rivers in Guangdong Province are high in northwest and low in southeast. The annual leading wind direction is eastward wind in the coastal area. Hence, the wind has a great effect on salinity intrusion. Different kinds of winds and their directions have different effects on the intrusion speed and distance for the salinity intrusion. If the wind direction is in accordance with the tide direction, the speed of salinity intrusion will be quicker and the intrusion distance is longer. But the effect of wind and its direction varies from place to place. For example, the eastward wind and northeastward wind can make the salinity intrusion disasters heavier in Tanzhou and Shenwan of Zhongshan City, and Hongwan of Zhuhai City, meanwhile, making the salinity intrusion disaster lighter in the northeast of Sanzhao of Zhuhai. The different wind directions in the different seasons can have different effects on salinity intrusion. However, the northwestward wind in winter can limit the salinity intrusion. But northeastward wind is unfavorable, which can make the salinity intrusion heavy as it may resist the tide going to the sea. This is because the flow directions of Modaomen and Hengmen waterways are both southeastward in Zhongshan City. The southeastward wind in spring can accelerate the salinity intrusion. The salinity intrusion is the most serious in March and April of each year, mainly due to the southeastward wind in the Pearl River Delta in spring.

Sustainable Utilization of Water Resources in Pearl River Delta

The salinity intrusion results from natural and human factors. The intensity of salinity intrusion is mainly controlled by the tide activity and upstream runoff. The tide activity is a natural phenomenon, which can be adjusted by human beings in a very limited degree. The reduction of the upstream runoff in recent years was caused by the global draught and upstream large water amount consumption which belongs to both human and natural factors. However, the upstream runoff can be adjusted by human beings to a certain extent. In fact, the water-holding capacity of the existing reservoirs in the upstream of the Pearl River cannot ensure the water supply of the Pearl River Delta. Some experts analyze that the water-holding amount in the upstream in winter and spring shall be 9,000,000,000 m^3, while the current water-holding amount is just 4,000,000,000 m^3. Even though regardless of the hydropower plants operations and the benefit of these enterprises, the problem of water supply cannot be solved either (Su and Luo, 2005). Prevention of the salinity intrusion and solution of the problem of water resources in the Pearl River Delta must be based on the unified dispatching and reasonable arrangement of water resources in the whole river basin.

First, according to above analysis of factors affecting the salinity intrusion, the decrease of upstream runoff in dry period has a great influence on the fresh water supply, but the runoff can be adjusted by the upstream key reservoirs to a certain extent. For the topography change of estuary and rivers, some measures can be taken, such as prohibiting from dredging river sand, limiting dredging channels, and so on, in order to prevent riverbed recession. The influencing factors, such as the rise of sea level resulted from global warming and the effect of wind and its wind direction on salinity intrusion, can be adjusted by human beings to a very limited extent, but the influence of the tide activity can be controlled by the engineering construction.

Second, a fundamental method is to construct a water-saving anti-polluting society. In recent 20 years, the demand of urban and rural water supply has increased quickly in the Pearl River Basin, especially Pearl River Delta, due to the rapid economic and social development and the quick urbanization. For example, the amount of water consumption in the Pearl River Delta increased from 950,000,000 m^3 in 1980 to 10,250,000,000 m^3 in 2000. The increase of the waste and polluted water amount and the amount of water consumption worsens the water environment of the major waterways and river networks in the Pearl River Delta further and reduces the usability of local water resources. In order to resist salinity intrusion effectively and protect the water supply in the Pearl River Delta, some effective measures must be taken to control the increase of water consumption and water pollution. In the long term, the Pearl River Basin shall construct a water-saving anti-polluting society center, establish a management system of water resources adaptable to the water rights index control by executing a reform of the water utilization system, establish an economic structural system adaptable to the carrying ability of regional water resources by adjusting the economic structure and industrial structure, and establish a hydraulic engineering system adaptable to the optimizing arrangement of water resources by constructing water resources arrangement and water-saving projects. Only by these can the efficiency and benefit of water resources utilization be increased and the sustainable development be realized.

Third, the hydraulic engineering construction shall be speeded up. The hydraulic engineering is the basis of water resources arrangement and water quantity dispatching. To solve the problem of water supply in Pearl River Basin, the hydraulic engineering construction in the basin shall be strengthened, which can adjust the upstream runoff in different seasons. At present, the developing ratio of water resources in the Pearl River is less than 18%; the total reservoir capacity just accounts for 11% of the annual runoff amount, much lower than the national level. There are no large projects which have regulating and controlling capability in the Pearl River basin, and there exists serious shortage of water. So we shall speed up the pace of the comprehensive planning of water resources in the basin and the water supply planning of cities in the Pearl River Delta, consider the safety of water supply in the basin, the Pearl River Delta, Hongkong and Macau as a whole, and adjust the geographical distribution of urban water supply. To clear the way for the construction of key hydro-projects, previous works such as the Dateng Gorge Hydro-project shall be speeded up. Meanwhile, all the cities in the Pearl River Delta shall build more water gates, pumping stations, reservoirs, water treatment plants, etc., enlarge the emergent water supply capacity, carry out the dredging, enlarging, maintaining and enforcing of the existing works, enhance the capacity of transferring and storing fresh water, and increase the guarantee of water supply.

Fourth, the function of the management organizations in the basin shall be given full attention and the unified management of water resources in the basin shall be strengthened, to realize the unified dispatching of the key reservoirs in the basin. The unified management of water resources means not only the combination of water basin management and administration regional management, but also the unified management of water resources in development, utilization, arrangement, prevention, treatment, etc. The unified management of water resources accords with the characteristics of water and adapts to the national condition. At present, we should base our planning on the existing engineering system in the Pearl River, emphasize the unified management of water resources in the whole basin, and reduce the effect of drought, saltiness and pollution by the scientific dispatching to ensure the water supply of the Pearl River Delta and hence increase the utilization rate of water resources.

Fifth, the fundamental research for the basin water resources management shall be carried out. The unified administrative law of water resources in accordance with the present situation of the Pearl River Basin shall be established as soon as possible. On the basis of the upstream runoff situation, the specific approaches of managing and dispatching water resources of the Pearl River shall be studied. The establishment of the dispatching and management procedure of the key reservoirs in the Pearl River Basin shall be speeded up to standardize the dispatching principle of the reservoirs for the flood and drought prevention. The mechanism of salinity intrusion in the Pearl River Delta shall be studied further and the pre-warning system of salinity intrusion shall be established, to provide the scientific support for preventing salinity intrusion and ensuring a reliable water supply.

Concluding Remarks

In recent years, due to successive dry seasons, the change of river topography, the rise of sea level, the effect of wind its direction, and etc. in the Pearl River estuary, the salinity intrusion becomes more serious in the Pearl River Delta. The drinking water is endangered in this area (esp. Macau, Zhuhai and Zhongshan), which has unfavorable or negative effects on the social and economic development.

It is predicted that in the future tens of years the economy of the Pearl River Delta will be increasing continually and stably. The population, the industry and urbanization will also increase. The demand of water resources will increase in both quantity and quality. Thus, the stress created from the economic development on the regional resources and environment will be even larger. Therefore, on the one hand, the measures for preventing the salinity intrusion should be put forward; and on the other hand, the sustainable utilization of water resources should be ensured to support the sustainable development of the economy and society.

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Water Resource Management in Asian Cities – Case Studies of Groundwater Management

Yatsuka Kataoka

Abstract Water resource in the Asian region is under pressure due to rapid population growth and economic development. In urban areas where population and economic activities tend to concentrate, water shortage and other water issues such as pollution problems have become constraints of sustainable future in the region. It is often pointed out that current water issues are largely caused by inadequate or insufficient management of water resources. Based on the case studies of groundwater management in two Asian cities, namely in Tianjin and Bangkok, this paper highlights some current issues of water management in Asian cities. For sustainable water use in cities, policies to maximize respective water resources shall be more encouraged.

Key words: Asian cities, groundwater management, urban water, water charge

Introduction

The Asian region witnessed significant increase in water consumption over the last century. Population growth and economic development are regarded as major factors of the increase of water consumption, and the increasing water demand has been pressured water resources in the region. The largest beneficial water use in Asia is agriculture with 80% of total water consumption in the region. On the other hand, when we consider the management of water resources in the future, the rate of increase of industrial and domesitic water demand shall be highlighted especially in urban areas where population growth and economic development are rather concentrated. In China, more than 400 among 668 cities are facing water shortage and 108 with serious water deficit, and the annual economic loss caused by such urban water supply shortage is estimated to be more than 200 billion Yuan in industrial

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production (Wang, 2006). Up to 2025, more than half the population of Asia is predicted to live in urban areas (UN, 2004) and the continious growth in population could accelerate the water shortage problem in cities. It is recognized that current water issues including water shortage largely depend on inappropriate or insufficient management of water resources, and therefore improvement of current management practices of water resources is the key for sustainable furure of water resources.

Considering the importance of sound water management experically in urban area for sustainable future of the Asian region, Institute for Global Environmental Strategies (IGES) are now conducting a research project entitled "Sustainable Water Management Policy (SWMP) in Asia" with particular focus on groundwater management issues in Asian cities. Under the research, case studies in Asian cities including Tianjin, China; Bangkok (Thailand), Bandung (Indonesia); Ho Chi Minh City (Vietnam). This paper intends to highlight some current urban water management issues based on case studies of these cities, with special focus on management issues in Tianjin and Bangkok.

Groundwater Use in Asian Cities

In principle, groundwater is a reliable, good quality and low-cost water resource for both drinking and production purposes. Many Asian cities where groundwater is available depends on groundwater in the course of the cities' development. Figure 1 shows the recent dependency of groundwater resource in total water use in SWMP case study cities. Except Bangkok where strict groundwater pumping control measures have been enforced since 1980s, the dependency of groundwater exceeds 50% of total water use.

In Bangkok, Bandung, and Ho Chi Minh City, the largest beneficial use of groundwater is industries, and agricultural use is much less as shown in Figure 2. On the other hand, in Tianjin, the agricultural sector is dominant. For the cities where industries consume more groundwater than other beneficial uses, we can see clear correlation between gross regional domestic production as shown in Figure 3.

Environmental Problems Due to Excessive Groundwater Use

Because groundwater is reliable in quality and quantity and the cost of exploitation is lower than the surface water exploitation, people tend to intensively utilize groundwater. As often the case, such intensive use takes place without proper control because groundwater use is decentralized and difficult to control. Because of uncontrolled intensive use, groundwater is often depleted and environmental problems emerge as the result, such as lowest water tables, land subsidence and salt water intrusion. For example, in Tianjin and Bangkok where groundwater use increased in the course of their development, land subsidence incidents were observed that

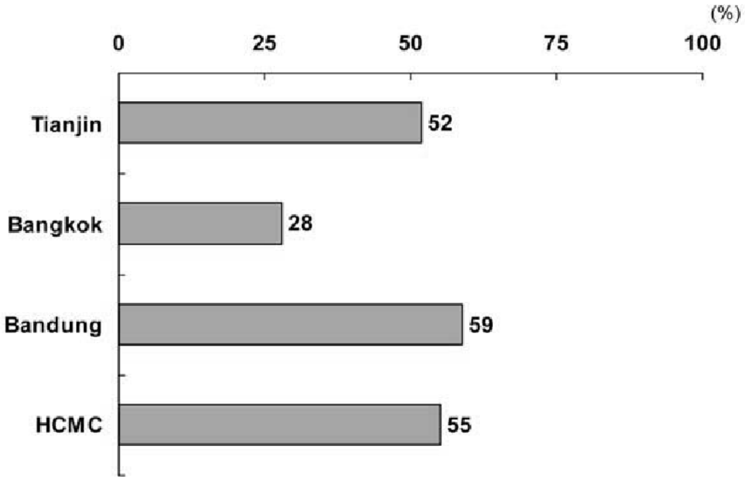


Fig. 1 Recent dependency on groundwater in Tianjin, Bangkok, Bandung, and Ho Chi Minh City.

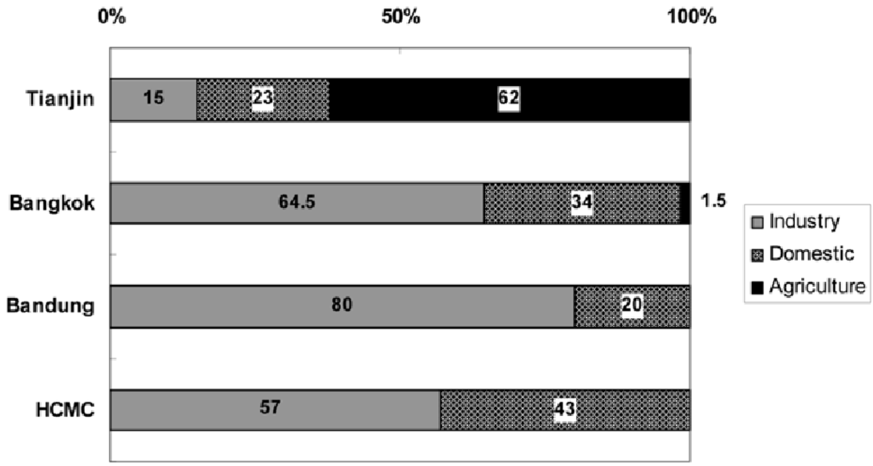
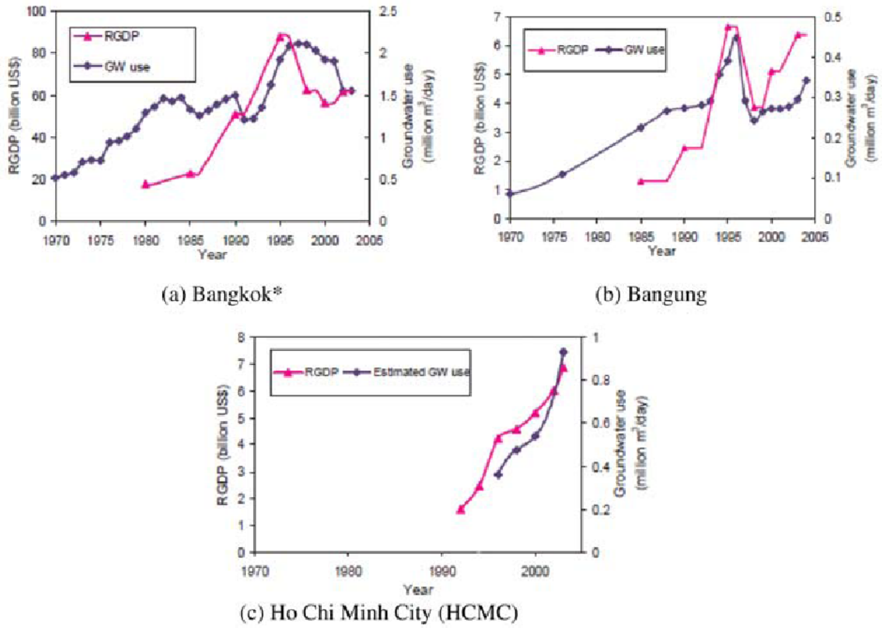


Fig. 2 Beneficial use of groundwater in SWMP case study cities.

caused damages to building infrastructure and the increase of vulnerability to flooding.

In Tianjin, the urban area was the most affected area with 119 mm of annual average of subsidence in 1981. Due to intensive measures to mitigate land subsidence in 1980, annual subsidence volume in urban areas and three districts in coastal areas decreased in 1990s, but subsidence is not completely stopped and still 20 mm/year subsidence was observed at the coastal area. For other areas of the city, groundwater use is even increasing mainly for agricultural purpose and the expansion of subsidence is suspected.



(a) Bangkok* (b) Bangung

(c) Ho Chi Minh City (HCMC)

Fig. 3 Regional GDP and groundwater abstraction. *In Bangkok, groundwater control was strengthened since 2000 and therefore correlation between RGDP and groundwater use is supposed to become weaker.

In Bangkok, land subsidence associated with salt water intrusion also became a big social problem since late 1960s. The affected area was very large and the average rate of subsidence in Bangkok City was at about 5 cm/year between 1978 and 1981, with maximum subsidence rates of more than 10 cm/year in the Eastern part of Bangkok. Due to groundwater abstraction control, the impact of land subsidence has been mitigated recently.

In Bandung and Ho Chi Minh City, severe land subsidence incidents such as those observed in Tianjin and Bangkok have not been observed yet, but water table drawdown became highlighted recently. In Bandung, the Geology Environmental Office observed the drawdown of water table in some areas. Maximum drawdown observed was 60 m from 1994 to 2004. In both cities, local governments now try to mitigate the drawdown by introduction of groundwater use control.

Groundwater Management Practices in Tianjin and Bangkok

To cope with the drawdown of water table and land subsidence, mitigation measures were introduced in case study cities. Except Ho Chi Minh City where actual control measures have not been introduced yet, groundwater control measures were introduced. The main constituents of control measures that are in common among Tianjin, Bangkok, and Bandung are regulations governing groundwater abstraction, groundwater charge, and development of other water sources that alternate groundwater. Since Tianjin and Bangkok have longer histories of mitigation measures among case study cities, this section highlights the groundwater management system and its effectiveness in these cities.

Regulations for Groundwater Use

In Tianjin, restriction of groundwater abstraction was introduced by a local administrative regulation entitled "Temporary Measures of Groundwater Management in Tianjin" in 1987. Under the regulation, all groundwater users are required to obtain permission for groundwater abstraction from a municipal authority except agricultural use. In the area designated as "land subsidence area" which included urban area, three coastal districts and the lower reaches of the Hai River, the regulation was strictly enforced and groundwater pumping was prohibited in urban areas in principle. In other areas, however, the enforcement was rather weak partly because agricultural groundwater use which was out of groundwater abstraction control was dominant.

In Bangkok, restriction of groundwater abstraction was introduced by the Groundwater Act in 1977 and under the Act, groundwater use control measures were instituted, including a licensing system for well-drilling and groundwater use. However, groundwater exploitation kept increasing and land subsidence was intensified and widespread in spite of the Act. In 1983, to strengthen the countermeasures, a cabinet resolution entitled the Mitigation of Groundwater Crisis and Land Subsidence in Bangkok Metropolis was issued. Under the resolution, critical zones were designated according to the magnitude of impact of land subsidence, and groundwater abstraction for public water supply by the Metropolitan Water Authority (MWA), which consumed about 30% of groundwater total abstraction volume in the MWA supply area, is mandated to phase out. In 2003, the Groundwater Act was amended, strengthening control measures including a strict levying system for groundwater use.

Groundwater Charge

The Groundwater Resource Charge was introduced in Tianjin in 1987 and increased in 1998. As shown in Table 1, the tariff was differentiated based on beneficial use. One of the reasons why more charges were imposed on petroleum and chemical corporations was that they consumed nearly 60% of total groundwater use in the industrial sector at that time (JICA1989). The charging system was changed in 2002 in accordance with governmental policy to promote water conservation ef-

Table 1 Groundwater resource charge in Tianjin (source: Xu and Zhang, 2006).

Year	For township enterprises (Yuan/m^3)	For petroleum and chemical corporations (Yuan/m^3)	Other Enterprises (Yuan/m^3)
1987	0.05	0.12	0.0968
1998	0.50	0.50	0.50
2002	Areas with tap water available 1.90	Areas without tap water supply 1.30	

Table 2 Groundwater charge in seven provinces in Bangkok (source: Babel and Donna, 2006).

Supply service user type	Area with public water supply	Area without public water supply
1. Domestic consumption	8.50 Baht/m^3	Exempt
2. Business		
Business not using agricultural products (proclaimed by minister) as raw material	8.50 Baht/m^3	Discount charge 75% of groundwater amount or charge with $8.50 \times 75\% = 6.375$ Baht/m^3
Business using agricultural products (proclaimed by Minister) as raw material	8.50 Baht/m^3	Discount charge 30% of groundwater amount or charge with $8.50 \times 30\% = 2.55$ Baht/m^3
3. Agriculture		
Crop cultivation	8.50 Baht/m^3	Exempt
Animal farm with groundwater use license not more than 50 m^3/day	8.50 Baht/m^3	Exempt
Animal farm with groundwater use license greater than 50 m^3/day	8.50 Baht/m^3	Discount for groundwater use >50 m^3/day charge 30% of groundwater amount or charge with $8.50 \times 30\% = 3.55$ Baht/m^3

forts. In the area with public water supply, groundwater charge increased from 0.5 to 1.90 Yuan/m^3. At the same time, water tariff of public water supply was also increased from 2.2 to 3.6 Yuan/m^3. This shows that even after the change of tariff structure, the advantage of groundwater use in terms of water user charge remains for all users. Moreover, the agricultural sector, the largest user of groundwater in the city, has been exempted from the charge since the charging system was introduced.

Bangkok introduced a groundwater charging system in 1985 in six provinces where land subsidence was intensified. The tariff was increased from 1.00 to 3.50 Baht/m^3 in 1994. At the same time, groundwater charges were introduced throughout the country. Between 2002 and 2003, the tariff increased again step by step up to 8.50 Baht/m^3 in the critical zone, seven provinces in Bangkok area. As shown in Table 2, groundwater charge is exempted or discounted for the groundwater user without public water supply. In addition to the increase of groundwater charge, groundwater preservation charge became imposed to all groundwater users in the critical zone. The usage of groundwater preservation charge is limited only for groundwater conservation purposes including research on groundwater conservation. The preservation charge was 1.00 Baht/m^3 at the initial stage and increased up to 17 Baht/m^3 step by step in 2006. By introducing the groundwater preservation charge, the cost of groundwater use in the critical zone is now higher than water provided by public water supply.

Encouragement of Using Alternative Water Sources

The regulations of groundwater abstraction and levying of groundwater charge are important components of groundwater control measures, but effectiveness of these measures depends on how the governmental sector can provide other water sources which could alternate groundwater and encourage the use of alternate water sources.

In Tianjin, water transfer from the Luan River, which is located 160 km north of Tianjin, started in 1970s and completed in 1983. The transferred volume of water from the Luan River should be 1 billion m^2 according to the Ministry of Water Resources, but the actual volume is considered to be lower. Water transfer from the Yellow River took place when the Luan River failed to supply enough water, and water supply of the urban area of Tianjin was totally shifted from Luan River to the Yellow River Basin since November 2004. The water transfer from Luan River was completed before the restriction of groundwater abstraction started in 1987; enforcement of the restriction was well implemented in the area with severe land subsidence incident. In Tianjin urban area, the abstraction volume decreased by about one-fourth between 1981 and 1990.

In addition to surface water, industrial and domestic wastewater reuse/recycling have been encouraged in Tianjin. Industrial water recycling rate in Tianjin increased from 40% in 1980s to 74% in the 1990s under the government policy to encourage water reuse and recycling in industries. Reclaimed water use for non-potable use is also promoted. For coastal area, sea water desalination is encouraged and used especially for industrial use.

Surface water provided by public water supply authority is expected to be the alternative water resources to replace groundwater use in Bangkok. However, public water supply could not be provided with enough reclaimed water to substitute for groundwater, and the delay of supply of alternative water resource caused continuous exploitation of groundwater until late 1990s. There are various interlinked reasons including but not limited to:

- Public water supply needed to depend on groundwater as its source till early 1980s to meet increasing water demands under the shortage of water source.
- Development of surface water was not implemented as planned.
- For the industries which consumed groundwater most in the city, reliability in quality and quantity of public water supply is relatively lower than groundwater use.
- Groundwater exploitation by governmental sector was exempted from groundwater charges and continued to use the groundwater until 2003 when the charging system was changed.

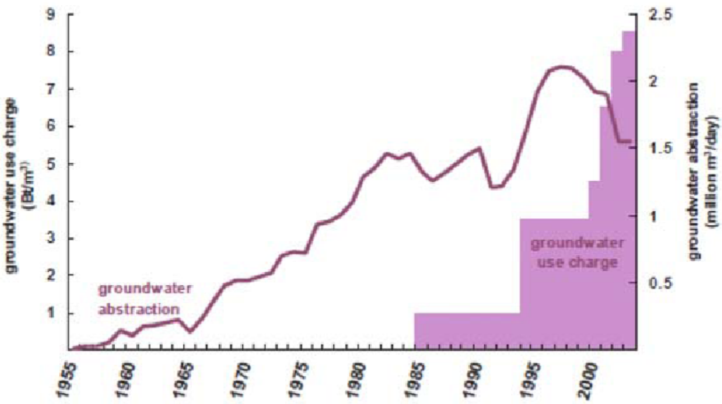


Fig. 4 Changes in groundwater abstraction volume and groundwater use charge in Bangkok.

The coverage of MWA water supply had been increasing since 1996 and now attained 100% supply to the population in the supply area according to MWA. With sufficient supply by MWA, there is no more excuse for groundwater use in the critical zone and therefore groundwater abstraction volume started dropped since late 1990s as shown in Figure 4. As described above, the groundwater charges increased and provide signal enough to encourage switching groundwater use to water supplied by a public water supply scheme. With provision of sufficient public water supply with lower charge than groundwater, groundwater abstraction volume is expected to keep decreasing.

Conclusions

Excessive groundwater use resulted in depletion of groundwater often associated with other problems such as land subsidence and salt water intrusion. To mitigate the groundwater problems, regulation of groundwater pumping and groundwater charges are useful tools to control groundwater exploitation, but the effectiveness largely depends on provision of other water resources that could substitute groundwater for large groundwater users as we see in Tianjin and Bangkok's cases. In most cities in Asia, there are not enough water resources to meet the increased demand and it is not easy to find alternative water sources since the cost to exploit of new water sources is often expensive. On the other hand, with proper management, groundwater can be used more sustainably as a very convenient resource for drinking as well as production purposes. However, as we see in Tianjin and Bangkok's cases, groundwater use is strictly prohibited once problems emerged. To maximize the benefit of groundwater, proper management shall be introduced in the area where groundwater use has not been intensified or groundwater related problems are not observed yet.

In addition, considering the increasing water demand within the limitation of water resources, urban water management shall put emphasis on encouragement of efficient use of water resources for sustainable future of both cities and water resources. Efficient use of water resources could be promoted by encouragement of such actions as rationalization of industrial water use by introducing water recycling in production process; reclaimed water use for non-potable use; mandate rainwater harvesting and/or reclaimed water use for non-portable use such as toilet flushing in the building code.

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Identification of Main Factors and Their Relationships in Urban Runoff Pollution of Macau Based on Statistical Techniques

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and Du Pengfei

Abstract In order to discover the hidden information of the urban runoff characteristics, three different statistical techniques were applied on the monitoring data of three catchments with different urban surface type in Macau. The measurement works were carried out during the rain periods from June 2005 to September 2006, and the water parameters such as pH, TSS, COD, TOC, TN, TP, Zn, Pb, and Cu was analyzed. Univariate statistical analysis, regression analysis and Principal Component Analysis were undertaken on the three catchments separately. The standard deviation (SD) for TSS, COD, TN, and TOC from YLF, ELH Park, and SXY roadway catchments is great. And the regression analysis shows the TSS has a close correlation between TN, TP, TOC or COD. Further, principal component analysis (PCA) was chosen to explain the type of pollution source and its mechanism in different urban surface type catchments, which had clarified the linkages between various pollutant parameters from urban runoff and correlations with different urban surface types. According to the above statistical analysis, it could be concluded that the structural best management practices (BMPs) such as detention basins or sediment traps would be effective in removing nutrients pollutants or oxygen demanding material in the urban runoff pollution of Macau.

Key words: Macau, management practices, urban runoff pollution

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Introduction

Macau is located on the Pearl River Delta in east south of Guangdong province, having been returned to China in December of 1999. Its area is less than 30 km^2 but a highly developed and post-urbanized city. Most of municipal wastewater in Macau was designed to be treated in three biochemical wastewater plants. But due to the 30% out-dated combined sewer pipe systems, part of municipal wastewater discharges into the receiving coastal water directly when the treatment system is overloaded. And because of the rain-rich character in Pearl River Delta, even the separated sewer pipes system will bring high urban runoff pollution to Macau coastal waters at the beginning of the rain periods.

Previous research on the characterization of urban surface runoff in Macau already shows that the commercial/residential urban catchment has a high level of COD, TN, TP, and the park urban catchment has high TN and TP concentration. Beside the major pollutant from urban roadway runoff is CODCr. Pb and SS are the other two major potential pollutants with rainfall intensity increasing (Huang Jing Liang et al., 2006). To clarify the complete data in the above results, it is necessary to relate urban runoff characteristics to land cover type by knowing specific drainage catchments with different predominate land cover (Rimer et al., 1978). Therefore, this paper will focus on the identification of major pollutants and the relationship between pollutants based on the univariate statistical analysis, regression analysis and the Principal Component Analysis (PCA).

Materials and Methods

Study Regions and Field Monitoring System

Three catchments with different characteristics in urban areas of Macau were selected. Sunyixian (SYX) roadway catchment, with an area of 3875 m^2, in which average daily traffic counts are 30000 vehicles, and the pavement is asphalt. SYX roadway is a medium-traffic site located on the south edge of Macau (Figure 1). The land-use around SYX roadway is mostly commercial and undeveloped. YaLianFang (YLF) catchment is intensively developed as residential/commercial catchments, and the percentages of impervious area are 60 with 20000 vehicles per day. There are 27000 habitants in this catchment. Erlonghou (ELH) Park catchment is just upstream of the YLF catchment. It comprised more than 70% of lawn, gardens and woods, 30% of road surfaces, tennis courts, etc. Figure 1 shows the location of the catchments studied.

Automatic monitoring stations were established at the outlet of each study catchment. Each station was equipped with an automatic event sampler (ISCO 6712) and rain gauge to grab samples and obtain rainfall during storms. Sampling was done at 5–10 min intervals in the first 60 min of storm events and then 30 min intervals

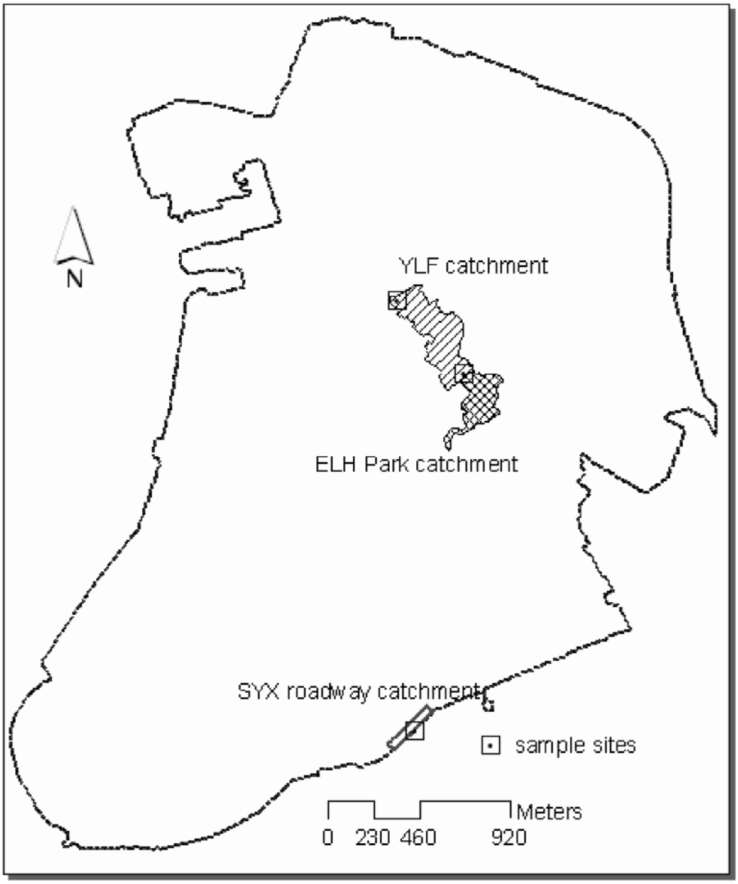

Fig. 1 Location of study catchments.

for receding flow stage. Samplings in the study catchments were carried out during the period from June 2005 to September 2006. The samples were collected and analyzed according to APHA standard methods (APHA, 1992). Water quality parameters included pH, Total suspended solid (TSS), COD_{Cr}, TOC, Total nitrogen (TN), Total phosphorus (TP), and heavy metals including Zn, Pb, and Cu.

Statistics Analysis

Because most of the runoff data has a great random variance, it is difficult to carry out monitoring and take control decisions. Analysis of the linkage among the pollutant parameters could simplify the quantity analysis and provide more evidence to select the strategies (Che, 2006). In this study, the data analyses were performed by means of the statistical software package SPSS 12.0 for Windows (2003). The univariate statistics was first to be done to calculate and display the mean and the standard deviation of each parameter, while the standard deviation is a measure of dispersion around the mean. Then the Linear Regression was used to estimate the coefficients of the linear equation, involving one or more independent variables, which show the correlations among different pollutant parameters. Besides, Multivariate technique including Principal Component Analysis (PCA), which has proved to be a viable tool to make water quality analysis (Wunderlin et al., 2001), was further done for pattern recognition. The PCA could reduce a set of raw data into a number of principal components which retain the most variance with the original data. Detail descriptions of PCA can be found in the literature (Zhang and Yang, 2002).

Results and Discussion

Statistical Results for Three Catchments

As the above description, the calculated results in each catchment would be displayed and discussed in detail. Not only to identify the particular main factors in the three catchments, but also to compare the discrimination among different urban surface type is more meaningful for further decision-making. Analysis of the storm water runoff data obtained at the automatic sampling stations permits generalized comparisons of runoff characteristics from different urban surface types. Univariate statistical analysis, regression analysis and Principal Component Analysis were carried out based on the data from June 2005 to September 2006.

YLF Catchment

Tables 1 and 2 and Figure 2 give the mean concentration and standard deviation (SD), Regression Correlations, and the PCA Bitplot of quality parameters for the YLF catchments. Due to higher percentages of impervious area, runoff from the YLF catchment exhibits higher concentration values of TSS, COD, TN and TP. The standard deviation (SD) for TSS, COD, TOC and TN reflects great uncertainties of storm water quality. From the regression table, TSS has a significant correlation with TN, COD and TP but no heavy metals including Cu, Zn and Pb. It is surmised that COD, TN, TP might be in particulate form and Cu, Zn and Pb in dissolved form. Cu, Zn and Pb correlated closely with each other. Also in Figure 2, PC1 connected with TSS, TN, COD and TP. Meanwhile, PC2 related to heavy metals including Cu, Zn, and Pb. The soil losses, nutrient and organic pollutants losses became the major pollution source instead of vehicles exhaust for YLF catchment. However, TOC has

Table 1 Univariate statistics (YLF).

Parameters	pH	TSS	Cu	Zn	Pb	COD	TOC	TP	TN
Mean	7.30	170.86	0.01	0.20	0.03	162.85	14.55	0.88	7.88
Std. deviation	0.28	394.38	0.01	0.22	0.06	246.45	24.35	0.75	7.8
Standard*	6–9	–	≤1	≤2	≤0.1	≤40	–	≤0.4	≤2

Note: standard * is Class V surface water standard developed by China SEPA.

Table 2 Regression correlations (YLF).

Parameters	pH	TSS	Cu	Zn	Pb	COD	TOC	TP	TN
pH	1								
TSS	–0.171	1							
Cu	–0.142	–0.125	1						
Zn	–0.160	0.345	0.728	1					
Pb	0.101	–0.113	0.755	0.581	1				
COD	–0.284	0.586	0.001	0.361	–0.085	1			
TOC	0.095	0.087	0.057	0.054	0.228	0.120	1		
TP	–0.124	0.479	–0.186	0.063	–0.193	0.322	0.367	1	
TN	–0.183	0.795	0.038	0.492	0.002	0.599	0.218	0.553	1

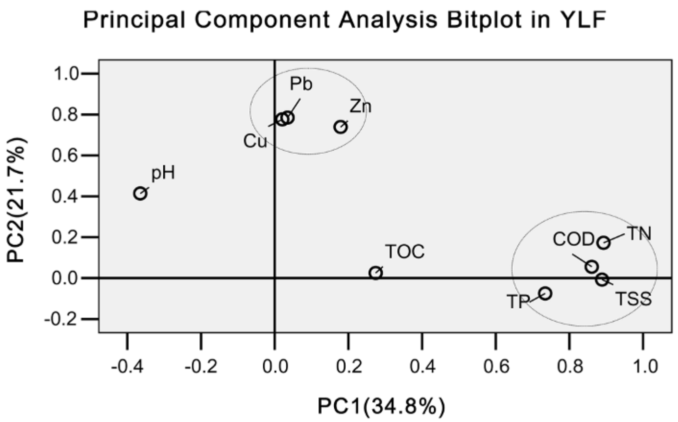

Fig. 2 Biplot for YLF catchment.

a weak correlation with PC1 and no correlation with PC2. Most TOC would be primarily in the dissolved form. As for the YLF catchment, 20000 vehicles per day might become the major source of heavy metals including Cu, Pb and Zn.

Table 3 Univariate statistics (SYX).

Parameters	pH	TSS	Cu	Zn	Pb	COD	TOC	TP	TN
Mean	7.53	417.21	0.04	0.24	0.06	114.97	17.75	0.24	3.58
Std. deviation	1.17	597.38	0.03	0.20	0.07	99.59	9.81	0.20	3.17
Standard*	6–9	–	≤1	≤2	≤0.1	≤40	–	≤0.4	≤2

Note: standard * is Class V surface water standard developed by China SEPA.

Table 4 Regression correlations (SYX).

Parameters	pH	TSS	Cu	Zn	Pb	COD	TOC	TP	TN
pH	1								
TSS	0.131	1							
Cu	–0.057	–0.223	1						
Zn	0.282	–0.009	<u>0.438</u>	1					
Pb	0.034	–0.165	0.406	<u>0.671</u>	1				
COD	–0.344	0.020	0.406	0.089	–0.124	1			
TOC	–0.142	0.081	0.326	0.059	–0.039	<u>0.416</u>	1		
TP	–0.135	<u>0.552</u>	<u>0.466</u>	0.247	0.102	<u>0.424</u>	0.159	1	
TN	–0.333	0.209	0.369	–0.001	–0.078	<u>0.497</u>	<u>0.548</u>	<u>0.441</u>	1

SYX Roadway Catchment

Major pollutants from urban roadway runoff are TSS and COD can be found in Table 3. And the TSS, TN, TP, COD and TOC closely correlated, which suggests that TN, TP, COD and TOC must be in sediment detached form. In other words, nutrients leaching and organic pollutants losses accompanied with wash off of constituents from urban roadway runoff. Few nitrogenous fertilizer used in the lawns planted in middle of the roadway is surmised to be its source. As an asphalt road, TOC in particulate form greatly depends on the vehicles activities (Sansalone and Buchberger, 1997). Figure 3 illustrates that PC1 was concerned with the heavy metals including Pb, Zn and Cu. As some researchers found that Pb, Zn, Cu and other heavy metals mainly sourced from vehicle's exhaust (Sansalone and Buchberger, 1997). Vehicles activities constitute the major sources of urban runoff, which sounds reasonable for an urban roadway with 30000 vehicles per day in Macau. In Figure 3, COD shows a slight correlation with PC2 but a medium correlation with PC1. It is understandable that the source of COD tends to be from vehicles activities. There is slight correlation between TSS and Cu, Zn and Pb. It is postulated that the heavy metals must be primarily in dissolved form. Moreover, Cu, Zn and Pb correlated closely with each other.

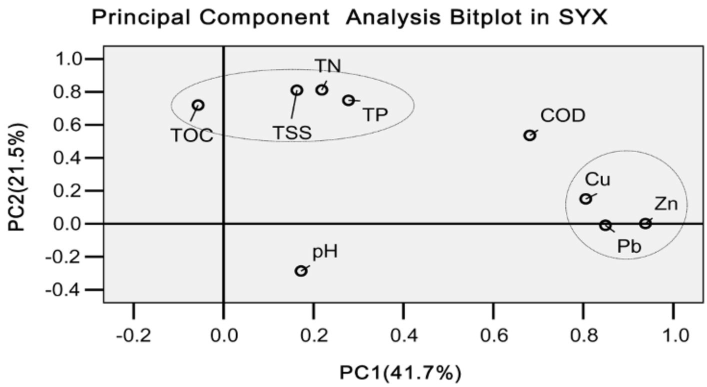

Fig. 3 Bitplot for SYX roadway catchment.

Table 5 Univariate statistics (ELH Park).

Parameters	pH	TSS	Cu	Zn	Pb	COD	TOC	TP	TN
Mean	7.27	82.80	0.02	0.12	0.10	103.06	17.19	0.55	5.26
Std. deviation	0.25	194.74	0.03	0.16	0.10	115.02	18.70	0.69	3.08
Standard*	6–9	–	≤ 1	≤ 2	≤ 0.1	≤ 40	–	≤ 0.4	≤ 2

Note: standard * is Class V surface water standard developed by China SEPA.

ELH Park Catchment

Because of the close situation, the pattern in ELH Park is similar to that of YLF catchment. The effects of usage of chemical fertilizers on the lawn and garden and soil losses during storms make TN, TSS, TP concentration high level from ELH Park urban runoff. The little difference is that for PC1 in ELH Park related closely to not COD but TOC. In ELH Park, extensive tree canopy and leaf litter can result in a high level of TOC in particulate form. TSS has a strong correlation with TN, TP, and TOC. Most TN, TP and TOC might be in particulate form. TSS did not correlate with Cu, Zn and Pb. Heavy metals including Cu, Zn and Pb might be primarily in dissolved form. PC2 connected with Cu, Pb, Zn, and pH. Heavy metals losses might not relate to soil losses, road surface in the Park may be the important influencing factor.

Discussion

According to the results by PCA in all three catchments, from a perspective of pollution source of urban runoff, two pollution sources were classified. The first one is concerned with TSS and TN, TP, TOC or COD, referred to as nutrients losses, soil

Table 6 Regression correlations (ELH Park).

Parameters	pH	TSS	Cu	Zn	Pb	COD	TOC	TP	TN
pH	1								
TSS	–0.259	1							
Cu	0.174	0.62	1						
Zn	–0.182	0.135	0.166	1					
Pb	–0.011	0.197	0.369	0.794	1				
COD	–0.344	0.487	–0.166	0.283	0.225	1			
TOC	–0.681	0.449	–0.158	0.209	0.028	0.680	1		
TP	–0.354	0.511	–0.228	0.167	0.068	0.907	0.683	1	
TN	–0.088	0.729	–0.008	0.187	0.241	0.507	0.379	0.513	1

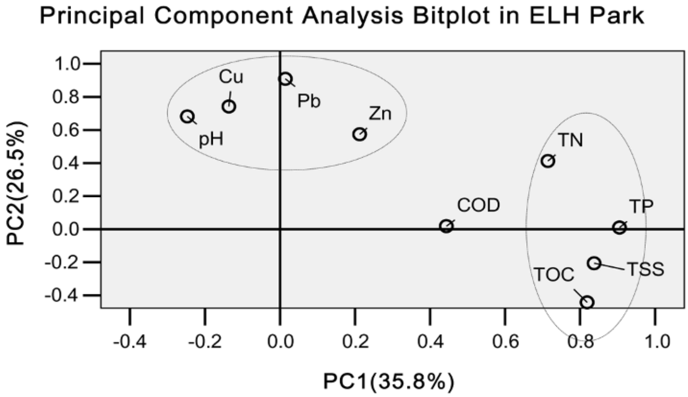

Fig. 4 Bitplot for ELH Park catchment.

losses and organic pollutants discharge, the second is related to heavy metals including Zn, Pb and Cu, referred to as heavy metals losses. Furthermore, each pollutant source underlined the important information regarding strong correlation of the quality parameters with each other, namely, TSS had close correlation between TN, TP, TOC or COD for the first pollution sources. Zn, Cu and Pb correlated closely with each other for the second pollution sources. For the first pollution source, structural best management practices such as detention basins or sediment traps would be effective in removing most of nutrients and oxygen demanding material. For the second pollution source, considering their concentration, it can be concluded that heavy metals (including Pb, Cu, Zn) losses is not a major problem for urban runoff in Macau.

Conclusions

Statistical analysis of urban runoff data enables general identification of runoff characteristics. Univariate statistical analysis and multivariate analysis (PCA) were coupled to identify the major pollutants and clarify the correlation between various pollutant parameters and different urban surface type catchments in Macau. The standard deviation (SD) for TSS, COD, TN, and TOC from YLF, ELH Park, and SXY roadway catchments is great. This makes urban runoff quality control more difficult. PCA was used as a viable tool to explain the type of pollution source and its mechanism for three different urban surface type catchments. In all the three study catchments with different urban surface type, TSS shows closely correlation with TN, TP, TOC or COD. From a management perspective, structural best management practices such as detention basins or sediment traps would be effective in removing nutrients pollutants or oxygen demanding material in the urban runoff.

Acknowledgement

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Assessment of Spatial Variations in Surface Water Quality of Kyeongan Stream, South Korea Using Multi-Variate Statistical Techniques

Janice B. Sevilla, Chang Hee Lee and Bum Yeon Lee

Abstract Kyeongan stream is one of the tributaries of the Paldang Reservoir which is the largest drinking water source in South Korea. It serves as one of the major contributors of pollution. In this study, the database obtained during the monitoring program was subjected to different multivariate statistical analyses (MVA) such as Cluster Analysis (CA) and Factor Analysis (FA) with a view to suggest a simple methodological approach for analysis and interpretation of complex data sets. Using CA, data rendered a dendrogram grouping all the monitored streams into three statistically significant clusters (high pollution, moderate pollution and low pollution regions). Through CA, it is possible to design a future spatial sampling strategy in an optimal manner through reducing the number of sampling sites and cost without losing any significance of the outcome. FA for the three data sets evolved five VFs for LP and MP regions and four VFs for HP region. The eigenvalue is greater than 1, explaining 74.24, 76.84 and 78.25% of the total variance in respective water quality data sets. This included the organic pollution group (municipal and industrial effluents), nutrients group (agricultural runoff) and EC and solids (soil leaching and runoff process).

Key words: Cluster analysis, factor analysis, multivariate analyses, water quality monitoring

Introduction

Water monitoring is one of the highest priorities in environmental protection policy (Boyacioglu, 2006). The quality of a river is identified in terms of physical, chemical and biological parameters. Rivers, in the assimilation of municipal and in-

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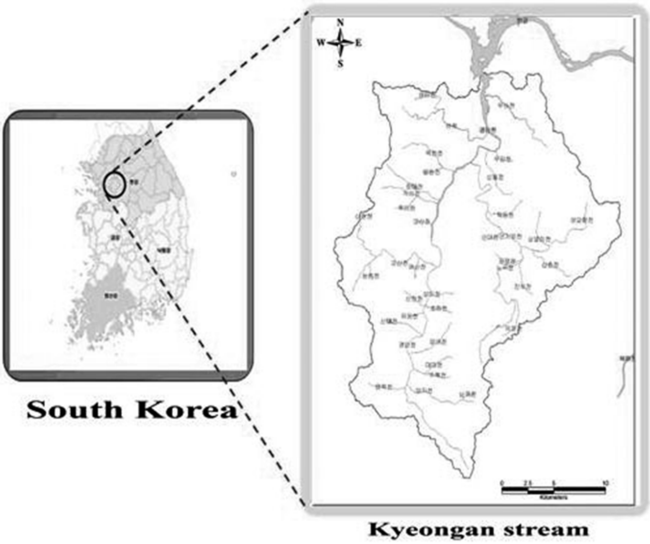

Fig. 1 Map of Gwangju City, South Korea.

dustrial wastewater and run-off from agricultural land in vast drainage basins, are among the most vulnerable water bodies to pollution. According to Saffran (2001), the major problem in the case of water quality monitoring is the complexity. This is associated with analyzing the large number of measured physicochemical parameters which are often too difficult to interpret and are not fully explored. Multivariate statistical techniques such as cluster analysis (CA) and factor analysis (FA) allow us to derive the hidden information from the data set about the possible influences of the environment on water quality through data reduction and classification. In this study, the database obtained during the monitoring program was subjected to different multivariate statistical analyses (MVA) with a view to suggest a simple methodological approach for analysis and interpretation of complex data sets, to identify pollution sources/factors affecting the river's water quality and to identify water quality parameters responsible for the spatial variations in river water quality.

Study Area

Kyeongan stream is located in Gwangju City, Gyeonggi Province (Figure 1). The total land area is about 432 km^2. Gwangju City is located away from the sea and has a relatively large amount of rainfall. Annual rainfall varies at about 1,054 to 2,204 mm and during winter only 50 mm. Average temperatures is 11 to 12.6°C. During summer the humidity ranges from 67 to 75%. The solar deflection reaches 1998 to 2366. Seoul and the surrounding regions make up half of the popultaion in

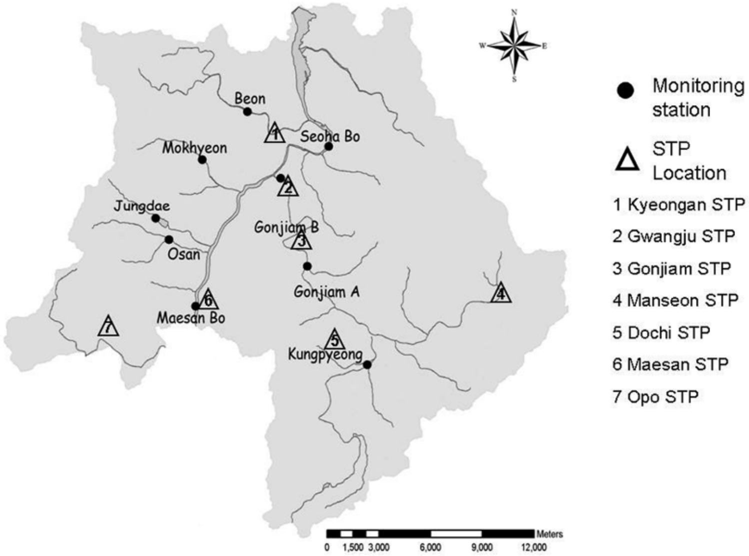

Fig. 2 Location of the monitored streams in Kyeongan stream.

Korea. Due to the dense population of the country, development has progressed in regions upsteram and the water quality of Paldang Reservoir, which is the largest drinking water source in Korea, has dropped from 1.633 ppm (BOD) in 1995 to 1.95 ppm (BOD) in 2000. Kyeongan stream is one of the tributaries of the Paldang Reservoir and serves as one of the major contributors of pollution.

The monitoring sites include nine monitored substreams shown in Figure 2. This includes Beon stream, Gonjiam A stream, Gonjiam B stream, Jungdae stream, Kungpyeong stream, Maesan Bo, Mokhyeon stream, Osan stream, and Seoha Bo. Maesan Bo and Seoha Bo were located in the mainstream. Beon stream was located in downstream of Kyeongan stream. Kungpyeong, Gonjiam A and Gonjiam B were located in upstream area.

The data sets consisted of 16 water quality parameters monitored every eight days from September 2004 to December 2006. Water quality parameters, their abbreviations and units are summarized in Table 1.

These data were used for calibration and verification of water quality model, estimation of delivery ratios of targeted pollutant, and evaluation of the relationships among water quality items and flow rates. The Kyeongan stream discharge was measured at each site using the calibrated water current meter and water temperature using mercury thermometer. All other water quality parameters were determined in the laboratory following the standard protocols (Eaton et al. 2005). Water samples were analyzed for selected water quality parameters including flowrate, water temperature, pH, electroconductivity, dissolved oxygen, 5-day biochemical oxygen demand, chemical oxygen demand, suspended solid, total nitrogen, dissolved total

Table 1 The water quality parameters, abbreviations and units.

Parameters	Abbreviations	Units
Flow rate	Q	m^3s^{-1}
Water temperature	WT	°C
pH	pH	pH units
Electrical conductivity	EC	µs cm^{-1}
Dissolved oxygen	DO	mg L^{-1}
Biochemical oxygen demand	BOD	mg L^{-1}
Chemical oxygen demand	COD	mg L^{-1}
Suspended solids	SS	mg L^{-1}
Total nitrogen	TN	mg L^{-1}
Dissolved total nitrogen	DTN	mg L^{-1}
Ammonia nitrogen	NH_4N	mg L^{-1}
Nitrate-N	NO_3N	mg L^{-1}
Total phosphorus	TP	mg L^{-1}
Dissolved total phosphorus	DTP	mg L^{-1}
Phosphate-P	PO_4P	mg L^{-1}
Chlorophyll-a	Chl-a	mg m^{-3}

nitrogen, ammonia-nitrogen, nitrate-N, total phosphorus, dissolved total phosphorus, phosphate-P, and chlorophyll-a.

Materials and Methods

Stream water quality data sets were subjected to cluster analysis (CA) and factor analysis (FA) (Singh et al., 2005). CA and FA were applied to experimental data and standardized through log-transformation. Data transformation according to Singh (2005) will minimize the influence of different units of measurement and renders the data dimensionless. All the mathematical and statistical computations were done using statistical software.

Cluster Analysis

Cluster analysis is a method for organizing objects into clusters (groups) such that objects within the same cluster have a high degree of similarity, whilst objects belonging to different clusters have a high degree of dissimilarity (San et al., 2004). It is widely used in various research fields, including biology, archaeology, computer science, and economics. This method gained popularity in health psychology research to empirically identify groups that might best benefit from medical interventions and research (Clatworthy, 2005). Cluster analysis classifies objects so that each object is similar to the others in the cluster with respect to a predetermined selection criterion. The resulting clusters of objects should then exhibit high internal (within-cluster) homogeneity and high external (between clusters) heterogeneity. The clustering technique employed followed the approach as described in Heir et al. (1995). A hierarchical procedure, which is the most common approach to give intuitive similarity relationships between any one sample and the entire data set, was used to determine the number of obvious clusters in the data. For this procedure, Euclidean distance for the similarity measure and the Ward's linkage method for clustering were used. These procedures generated a graphical output called a dendrogram (tree diagram). The graph shows the appropriate number of clusters for the dataset. On one hand, according to Acosta (2005) a matrix of optimal Euclidean distance and squared Euclidean distance values were reported to reveal the relative differences between cluster groups. The higher the values of the Euclidean distance of a cluster vis-à-vis the other clusters, the more divergent the attributes of the clusters from each other. On the other hand, Ward's method uses an analysis of variance approach to evaluate the distances between clusters in an attempt to minimize the sum of squares (SS) of any two clusters that can be formed at each step. The spatial variability of the water quality in the whole river basin was determined from CA using the linkage distance as reported $D_{\text{link}}/D_{\max}$ which represents the quotient between the linkage distances for a particular case divided by the maximal linkage distance, multiplied by 100 as a way to standardize the linkage distance represented on the *y*-axis (Singh, 2005; Shrestha and Kazama, 2006).

Factor Analysis

Factor analysis attempts to explain the correlation between the observations in terms of the underlying factors, which are not directly observable (Yu et al., 2003; Boyacioglu, 2006). The generated correlation coefficient matrix measures how well the variance of each water quality parameters can be explained by the relationship with each other. Gupta et al. (2005) and Boyacioglu (2006) stated that factor analysis has three stages:

- For all the variables a correlation matrix is suggested.
- Factors are extracted from the correlation matrix based on the correlation coefficients of the variables.
- To maximize the relationship between dome of the factors and variables, the factors are rotated.

In order to maximize the relationship between dome of the factors and variables, the factors are rotated. Factor rotation is used to facilitate interpretation by providing a simpler factor structure (Zeng and Rasmussen, 2005; Boyacioglu, 2006). Using the Varimax rotation criterion it is therefore possible to rotate the principal component analysis (PCA) axes so that they go through clusters or subgroups of the points representing the response variables and extract a new groups of variables known as varifactors (VF). Varimax procedure was used in order to achieve a "simple structure" which means producing as many loadings of near-zero and high. Factor analysis in the basic concept (Singh et al., 2005; Shrestha and Kazama, 2006) can be expressed as:

$$z_{ji} = a_{f1}f_{1i} + a_{f2}f_{2i} + a_{f3}f_{3i} + \cdots + a_{fm}f_{mi} + e_{fi}$$

where z is the measured value of a variable, a is the factor-loading, f is the factor score, e is the residual term accounting for errors or other sources of variation, i is the sample number, j is the variable number, and m is the total number of factors. Ouyang et al. (2006), in their study on assessment of seasonal variations in surface water quality, used the factor analysis technique to extract the parameters that are most important in the assessing seasonal variations of river water quality.

Results and Discussion

Cluster Analysis

Using the cluster analysis technique, data rendered a dendrogram grouping all the monitored streams. Results generated three statistically significant clusters as shown in Figure 3. Streams within the same group have similar characteristic features and natural background source types. The main stream comprising Seoha Bo and Maesan Bo and upstream Beon belong to High Pollution (HP) region. Moderate Pollution (MP) region includes Osan, Mokhyeon and Jungdae streams. Low Pollution (LP) region includes Kungpyeong, Gonjiam A and Gonjiam B streams. Through CA, it is possible to design a future spatial sampling strategy in an optimal manner through reducing the number of sampling sites and cost without losing any significance of the outcome.

Factor Analysis

Factor analysis was applied to the log-transformed (normalized) data sets of 16 variables separately for the three different spatial regions generated using CA technique (HP, MP, LP). FA were done in order to compare the compositional patterns between the analyzed water samples and to identify the factors that influence each other. The input data matrices (variables $\times$ cases) for FA were $[16 \times 270]$ for LP, MP and HP. FA for the three data sets evolved five VFs for LP and MP regions and four VFs for HP region. The eigenvalue is greater than 1, explaining 74.24, 76.84 and 78.25% of the total variance in respective water quality data sets. Table 2 presents the corresponding VFs, variable loadings and variance for the three regions.

For the data set pertaining to LP, VF1 explains 20.69% of total variance has strong negative loadings (>0.70) on Q and SS and strong positive loadings on EC and DO. It has a moderate negative loading on WT. These show the seasonal im-

Table 2 Loadings of experimental variables (16) on significant principal component for the three regions dataset.

Parameters/VFs	LP region					MP region					HP region			
	VF1	VF2	VF3	VF4	VF5	VF1	VF2	VF3	VF4	VF5	VF1	VF2	VF3	VF4
Q	-0.800976	0.081193	0.324278	-0.137091	0.04906	-0.665739	-0.028797	0.11739	-0.299071	-0.405543	0.05319	0.078253	-0.081318	0.891883
WT	-0.636589	0.032625	-0.42342	-0.014125	-0.338957	-0.618599	-0.111475	-0.546462	-0.297471	-0.233004	-0.820967	0.215756	0.054468	0.319362
pH	0.234801	0.086175	-0.087492	0.149277	-0.771433	0.13369	0.147078	-0.816424	-0.162099	-0.285166	-0.266509	0.748881	-0.121153	-0.169816
EC	0.738528	0.135939	-0.00624	0.346452	-0.152668	0.552072	-0.167804	0.122561	0.457993	0.396834	0.50091	0.261128	0.293565	-0.653441
BOD	0.281022	0.056748	-0.10054	0.809683	0.070454	0.220184	0.101317	0.001976	0.790987	0.143117	0.315762	0.799633	0.093889	0.004766
COD	-0.069037	0.225504	0.116357	0.716218	0.14024	0.017816	0.192732	-0.028149	0.850899	0.045409	0.315003	0.726766	0.178701	0.117982
TN	0.021383	0.12974	0.956971	0.010954	0.127417	0.116422	0.406172	0.030485	0.025036	0.830104	0.906524	0.226759	0.170052	0.014994
DTN	0.090229	0.08692	0.944974	-0.03689	0.134635	0.144561	0.328276	0.074369	0.020554	0.86111	0.908634	0.160447	0.206193	-0.053621
NH_4N	-0.055146	0.030285	0.063348	0.075137	0.747404	0.056713	0.088483	0.432443	0.370345	0.546129	0.852819	0.009285	0.21211	0.009714
NO_3N	0.318997	-0.018145	0.232824	0.00379	0.423711	0.045076	-0.041867	0.088601	0.125379	0.733361	0.548173	-0.02303	0.229156	0.011702
TP	-0.077791	0.942421	0.052171	0.138375	-0.025118	-0.056472	0.782141	-0.04073	0.377249	0.19281	0.149928	0.229503	0.917025	-0.022095
DTP	-0.026174	0.957952	0.129294	0.093322	-0.038318	0.029596	0.937881	-0.020875	0.064344	0.125126	0.179634	-0.010168	0.950797	-0.081017
PO_4P	0.025557	0.952243	0.03599	-0.011617	0.002732	0.044959	0.919884	0.143655	0.010818	0.140657	0.226408	-0.092656	0.90795	-0.125232
SS	-0.738042	0.091008	-0.045793	0.390547	0.018629	-0.700611	0.138841	0.051988	0.436576	0.074352	-0.143831	0.642508	-0.084656	0.622692
DO	0.785229	-0.040437	0.272214	0.060435	-0.152126	0.836453	0.128399	-0.069368	0.141214	0.008358	0.512616	0.332263	-0.289385	-0.382559
Chl-a	-0.019489	-0.066359	-0.045136	0.767016	-0.271461	0.012276	-0.187456	-0.796998	0.297072	0.091322	-0.002566	0.91348	0.036642	0.046628
Eigenvalue	3.31	3.07	2.63	1.69	1.17	5.04	2.46	1.9	1.65	1.25	5.44	3.27	2.25	1.56
% Total variance	20.69	19.22	16.42	10.57	7.34	31.48	15.35	11.91	10.29	7.81	34.03	20.43	14.04	9.75
Cum. % variance	20.69	39.91	56.33	66.9	74.24	31.48	46.83	58.74	69.03	76.84	34.03	54.46	68.5	78.25

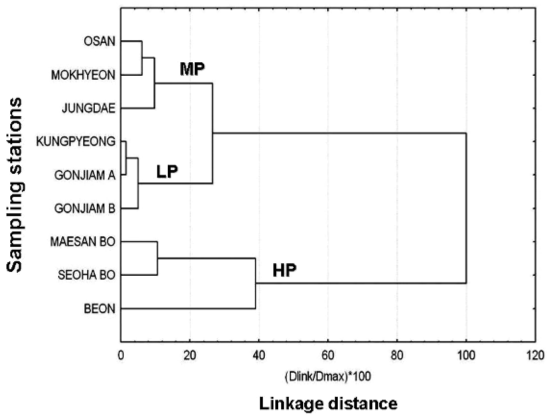

Fig. 3 Dendrogram showing clustering of sampling sites according to surface water quality characteristics of Kyeongan stream.

pact of these parameters on the river's water quality. Data shows also the inverse relationship of Q with EC as well DO with WT. This may represent the influence of high load of solids and waster disposal activities. WT on the other hand was affected by the seasonal changes. VF2 explaining 19.22% of total variance has strong positive loadings on TP, DTP and PO_4P. This group represents the effect of agricultural runoff from the low pollution region. VF3 explains 16.42% of the total variance and has strong positive loadings on TN and DTN. VF4 explains 10.57% of the total variance. It has strong positive loadings on BOD, COD and Chl-a. VF3 and VF4 basically represent the organic pollutant group usually from pollution sources from point sources such as wastewaters from domestic and industries. VF5 explains only 7.34% of the total variance. It has a strong positive loading on NH_4N and strong negative loading on pH. Due to the formation of ammonia and acids there was a decrease in measured pH (negative correlation). This group corresponds to the nutrient group from industrial activities.

For the data set pertaining to water quality in MP region, VF1 explaining 34.03% of total variance has strong positive loadings on SS and DO and moderate loadings on Q, WT and EC. The inverse relationship of EC and Q shows the dilution effect. On the other hand, DO and SS may be due to the erosion from the upland area affecting the water quality of the streams included in the MP region. High loadings on SS and WT may be due to natural processes of dissolution of soil constituents and high waste disposal activities since this VF was considered as a high solid group. VF2 explaining 15.35% of the total variance has strong positive loadings on TP, DTP and PO_4P. It is, thus, a group of high agricultural run off. VF3 explaining 11.91% of the total variance has strong negative loadings on pH and Chl-a. It has a moderate negative loading WT. VF4 explains 10.29% of the total variance. It has strong positive loadings on BOD and COD. This is a purely organic pollution indicator parameter. VF5 has the lowest percent of the total variance (7.81%). It has high positive loadings on TN, DTN and NO_3N and moderate positive loading on NH_4N. This VF possibly represents the nutrient group coming from nonpoint pollution sources.

Lastly, for the data set representing the HP region, four significant VFs were generated, VF1 explaining about 34.03% has high positive loadings on TN, DTN, and NH_4N and strong negative loading on WT. Thus, it represents the organic pollutant group. VF2 explaining 20.43% of the total variance has strong positive loadings on pH, BOD, COD, and Chl-a. It also has a moderate positive loading on SS. This also represents the organic pollutant group. COD and SS may be from the erosion experienced in the region due to the high intensity of rainfall and also COD was from decayed organic matter. VF3 has 14.04% of the total variance. It has strong positive loadings on TP, DTP, and PO_4P. This variation may be due to the pollution coming from agricultural runoff in the area. Finally, VF4 explains only about 9.75% of the total variance. It has a strong positive loading on Q. It has a moderate negative loading on EC and moderate positive loading on SS. Again here, EC and Q demonstrate the dilution effect.

Conclusions

In this study, different MVAs were used to evaluate spatial variations in surface water quality of Kyeongan stream. Hierarchical CA grouped the nine streams into three clusters of similar water quality characteristics. Based on the obtained information, it is possible to design a future, optimal sampling strategy which could reduce the number of sampling monitoring stations and associated cost.

Factor analysis helped to extract and to identify the factors and/or sources responsible for variations in the river water quality FA for the three data sets evolved five VFs for LP and MP regions and four VFs for HP region. The eigenvalue is greater than 1, explaining 74.24, 76.84 and 78.25% of the total variance in respective water quality data sets. The parameters responsible for water quality variations are mainly related to discharge and temperature (natural), organic pollution (municipal and industrial effluents) and nutrients for HP region. Additionally, major pollution sources for LP and MP regions include nutrients (non-point source: agricultural runoff, orchard, forest) and organic pollutant for MP region (domestic and industries). MVA illustrates its usefulness for the analyses and interpretation of complex data set.

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Real-Time Water Resources Analysis and Assessment for Supporting Beijing Water Sustainability

Yan Xue and Jinping Liu

Abstract Water is critical to sustainability. Beijing is located in a semiarid region and has been suffering from water resources shortage in recent decades. The per capita water resources is less than 300 m^3, which is about 1/8 of the national average and 1/30 of the world average. Meanwhile, the precipitation in the Beijing region shows its trend of decreasing since 1980s. Thus, to understand the situation of real-time water resources timely and correctly is of vital importance to achieve sustainable water resources utilization and management in Beijing. The paper introduces the current situation of water resources in Beijing and describes a technical framework of approaches of real-time water resources assessment and the analysis method of water resources amount generated by real-time rainfall events based on the theory of water balance and the distributed rainfall-runoff model with 1km x 1km grid. The advanced operational water resources analysis platform with interactive function is developed based on WebGIS and B/S structure and the application effect on the sustainability of society, economy and environment in Beijing is indicated. This technique development provided a functionalized tool for Beijing municipal decision-makers to effectively dispatch water resources and fully use the resources of urban rainfall and flood water.

Key words: Real-time analysis and assessment, sustainability, water resources

1 Introduction

Beijing is the capital city of China and has a population of more than 13 million. The city is located in the northern part of the North China Plain in a semiarid and

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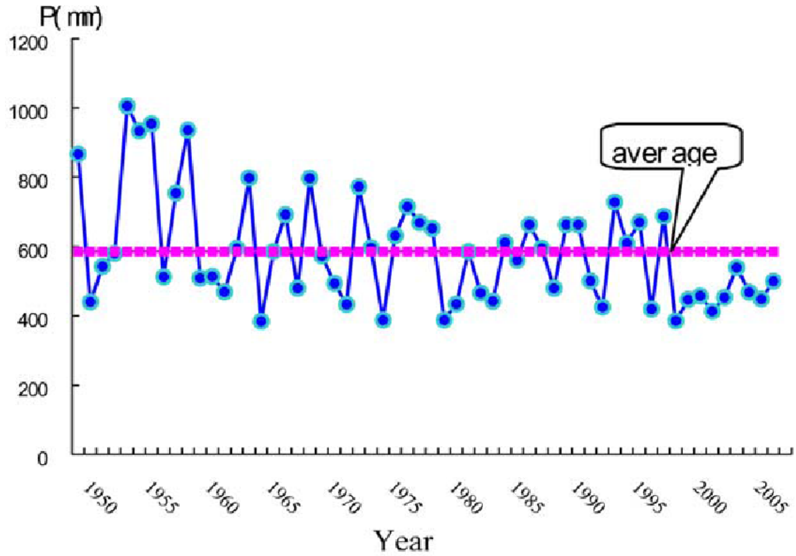

Fig. 1 The variety of the precipitation in Beijing from 1950–2007.

semihumid climate zone and has a seasonal temperate continental monsoon climate. Storms reach the city frequently during the period June to September. Average annual precipitation in Beijing is about 585 mm and is unevenly distributed, with periods of drought in spring. About 75% of the rainfall is concentrated in summer season and appears in the form of rainstorms. About 30% of annual precipitation may fall in just three days. The maximum recorded annual precipitation was 1006 mm in 1954, and a minimum of only 242 mm was recorded in 1869. Surface runoff during the flood season is 310 times higher than that during the dry season. Evaporation is about 450 mm from the land surface and 1200 mm from water surfaces. This characteristic is a great disadvantage for water resources utilization.

Beijing is located in the centre of a region of water shortage. According to observation and analysis, the multi-annual average available and feasibly exploitable water resources in Beijing is 3.74 billion m^3 per year, one third from surface water and two thirds from groundwater. Annual water use per capita in Beijing is less than 300 m^3, which is only one eighth of the average of China and one thirtieth of the world average. Since 1999 Beijing has been suffering from nine years of continual drought. The yearly average precipitation in the period from 1999 to 2007 is about 457 mm, which amounts to only 78% of normal annual average. Figure 1 shows the variety of the precipitation in Beijing region from 1950 to 2007.

In 2007, the total amount of available water resources in Beijing is about 2.38 billion m^3 which is 36% less than the multi-annual average, in which 0.76 billion m^3 from surface water and 1.62 billion m^3 from groundwater. The continual drought caused the problem of unbalance between exploiting and supplementing groundwater. At the end of 2007, the average groundwater level in the plain area of Beijing was

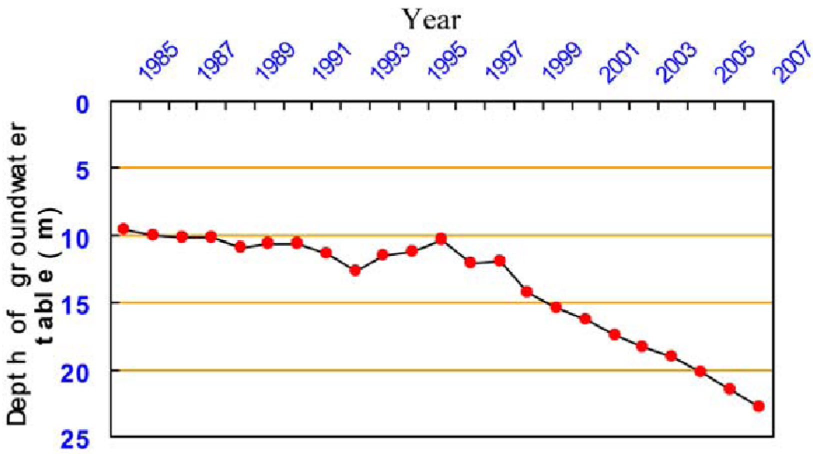

Fig. 2 The variety of underground water level in Beijing City from 1985–2007.

1.27m lower than that in the corresponding period of 2006, the storage of groundwater was 0.65 billion m^3 less than that in 2006, 7.96 billion m^3 less than that in 1980 and 10.04 billion m^3 less than that in 1960. Figure 2 illustrates the variety of groundwater level in Beijing area.

The total inflow amount of water resources into Beijing in 2007 is about 0.36 billion m^3 while total water-outflow amount from Beijing is about 0.74 billion m^3 including 0.56 billion m^3 sewerage and regenerated water. As the main surface water resources for urban water supply, Miyun and Guanting reservoirs totally stored 1.11 billion m^3 water at the end of 2007, which is 2.26 billion m^3 less than the storage in 1999. It is obvious that the water resources in Beijing are not in an advantageous position. With the rapid development of its economy, industry and agriculture, the demand for water in Beijing is increasing constantly and the problem of water shortage becomes more and more severe. The municipal government is compelled to take effective measures to control the water consumption. Up to 2007, the total water consumption in Beijing was slightly decreasing from more than 4 billion m^3 in the beginning of 2000 to about 3.48 billion m^3 in 2007, especially the water consumption for industry and agriculture while the water consumption for domesticity and environment shows a trend of increasing (Figure 3).

Statistics and analyses show that the annual average available water resources generated in recent years is about 2 billion m^3 while the annual water resources demand is about 3.5 billion m^3 at least. The conflict between water supply and water demand is very severe in Beijing. Water resources shortage is now a limiting factor that affects the sustainable development of the city. In order to solve the water resources problem, the central and municipal governments have been implementing a series of measures such as broadening its water resources, reducing water consumption, and protecting and managing the water environment effectively in a sustainable way, all of which helped the city to overcome these difficulties and ex-

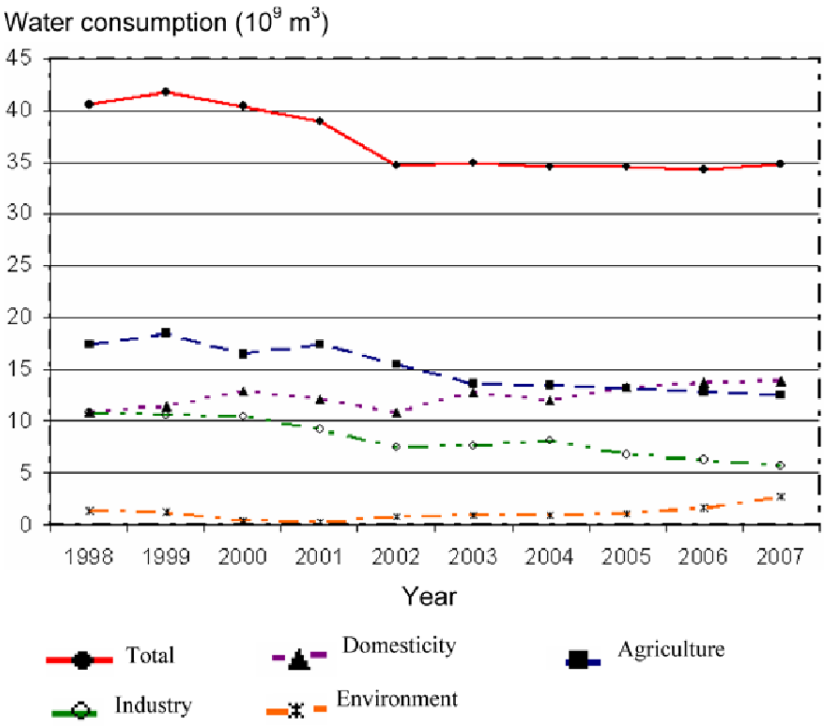

Fig. 3 The situation of water consumption in Beijing.

pedite development. Now, Beijing municipal government requires taking advantage of urban rain water and flood water as water resources to support the city's water sustainability.

2 Methods

The purpose of water resources assessment is to analyze, compute and predict the amounts of all different components of water resources generated by real-time rain events exactly and timely for scientifically dispatching water resources and utilizing rain and flood water. Real time water resources assessment for Beijing water sustainability includes individual rain-water resources assessment and continual water resources assessment. Individual rain water resources assessment intends to provide real-time daily water resources situation and/or water resources situation generated by individual rain events. Continual water resources assessment focusses on the monthly, seasonal and/or yearly water resources inventories. The major assessment factors include total precipitation, evapotranspiration, water resources inventory, surface runoff rate, infiltration, water inflow and outflow rate, surface water resources amount, groundwater replenishment amount and soil water content. The water balance equation employed in this study is the following:

$$W_{t+1} = W_t + P - E - R_s - R_g \quad (1)$$

in which W_{t+1} – soil water storage of $(t+1)$-th day; W – water storage of t-th day as initial storage of W_{t+1}; E – evapotranspiration; P – rainfall; R_s – surface runoff; R_g – underground runoff.

2.1 Water Resources Assessment Zoning

2.1.1 Rainfall-runoff Computation Grids

In order to consider the uneven rainfall distribution spatially and the difference of underlying condition in river basins and to downscale the information of runoff generation and the results of water balance analysis to the area of counties or districts even villages, the real-time water resources assessment for Beijing water sustainability is built upon distributed rainfall runoff model with 16372 grids of 1 km × 1 km.

2.1.2 Model's Parameter Calibration

According to the river system and the geographic and topographic conditions, the whole Beijing is divided into 43 sub-basins including mountain area, plain area and urban area, by using software tool AVSWAT based on the 1:250,000 DEM issued by the National Fundamental Geographic Information Center of China. Figure 4 shows the water systems and sub-basins distribution in Beijing municipal region.

Statistical and Analytical Units

In order to meet the various needs of the Administrations at all levels for information about water resources assessment, the related results of water resources assessment are provided based on three kinds of units: (1) administration districts, including 1 urban area, 4 suburban areas, 8 exurb areas and 2 counties; (2) river basins, including 5 water systems and 43 sub-basins; and (3) topographic zones, including massif area, plain area and urban area.

Fig. 4 Sub-basins for water resource assessment.

Assessment Methods for Major Factors of Water Resources

Mean Area Precipitation (MAP)

Every rainfall-runoff grid was calculated based on real-time rainfall observation data by using Thiessen Polygon method (TP) and Inverse Distance Weighting Method (IDW). The users can select the recommended computation methods or self-determined methods according to the rainfall type and the topographic zone in which the computating grid is located.

Evapotranspiration Loss (EL)

Computation was considered for raining period and non-raining period, respectively. For the raining period, EL is accounted as the capacity of evapotranspiration or calculated by experiential methods. For the non-raining period, EL in the pervious area is regarded as 0 and in the impervious area EL is calculated as

$$E = \frac{\frac{1}{2}(W_t + W_{t+1})}{W_m} \cdot E_p \tag{2}$$

in which W_m is maximum soil moisture capacity; E_p is derived from water surface evaporation measured by evaporating dish of E601 type and converting coefficient α (0.61–0.65).

Surface Runoff Generation (R)

It was determined primarily by the amount of precipitation and by infiltration characteristics related to soil type, soil moisture, antecedent rainfall, cover type, impervious surface, and surface retention. Surface runoff computation adopts runoff coefficient method ($Rs = \alpha \times P$) and the experiential correlation of $P(+Pa) \sim R$. Runoff coefficient α indicates the effect of rainfall intensity, land use and other factors to runoff generation. The experiential correlation of $P \sim R$ can be established based on historic data for mountain area, plain area and urban area, respectively.

Underground runoff generation (R_g) is supposed to have a linear correlation with soil moisture. Thus, the following equations can be deduced:

$$R_g = k \cdot W$$
$$R_g = \frac{1}{2}(W_t + W_{t+1}) \quad (3)$$

The Amount of Infiltration is defined as the portion of ground rainfall penetrated into soil. It is estimated by $I = P - E - Rs$.

The Groundwater Replenishment Amount is defined as the portion of rainfall which will be potentially returned to the groundwater. It is estimated as $R_{gp} = \beta \times P$, in which β is the groundwater replenishment coefficient.

The Temporary Soil Water Content is defined as the portion of rainfall infiltrated into soil and existing temporarily as soil evaporation or replenishment of groundwater. It is estimated by the equation $W_{ST} = \mathrm{MAX}(P - E - R_s - R_g, 0)$.

The Water Resources Inventory generated by individual rainfall process consists of surface runoff and groundwater replenishment. It is estimated by $W = R_{s1} + R_{s2} + R_{s3} + R_{g1} + R_{g2} + R_{g3}$, in which R_{s1} and R_{g1} expresses surface runoff and groundwater runoff in massif area, respectively, R_{s2} and R_{g2} expresses surface runoff and groundwater runoff in plain area, respectively, while R_{s3} and R_{g3} expresses surface runoff and groundwater runoff in urban area, respectively. Table 1 lists the components of water resources inventory in three different areas.

Application

There are four major parameters used in the real-time water resources assessment in Beijing. The parameters calibration adopts the automatic optimizing method combined with the manual adjustment method. An objective function is used in the automatic optimizing. The calibrated model's parameters are listed in Table 2.

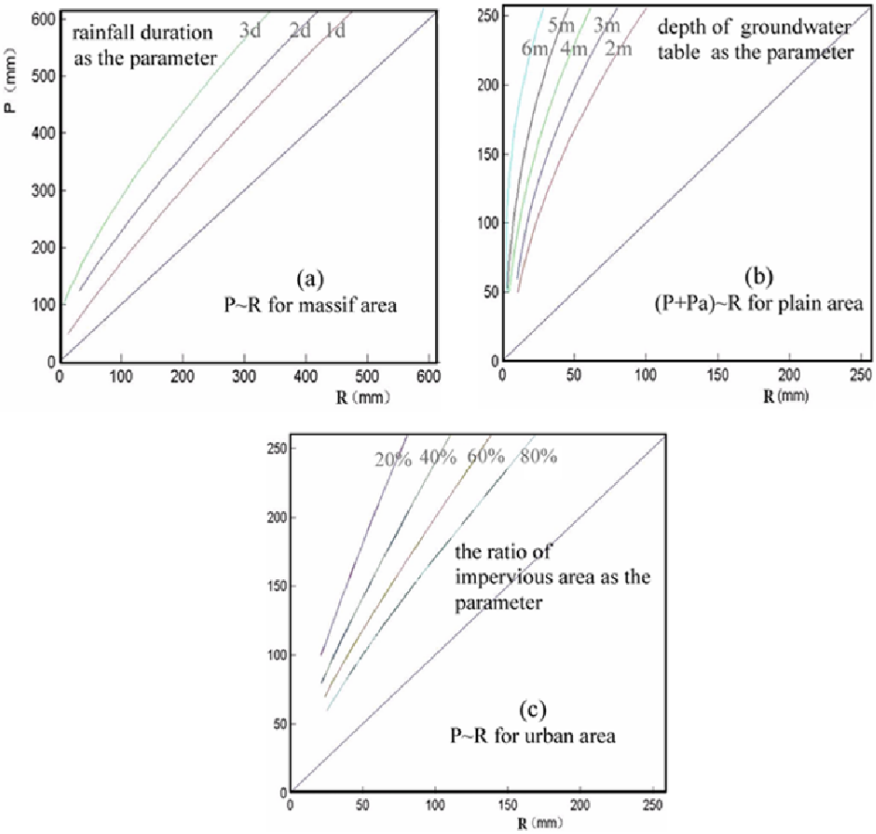

Fig. 5 The experiential correlation of $P \sim R$ for runoff generation computation in Beijing.

Table 1 The components of water resources in different zones.

Zone	Amount of surface water resources	Groundwater resources	Water resources inventory
Massif area	R_{s1}	R_{g1}	$R_{s1}+R_{g1}$
Plain area	R_{s2}	R_{g2}	$R_{s2}+R_{g2}$
Urban area	R_{s3}	R_{g3}	$R_{s3}+R_{g3}$
Total summation:	$R_{s1}+R_{s2}+R_{s3}$	$R_{g1}+R_{g2}+R_{g3}$	$R_{s1}+R_{s2}+R_{s3}+R_{g1}+R_{g2}+R_{g3}$

An operational real-time water resources assessment system with B/S structure is established based on WebGIS space analysis technology. This operation system built up a platform for integrated water resources assessment coping with flood control. The characteristics for interactive, operable, visible and flexible enable the water resources assessment to be implemented easily. Figure 6 shows the real-time distribution of precipitation and surface runoff in the period of 10–11 July 2004.

Table 2 The calibrated model's parameters for the real-time water resources assessment.

Parameters	Massif area	Urban area	Plain area
Maximum soil moisture capacity	130 mm	140 mm	120 mm
Groundwater storage coefficient	0.0216	0.0180	0.0201
Groundwater replenishment coefficient	0.25	0.25	0.25
Rainfall runoff interception	30 mm	12 mm	15 mm

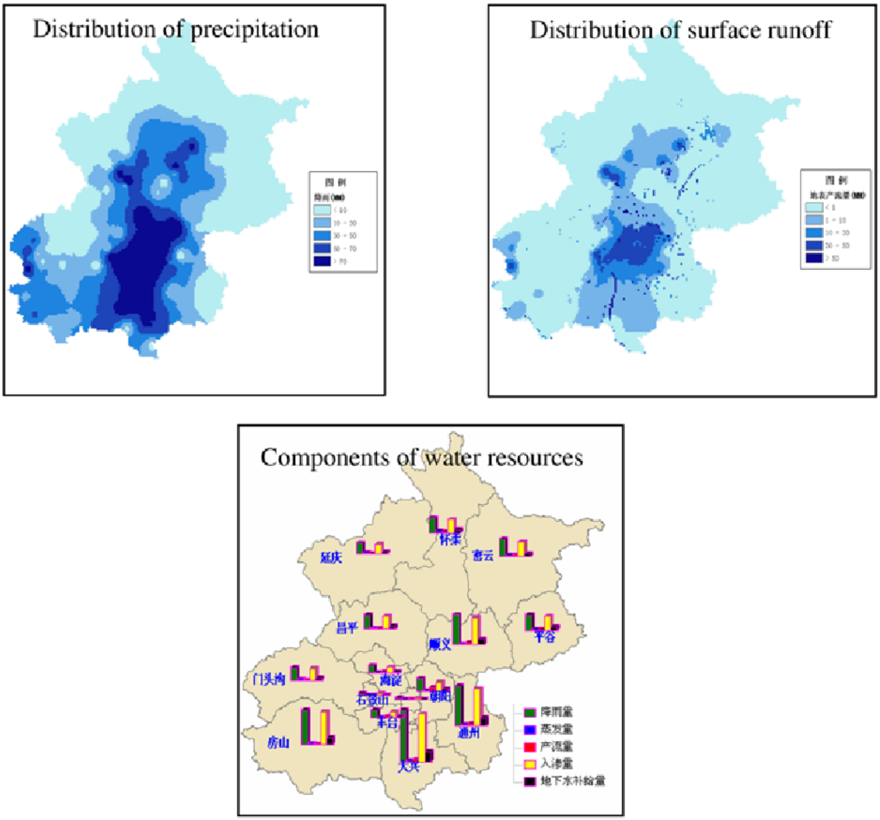

Fig. 6 Displaying of water resources assessment in the period of 10–11 July 2004.

For example, the results of continual water resources assessment for the rainy year of 1998, the normal year of 2004 and the low-water year of 2005 are listed in Table 3, and the results of individual water resources assessment for the rain event in the period of 10–11 July 2004 are listed in Table 4.

Table 3 Results of continual water resources assessment in the years 1998, 2004 and 2005.

		Water resources inventory (10^4 m^3)		Surface water resources (10^4 m^3)		Groundwater resources (10^4 m^3)		
Year	Rainfall (mm)	Esti-mated	Issued by gov't	Esti-mated	Issued by gov't	Esti-mated	Issued by gov't	Note
1998	686	39.02	37.70	14.32	13.33	24.71	25.43	rainy year
2004	539	21.66	21.35	7.23	5.88	14.43	15.47	normal year
2005	468	16.96	17.77	4.54	4.1	12.41	13.67	low-water year

Table 4 Assessment result of water resources generated by individual rainstorms during 10–11 July 2004.

Zoning	Region	Area (km^2)	Rainfall (mm)	Volume of rainfall (10^4 m^3)	Volume of evapo-transpiration (10^4 m^3)	Volume of runoff (10^4 m^3)	Volume of infiltration (10^4 m^3)	Volume of groundwater replenishment (10^4 m^3)	Volume of soil water content (10^4 m^3)
by district	4 urban districts	89	67	600	10	248	342	120	222
	Chao Yang	453	49	2219	44	784	1392	444	948
	Feng Tai	312	52	1636	34	464	1139	327	811
	Shi Jing Shan	84	52	438	9	143	286	88	199
	Hai Dian	426	41	1745	38	597	1111	349	762
	Men Tou Gou	1430	15	2183	97	247	1839	437	1403
	Fang Shan	2001	27	5343	171	374	4798	1069	3729
	Tong Zhou	898	12	1071	49	65	959	214	745
	Shun Yi	1020	20	2026	68	169	1790	405	1385
	Chang Ping	1348	28	3795	111	609	3077	759	2318
	Da Xing	1044	37	3884	95	495	3296	777	2519
	Huai Rou	2121	15	3197	136	525	2547	639	1907
	Ping Gu	925	1	87	37	3	53	17	36
	Mi Yun	2224	6	1353	111	193	1064	271	793
	Yan Qin	1978	8	1486	109	44	1335	297	1038
by river basin	Chao Bai river	5499	11	6008	317	852	4867	1202	3665
	Ji Yun river	1274	3	325	54	5	272	65	207
	Yong Dian river	3178	17	5499	215	725	4562	1100	3462
	Bei Yun river	4255	32	13459	349	2883	10231	2692	7540
	Da Qing river	2147	27	5784	183	495	5106	1157	3949
by landform	Urban area	1225	51	6190	122	2132	3937	1238	2699
	Plain area	5009	25	12643	369	1417	10867	2529	8338
	Massif area	10119	12	12226	627	1410	10220	2445	7775
Total	Whole Beijing	16353	19	31059	1118	4959	25024	6212	18812

Conclusions

Water resources shortage is a limitation factor to development of economy, industry and agriculture in Beijing. Timely and exact water resources assessment is vitally important for water sustainability in Beijing metropolis. The study on real-time individual and continual water resources assessment may provide a scientific foundation for effective management of water resources and water sustainability in Beijing.

The study established the technical framework of real-time water resources assessment based on the distributed rainfall-runoff model with 1 km $\times$ 1 km grid and the theory of individual rain water balance. This new method with the characteristics of practicability and celerity provided an approach for water resources assessment of discretionary period in real time. The results of assessment have been widely used in the decision-making of water resources utilization, protection and management in Beijing municipal government.

The short-term water resources analysis and assessment in real time is a tough puzzle as well as an imperative demand in practice. It lacks a proven matured and operational technique and methodology at present because water resources assessment has to be done in a time scale of monthly or yearly range. Some estimated parameters are applied in this study due to the lack of hydrological experimental data. There are some technical issues that need further studying.

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A GIS-Based Bio-Economic Model Applied in Water Resource Management in Shiyang River Basin, Gansu Province, China

Minjun Shi, Weichun Tao and Xuetao Zhao

Abstract This paper focuses on the application of a GIS-based bio-economic model (GBEM) in water management in the case of Shiyang River basin, Gansu Province. By integrating analysis at household level and river basin level, GBEM can provide an analytical tool and insight to optimization of spatial allocation of water resource and its effects on tradeoff between economic goals and ecological goals. Especially in spatially heterogeneous river basin, spatial allocation of water resource is very important to raise water productivity in water management. According to the Rehabilitation Plan of Shiyang River Basin, after reduction of agricultural water use for environmental rehabilitation, even if combined measures were implemented, including extension of water-saving technologies and solar greenhouse and increase in off-farm employment opportunities, farmers' income in Minqin cannot rise to the level before. Reallocation of water resource based on water use efficiency may raise water productivity at the river basin level. With compensation from the gainer to the loser, both Minqin and Liangzhou may realize an increase in farmers' income. Therefore, reallocation of water resource with compensation may promote simultaneously environmental rehabilitation and improvement of farm income.

Key words: Environmental rehabilitation, GIS-based bio-economic model, Shiyang River basin, spatial allocation of water resource

Introduction

Persistent increasing water demand with population growth and economic development has caused overuse of water resources in arid areas of northwestern China.

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Land degradation and desertification induced by overuse of water resources have become a serious environmental problem (Yang et al., 2002). The water table declined so much that a large funnel of ground water has shaped accompanied by a rapid rise of ground water mineralization and soil salinization. As the result, land salinization and abandoning was accelerated (Tang et al., 2004; Liu et al., 2005; Ma et al., 2006). Ecological restoration brooked no decay. As agricultural activities consumed the most of the water resources (Evans et al. 2003), it is most important to reduce the agricultural water use for achieving the restoration goal (Sun, 2004). While farmers earn their living mainly on agricultural activities, a dilemma appears how to trade off farmers' welfare and ecological security (Bao and Fang, 2006). Water-saving technologies, off-farm employment opportunity and solar greenhouse are considered as important measures to enhance the efficiency of water use and farmers' income (Li, 2002; Zhou, 2002; Yang et al., 2002; Liu et al., 2004). Due to the huge spatial heterogeneity in river basins of arid areas, it is recognized that water allocation is important to raising water productivity at basin level. For analysis of water allocation in a spatially heterogeneous basin, this paper developed a GIS-based Bio-economic model (GBEM) to simulate how water allocation may raise water productivity at basin level.

Study Site

Agricultural Development and Ecological Degradation in Shiyang River

The Shiyang River basin lies in the east of Hexi corridor. The annual precipitation is 50–600 mm, decreasing from south to north, together with a much higher evaporation which is almost more than 2,600 mm in the north. Mainly supplied by melt water of glacier and precipitation in the Qilian Mt. area, the runoff is relatively steady with a mean annual inflow of $1{,}560 \times 10^6$ m^3, used in Wuwei oasis which lies in the upper reaches, then gathered to become the Shiyang River down to Minqin oasis and depleted. The water resources combined with abundant sunlight and rich land resources has contributed to the development of agriculture and elevated the oasis to the role of the most important grain production base in Gansu.

Since 1950s, with the improving of facilities, the irrigated area increased by 30% and grain output increased by 45% in the past decades. In Liangzhou the main body of Wuwei oasis, the developing speed is much more rapid than that in Minqin which lies in the lower reaches (Figures 1 and 2). The total sowing area in Liangzhou has increased from 80×10^3 ha to 118.7×10^3 ha accompanied with a relative steady grain crops sowing area. While grain production kept increasing from 100×10^3 t to 630×10^3 t, and accounted for 66% of the total production of the river basin, three times higher than that in Minqin. In 2006, the grain production per capita in Liangzhou was about 1,320 kg, 1.3 times higher than that in Minqin. The net sale of wheat per capita reached 668 kg, 1.8 times higher than that in Minqin. The expansion of the sowing area resulted in a sharp increase in the amount of water use.

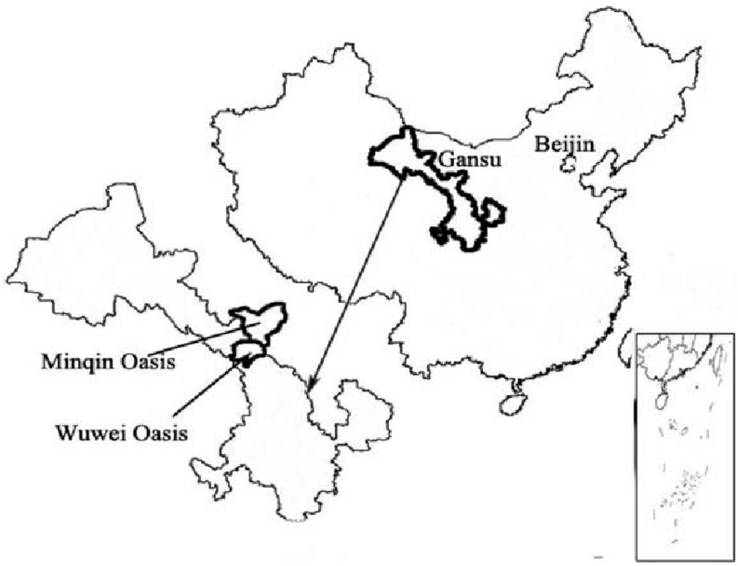

Fig. 1 Map of Shiyang River basin, Gansu Province, China.

The total amount of water use increased from 0.57×10^9 m^3 in 1950s to 1×10^9 m^3 in 2003. In Wuwei oasis, people consumed almost 80% of the total water resources in the river basin. The runoff down to Minqin decreased badly from 0.5×10^9 m^3 in 1950s to 0.1×10^9 m^3 now.

Accompanied by the decrease in runoff, the agriculture in Minqin developed rapidly, resulting in a severe situation in water scarcity. Since 1950s, there was a relative steady total sowing area with a little decrease in grain crop area, while the total grain production increased from 40×10^3 t to 180×10^3 t (Figure 2). It is clear that the increase in grain yield calls for an increase in water consumption. Consequently, the gap between water use and water supply was enlarged more and more followed by an increase in ground water mining to fill up the gap. In the last 30 years, the amount of pumped well has increased rapidly to 7,000 and overexploited ground water at 0.296×10^9 m^3/a.

As a result, ecological system deteriorated severely. The water table declined from 0–1 m in the 1970s to 18–30 m nowadays, and reached 35 m at the deepest point (Tang et al., 2004; Ma et al., 2006). A funnel about 1,000 km^2 of ground water has shaped. The mineralization of ground water rise at 0.12–16 g/l annually. The deterioration of ground water quality has made it unsuitable for drinking and aggravated soil salinization (Tang et al., 2004). The salinization area increased by 6,700 ha annually, and the area of arable land abandoned in north of Minqin reached 40,000 ha (Liu et al., 2005). A lot of trees died at the edge of oasis. The ecological restoration is urgent.

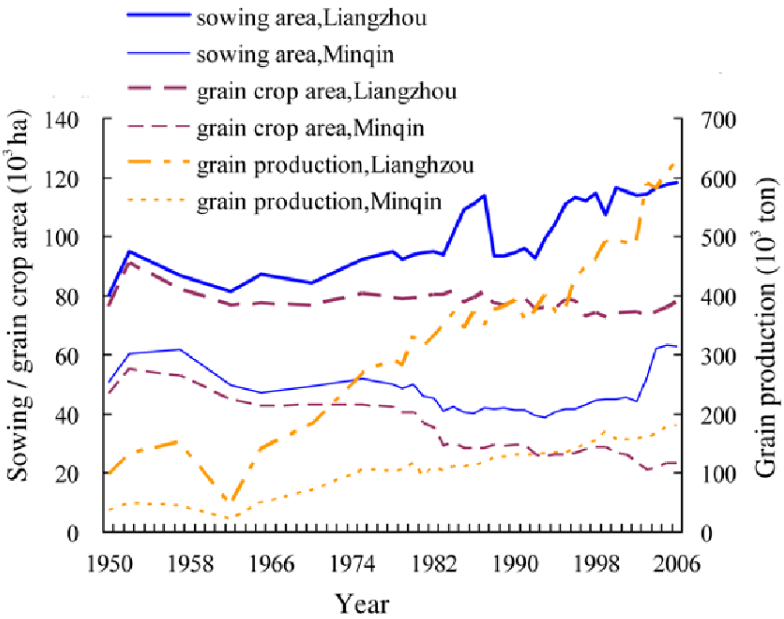

Fig. 2 Agriculture in Liangzhou and Minqin.

Measures of Environmental Rehabilitation

The ecological degradation directly resulted from the over mining of ground water which brought an increase in water consumption, while in reality it was caused by the problem that the agricultural development both in upper and lower streams. First, reduction of total water consumption should be taken into account in environmental rehabilitation. Especially, the over mining of ground water in Minqin should be effectively restrained.

Second, it needs to raise efficiency of water use through expansion of water-saving technologies including border irrigation, pipe and drip irrigation, and solar green house. Raising water use efficiency may help to mitigate negative effects of reducing water on farm income. Whether farmers adopt such measures or not depends on their cost/benefit ratios (Table 1). For border irrigation, the input of a labor force is needed rather than assets investment and the variable run cost followed by a relative low water-saving efficiency. Pipe irrigation and drip irrigation may save water much more effectively, but it generated much higher fixed and variable costs. Solar greenhouse is quite different in that the highest water-saving efficiency is not attributed by the lowest water consumption but by the highest water productivity, although either fixed cost or variable cost of it is highest (Yang et al., 2005; Ma et al., 2006). Off-farm employment opportunity is one of the important ways to reduce the water stress. Currently, the employment rate is 17% in Minqin, 20–25% in Liangzhou, slightly lower than the average level of Gansu province (25%). It may

Table 1 Cost of water-saving technologies and solar greenhouse.

Item	Unit	Border irrigation	Pipe irrigation	Drip irrigation	Solar greenhouse
Water saving effects	%	10	10–20	30–40	50
Fixed invest	yuan/ha	0	1500	24000	300000
Variable cost	yuan/ha	0	750	3750	18000

Table 2 Water allocation according to rehabilitation plan (10^8 m^3).

Region	Allocation	2003	2010
Upstream	Surface water	9.72	8.82
	Ground water	7.47	4.18
Downstream	Surface water	0.98	2.5
	Ground water	5.17	0.89

be expected that the employment rate would reach the average level of Gansu or much higher in the near future.

Finally, reallocation of water resources between upstream and downstream should also be taken into account to increase the runoff to Minqin. According to the Shiyang River Rehabilitation Plan, the ecological rehabilitation in downstream flow would be the main target, so that extraction of ground water should be reduced largely, especially in downstream flow. Table 2 shows the water reallocation based on the Rehabilitation Plan.

Methods

Model

A bio-economic model can provide an integrated framework to link household economic activities with bio-production activities (Heerink et al., 2001; Shi et al., 2004, 2005, 2006; Janssen and Van Ittersum, 2007). The model can simulate household behavior by maximizing net income under constraints such as land, water, labor, food supply and demand, imperfect market and budget, etc. When water supply, off-farm employment opportunity or water use technologies, etc. changes, a new household behavior is output. This paper makes a bio-economic model based on linear programming. For combining the farm level and regional level, we construct the GBEM model whose framework is shown in Figure 3.

The parameters in the model were calculated based on farm surveys in Minqin and Liangzhou (Figure 4). The land resource constraint parameter in the models was from a GIS database of land use. The water resources constraint parameter was confirmed according to the Shiyang River Rehabilitation Plan and water use alloca-

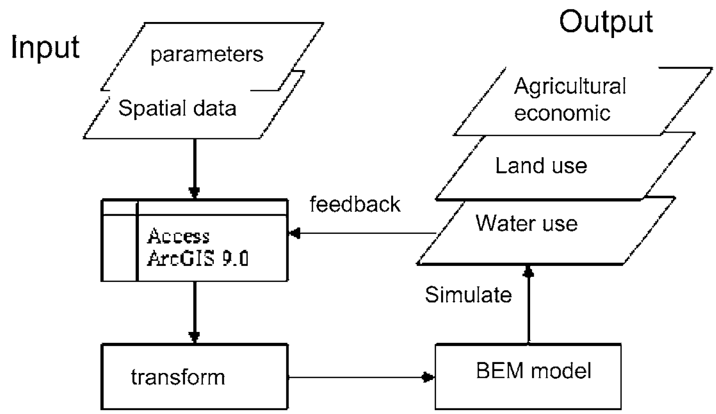

Fig. 3 The framework of GBEM model.

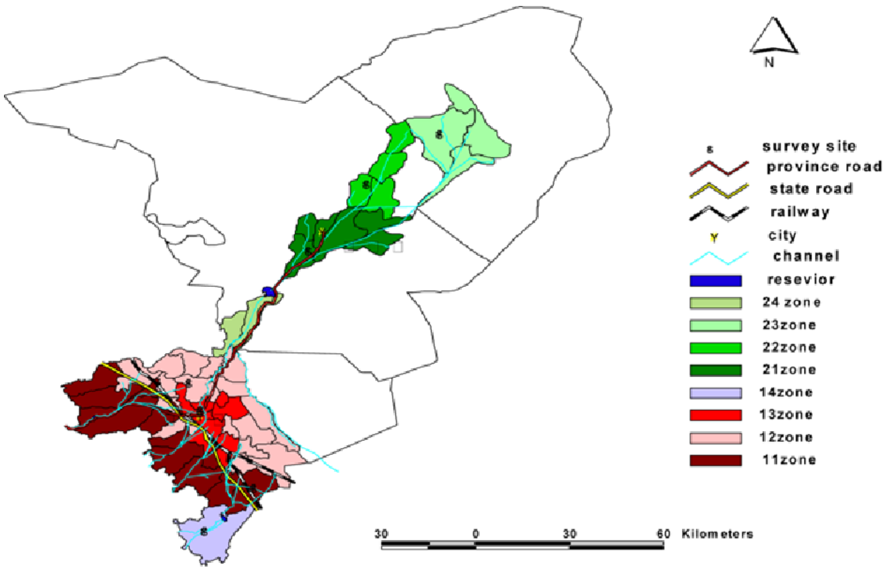

Fig. 4 Subzones in the Shiyang River basin.

tion plan of the Minqin Water Bureau, Liangzhou Water Bureau and Administration Bureau of the Shiyang River basin. The labor resource constraint parameter was calculated according to the statistical data.

Table 3 Scenario definition.

Scenarios	Definition
A	Base run
B	Reduction of water resource
C	Water-saving technologies + off-farm employment
D	C + water reallocation

Table 4 Water reallocation.

Region	Population 10^3 person	Surface water allocation according to plan 10^3 m^3	Ground water allocation according to plan 10^3 m^3	Water reallocation 10^3 m^3	Changes 10^3 m^3
Minqin	226.74	210358	72007	225933	–56432
Liangzhou	209.63	80234	35359	172025	56432

Scenario Design

Based on the measures of environmental rehabilitation mentioned above, a series of scenarios are designed as shown in Table 3. Scenario A is a base run that represents the current situation. Scenario B is for simulating the effects on farmers' income of reducing water allocation with adjustment of agricultural structure. Scenario C is designed for simulating the possible effects on income of the combined measures of water-saving technologies, solar greenhouse and off-farm employment under the water allocation of Rehabilitation Plan.

Scenario D is an alternative to raise water productivity by reallocating water resource (Table 4, Figure 5). Due to the huge spatial heterogeneity in natural condition, there is significant regional difference in efficiency of water use in Shiyang River basin. Generally, the water use efficiency in Minqin is lower than that in Lianghzou. The Rehabilitation Plan allocates much water to downstream because it combines ecological water with agricultural water. As it may result in a low efficiency of water use, optimization of water allocation is considered to raise water productivity. The income change with water reallocation should be compensated from the gainer to the loser.

Results and Discussions

Impacts of Environmental Rehabilitation on Farmers' Income

With the reduction of water resource, water constraint would become much more rigorous. If there is no adjustment to land use, farm income would decrease by a same proportion to the amount of water use, namely reduced to 53% in Minqin and

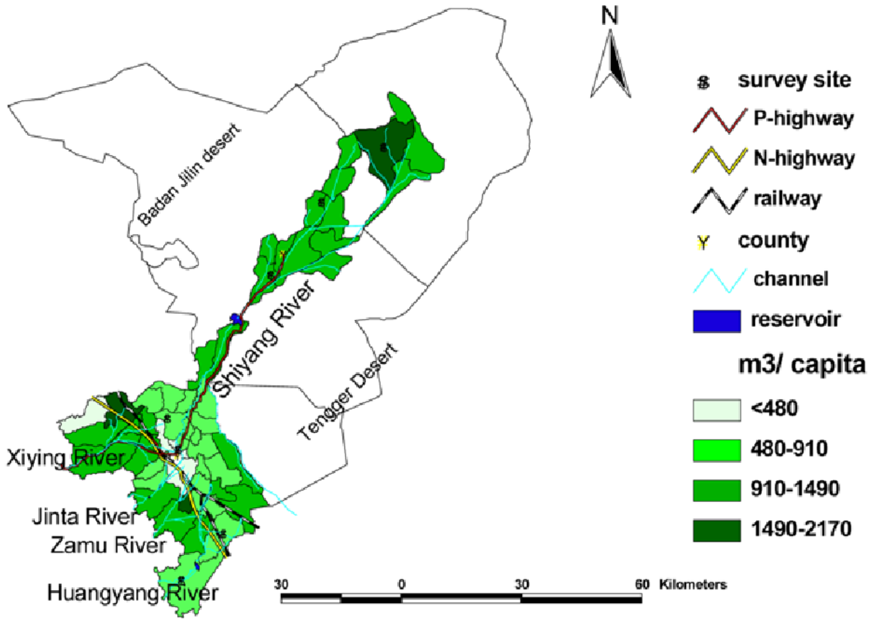

Fig. 5 Water allocation after water reduction.

Table 5 Change in farmer's net income.

	Unit	A	B	C	D: No compensation	D: With compensation
Whole basin	%	100	92	116	118	118
Liangzhou	%	100	98	121	125	123
Minqin	%	100	71	97	93	102
Whole basin	Yuan per capita	3267	2998	3797	3862	3862
Liangzhou	Yuan per capita	3381	3297	4104	4228	4142
Minqin	Yuan per capita	2906	2052	2829	2703	2976

76% in Liangzhou of the current level. Actually, farmers will change their land use and adjust cropping system to adapt new resource constraints. As a result, water productivity would be improved. Farmer's income per capita would reach 2005 yuan, 69% of current level in Minqin, and 3297 yuan, 98% of current level in Liangzhou (Table 5).

Effects of Extending Water-Saving Technologies, Solar Greenhouse and Off-Farm Employment

If subsidy is not given to the water-saving technologies, drip irrigation cannot be adopted successfully. In contrast, pipe irrigation can be adopted more widely due to the moderate costs, the adopted rate may reach 60% on average. The regions where the pipe irrigation is adopted most widely would be in both the upstream and downstream edges of the river basin where the comparative advantages of cash crop and solar green house are lower. In the center zone of the river basin, the adopted rate of solar green house would be largest.

If subsidy is provided for solar greenhouse, farmers' income may increase to 112 and 82% of the base run in Liangzhou and Minqin respectively. When the off farm employment opportunity reaches about 30%, farmers' income may increase further to 121 and 95% of the base run in Liangzhou and Minqin respectively (Table 5). The simulation results show that farmers' income in Minqin is unable to return to the level of the base run, although the combined measures with subsidy are implemented.

Effects of Water Reallocation and Compensation

If water resource is reallocated based on water use efficiency, farmers' income in Minqin may decrease by 28.57 million yuan, while the income in Liangzhou may increase 89.17 million yuan. Thus the net increment of income in the river basin will be 60.6 million yuan. The simulation results show that optimizing water allocation may raise water productivity at the river basin level.

As Minqin will be the loser due to much more water reduction, Liangzhou should compensate the income loss to Minqin. In addition, the net increment of income should also be taken into account regarding compensation. If the net increment of income will be shared as an average per person, the net income per capita in Liangzhou may reach 4,142 yuan, 123% of the base run. For Minqin, after compensation by income loss and net increment share, the net income per capita may increase to 2,976 yuan, 102% of the base run. The net income per capita in the river basin would reach 3,862 yuan, 118% of the base run (Table 5).

Conclusions and Implications

Based on the above results, this paper can be concluded as follows:

- In such a spatially heterogeneous river basin, spatial allocation of water resource is very important to raise water productivity in water management. A GIS-based bio-economic model can provide an analytical tool and insight to optimization of spatial allocation of water resource and its effects on tradeoff between economic goal and ecological goal.

- Reduction of agricultural water use for environmental rehabilitation will cause negative effects on income of local households. Even if combined measures are implemented, including extension of water-saving technologies and solar greenhouse and increase in off-farm employment opportunities, farmers' income in Minqin cannot return to the level that existed before reducing agricultural water. That means that it will be impossible to achieve the target of the Rehabilitation Plan.
- One of the reasons is that the Huqu irrigation zone with low water productivity will consume a lot of water resource according to the Rehabilitation Plan because it combines ecological water with agricultural activities. Optimization of spatial allocation of water resource is considered as a solution to raise water productivity at the river basin level. Reallocation of water resource based on water use efficiency may raise water productivity at the river basin level. Through compensation from the gainer to the loser, both Minqin and Liangzhou may realize an increase in farmers' income. Therefore, reallocation of water resource with compensation may promote simultaneously ecological rehabilitation and improvement of farm income.

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On the Change of Virtual Water in China under Regional Restructuring from 1997 to 2000

Takaaki Okuda and Chengwei Ni

Abstract The Chinese government started reforms and open-door policies in 1978, and the policies have continued to contribute to its economic growth. However, as a result of dynamic growth in the economy, water demand has been increasing and it also has worsened the water shortage. To achieve a sustainable economic development, economic planners must develop an understanding of the actual dynamics of water usage as it relates to the economics of interregional trade. In this study we show a structure of water demand in China by using the concept of virtual water. In particular we estimate multi-regional I-O tables in 2000, and calculate the amount of virtual water required. In addition, we analyze the transformation of virtual water by comparing the 2000 figures with those of 1997. The comparison suggests that the virtual water displacement from the southern coastal area toward other areas would have increased. In the view of Yellow River Basin, where water shortage is serious, virtual water transformed increasingly from the developed downstream. At the upstream basin, the forms of agriculture were encouraged to change and water demand to increase, too.

Key words: Comparison in time, MR IO analysis, regional development, virtual water, Yellow River basin

Introduction

China has realized a rapid economic growth due to the reform and open-door policies adopted since 1978. However, to achieve more economic development, several challenges had to be met. In the Yellow River Basin, a rapid economic growth caused serious water problems and administration of the water resource emerged

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as an important issue (Allan, 1997). In order to manage water resources in a vast basin like the Yellow River, it is important to conduct water management based on scientific principles after determining the actual conditions of water usage. On the other hand, China' s regional division of work has progressed due to the introduction of a market economy, thus this situation is enabling China to transport a product from a water-abundant region to a water-deficient one. Based on this problem consciousness, we have introduced the concept of virtual water for the analysis of water demand in China and we have sharpened our understanding of the actual condition of multi-regional transfer of virtual water with domestic multi-regional trading (Allan, 1998).

In China, however, economic growth continued rapidly in the late 1990s, and this growth resulted in modifying the domestic production system dramatically. In addition, it might be expected that this changes its trade practices due to economic growth would bring a drastic change in the virtual water transfer in China. We believe that several suggestions could be provided to consider how China's water demand would change and how China would have to modify its water resource management by correlating the change of water demand with the economic growth. In order to provide such a suggestion, we conducted a study of the actual conditions of virtual water transfer in 2000 and an analysis of China's multi-regional virtual water transfer in 1997. With comparison of both results, we aim to reveal how virtual water transfer among regions changed due to the economic growth in the late 1990s. This paper consists of the following chapters; explanation of relevant studies on virtual water is provided in the second section. In the fourth section we demonstrate the actual condition of virtual water transfer in the year 2000 by employing the MRIO tables for water analysis, and we describe the results of analysis on the modification from 1997 to 2000.

Previous Relevant Study

Studies on Virtual Water

In the 1990s, Allan introduced the concept of virtual water (Allan, 1997, 1998). Production of agricultural or industrial goods usually needs a water resource, indicating the simultaneous occurrence of indirect water export and import with trading of goods. Virtual water indicates the volume of water that would be required if all imported products were made in a demanding region. Studies on virtual water analysis for imported agricultural products have been conducted because agricultural production needs a large water resource. Miyake et al. (2002), for example, revealed the virtual water transfer with importing of agricultural products in Japan.

Studies on Virtual Water in China

However, in a country like China, which has a vast land area and water resource is eccentrically located, there arises a problem relating to virtual water transfer with domestic trading. Based on awareness of the problems, we have proposed a new application for China's multi-regional trading with virtual water analysis which has been targeted to international trading. And using this method, we analyzed China's virtual water condition in 1997 (Allan, 1998). In this study, multi-regional input-output tables for water analysis divided into 29 provinces were employed, resulting in finding the impact of virtual water transfer on the existing water resource with intermediate goods as well as final ones.

Positioning of the Study

China's domestic production system was transformed by to the economic growth in the late 1990s. In consequence, multi-regional virtual water transfer had to be forced to change drastically. Although a traditional virtual water analysis has been conducted to confirm the conditions of multi-regional transfer of water at a specific point in time, it can be predicted how the structure of water demand would be changed if comparing them at plural points in time. For a country like China attaining rapid economic growth, if one can grasp the condition of these water demand changes, it will be useful information to estimate the change of the structure by further economic growth. Considering the background, in addition to our former study on China's multi-regional virtual water transfer in 1997 we demonstrate the status of virtual water transfer in 2000, and try to clear up the changes of the transfer between the period.

Comparative Analysis at Two Points in Time on Virtual Water

Estimation Method of the Volume of Virtual Water

Virtual water transfer can be made clear in consideration of not only water resource required to produce a final product, but also that required to produce an intermediate product, by conducting MRIO analysis with use of the MRIO table for water analysis. In this study, in order to do MRIO analysis by using a competitive import type of MRIO table, we employed the Cheney–Moses model as follows:

$$X = \left[I - (I - \hat{M})TA\right]^{-1} \left[(I - \hat{M})TF + E\right] \quad (1)$$

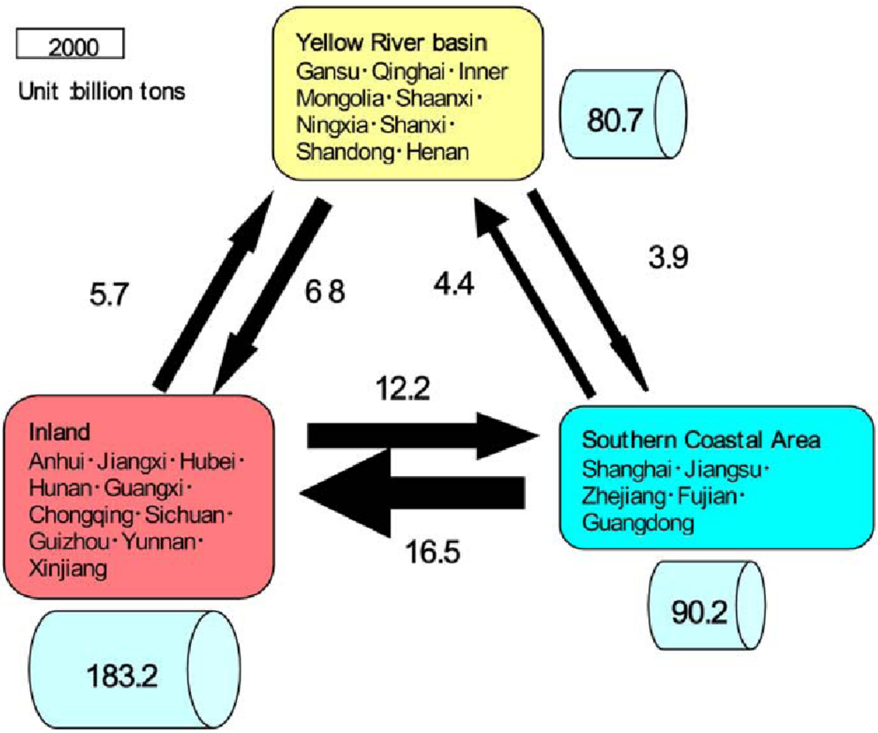

Fig. 1 Virtual water transfer in China in 2000.

where X: production vector, F: final demand vector, E: export vector, A: input coefficient matrix, T: multi-regional trading matrix, $\hat{M}$: import coefficient matrix.

Provided that final demand vector at region s be given as F^s, the production inducement X^s by final demand shall be as follows:

$$X^s = \left[I - (I - \hat{M})TA\right]^{-1}(I - \hat{M})TF^s \tag{2}$$

Thus, with this equation it is possible to make clear the actual conditions of production and their location by a final demand at region s. As shown in the second section, virtual water represents the volume of water which would be needed if a relevant region s produced these goods. In that sense, virtual water transfer to region s can be set up by multiplying the production calculated by the water input coefficients at region s (Equation 3):

$$W^s = B^s X^s \tag{3}$$

where W^s: virtual water transfer toward region s, B^s: water input coefficient matrix at region s.

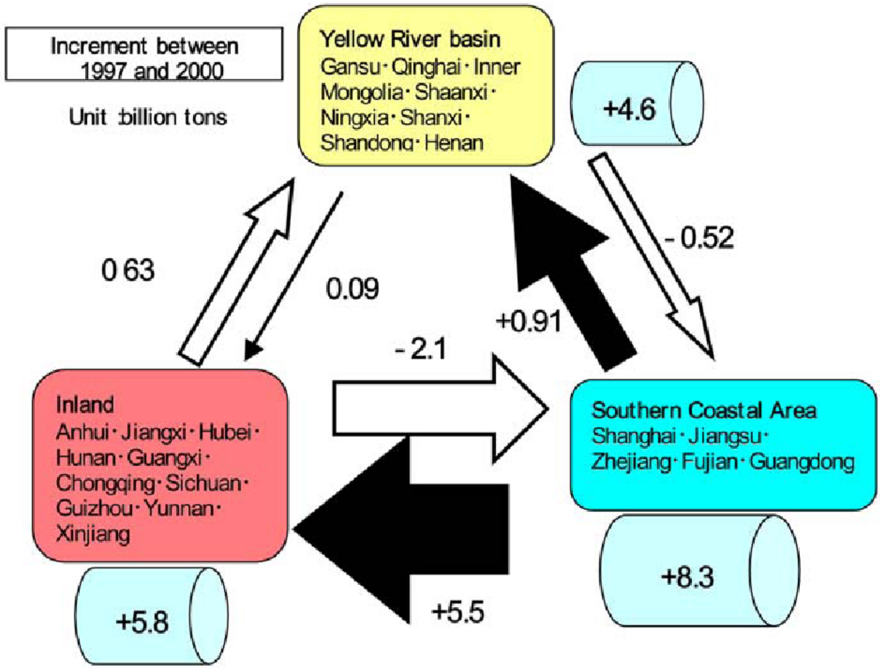

Fig. 2 Change of virtual water transfer in China (1997 to 2000).

Virtual Water Transfer in China

We wish to indicate the result of virtual water transfer among the southern coastal area (SC), the inland (IL) and the Yellow River basin (YR) in 2000, respectively. In Figure 1, arrows show the volume of virtual water that transfers among the regions, and cylinders do the volume of virtual water generated within each region. Taking notice of the relation between SC and IL, the volume of virtual water from SC into IL accounts for 16.5 billion tons in 2000, and the inverse flow for 12.2 billion tons. It indicates that excessive virtual water may have transferred from the water-abundant southern coastal toward the water-deficient inland. On the relation between SC and YR, 4.4 billion tons of virtual water flew in YR from SC and 3.9 billion tons flew inversely, indicating that it might be confirmed an excessive transfer from SC toward YR with less water resources like IL. The main reason supporting this fact is that these water-deficient areas imported the secondary products from the southern coastal area. The SC locates along the downstream of the Yangtze River, and this means the area yields industrial products that require much water and exports them toward the inland or the Yellow River basin where water resource relatively runs short.

Figure 2 shows the change of virtual water transfer from the year 1997 to 2000. In the figure, black arrows indicate an increase in virtual water transfer and the white a decrease. It provides the facts that 0.91 billion tons of virtual water increased from SC to YR and 5.5 billion tons to IL. The reason may be thought as that in Figure 2, namely SC increased exports of the secondary products to these water-deficient areas. In contrast, 0.52 billion tons of virtual water from YR to SC was reduced between the two time periods and 2.1 billion tons came down from IL to SC. This may result in a reduction in export of primary and secondary goods from these areas to SC.

The southern coastal area is a region that was the center of China's economic growth in the 1990s. In the region some items have been increasing, including not only input of labor and capital with an increase in production but also drastic water input. In addition, the regional structure, from which goods produced in the SC would be exported to the IL and the YR, has become dominant. On the other hand, the Chinese government has willingly developed the inland to solve the income disparities between the inland and the coastal area. However, in order to promote development in the inland with less water resource, it should be necessary to make enough examinations such as: (1) how to establish the water resource and (2) how to utilize it effectively. And for a region that has difficulty in keeping water resources despite their efforts, it is also natural to examine (3) how to import intermediate goods from a water-abundant area.

Virtual Water Transfer in the Yellow River Basin

Figure 3 shows a division of the Yellow River basin into three regions of upstream, midstream and downstream, and their transfer of virtual water in 2000. The figure provides that 0.94 billion tons of virtual water flew from the downstream area to the midstream and 0.72 billion tons from the upstream to the midstream. The midstream is located in the arid region and runs relatively low on the water resource. This climate condition may force the midstream to import primary goods from the up or downstream, resulting in a great volume of virtual water transfer.

Figure 4 indicates the change of virtual water transfer from 1997 to 2000. This figure also says that the change in virtual water from the upstream to the midstream increased 0.24 billion tons between the two periods, as well as that from the downstream to the midstream increased 90 million tons. In particular, the transfer from the upstream to the midstream had greatly increased due to an increment in primary goods importation. These results can be explained as follows: (1) in the upstream, production structure in agriculture would have changed to highly valued stock farming from grain production, (2) in the midstream, demand for meat may have increased because of the change of diet with income gaining. Moreover, with the changes in China, industrialization has advanced and production of secondary goods has increased in the downstream. Since these goods began to supply toward the upstream and the midstream, it would be clear the increase of virtual water transfer from the upper to the midstream and the downstream.

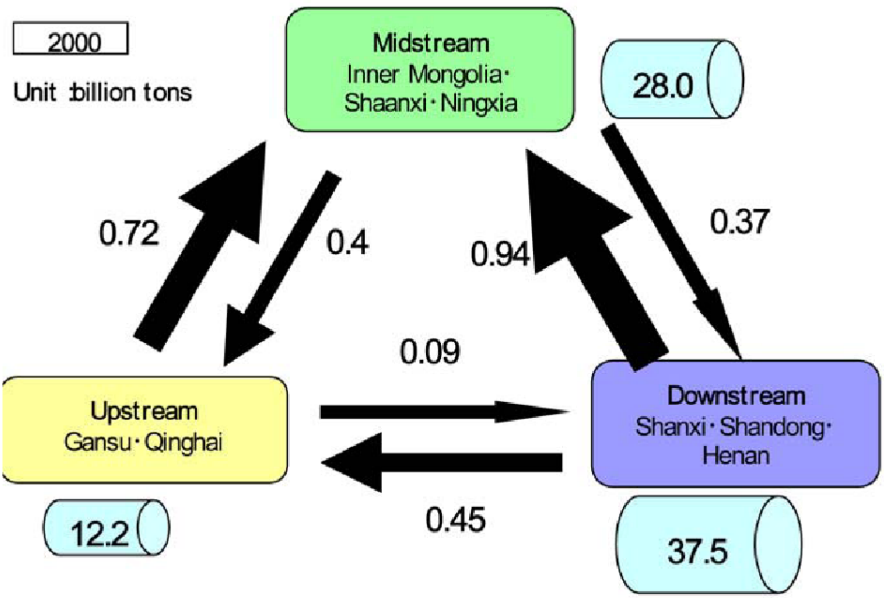

Fig. 3 Virtual water transfer in the Yellow River basin in 2000.

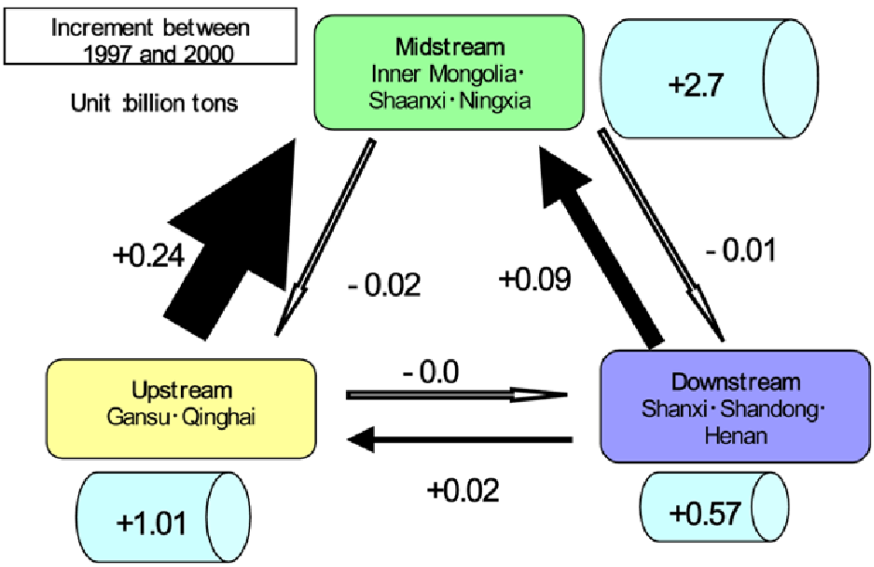

Fig. 4 Change of virtual water transfer in the Yellow River basin (1997 to 2000).

Water goes down from the upstream to the downstream through the midstream in the whole Yellow River basin. However, this water resource is being utilized to produce in the downstream and the products being supplied to the midstream and the upstream. It may be constructive that a new water circulation system would be formed along the whole basin by the regional structure reform. Other production systems have also changed in the upstream and the midstream, and the regions begin to seek new water resources due to changes of lifestyle. As water use increases in the upstream or the midstream, it is natural to decrease available water resource in the downstream. From that viewpoint, it is concluded that China's economic growth converts the interdependent relationship in the Yellow River basin by introducing a market economy and policy makers have to reconsider the contemporary water use after mutual consideration of such changes.

Conclusions

In this study we demonstrated the virtual water transfer in 2000 in China as well as our former analysis in 1997. In addition, we also demonstrated how the inter-regional transfer had changed with the economic growth in the late 1990s in comparison with both results. First, the analysis of three regional divisions in China (southern coastal, inland and Yellow River basin) provided evidence that the industrialized southern coastal area focused water resource on industrial products, which enabled the other two regions to receive supplies from the southern coastal area, and this new regional structure resulted in an increase in virtual water transfer to the inland or the Yellow River basin. Second, the analysis of three divisions in the Yellow River basin (upstream, midstream and downstream) showed that the downstream, which is relatively industrialized in the basin, supplied the manufactures to the upstream or the midstream area. The result demonstrated that virtual water transfer increased to the upper two basin areas, changes in production and dietary life forced water demand to increase in the upstream and the midstream. Finally, after due consideration on the changes in such regional relationships, we concluded that it would be just the time to review the way to use the water resource in the whole basin.

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PART 2

Sustainability in Local Water Use

Potential Reuse of Wastewater Effluent in Macau

Kwok Ho Chan, Jie Sun and Hojae Shim

Abstract Proper use of treated wastewater is gaining acceptance of the public around the world, as a means of supplementing scarce fresh water resources. The aim of this study is to investigate the most feasible tertiary treatments to be added to one of the existing Macau wastewater treatment plants in order to find an economic way to attain for its treated wastewater a number of recognized qualities that would make it suitable for region-specific reuse purposes such as street washing, landscape irrigation, etc. Sand filtration and microfiltration by membrane filters, either alone or followed by UV disinfection downstream, were tested experimentally. Results show that sand filtration is not good enough, while membrane filtration with UV sterilizer delivers promising results.

Key words: Carbonaceous biochemical oxygen demand ($CBOD_5$), filtrate, permeate, suspended solids (SS), total coliforms (TC), treated wastewater

Introduction

The reuse of treated wastewater as a means to supplement fresh water resources has long been practiced in arid or water scarce areas around the world. The largest application is in agricultural industry which needs huge quantities of water. Applications like street washing, car washing, landscape irrigation as well as toilet flushing are widely accepted as well. Some countries like Singapore, for example, even promote high-quality treated wastewater as bottled water. Macau is a small city with practically no water sources. According to data released by the Statistics and Censors Bureau of Macau's SAR government, the yearly water consumption increased from 51.63 Mm^3 in 2003 to 65.83 Mm^3 in 2007, representing a 27.5% growth in five

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Table 1 Region-specific reuse quality goals for treated wastewater.

Water Quality Parameter	Reuse Quality Goal
SS (mg/l)	≤ 10
Turbidity (NTU)	≤ 2
BOD_5 (mg/l)	≤ 10
Total coliforms (MPN/100 ml)	≤ 2.2

years. It is believed that more than 98% of the water used by Macau has to be imported and purchased from a nearby area: Zhuhai of Guangdong province. Due to abnormal drought conditions in recent years, Macau's fresh water source has faced seawater intrusion and contamination of its water origins every winter since 2001. During these years the chloride content of the city water rose first to 350 ppm, then continued to worsen, up to a point when Macau was threatened in February of 2006 with a disruption of its fresh water supply. With rapid industrial and urban development prompting high internal water demand in areas upstream of Macau, such as Zhuhai, coupled with continuation of the strong economic growth of Macau itself, it can be expected that the supply of drinking water to Macau will be under great tensions in the coming years. Therefore, Macau needs to take action to both maintain and broaden its fresh water resources as well as to change its water consumption pattern – reusing treated wastewater is one of the possible ways.

Since the regulations of Macau's wastewater treatment plants were enacted some 15 years ago, the qualities required for treated effluent are much less stringent than the qualities recognized internationally for safe reuse, and there are as of now still no official regulations of reuse water in place in Macau for any specific purposes. Therefore, in order to reuse treated effluent in Macau, one of the most important issues, among others of varying degrees of urgency, is to set up quality goals for treated effluent that can render safe reuse. After extensive literature research, the quality goals for some principal parameters of treated effluent suitable for the current conditions of Macau are proposed in Table 1.

Certainly other parameters, such as heavy metal concentrations, are of concern as well, but are less important comparatively since Macau is a city with no heavy industries. There are currently three main secondary wastewater treatment plants (WWTPs) under operation in Macau as of May 2008 – one for Macau peninsula, one for Taipa Island and one for Coloane Island. All three WWTPs are biological treatment plants, currently producing no treated wastewater that meets the standards recognized internationally for safe reuse in unrestricted urban areas for any purposes. Therefore, further tertiary treatments are needed to render the treated wastewater safe for reuse for some region-specific purposes. The aim of this study is to explore the potential uses of treated effluent in Macau, to propose the required qualities, and to investigate the necessary tertiary treatments, either physico-chemical or biological, that can be added to the Taipa WWTP and can further improve the quality of the secondary treated wastewater, rendering it to be reused for some specific purposes in a safe and economic manner. The Taipa WWTP was selected as the first plant for this study since the published data of its effluent show the best quality, thus possibly requiring the least modifications and capital inputs.

Materials and Methods

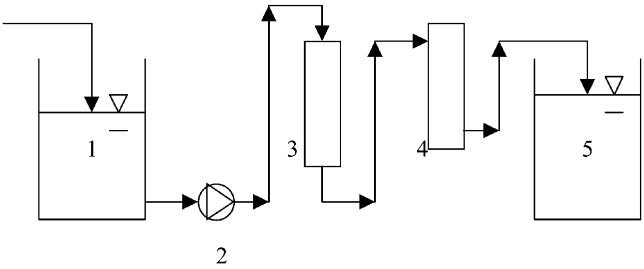
After confirming the qualities of the effluent from the Taipa WWTP by preliminary analyses, sand filtration and microfiltration with a membrane filter were identified as the most feasible solutions, and then laboratory-scale experiments were set up for testing the treated effluent of the Taipa WWTP. Analyses of parameters of chemical oxygen demand (COD_{Cr}), carbonaceous biochemical oxygen demand ($CBOD_5/BOD_5$), suspended solids (SS), total coliforms (TC) and turbidity of the effluent and filtrate/permeate were undertaken after thorough mixing of collected samples. The testing methods for parameters were based on "The Standard Methods for the Examination of the Water and Wastewater" (APHA/AWWA/WEF, 1995) and the HACH methods accepted by the United States Environmental Protection Agency (USEPA, 2004).

Analytical Methods

COD was checked with Hach's reagent, ranged from 0 to 1,500 mg/l and measured by spectrophotometer DR 2400. $CBOD_5/BOD_5$ and was analyzed using Hach's BODTrak with or without nitrification inhibitor at 20°C for five days. SS was measured using 47 mm filter papers (Whatman 934-AH) with a three-piece filter funnel (Whatman) connected to a vacuum pump (Fisherbrand 70155). TC was analyzed with Hach's MPN method. Turbidity was measured with Hach's turbidimeter 2100 N.

Sand Filtration

The schematic diagram of the sand filtration setup is shown in Figure 1. The sand used in the sand column was from Red Flint Sand and Gravel, a company selling commercial media used specifically for the water filtration industry. A detailed configuration of the sand column is shown in Figure 2. The grab samples (about 35 l) of treated effluent were collected from the Taipa WWTP once a week for a total period of eight weeks, and were fed through the sand column with a UV sterilizer downstream by a booster pump. The UV dosages were determined by the filtration flow and were to be kept constant in each test, ranging from 100 to 106 mJ/cm^2. Samples of the treated effluent from the Taipa WWTP and the filtrate after the sand filtration were collected for the later analyses of BOD_5, COD, SS, TC and turbidity.



1 : Secondary treated effluent from WwTP
2 : Booster pump
3 : Sand column
4 : UV sterilizer
5 : Filtrate

Fig. 1 The schematic diagram of the sand filtration setup.

Table 2 Specifications of the membrane filter used for microfiltration.

Manufacturer	Tianjin Membrane Fiber Technology Limited
Material of hollow fibre filter	Polyvinylidenefluoride (PVDF)
Total filter surface area	4 m^2
Nominal pore size	0.2 μm
Recommended flux for secondary treated effluent	50 l/m^2*h
Max transmembrane pressure allowed	1.5 bar

Membrane Filtration

Membrane filtration was performed with a hollow fiber membrane filter with a total filtration area of 4 m^2. The specifications of the filter are listed in Table 2.

The experimental setup was very similar to that of the sand filtration, with the sand column replaced by the membrane filter and the addition of a flow indicator upstream of it for convenience as shown in Figure 3. The UV sterilizer was installed downstream of the membrane filter after a series of filtration experiments with the membrane filter alone showing the presence of total coliforms in the permeate. The UV dosages were determined by the filtration flows which were kept constant in each test, and ranged from about 64 to 72 mJ/cm^2. The grab samples (about 65 l) of treated effluent were collected from the Taipa WWTP, once or twice per week, for a total period of ten weeks. The filtration of the collected effluent was performed within four hours and the qualities of treated effluent and filtration permeate were analyzed accordingly.

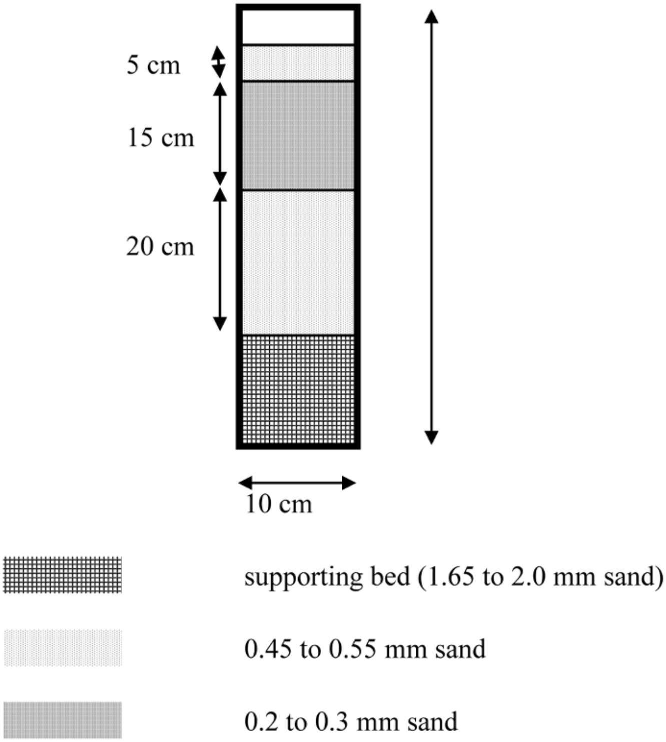
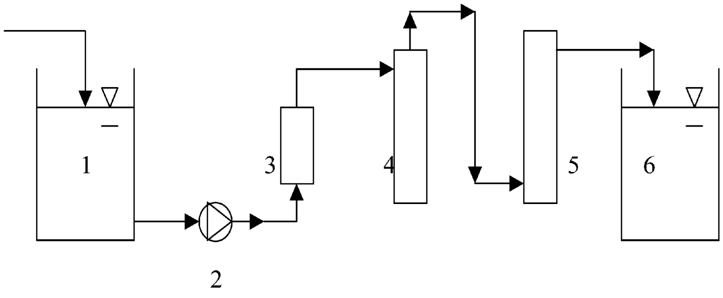


Fig. 2 The detailed configuration of the sand column.

Results and Discussion

The results for the qualities of the sand filtration experiments are shown in Table 3. The qualities of both SS and turbidity, especially the turbidity, of the filtrates were found to be higher than the reuse goals. The poor qualities of the effluent from the WWTP also attributed to these results. The average removal efficiencies of sand filtration for SS and turbidity were about 45 and 47%, respectively, which are in line with results observed by Illueca-Muñoz et al. (2008), who reported a 50% removal efficiency for SS and turbidity in a similar experiment. On the other hand, the UV dosage level could effectively inactivate the TC most of the time (data not shown), except for one occasion with a particularly high TC level, resulting in overall incompliance. The BOD_5 results are not shown due to an experimental error. Most of the time the results were abnormal, as justified from the BOD_5 trends recorded on the BOD_5 measuring device, with sometimes the filtrate BOD higher than that of the effluent. Since this phenomenon was suspected of being due to the occurrence of nitrification, the nitrification inhibitor was added to the permeate samples from the membrane filtration for subsequent BOD_5 tests.



1 : Secondary treated effluent from WwTP
2 : Booster pump
3 : Flow indicator
4 : PVDF hollow membrane filter
5 : UV sterilizer
6: Permeate from membrane filter

Fig. 3 The experimental setup of membrane filtration.

Table 3 Qualities from sand filtration.

	Taipa Effluent	Filtrate	Removal Efficiency (%)
COD (mg/l) ($n = 8$)	81.71 ± 32.5	64.42 ± 35.97	23.92 ± 17.4
SS (mg/l) ($n = 8$)	29.08 ± 10.4	15.9 ± 7.64	44.69 ± 15.11
Turbidity (NTU) ($n = 8$)	23.36 ± 16.8	12.81 ± 10.98	46.95 ± 15.14
Total coliforms (MPN/100 ml) ($n = 7$)	n.m.	6.43 ± 11.72	n.a.

n.m. = not measured; n.a. = not applicable

In comparison, the membrane filtration was shown to have more promising results. Table 4 shows the analytical results for effluent and permeate from the microfiltration experiments. As shown, the levels for SS, turbidity and $CBOD_5$ were well below the reuse goals, 1.39 mg/l, 0.26 NTU and 5.65 mg/l, respectively, in case of membrane filtration alone and 0.88 mg/l, 0.3 NTU and 5.43 mg/l, respectively, in case of membrane filtration followed by a UV sterilizer. The removal efficiencies for SS and turbidity were over 90%, although total coliforms more than the reuse goal were still detected in permeate when the UV disinfection was not in place. The full compliance of reuse goals was achieved after addition of UV disinfection at an average dosage of 67.5 mJ/cm^2.

The exact reason for the TC presence in permeate with membrane filtration alone has not been identified. It has been reported (Zhang and Farahbakhsh, 2007) that the presence of total coliforms in the permeate of an intact membrane filter could possibly be due to the biofilm formed inside the permeate lines downstream. Another

Table 4 Qualities from microfiltration with or without UV disinfection.

	Without UV Sterilizer			With UV Sterilizer (average UV dose = 67.5 mJ/cm^2)		
	Taipa Effluent (mg/l)	Permeate (mg/l)	Removal Efficiency (%)	Taipa Effluent (mg/l)	Permeate (mg/l)	Removal Efficiency (%)
Sample size	$n = 13$	$n = 13$	$n = 13$	$n = 3$	$n = 3$	$n = 3$
COD (mg/l)	97.57 ± 71.69	42.57 ± 33.27	50.89 ± 19.99	59.78 ± 29.41	18.44 ± 2.01	62.05 ± 21.64
SS (mg/l)	29.46 ± 26.13	1.39 ± 1.24	91.94 ± 7.53	21.67 ± 15.53	0.88 ± 1.52	97.44 ± 4.43
Turbidity (NTU)	17.67 ± 22.2	0.26 ± 0.09	96.99 ± 2.34	12.28 ± 8.78	0.3 ± 0.19	96.1 ± 3.13
$CBOD_5$ (mg/l)	21.74 ± 19.18	5.65 ± 1.69	63.24 ± 19.22	14.83 ± 14.76	5.43 ± 1.7	46.49 ± 40.38
Total coliforms (MPN/100 ml)	n.m.	381 ± 761	n.a.	n.m.	¡ 2 ± 0	n.a.

n.m. = not measured; n.a. = not applicable possibility is that since the absolute pore size of the membrane filter is unknown, some pores might be large enough for coliforms to pass through. Alternatively, some of the hollow fibre filters of the membrane filter might have been damaged so coliforms can pass through. Further work is warranted to determine the reason.

Conclusions

The proper reuses of treated wastewater have been practiced worldwide and are becoming more popular nowadays as an effective means to save scarce fresh water resources. Considering the rapid development of its economy in the past few years, it is now the right time for Macau to do the same. Lab-scale experiments have been performed with the effluent from one local wastewater treatment plant in order to find the most economic way to further treat the effluent to the extent that it can be safely reused in the city. After sand filtration and membrane filtration were tested, both with and without UV disinfection, sand filtration followed by UV disinfection could not produce a treated water sufficient to meet the reuse quality goals, while membrane filtration alone met almost all the goals, except TC. The performance of membrane filtration was twice as good as that of sand filtration, with removal efficiency higher than 90% for SS and turbidity. With the addition of a UV sterilizer downstream, the membrane filtration showed very promising results, meeting all reuse quality goals. The short-term performance of membrane filtration was proven to be very good, while the long-term performance in a continuous running mode still warrants further studies.

Acknowledgement

The authors would like to thank the University of Macau Research Committee for its financial support.

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Ozone Used as a Technology for Reducing the Risk of Wastewater Reuse

Yiyuan Jiang, Yu Zhang, Nan Cao, Jun Zhou, Min Yang and Juni Hirotsuji

Abstract Secondary effluent from a sampling of municipal wastewater was treated by an ozone-ceramic biofilter (O_3-CBF) system following treatments with coagulation, sedimentation and sand filtration. The system was operated under an ozone consumption dose of 5 mg/L and different HRTs of CBF (10–30 min) for over eight months. The mean removals of COD_{Mn}, DOC, UV_{254}, and chroma were 31.0, 24.0, 42.2 and 79.3%, respectively, under a CBF HRT of 10 min. Further increasing HRT did not lead to a remarkable improvement in pollutant removal. Ames test results showed the existence of frame-shift mutagens and direct mutagens in the secondary effluent. The mutagenic activity in TA98-S9 was decreased from 2.97 to 1.45 (MR/L) by O_3, and to 1.3 (MR/L) by the following CBF treatment. $10^5 \sim 10^8$ count/L of total bacteria and $10^2 \sim 10^5$ count/L of E. coli were detected in the conventional treatment effluent, which could not satisfy the hygienical requirements for reclamation. Batch O_3 tests demonstrated that complete inactivation of E. coli could be achieved at an ozone dose of 12 mg/L.

Key words: Advanced treatment, mutagenicity, ozonation, safety of reclaimed wastewater

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Introduction

With the widespread occurrence of water shortage problems, secondary effluents from municipal WWTPs, with a constant water quality and quantity, have been considered as a potential water resource for cities. Conventional processes for water reclamation, which include coagulation, flocculation, sedimentation and filtration, focus mainly on particle removal, nevertheless the performance in removing the color, odor and health-related substances from the secondary effluents has not been satisfactory (Farré and Barceló, 2003). On the other hand, although chlorine is an effective disinfectant, the formation of harmful disinfection byproducts can not be neglected (von Gunten et al., 2001). So, it is necessary to develop a new process which can ensure high quality and safety during wastewater reuse (Lazarova et al., 1999).

Ozone has been known to selectively destroy the unsaturated bonds of target substances, making itself an effective alternative for the removal of odor and color substances (Lacy and Rice, 1977; Ferguson et al., 1990; Masten and Daves, 1994). Many toxic organic compounds with benzene-bearing molecular structures can be easily decomposed by ozone (Camel and Bermond, 1998). Furthermore, ozone is also a strong disinfectant, which can not only inactivate bacteria and viruses, but also kill cryptosporisium which can tolerate high level chlorine (Facile et al., 2000). In this study, the effluent from a municipal wastewater plant was further treated on a pilot scale by the ozone-ceramic biofilter (O_3-CBF) system following successive coagulation, sedimentation, and sand filtration treatments for the purpose of wastewater reclamation. The use of CBF was to ensure the biostability of the ozonated effluent because some biodegradable organic substances would be produced during ozonation (Ferguson et al., 1990; Carlson and Amy, 2001). The system was operated continuously for eight months, and some batch tests were conducted using an ozonation reactor for investigating the disinfection effects of ozone on E. coli. Changes of mutagenicity during the treatments were investigated using an Ames test.

Materials and Methods

Raw Water

The secondary effluent from a municipal wastewater plant in Beijing was used as raw water followed by a successive treatment of coagulation (15 mg Al_2O_3/L PAC), sedimentation, and sand filtration. The characteristics of this water are shown in Table 1.

Table 1 Characteristics of raw water.

COD_{Mn} (mg/L)	BOD_5 (mg/L)	DOC (mg/L)	NH_4^+-N (mg/L)	TP (mg/L)	Turbidity (NTU)	UV_{254} (cm^{-1})	Chroma (cu)
4.2–8.8	≤4	3.9–8.2	0.0–18.8	0.5–3.1	0.0–2.5	0.07–0.156	5.5–18.6

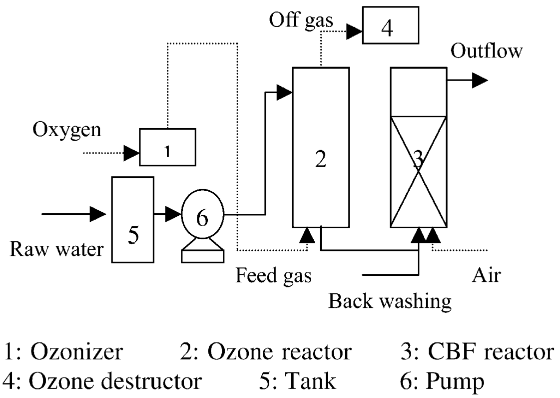

Fig. 1 Flowchart of O_3 – CBF treatment process.

Experimental Apparatus

Figure 1 illustrates the schematic diagram of the experimental system. It consisted of an ozonizer, a counter-flow ozone contactor (effective height 2.5 m; diameter 10 cm) and a biofilter column (effective height 1.5 m; diameter 15 cm). Raw water, after successive coagulation, sedimentation, and sand filtration treatments, was pumped to the top of the ozone contactor, and ozone gas generated by the ozone generator (OS-1N, Mitsubishi Electric Co.) was bubbled from the bottom of the contactor through a titanium diffuser. The media in the bioreactor was ceramic particles with a diameter of 2.5 ∼ 4.0 mm. The experiment was started from March, 2003, and lasted for eight months. The ozone dose and contact time was fixed at 5 mg/L and 10 min during the normal operation, respectively, except for disinfection experiments. The CBF was started up by feeding raw water directly under an empty bed contact time (HRT) of 60 min. A month later, the CBF was fed with the ozonated effluent, and the CBF operated for a long period under different HRTs of 30, 20, 15, and 10 min respectively. For disinfection experiments, the ozone dose was changed from 5 to 12 mg/L.

Analytical Methods

Ozone concentrations in the feed gas and off gas were determined by the KI-starch titration method. The resolved ozone in water was also determined by the same method. The amount of ozone consumption was calculated from the difference between the feed ozone and off gas ozone. DOC was determined by a Total Organic Carbon Analyzer (Phoenix, 8000, Tekamr-Dohrmann Co.), UV_{254} and chroma (absorbance at 390 nm) were determined by UV3100 (Japan, Uitachi Co.) after filtration with 0.45 μm membrane filters. CODMn, total bacteria and E. coli were determined according to the Standard Methods of Water and Wastewater Monitoring of China. The silt density index (SDI) was conducted by using equipment purchased from the Millipore Co.

Mutagenicity Assay

Ames tests were carried out following the standard plate incorporation test protocol (Maron and Ames, 1983). Two strains of Salmonella Typhimurium, TA98 and TA100, were used with and without exogenous metabolic activation (±S9 mix). The TA98 is to detect the frameshift mutagens and TA100 for base-pair substitute mutagens. The assay was performed on the water extract using three-dose levels equivalent to 0.1, 0.5 and 1.0 L per plate, respectively, with triplicate plates per dose. Spontaneous revertants of TA98 and TA100 were within the normal range (30–50 for TA98 and 120–150 for TA100) in all the Ames tests conducted. Each experiment included solvent control and diagnostic positive control. Dimethyl sulfoxide (DMSO) was used as solvent control. Metronidazole and sodium azide were used as diagnostic positive control in TA98 and TA100 assay respectively without metabolic activation and 2-AF for that with metabolic activation. The result is expressed by MR value, which is the ratio between the average number of revertants in the presence of the sample and the average number of spontaneous revertants. A MR value over 2 and clear dose response can be regarded as a positive response. Water samples with 50 L for the Ames test were acidified to pH = 2 and then loaded to the mixed XAD resin for adsorption of organic pollutants. Pollutants adsorbed by the resin were eluted with dichloromethane (DCM) and then reduced to 0.2 ml.

Results and Discussion

Removals of Organics

Variations of CODMn, DOC, UV254 and chroma over the system operation are shown in Figures 2 to 5, respectively. The average COD_{Mn}, DOC, UV_{254} and

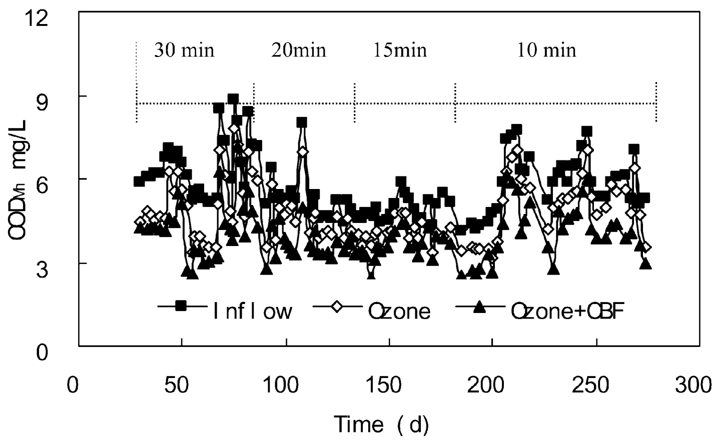

Fig. 2 Variations of COD_{Mn} with time.

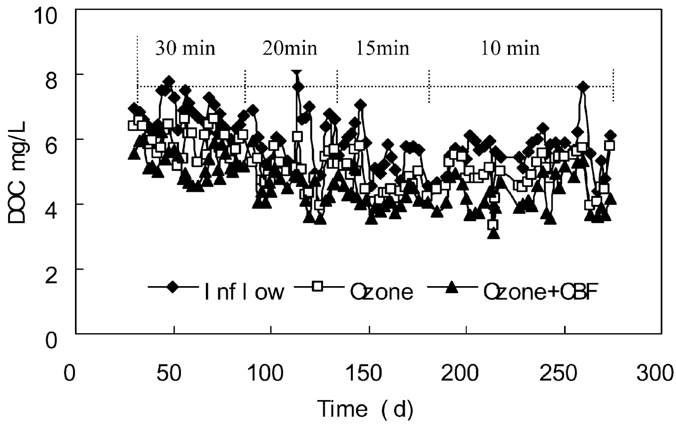

Fig. 3 Variations of DOC with time.

chroma of the influent were 5.7 mg/L, 6.0 mg/L, 0.107 cm^{-1} and 10 cu, respectively, which decreased to 4.8 mg/L, 5.2 mg/L, 0.068 cm^{-1} and 2.2 cu through ozonation under an ozone consumption amount of 5 mg/L. Ozonation was very effective for removing UV_{254} and chroma. The removals of COD_{Mn} and DOC, however, were not so high, indicating that the high removals of UV_{254} and chroma only resulted from structural destruction. The COD_{Mn}, DOC, UV_{254} and chroma after CBF treatment further decreased 3.9 mg/L, 4.3 mg/L, 0.059 cm^{-1} and 2.1 cu, respectively. The average removals for COD_{Mn} and DOC by the O_3-CBF treatment were 31.0 and 24.0%, respectively, indicating that the combination of ozone and biological treatment resulted in the mineralization of part organic compounds. When the HRT of the CBF was changed from 30 to 10 min, the removals of COD_{Mn}, DOC, UV_{254}

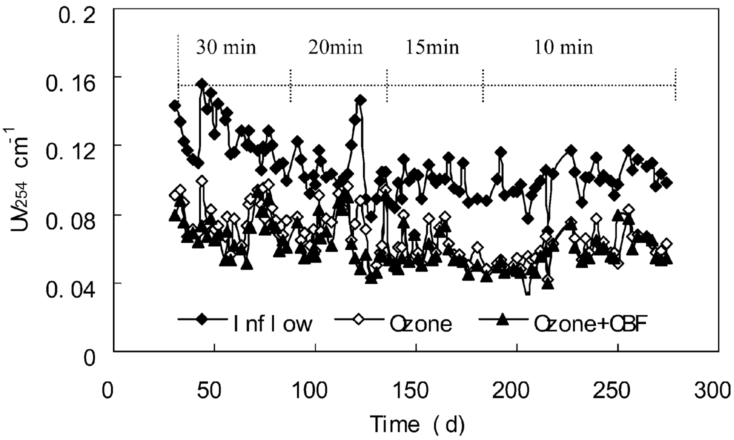

Fig. 4 Variations of UV_{254} with time.

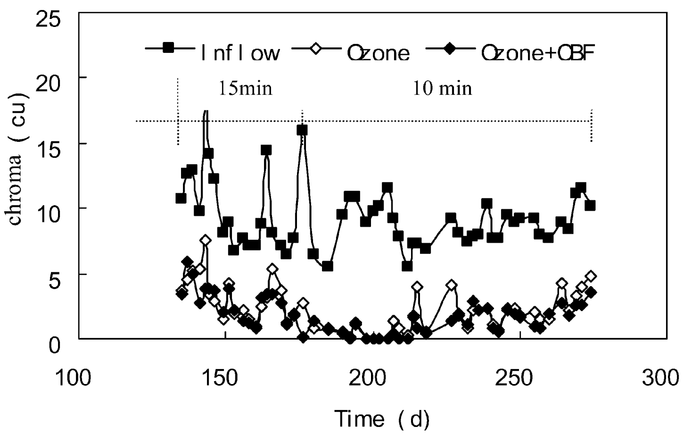

Fig. 5 Variations of chroma with time.

changed from 34, 24, 44 to 29, 21, 42%, respectively, indicating that the organic removal performance was not notably affected by the decrease of HRT.

Disinfection Effects

Figure 6 shows that the total bacteria and E. coli ranges in the secondary treatment effluent were $10^6 \sim 10^9$ count/L and $10^3 \sim 10^6$ count/L, respectively. The conventional treatment only resulted in one to two logs removal of bacteria and E. coli, which is far from the strict hygienical requirements for reclaimed wastewater. Further disinfection measures should be taken to ensure microbial safety. The

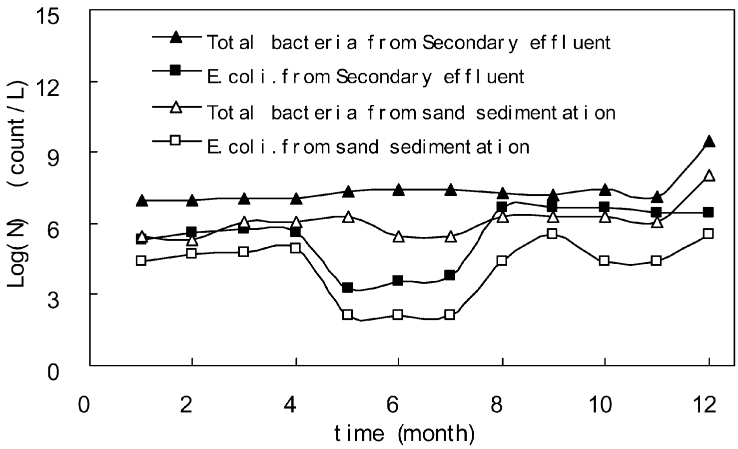

Fig. 6 Variations of E. coli and bacteria with time.

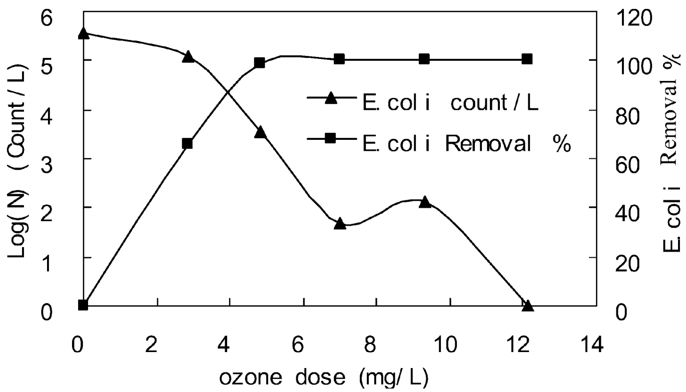

Fig. 7 The removal of E. coli by ozone application.

disinfection test results are shown in Figure 7. The inactivation efficiency for E. coli improved with an increase in the amount of O_3 consumption. Almost complete inactivation of E. coli was achieved at an O_3 consumption amount of 12 mg/L.

Ames Test Results

The Ames test results, using TA98±S9 and TA100±S9, are shown in Figure 8. The higher MR values in TA98 without addition of S9 suggested the predominant presence of direct frameshift mutagens in the secondary effluent. After the conventional treatment, both direct and indirect frame-shift mutagenic effects decreased from 3.85 (MR/L) to 2.97 (MR/L) in TA98-S9 and 1.98 (MR/L) to 1.18 (MR/L) in

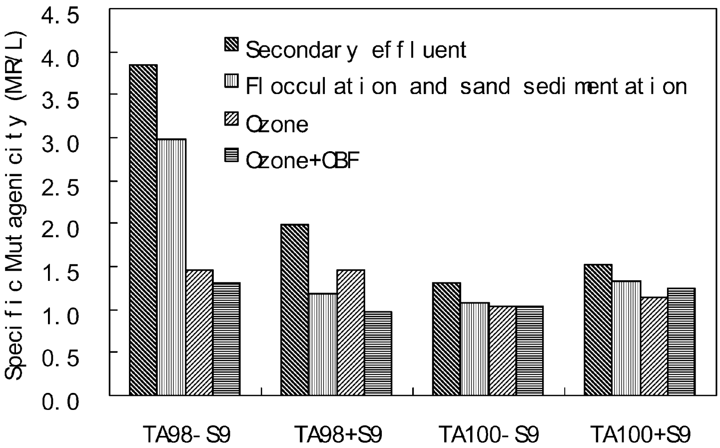

Fig. 8 Variations of specific mutagenicity.

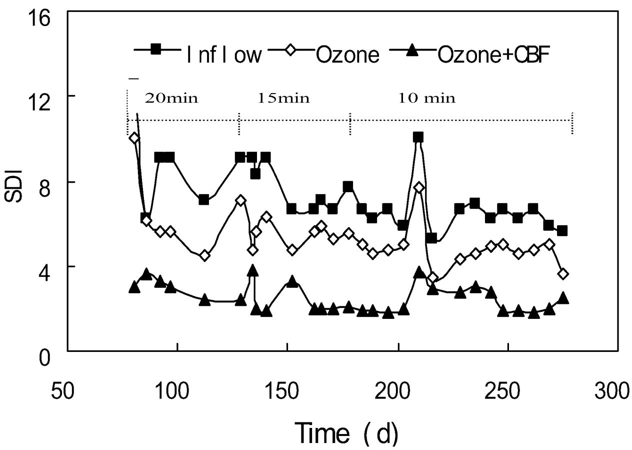

Fig. 9 Variations of SDI with time.

TA98+S9, indicating that conventional treatment could not efficiently remove the direct frame-shift mutagens. The mutagenic activity in TA98-S9 decreased from 2.97 to 1.45 (MR/L) by O_3, and to 1.3 (MR/L) after CBF treatment. The results demonstrated that ozone is very useful in ensuring water safety by effectively removing mutagens from the reclaimed wastewater.

Removal of SDI

In some cases, RO or NF would require removal of minerals from the reclaimed water. In order to obtain a stable membrane flux, it is usually recommended that the SDI of feed water should be below 4. So, variations of SDI during the O_3-CBF treatment were also checked, and the results are shown in Figure 9. The inflow SDI was 7.7, which decreased to 5.6 following ozonation, and was constantly below 4 after CBF treatment, indicating that the combination of O_3 and CBF can be used as an efficient pretreatment for RO system.

Conclusions

The performance of O_3-CBF treatment process was investigated for the safe reclamation of municipal wastewater, and the following conclusions can be derived:

- The long term test shows that the O_3-CBF treatment following coagulation, sedimentation and sand filtration could remove COD_{Mn}, DOC, UV_{254}, and chroma by 31.0, 24.0, 42.2 and 79.3%, respectively, under the conditions of ozone consumption of 5 mg/L and CBF's HRT of 10 min. With an SDI lower than 4, the treated effluent was suitable as the feeding water of RO systems.
- The O_3-CBF effectively removed mutagens from the reclaimed wastewater, which could be removed by the conventional treatment process.
- E. coli, which exists at a high level even after sand filtration, could be effectively inactivated by ozone. Almost complete inactivation of E. coli could be achieved at an ozone consumption dose of 12 mg/L.

Acknowledgement

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Sustainable Water Management of Reclaimed Water Use: Case Study of Tianjin

Xu He and Wen Chen

Abstract Tianjin, due to its severe shortage and inefficient use of water resources, is now facing many problems such as quality of soil substance, pollution from wastewater irrigation, etc., which will restrict sustainability in the development of its social economy. As a potential new and unconventional water resource that has proved to be useful elsewhere, reclaimed water can be used broadly to improve the unsatisfactory state of water utilization in Tianjin. In this paper, based on an analysis of the status quo of an existing reclaimed water use project and associated plans for future reclaimed water utilization, the authors discuss the problem in detail, and put forward some alternative suggestions and recommendations to improve the sustainable management of reclaimed water utilization in Tianjin.

Key words: Reclaimed water, sustainable management, Tianjin, wastewater treatment

Introduction

As we know, Tianjin is badly short of water resources and is famous for its scarcity of freshwater, not only because of natural, geographic and climatic conditions but also because of its current inefficient use of water resources. The existing water sources cannot satisfy the demand, which results in overexploitation of groundwater and many associated problems. In Tianjin, the water availability per capita is 160 m^3 which is only 1/15 that of the national average and 1/60 of the world average. Even with the transferred water added, water availability per capita is less than 360 m^3 which is also far lower than the national average of 2,200 m^3. Thus, Tianjin suffers from a severe water shortage. As a result of limitations on its traditional management system, immaturity of its relative policies and regulations, failure of the marketplace

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to play the powerful role that it should, lack of funding for reutilization programs, etc., the rate of re-circulating utilization of the limited water resource that does exist is still very low. A large-scale industry to use the reclaimed water has not yet been formed; the waste of the secondary effluent water has been very serious; and benefits from saving water have not been fully demonstrated. Thereby, speeding the pace of popularizing the use of reclaimed water and improving the efficiency of the scientific use of water resources are very important study subjects that we are addressing today.

Methodology

This paper is based on a case study funded by the Institute for Global Environmental Strategies (IGES). The general approach in this research is to collect information through survey of experts and interested parties, expert interviews, together with a review of comprehensive literature including chronological statistics yearbooks and various professional documents. At the end of the report, based on the data collected, the authors analyze the existing problem of water use in Tianjin and put forward alternative suggestions and recommendations.

Reclaimed water use in Tianjin

The so-called “reclaimed water” is wastewater that has been subjected to secondary and deep processes to meet a certain water quality standard and can be used for industrial production, agricultural irrigation, daily living, etc. Presently in Tianjin, there is no large-scale utilization of reclaimed water; however, systems of wastewater recycling and reutilization have been developed in many places. In this paper we discuss in detail two specific reclaimed water projects, one in Jizhuangzi and the other in the Technologic-Economic Development Area (TEDA) of Tianjin.

Jizhuangzi Reclaimed Water Use Project

The Jizhuangzi reclaimed water use project, which has the broadest use and the most advanced technique among the pilot projects of China, includes a wastewater treatment plant, a reclaimed water plant and a water transportation network. Some characteristics of these plants are listed in Table 1.

Table 1 Characteristics of Jizhuangzi wastewater treatment plant and reclaimed water plant.

Item	Jizhuangzi WTP	Jizhuangzi RWP
Time of putting in to service	1984	2002
Design scale	260,000 m^3/d	30,000+30,000 m^3/d
Treatment technique	A/O	CMF+O_3
Influent water	Wastewater	Water from Jizhuangzi WTP
Effluent water	Secondary effluent	Reclaimed water
Effluent water drainage	Discharge into Dagu Drainage channel	Used for landscape or industrial cooling water

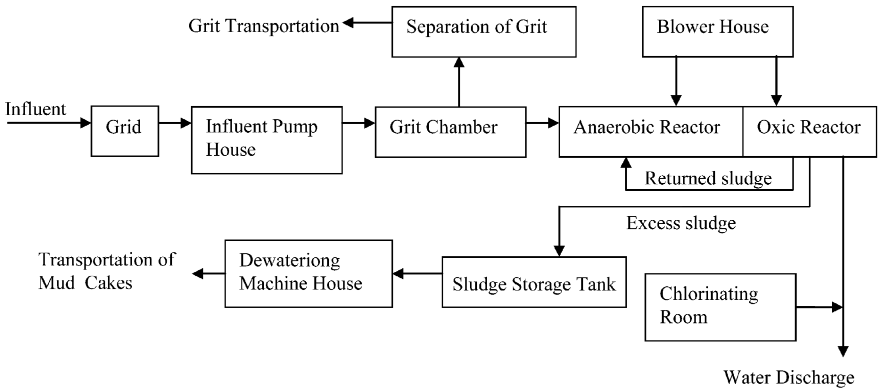

Fig. 1 Process flow of wastewater treatment in the Jizhuangzi WTP.

The Jizhuangzi Wastewater Treatment Plant

The Jizhuangzi wastewater treatment plant, the first large-scale urban wastewater treatment plant in China, mainly treats wastewater from Heping District, Hexi District, and Nankai District. In this plant, a technique called Anaerobic-Oxic (A/O) dephosphorization craft is used. As shown in Figure 1, after being given a primary treatment such as gridding or sedimentation, the wastewater enters an activated sludge reactor. The former part of this tank is anaerobic, and the latter is oxic, in which a large proportion of the phosphor compounds will be removed, and the wastewater will be purified.

The Jizhuangzi Reclaimed Water Plant

In this plant, there are two different kinds of treatment process. The first one is a traditional process designed for industrial use which employs the processes of coagulation, sedimentation, ordinary filtration and disinfection, as is shown in Figure 2. The design scale of the traditional treatment process is about 30,000 m^3/d, and the

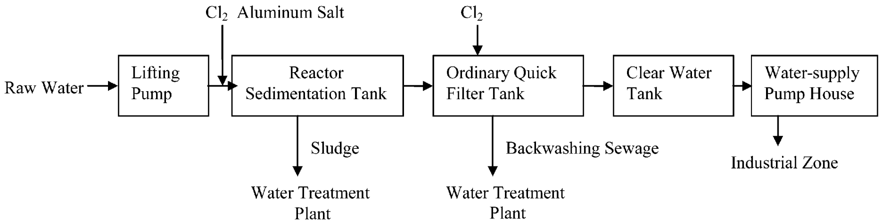

Fig. 2 Process flow of traditional water treatment in the Jizhuangzi RWP.

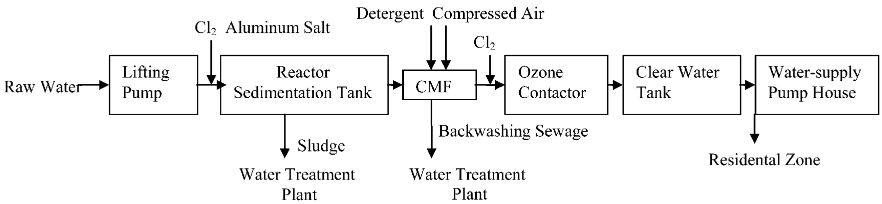

Fig. 3 Water treatment process flow of CMF+O_3 in the Jizhuangzi RWP.

reclaimed water will be used for industrial cooling or industrial production, such as paper mills, or a thermal power plant in the Chentangzhuang industrial area.

The other treatment technique is CMF+O_3. The process of this technique is almost the same as that of the traditional technique. It is different in that an advanced filtration called continuous micro-filtration (CMF) is adopted, replacing the ordinary filtration, and a process of ozone oxidation is added between CMF and disinfection. That is the very reason the water quality is much better than that of the traditional process. In this project, the design scale of the new treatment process is about 30,000 m^3/d, whose effluent water will be transferred to many residential areas such as Meijiang, Meijiangnan, Weinanwa, etc., and be used for toilet washing, greenbelt watering, landscape and so on.

Reclaimed Water Use Project in TEDA

TEDA Wastewater Treatment Plant

In TEDA WTP, a technique of DAT-IAT (Demand Aeration Tank – Intermittent Aeration Tank) is used to treat wastewater. In general, wastewater is fed into the DAT in continuous flows at intermittent intervals; the effluent of DAT also enters IAT continuously, and com- pletes other working procedures including reaction, sedimentation etc. The typical work flow of DAT-IAT is shown as follows.

By using a management style of central control together with decentralized local management, the management layer and control layer can be distinguished. As a

Table 2 Characteristics of TEDA wastewater treatment plant and reclaimed water plant.

Items	TEDA WTP	TEDA RWP
Time of putting in to service	1999.12	2003.4
Design scale	100,000 m^3/d	20,000+10,000 m^3/d
Treatment technique	SBR–DAT/IAT	CMF+RO
Influent water	Wastewater	Water from TEDA WTP
Effluent water	Secondary effluent	Reclaimed water
Effluent water drainage	–	Used for landscape or industrial production

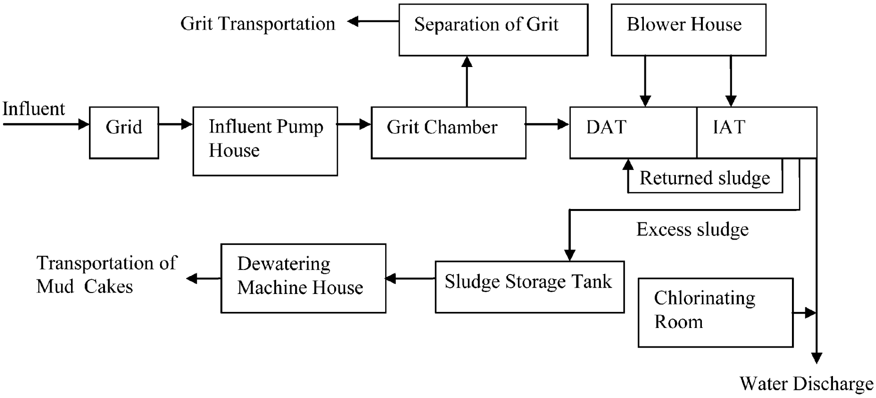

Fig. 4 The process flow of wastewater treatment in the TEDA WTP.

result, the impact of any failure in operation of the process will be reduced, while the reliability of the wastewater treatment system will be increased.

TEDA Reclaimed Water Plant

In the reclaimed water plant of TEDA, an international advanced deep water treatment process called “double-membrane” is used, with a purified technique of continuous microfiltration (CMF) in water pretreatment, and a desalination technique of RO in the main treatment process, as is shown in the following figure. In this process, those matters including SS, bacteria, and organisms whose diameter is larger than that of the membrane, will be dealt with, and the water will be purified.

The total scale of the TEDA RWP is 30,000m^3/d, of which 10,000m^3/d with entirely treated water is used for industrial production and daily life use of TEDA, and 20,000m^3/d, being treated only by CMF, is used for landscape and green watering.

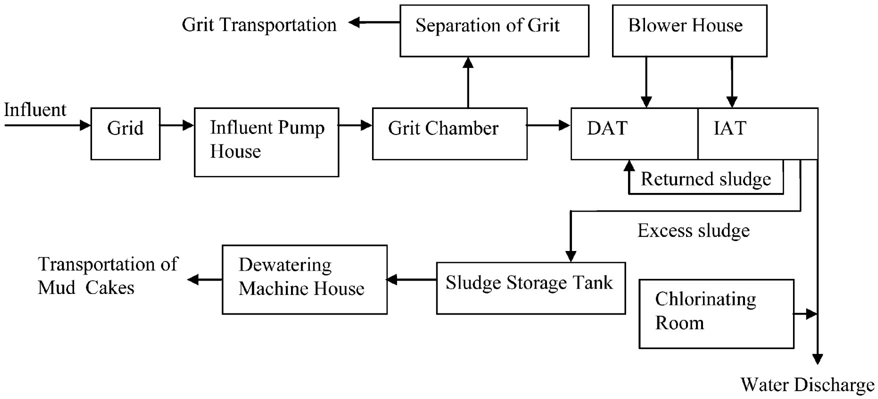

Fig. 5 The process flow of wastewater treatment in the TEDA reclaimed water plant.

Future Reclaimed Water Use Project in Associated Plans

According to the "Plan of the Reclaimed Water Use in Urban Areas of Tianjin", the reclaimed water will be mainly used in the central areas of the city and the areas within 5 km outside of the outer ring road, especially for those of domestic life, industrial cooling, landscaping and agriculture irrigation, whose requirements for water quality are comparatively low and whose consumption of water is great. Besides, a centralized utilization style of reclaimed water will be the main stream in the future, with the decentralized utilization as a supplemental measure.

Different Systems of Public Reclaimed Water in the Urban Area of Tianjin

To make full use of reclaimed water, achieve the optimal allocation of water resources, and meet the requirements for safe water supply in the city, wastewater treatment plants will become centers for the production of reclaimed water and public reclaimed water plants will be constructed at the same time. This decision is based on the relevant policies set by the country, with due consideration to the characteristics of Tianjin and the limited time period of the plan. By 2010, six water supply centers for public reclaimed water will be built in the central city (Table 3).

According to the capacity and service area of those public reclaimed water plants, the system of reclaimed water supply in the urban area of Tianjin can be divided as shown in Figure 6. Those systems are relatively independent, also connected, and form a multi-source water supply system.

Table 3 Public reclaimed water supply sources in the urban area of Tianjin.

No.	Reclaimed Water Supply System to Be Built	Service Area of Each System (km^2)	Design Scale of Reclaimed Water Plant (ton/d)
1	Xianyanglu	72.6	220,000
2	Dongli	52.9	170,000
3	Shuanglin	13.7	60,000
4	Beicang	83.3	160,000
5	Zhangguizhuang	45.6	160,000
6	Jizhuangzi	65.1	150,000

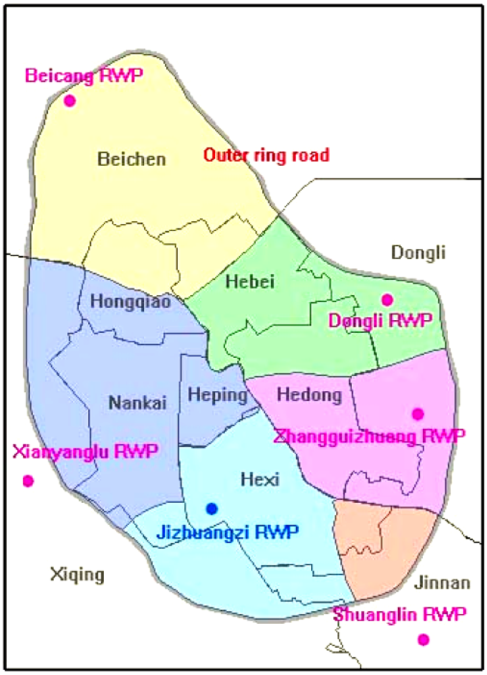

Fig. 6 Reclaimed water supply system of Tianjin.

Existing Problems, Challenges and Recommendations in Sustainable Management of the Reclaimed Water Utilization in Tianjin

Although remarkable progress on wastewater reuse has been made in Tianjin since 2000, there continue to exist many problems in the fields of management, law and regulation, water market, and technology, which need to be resolved as soon as possible.

Management Mechanism

Presently in Tianjin, water is managed by many kinds of authorities separately, e.g., water allocation is conducted by the Water Conservancy Bureau, while reclaimed water use is under the control of the Municipal Engineering Bureau. They fail to reach an accordant management in water affairs, and every unit conducts their own management according to their own policies. As a result, the whole situation falls into disorder and it is very difficult to achieve harmony allocation and development of water sources on the whole. Considering the decentralized management of water resources in Tianjin, a ?team to guide the work of water re- sources utilization in Tianjin? should be set by the municipal government to manage and allocate the utilization of water resources by integrated planning, and a system of mediating water affairs by share holders should also be established as soon as possible.

Reclaimed Water Price and Economic Stimulation Mechanism

Currently, the surface water price in Tianjin is about 1.0 RMB/tons, and the price of groundwater is about 0.5 RMB/tons, while for reclaimed water, its price is 1.3 RMB/tons on average. As a result, enterprises would prefer to use surface water and groundwater rather than reclaimed water. At the same time, because of the early stage of reclaimed water use, relative fostering policies are very few. According to existing regulation, the city water supply section carries a value-added tax of 6%, but because the business of reclaimed water does not belong to this category, a tax of 17% is levied for all reclaimed water, which weakens the competitive power of this industry. So, to quicken the utilization of reclaimed water, a rational price system must be formed to demonstrate the price advantage of reclaimed water. Prices of tap water and well water will be boosted gradually to extend the price gap between reclaimed water and other water resources. Besides, companies providing reclaimed water should be offered support with respect to credit, revenue taxation, and other aspects. The government should offer appropriate allowances to those reclaimed water companies who can not sell the water at its cost temporarily, and necessary allowance should be granted for the use of reclaimed water in agriculture. While for those companies who use reclaimed water according to relevant regulations, they should be awarded for saving water and treated as environment protecting companies; and their construction and operation fees also should be reduced and/or remitted.

Planning Infrastructure

In Tianjin, there exist several reclaimed water use projects, which are capable of providing a large volume of reclaimed water. However, because of faults in the water pipe network, the reclaimed water cannot be transferred to other locations; so, it has to be discharged into the drainage system of the city and cannot be reused.

In order to solve this problem, many measures could be taken. For instance, pipe networks along roads must be considered during the design of the overall road system and construction of residential communities in the city; if possible, pipes for reclaimed water should be buried first to avoid necessary future destruction of the roads for setting the pipes; watercourses used to transfer reclaimed water should be maintained properly to make sure that water can be drained smoothly; and the sullage in the bottom of river ways should be cleaned regularly to avoid secondary pollution during transfers of reclaimed water.

Support for Science and Technology

At present, to realize a sufficiently wide use of reclaimed water, the support of mature techniques is still lacking, and quality standards for water, i.e., examination, monitoring and other relevant techniques for solving problems, have not been established. There exist many questions, for example, what crops can be irrigated with reclaimed water? How can we design a program to achieve safe irrigation? What should be the irrigation regulations? How can we assess the impacts of reclaimed water irrigation on the soil, groundwater and crops?

The development of utilization of reclaimed water must depend on the development of science and technology. Advanced techniques are necessary for endurance and support. If reclaimed water is to be used safely in agriculture, ecology, municipal works and industry, attention must be paid to the study of water purification, water stability and insurance of intelligent management of proven techniques related to the facilities. In addition, attention also must be paid to establishment of model projects. For instance, model projects for utilizing reclaimed water in agriculture should be built as soon as possible to make the problems and solutions clear: what crops can be irrigated by reclaimed water; how to design a safe irrigation process; how to set irrigation regulations; how to assess the ecological influence of reclaimed water irrigation on soil, groundwater, and crops; and how to regulate the techniques of water storage. At the same time, analysis and assessment of the benefits and risks should be made in time, for effective control and management. In this way, safety concerning the utilization of reclaimed water will be improved and ensured.

Laws and Policies

In order to advance the standardization of the use of reclaimed water, a set of criteria for water quality standards and wastewater reuse techniques criterion must be developed and implemented as soon as possible. Such as, water quality standards for different grades of reclaimed water; quality standards for wastewater discharge; regulations set for the design of reclaimed water utilization projects, laws for the construction, operation, management and supervision of these projects etc. In this period, a set of especially important factors should be taken into consideration, such as reclamation processes, pathogens removal, typical water quality index, performance control & monitoring, etc.

Supervision System and Public Participation

Specific institutions and departments should be set to deal with the problems of the regeneration and reuse of wastewater; the responsibilities of these departments are to manage the facilities and pipe networks; be in charge separately of examination and operation of the projects, supervise water fees and water quality; and develop relevant policies or regulations concerning reclaimed water use and reclaimed water quality; establish associated plans for emergent situation and other relevant issues. Besides, It is necessary to make the public realize the severe situation of water scarcity and the necessity of using reclaimed water. Knowledge of reclaimed water should be popularized among the public to facilitate the further utilization of reclaimed water.

Acknowledgement

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Organic Hindrance in Groundwater Arsenic Removal Practice

Khondoker Mahbub Hassan, Kensuke Fukushi, Fumiyuki Nakajima and Kazuo Yamamoto

Abstract Arsenic contamination of groundwater has been reported in several Asian countries. Particularly in view of the presence of elevated levels of iron in groundwater, large numbers of arsenic and iron removal units were installed in many regions. The geochemical and biological importance of organic matter interactions for arsenic sorption and mobility is great. This study revealed the influence of organic matter on the arsenic treatment process for drinking water. Organic contamination in the treatment process caused high concentrations of arsenic in effluent water. Types of organic matter also influenced the removal efficiencies of arsenic and iron. Nevertheless, bioleaching of arsenic from the accumulated As-Fe precipitates in the filter bed was evident in the non-operational stagnation condition of the treatment units. In this study, the chemical and biological effects of organic contamination on the arsenic removal practice is elucidated, which might contribute in designing safe options for drinking water.

Key words: Adsorption, arsenic and iron removal unit, bioleaching, organic matter

Introduction

The incidence of high concentrations of arsenic in drinking-water has emerged as a major public-health concern in several parts of the world. With newer-affected sites discovered during the last decade, a significant change has been observed in the global scenario of arsenic contamination, especially in Asian countries. Before

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2000, Bangladesh, West Bengal in India and sites in China were the major incidents of arsenic contamination in groundwater. Between 2000 and 2005, arsenic-related groundwater problems have emerged in different Asian countries, including new sites in China, Mongolia, Nepal, Cambodia, Myanmar, Afghanistan, DPR Korea, and Pakistan (Mukherjee et al., 2006). There are reports of arsenic contamination from Kurdistan province of Western Iran and Vietnam where several million people may have a considerable risk of chronic arsenic poisoning. During 1998, 41 of the 64 districts in Bangladesh were identified as having concentrations of arsenic in groundwater exceeding 50 μg/L (Sengupta et al., 2003). It is apparent from the current arsenic research in China that the epidemic area is still expanding. Recent updates on chronic arsenicism in PR China (Xia and Liu, 2004) state that, up to now, chronic arsenicism via drinking-water was found in Taiwan, Xinjiang, Inner Mongolia, Shanxi, Ningxia, Jilin, Qinghai, and Anhui provinces, and in certain suburbs of Beijing. In a long-term survey on 140,150 water samples from hand-tubewells in West Bengal found that 48.2% had arsenic concentrations of > 10 μg/L (WHO guideline value for drinking water) and 23.9% had > 50 μg/L (Mukherjee et al., 2006). Arsenic contaminations of the Red River Delta in Hanoi city and the surrounding rural districts of Vietnam were first reported in 2001 (Berg et al., 2001). Analysis of raw groundwater pumped from the lower aquifer for the Hanoi water supply showed arsenic levels of 240–320 μg/L in three of eight arsenic treatment plants. In Cambodia, the natural arsenic originates from the upper Mekong basin, and is widespread in soils. Within the lower Mekong delta, 5.7% of all groundwater samples exceeded 50 μg/L, while 12.9% exceeded 10 μg/L (Stagner et al., 2005). A small scale health survey conducted in Myanmar in 2002 observed that 66.6% of the water samples from wells have arsenic levels of > 50 μg/L (Tun et al., 2002). In 1987, skin manifestations of chronic poisoning of arsenic were first diagnosed among the residents of Ronpibool district of Thailand (Choprapawon and Rodcline, 1992). The people of this district use water, which drains from the highly-contaminated areas of the Suan Jun and Ronna Mountains having 0.1% arsenopyrite.

Mobility of arsenic is primarily controlled by sorption onto metal oxide surfaces and the scope of this sorption is highly influenced by the presence of organic matter. Ligand exchange-surface complexation, between carboxyl/hydroxyl functional groups of organic matter and metal hydroxides, was found as the dominant interaction mechanism, under circumneutral pH conditions (Gu et al., 1994). Therefore, they tend to compete with arsenic anions for adsorption to the solid surfaces. However, organic decomposition due to microbial action may lead to anaerobic conditions and hence anaerobic bacteria can greatly affect the mobilization of arsenic from the associated solid phase by either an indirect or a direct mechanism (Zobrist et al., 2000). The former is the reductive dissolution of iron hydroxide minerals, leading to the release of associated arsenic into solution. The latter is the direct reduction of arsenate associated with a solid phase to the less adsorptive arsenite. The reaction is energetically favorable when coupled with the oxidation of organic matter because the arsenate/arsenite oxidation/reduction potential is +135 mV (Oremland and Stolz, 2003). Thus, organic matter present in groundwater and from

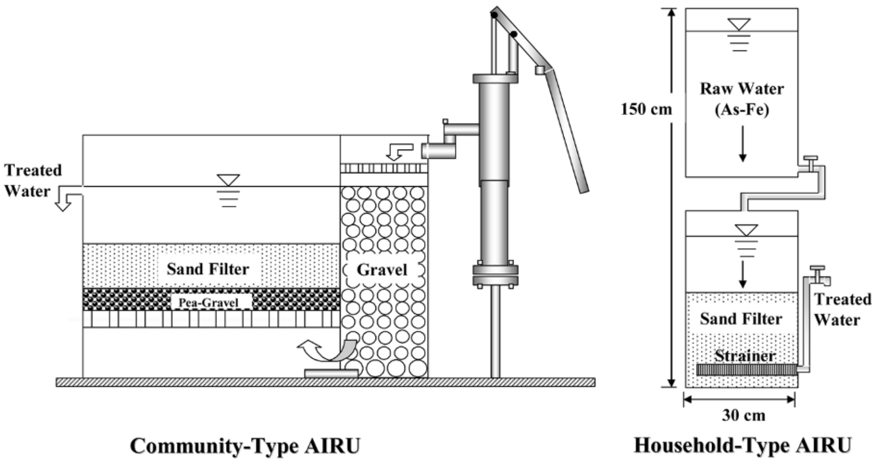

Fig. 1 Typical arsenic and iron removal units (AIRU).

unsanitary operation and maintenance of the arsenic and iron removal units (Figure 1) would greatly influence on the treatment performance. This study revealed the consequence of organic contamination on the arsenic removal practices through chemical and biological processes.

Materials and Methods

Preliminary minor-scale field inspection was made in Bangladesh to estimate the level of organic contamination in the existing arsenic and iron removal units and their removal performances. Then, in the laboratory study, household-type AIRU (Figure 1) was tested under variable dosages of organic matters. The sand (effective size, $D_{10} = 0.4$ mm; uniformity coefficient, $U_C = 1.7$) filter bed having a depth of 300 mm was used. The filtration rate was kept around 0.6–0.7 m/hr, which is the highest permissible filter loading rate for slow sand filtration (Montgomery, 1985). Contaminated groundwater was prepared artificially using a stoichiometrically calculated amount of arsenate (H_3AsO_4) and ferrous sulphate ($FeSO_4 \cdot 7H_2O$) in Milli-Q water and then the pH was adjusted to 7 by using sodium hydroxide (NaOH) reagent. The simulated wastewater was prepared by using tryptone (T), yeast extract (Y) and glucose (G) in pure water following Standard methods (2005) for plate count (G:Y:T · 1:2.5:5 wt/wt) excluding agar. Laboratory reagent grade chemicals from BD, USA were used in the above preparation. Moreover, humic acid, contributing the major part of organic contents in groundwater, was used separately to find its impact on the arsenic and iron re- moval performances in AIRU. Humic acid reagent grade chemicals from Aldrich, USA was used in this study. Each organic contamination dosage was maintained for 10 bed volumes (volume of permeate/volume of filter bed) of effluent water and sampling was done at the end of the operational phase. On the other hand, observation of arsenic bioleaching from the accumulated As-Fe precipitates in sand filter bed was conducted under the nonoperational stagnation condition of the treatment units and the sampling interval was 24 hours. In another observation, antibiotic (tetracycline hydrochloride, 8 mg/L) was added to control the microbial activity in the bioleaching process. The treatment units were operated in both the "continuous flow" and the "intermittent flow" modes as per usual practice at the field level. Laboratory analyses for total arsenic and iron concentrations in sample waters were carried out by inductively coupled plasma mass spectrometry (ICP-MS, hp 4500, Yokogawa), which allowed detection of arsenic and iron species with limits of 2 and 0.3 ng/L, respectively. The organic matter concentrations in stock solution and in other water samples were determined by using a total organic carbon analyzer (TOC-VCSH, Shimadzu), which allowed detection limit of 4 µg C/L. Standard methods (APHA et al., 2005) were followed in all laboratory analyses of the test samples.

Results and Discussion

Field Inspection of the Treatment Units

Influent and effluent water samples from the six AIRUs (I VI) at the field level were collected from arsenic contaminated groundwater areas in Bangladesh. Laboratory analyses of the field water samples concluded that most of the groundwater sources had significant organic contamination (Table 1). In AIRUs (I–IV), in spite of having adequate iron concentrations 3.4–6.9 mg/L in the influent water to enable adsorption and co-precipitation of arsenic, the effluent arsenic concentrations were beyond 50 µg/L, which is the acceptable limit of Bangladesh standards for drinking water. In these cases, significant organic contaminations 25.8–51.4 mg/L of TOC were observed in the influent water. High organic concentrations in the influent water might hamper the arsenic treatment process, and ultimately high concentration of arsenic would appear with the effluent water. On the other hand, for AIRUs (V and VI), which were free from organic contamination and having iron concentrations of 2 and 5 mg/L, respectively, in the influent water could satisfactorily treat the arsenic concentration less than 40 µg/L in the effluent water. Significant organic contamination in the effluent water from AIRU-A (household-type) was noticed, possibly due to less efficient filtration process in comparison to all other community-type units.

Table 1 Effect of influent organic concentrations on the arsenic removal performance through field-AIRUs in Bangladesh.

Field	Influent Water Quality				Effluent Water Quality		
AIRUs	pH	As (μg/L)	Fe (mg/L)	TOC (mg/L)	As (μg/L)	Fe (mg/L)	TOC (mg/L)
I	6.9	202	5.5	51.4	85	0.2	45.1
II	7.1	211	5.0	38.0	99	0.8	<0.004
III	7.0	199	6.9	28.1	56	1.2	<0.004
IV	7.0	182	3.4	25.8	83	0.1	<0.004
V	7.1	98	2.0	0.2	39	0.1	0.7
VI	7.0	160	5.0	<0.004	32	0.6	<0.004

AIRU-I was a household-type unit while all others (II–VI) were community-type units.

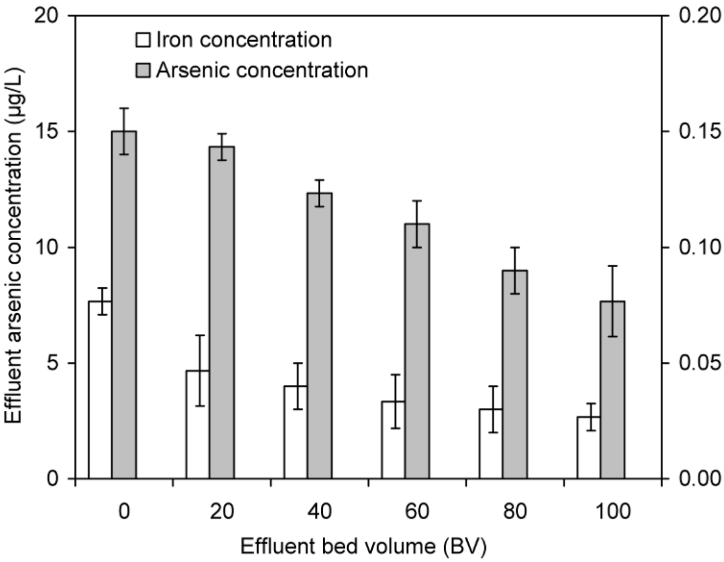

Fig. 2 Arsenic and iron removal performance of laboratory AIRU (control) which was free from organic contamination. Arsenic and iron were spiked in influent water to concentrations of 500 μg/L and 5 mg/L, respectively. Column values represent the average of triplicate samples, and error bars show the range of standard deviation.

Performance of the Laboratory AIRU

The removal efficiency of arsenic and iron in the developed AIRU at the laboratory was monitored in controlled conditions where organic contamination was totally avoided. Arsenic and iron concentrations in effluent water never exceeded 15 μg/l and 0.1 mg/L, respectively from their influent concentrations of 500 μg/l and 5 mg/L, respectively indicating removal efficiencies over 97% for arsenic and 98% for iron (Figure 2). Gradually higher removal performance with increased bed volume of treated water was due to deposition of iron hydroxides within the in-

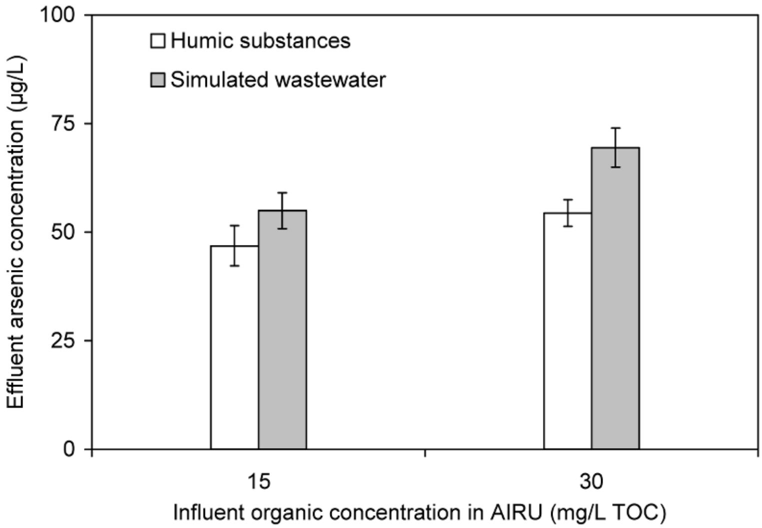

Fig. 3 Effect of influent organic concentrations and types on the arsenic removal performances in laboratory AIRU. Arsenic and iron were spiked in influent water to concentrations of 500 µg/L and 5 mg/L, respectively.

terstices of the filter bed media which provided increased adsorption surfaces and mechanical straining as well.

Organic Matter Causes Chemical Leaching of Arsenic in AIRU

The leaching of arsenic and iron through chemical phenomena in the presence of organic matter in AIRU feed water was investigated under dosage-response observations in multiple sets of laboratory reactors. In case of simulated wastewater organic contaminations of 15 mg/L and 30 mg/L of TOC in the influent water of the AIRU, arsenic concentrations of 55 µg/L and 70 µg/L, respectively was observed in the effluent water (Figure 3), whereas, in absence of organic contamination, effluent arsenic concentration never exceeded 15 µg/L (Figure 2). Ligand-exchange surface complexation, between anionic functional groups of organic matter and iron hydroxide, is similar to that proposed for the sorption of arsenic and, therefore, organic matter tends to compete with arsenic for adsorption to the solid surfaces (Xu et al., 1988). Thus, a high concentration of arsenic unable to co-precipitate with the iron hydroxide solid phase due to competitive binary adsorption with organic matter appeared with the effluent water. The organic contents in groundwater are mostly contributed by humic substances. Thus, the impact of humic acid contamination on the arsenic and iron removal performances in treatment units was also studied. The concentration of arsenic with effluent water in this case was less in comparison to

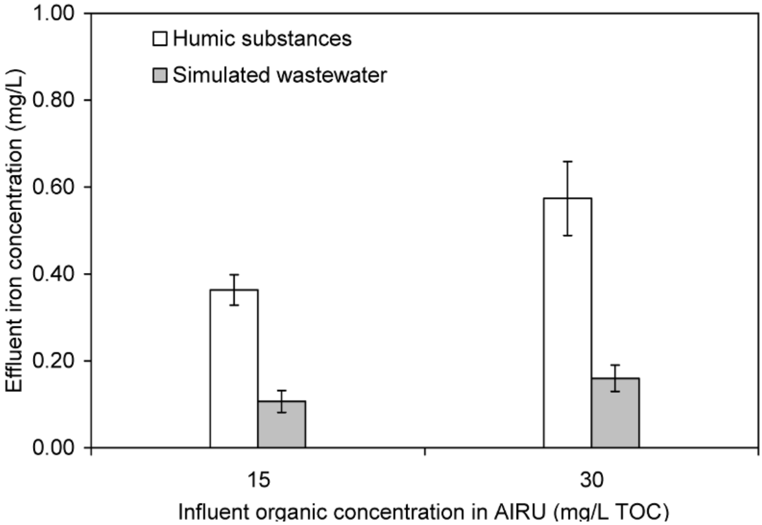

Fig. 4 Effect of influent organic concentrations and types on the iron removal performances in laboratory AIRU. Arsenic and iron were spiked in influent water to concentrations of 500 µg/L and 5 mg/L, respectively.

previously used simulated wastewater, possibly due to having fewer adsorption sites in higher molecular weight humic acids.

On the other hand, iron concentration with effluent water was found to be higher in case of humic acid contamination (Figure 4), possibly due to delaying the precipitation process of iron hydroxides. A physiochemical explanation for the decrease in hydration reaction has been proposed by Ong and Bisque (1968) on the basis of the Fuoss-effect. Mutual repulsion of the negatively charged functional groups of humic acid (carboxyls and hydroxyls) causes the polyelectrolyte to adopt a stretched configuration. Cations like ferric ions attaching themselves to the negatively charged groups cause a reduction in the intermolecular repulsion in the polymer chain favoring coiling. Coiling expels a portion of the water of hydration that surrounds the molecule, changing it from hydrophilic to a hydrophobic colloid. Thus, the soluble complexes of iron-humic substances appeared with effluent water.

Organic Matter Causes Bioleaching of Arsenic in AIRU

Bioleaching of arsenic and iron were studied in the laboratory under nonoperational stagnation conditions of the AIRU. Initially, formation of aerobic biofilm within the AIRU sand filter bed due to microbial degradation of organic matter (GYT) was responsible for the greater retention of As-Fe precipitates (Figure 5). In the course of biodegradation of organic matter, dissolved oxygen was used up by microbial action.

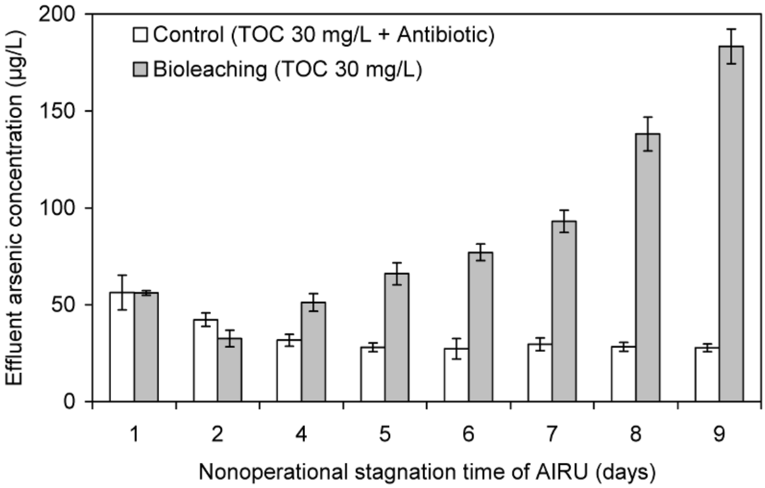

Fig. 5 Effect of organic contamination (30 mg/L of TOC) on the bioleaching of arsenic from the accumulated As-Fe precipitates in a filter bed under nonoperational stagnation condition of the AIRU at the laboratory.

A fully anaerobic condition was observed within the accumulated As-Fe precipitates in the sand filter bed through micro-electrode studies for dissolved oxygen concentration (data not shown). Gradually increased arsenic concentration in effluent water was found in organic contaminated bioleaching observation, possibly due to microbial action. The initial decreasing pattern of arsenic leaching in control observation, where organic matter (GYT) and antibiotic were used simultaneously, was due to less stable iron-arsenic complexes, which were driven out at the first stage. On the other hand, effluent iron concentration in organic contaminated bioleaching observation was always less than 0.22 mg/L (data not shown). It was evident from other studies that arsenic release from contaminated soils and sediments proceeds considerably faster under conditions favoring dissimilatory reduction of ferric iron leading to the dissolution of sorbing phases (Langner and Inskeep, 2000) and the reduction of arsenate plays a relatively minor role in the solubilization of arsenic sorbed to iron hydroxides. The top layer of the sand filter bed contained the major portion of As-Fe precipitates. Under anaerobic condition, bioleaching of arsenate, arsenite and ferrous iron took place. In the course of sampling and collection of effluent water, intrusion of the supernatant aerobic water occurred. Thus, ferrous iron became oxidized to insoluble ferric iron and was trapped by the mechanical straining mechanism. Due to inadequate concentration of the ferric hydroxide solid phase at the bottom part of the sand filter bed, adsorption of arsenic was limited. As a result, the effluent arsenic concentration was high while the iron concentration was less.

Conclusions

For thousands of years, groundwater has served as a unique and reliable source of potable water in developed as well as developing countries in Asia. High concentration of arsenic in drinking water and the food chain has caused severe health problems in many regions. It is necessary to seek techniques of low-cost arsenic removal from groundwater suitable for drinking and irrigation purposes in those areas. Organic matters prevailing in groundwater and also from external contamination of the treatment units, substantially affect the arsenic removal process. This study exposed the chemical and biological incidents concerning the consequence of organic contamination on the arsenic removal practice as outlined below:

- organic matter impedes the sorption process of arsenic into an iron hydroxide solid phase in the AIRU treatment process and consequently instantaneous leaching of arsenic with effluent water was noticed depending on organic types and concentrations; and
- bioleaching of arsenic from the accumulated As-Fe precipitates in a filter bed was found in organic contamination under nonoperational stagnation conditions of the AIRU.

Thus, the geochemical and biological importance of organic matter interactions for arsenic sorption and mobility is great and it deserves special attention as well as international programs on drinking water issues.

Acknowledgement

This work was supported by the Japan International Cooperation Agency (JICA), the University of Tokyo, IR3S (through Special Coordination Funds for Promoting Science and Technology, MEXT, Japan), and JSPS (Kakenhi) Project No. 18404011.

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Factors Associated with Faecal Contamination of Household Drinking Water in a Rural Area, Vietnam

Vuong Tuan Anh, Kåre Mølbak, Phung Dac Cam and Anders Dalsgaard

Abstract A cross-sectional study was conducted in a rural district in the highland area of Vietnam in order to identify risk factors for faecal contamination of household drinking water. In the study, the water supplies of 146 households were assessed initially in the rainy season and then were reassessed in the dry season. Water sampling in water sources and at the point-of-use in these households was done in both seasons. Water samples were considered feacally contaminated if containing presumptive thermotolerant coliforms (pThC). Univariate and multivariate logistic regression were applied for data analyses. In water sources, the highest faecal contamination levels were seen in water from dug wells. Collecting water stored in household tanks by a hand-held ladle was a risk factor for faecal contamination for this water only in the rainy season. In spite of the widespread practice of boiling water for drinking purposes, 33 and 18% of boiled drinking water samples contained pThC in the rainy and dry seasons, respectively. Scooping water by a cup, a visually dirty container, and household size ≥ 5 members were risk factors for faecal contamination of boiled drinking water in the rainy season. In the dry season, only the scooping of water by a cup was a risk factor. In conclusion, scooping water by using a hand-held ladle or a cup is the most important risk factor of faecal contamination of household drinking water. Safe drinking water storage and appropriate handling combined with treatment in the households can effectively prevent faecal contamination of household drinking water.

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Key words: Drinking water, faecal contamination, risk factors, thermotolerant coliforms, Vietnam

Introduction

The World Health Organisation (WHO) recommends that water intended for human consumption should contain no micro-organisms, including disease causing pathogens or any bacteria indicative of faecal pollution. A detection of *Escherichia coli* (*E. coli*) or thermotolerant coliforms in water indicates a faecal pollution (WHO, 2004). In developing countries, drinking water is often collected from sources located at some distance from the household. Studies indicate that stored household water is frequently faecally contaminated either during collection from the source, during the transport and/or storage, and that such contamination poses risks of infectious diseases such as diarrhea to users (Sobsey, 2002; Gundry et al., 2004; Wright et al., 2004).

The total population of Vietnam is approximately 80 million, of which nearly 50% have access to unsafe water (Vietnam Ministry of Health, 2002). The majority of rural households use individual household water supply facilities such as dug wells, or rainwater tanks and 80% of individual rural water supplies are of poor quality (Vietnam Government, 2000). As reported by the Vietnam National Institute of Occupational and Environmental Health, faecal contamination of drinking water sources is widespread in the rural areas of Vietnam (Trung et al., 1999). Vinh (1998) found that dug wells in highland areas in southern Vietnam were highly faecally contaminated. The major aim of the present study was to assess important risk factors for faecal contamination of drinking water in (a) the water sources and (b) at the point-of-use in rural households in central highland area of Vietnam.

Area Description

Research was conducted in the Cu Jut district which is located south-east of the provincial capital Buon Ma Thuot city in the Dak Lak province in the central highlands of Vietnam. Presently Cu Jut district belongs to Dak Nong province. The district consists of 10 communes representing more than 10 different ethnic groups. The inhabitants are farmers with an average monthly per capita income of approximately US$2 at the time of the study. The rainy season in 2002 was from May to October and the subsequent dry season from November 2002 to April 2003 with ground water levels at their lowest at the end of the dry season.

Methods

Study Design, Study Population and Household Selection

Household interviews and water sampling were carried out at two points of time. We visited 146 households in the rainy season and re-visited these households in the dry season. Firstly, we selected randomly six communes from the 10 communes. Prior to the selection of households and based on available information, all households in the six selected communes were listed and classified according to what type of water source they used for the collection of drinking water. There were three types of water sources including dug well, borehole or mixed dug well-borehole. A mixed dug well-borehole is a well where a new borehole has been drilled at the bottom, typically protected by a plastic (PVC) tube. From each group of households using the same type of water source, we chose 52 households using dug wells, 47 households with boreholes, and 47 households using mixed dug well-boreholes as their main sources for water. In our study each household generally had their own private water source located within the household perimeter. Few households shared the same water sources. Water collected from sources then often was stored in main household tanks. For drinking, water was collected from the main household tanks and treated by boiling and filtering.

Water Sampling and Enumeration of Presumptive Thermotolerant Coliforms in Water Samples

During each household interview, water samples were collected from (a) the water source; (b) the main household tank; and (c) the small household container used for storage of treated drinking water. In the rainy season, we collected 143 source water samples, 136 tank water samples and 144 treated drinking water samples. In the dry season, due to some households not allowing us to sample water at their houses, we collected 104 source water samples, 100 tank water samples and 105 treated drinking water samples. Water samples from wells were collected with a special equipment allowing a sterile glass bottle to be filled below the water surface. Samples from household tanks were usually collected from a tap which was opened 30 sec before the water sample was obtained. Water samples from the small containers with treated drinking water were collected by pouring the water directly into a sterile glass bottle. The glass bottles (330 ml-volume) were immediately transported in insulated boxes with ice to a laboratory in Buon Ma Thuot city where the analysis was undertaken within the same day. Each water sample was analysed for numbers of presumptive thermotolerant coliforms (pThC) by a Most Probable Number (MPN) test tube method (3×5 test tubes) where lactose fermentation and gas production were assessed in tubes with MacConkey broth (Bio-Rad, Marnes-La-Coquette, France) incubated at $44 \pm 0.5°C$ for 24 hours with negative tubes being incubated for another 24 hours. The number of positive test tubes was noted and a MPN table was used to calculate the pThC numbers in 100 ml water (Gleeson and Gray, 1997). Water samples containing pThC were considered faecally polluted.

Data Collection and Analysis

Information about faecal pollution risk factors was collected through (a) household interviews with structured questionnaires and (b) observations during the interviews. The collected data were recorded in a spreadsheet (Microsoft Excel 2002) and then imported into the SPSS software version 10 for statistical analysis. Initial univariate analyses were done for all exposure variables to assess the effect of a number of independent variables on the binary dependent variable (the presence/absence of pThC in the water samples). Variables with p-values <0.1 in the initial univariate analysis were included in a multivariate logistic regression to assess the association between the exposure variables and the binary dependent variable. A full model was fitted and subsequently reduced in a stepwise fashion to a final model which only included variables with p-values ≤ 0.05.

Ethics

This study was approved by the Ethics Committee of the National Institute of Hygiene and Epidemiology, Hanoi, Vietnam. Before commencement of the study, all heads of households had given informed consent.

Results

In the rainy season, 104 (73%) of 143 samples of source-water, 127 (93%) of 136 samples of untreated water stored in household tanks, and 47 (33%) of 144 samples of treated household drinking water were faecally contaminated. In the dry season, faecal contamination was found in 83 (80%) of 104 samples of source-water, 91 (91%) of 100 samples of untreated stored household water and 19 (18%) of 105 samples of treated household drinking water. Interviews' results showed that drinking water was boiled in 144 (98%) and 142 (97%) study households in the rainy and dry seasons, respectively.

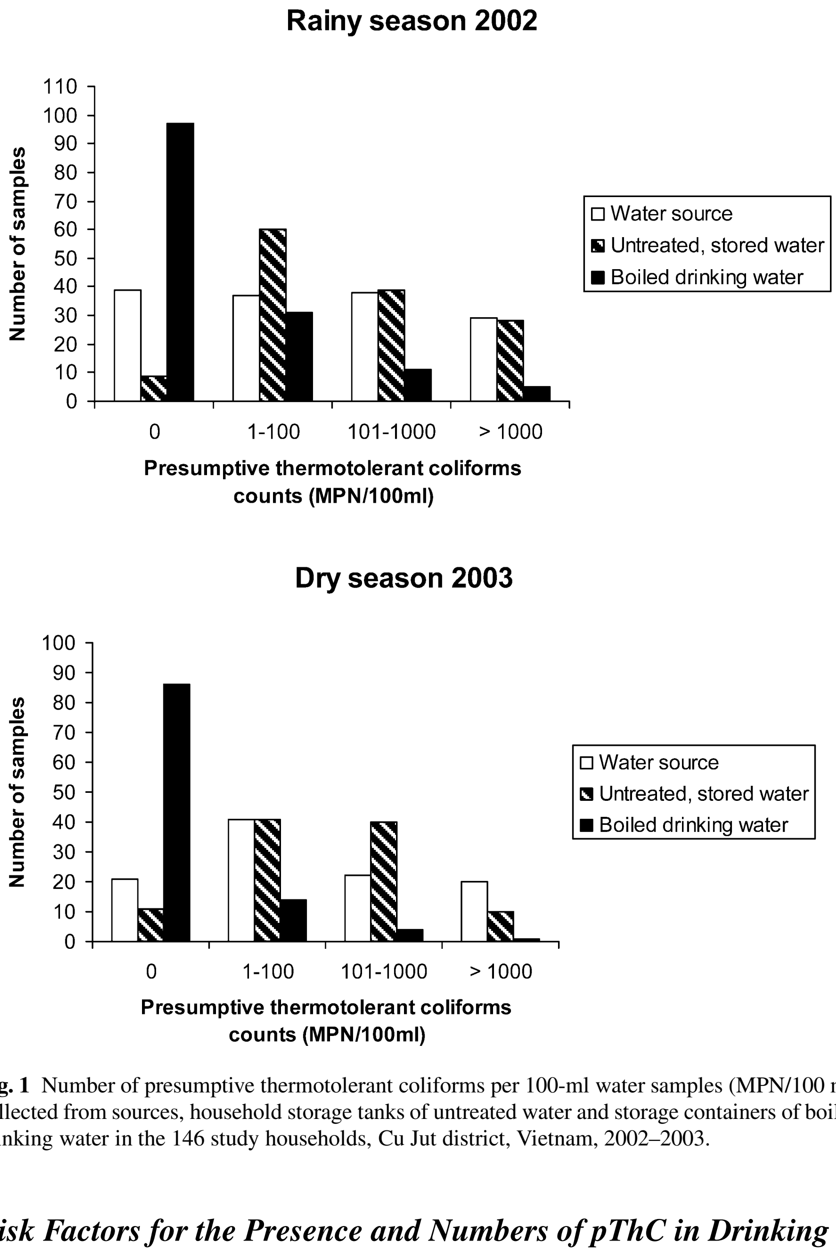

Fig. 1 Number of presumptive thermotolerant coliforms per 100-ml water samples (MPN/100 ml) collected from sources, household storage tanks of untreated water and storage containers of boiled drinking water in the 146 study households, Cu Jut district, Vietnam, 2002–2003.

Risk Factors for the Presence and Numbers of pThC in Drinking Water Sources

The results from the univariate risk factor analyses showed, with some differences between the two seasons, that the type of well, well cover, well depth, availability of a protective well wall, means of water collection, and ways of waste disposal in households were all significantly associated with faecal contamination of well water (data not shown).

Multivariate logistic regression analyses were used to assess the relative importance of these risk factors and to adjust for confounding (Table 1). Water samples collected from dug wells in the dry season contained significantly more pThC compared with the two other types of sourcewater. In addition, disposal of waste by burning was associated with a reduced risk of contamination. In the rainy season, using drums/buckets or un-submersible motor pumps placed on the ground next to the wells were the only factors independently associated with an increased risk of faecal contamination. Observation results indicated that drums/buckets or un-submersible motor pumps were often used to collect water from dug wells/mixed dug well-boreholes.

Risk Factors for the Presence and Quantity of pThC in Untreated Water Stored in Household Tanks

Each household had a tank, often built in concrete, for storage of water collected from the outdoor water source. In the univariate analyses, source-water quality, means of water collection from the household tanks, whether covering the household tank, hand-washing practices of family members, and number of children aged 6–10 years in the household were significantly associated with the presence of pThC but there were variations between the two seasons (data not shown). In the multivariate regression model, collection of water from the household tanks by scooping, typically with a hand-held ladle, was a strong risk factor for faecal contamination (Table 2). In the dry season, tanks with no protective covers were less faecally contaminated.

Risk Factors for the Presence of pThC in Treated, Stored Household Drinking Water

The untreated water stored in the household tanks was used for various domestic purposes, including drinking, cooking, personal hygiene, etc. Of the 146 households studied 144 (98%) and 142 (97%) boiled water for drinking with subsequent storage in small-sized household containers in the rainy and dry seasons, respectively. However, water testing results indicate that in the rainy season 11% (16), and in the dry season 5% (5) of such point-of-use drinking water (boiled drinking water) samples contained >100 pThC per 100 ml (Figure 1). Additional drinking water treatment method was filtering boiled water through filtering equipment (Figure 2). Table 3 shows that 47 (33%) and 19 (18%) boiled drinking water samples contained pThC in the rainy and dry seasons, respectively. Thus, although almost all households boiled their drinking water, such water often became faecally contaminated later,

Fig. 2 Filtering equipment

during storage. For the rainy season, the univariate analyses showed that water boiling, scooping boiled drinking water by a hand-held cup from household containers, a visually dirty storage container, and household size $\geq$5 people were significantly associated with the presence of pThC in the water (data not shown). In the multivariate regression model, scooping boiled drinking water by a hand-held cup, a visually dirty container, and a household size $\geq$5 people were all independently associated with faecal contamination of boiled drinking water. For the dry season, the initial univariate analysis showed that only the scooping of boiled drinking water by a hand-held cup was significantly associated with faecal contamination, and we did therefore not fit a multivariate regression model (Table 3).

Discussion

Nearly all study households (97–98%) reported that drinking water was boiled before consumption. The widespread practice of boiling drinking water has for many years been recommended and promoted in Vietnam at national and local levels through mass media like radio, television, and posters. In schools, children are taught to only drink boiled water and informed that drinking unboiled water is likely to cause diarrhoea (Japan International Cooperation Agency, 2001). Phuong (2003) described how rural household members in the Nghe An province in central Vietnam had a good knowledge of how boiling would make water safe for drinking. The main

Table 1 Multivariate logistic regressing analyses of risk factors for presence of presumptive thermotolerant coliforms (pThC) in the water sources.

Variables	Rainy season			Dry season		
	Nos of water samples	Positive for pThC (%)	Adjusted OR (95% CI)‡	Nos of water samples	Positive for pThC (%)	Adjusted OR (95% CI)‡
Type of well			NS§			
Dug well	50	44 (88%)		32	31 (97%)	**28.2 (2.4-331.4)**
Mixed well	47	35 (75%)		32	24 (75%)	1.03 (0.3-3.4)
Borehole	46	25 (54%)		40	28 (70%)	1
Well cover			NI†			NS
No	57	44 (77%)		33	30 (91%)	
Yes	86	60 (70%)		71	53 (75%)	
Well depth			NS			NI
<10 m	24	21 (88%)		16	16 (100%)	
10-30m	33	30 (91%)		20	18 (90%)	
30-50m	38	24 (63%)		29	22 (76%)	
≥50m	48	29 (60%)		39	27 (69%)	
Availability of the protective well wall			NS			NI†
Unavailability	34	28 (82%)		19	16 (84%)	
Availability	63	51 (81%)		45	39 (87%)	
Borehole	46	25 (54%)		40	28 (70%)	
Means of water collection						NI
Drum/bucket	29	25 (86%)	**4.6 (1.3-16.5)**	17	17 (100%)	
Hand pump	9	7 (78%)	1.5 (0.2-9.7)	5	5 (100%)	
Un-submersible pump	54	4 (89%)	**6.9 (2.1-22.2)**	29	25 (86%)	
Submersible pump	50	23(46%)	1	53	36 (68%)	
Means of waste disposal in households			NI			
Buried	24	16 (67%)		20	17 (85%)	1
Burned	26	17 (65%)		17	8 (47%)	**0.1 (0.0-0.5)**
Discharged into the environment	92	71 (77%)		67	58 (87%)	1.3 (0.3-5.6)

† Multivariate logistic regression: adjusted odds ratio (OR) and its 95% confidence interval (CI)
‡ Not included in multivariate regression analyses because p-value > 0.1 in univariate analyses
§ Not significant in multivariate regression analyses

Table 2 Multivariate logistic regressing analyses of risk factors for presence of presumptive thermotolerant coliforms in untreated water stored in households.

Variables	Rainy season: Nos of water samples	Rainy season: Positive for pThC (%)	Rainy season: Adjusted OR (95% CI)†	Dry season: Nos of water samples	Dry season: Positive for pThC (%)	Dry season: Adjusted OR (95% CI)†
Type of well			NI‡			NI
Dug well	43	42 (98%)		29	26 (90%)	
Mixed well	45	42 (93%)		31	29 (94%)	
Borehole	45	40 (89%)		40	34 (85%)	
Covering household tanks			NI			
No	61	59 (97%)		41	33 (81%)	**0.2 (0.1-0.9)**
Yes	72	65 (90%)		56	53 (95%)	1
Means of water collection						NI
Scooping by a hand held ladle	75	74 (99%)	**9.5 (1.1-79.0)**	51	45 (88%)	
Tap/pouring	61	53 (87%)	1	49	44 (90%)	
Hand washing practices			NS§			NS
Only water	57	56 (98%)		49	43 (88%)	
Water and others eg. soap...	72	71 (90%)		53	48 (91%)	
Number of children 6-10 years old			NS			NI
No children	75	72 (96%)		53	47 (89%)	
1 child	40	38 (95%)		31	28 (90%)	
≥ 2 children	21	17 (81%)		18	16 (89%)	
Source-water quality (nos of pThC/100 ml)			NI			NS
0	38	31 (82%)		20	15 (75%)	
1-100	33	33 (100%)		41	39 (95%)	
101 - 1000	34	32 (94%)		21	20 (95%)	
> 1000	28	28 (100%)		18	15 (83%)	
Availability of soap/detergent			NI			NI
Yes	135	126 (94%)		101	90 (89%)	
No	1	1 (100%)		1	1 (100%)	

† Multivariate logistic regression: adjusted odds ratio (OR) and its 95% confidence interval (CI)
‡ Not included in multivariate regression analyses because p-value > 0.1 in univariate analyses
§ Not significant in multivariate regression analyses

Table 3 Multivariate logistic regressing analyses of risk factors for presence of presumptive thermotolerant coliforms in treated drinking water stored in household containers.

Variables	Rainy season			Dry season		
	Nos of water samples	Positive for pThC (%)	Adjusted OR (95% CI)†	Nos of water samples	Positive for pThC (%)	Univariate OR (95% CI)*
Drinking water treatment method			NS§			
Boiling	114	44 (39%)		79	15 (19%)	
Boiling and others	30	3 (10%)		26	4 (15%)	
Hygiene of household containers						
Dirty	67	29 (43%)	**2.4 (1.1-5.2)**	60	13 (22%)	
Clean	77	18 (23%)	1	45	6 (14%)	
Means for collecting water						
Hand held cup	26	15 (58%)	**3.1 (1.3-8.7)**	18	8 (44%)	**6.1 (1.9-19.6)**
Long handled ladle	14	5 (36%)	1.2 (0.3-4.3)	9	2 (22%)	2.2 (0.4-12.2)
Pouring/Tap	104	27 (26%)	1	78	9 (12%)	1
Hand washing practices						
Only water	60	24(40%)	NI‡	49	12 (25%)	
Water and others, i.e. soap…	84	23 (27%)		56	7 (13%)	
Household size						
≥ 5 persons	52	23 (42%)	**2.5 (1.1-5.6)**	40	9 (23%)	
< 5 persons	92	24 (26%)	1	65	10 (15%)	
Pig husbandry in households			NI			
No	48	12 (25%)		34	5 (15%)	
Yes	96	35 (37%)		71	14 (20%)	

† Multivariate logistic regression: adjusted odds ratio (OR) and its 95% confidence interval (CI)
‡ Not included in multivariate regression analyses because p-value > 0.1 in univariate analyses
§ Not significant in multivariate regression analyses
* Unadjusted/univariate odds ratio (OR) and its 95% confidence interval (CI)

reason for promoting the use of boiled water is that drinking water sources are often unsafe and drinking source water directly may cause diarrhoea. We did not collect information about, or observe the practices of boiling water in the households and therefore rely on self-reported data. However, boiling water is a generally recognized method and even a boil of a short duration will effectively kill most bacterial, fungal, viral and parasite (mainly protozoan) water-borne pathogens (Lehloessa and Muyima, 2000; Sobsey, 2002).

A high proportion of water that had been boiled was faecally contaminated in our study. Recontamination of boiled drinking water was mainly due to "scooping water by a hand-held cup". By observations during household interviews, boiled drinking water was typically stored in 2–4 litre uncovered small household containers which in most cases allowed direct contact between the stored water and hands, e.g. of children. In rural Vietnam children will scoop water whenever they want from the storage containers. In rural areas, children are often allowed to defecate freely within the household perimeter as their faeces are seen as less risky to human health compared with faeces from adults. In-depth studies are required to assess the relative importance of children and their hygiene practices, household animals, etc as sources of faecal contamination of household drinking water. Trevett et al. (2005) showed in rural Honduran communities that 44% of hands of women involved in housework and collection of water was faecally contaminated. In a Kenyan study, unwashed hands were found to be significantly associated with faecal contamination when household members used scoops or bowls to collect water from household storage containers and thus dipping their hands into them (Chemuliti et al., 2002). Containers with narrow mouths or connected with spigots are recommended in many settings to prevent contact between users' hands and household drinking water (Quick et al., 1996; Mintz et al., 2001; Jensen et al., 2002; Makutsa et al., 2006). Intervention studies are needed in Vietnam to assess the efficiency of improved designs of storage containers in reducing faecal contamination.

Information about hand washing practices of family members were collected in our study but the results showed no significant association between hand washing practices and faecal pollution of drinking water. It should be noted that information on hand washing practices generally was of adults and that we did not collect information about such practices of children. Other studies have found that hand washing after toilet usage reduced faecal contamination of stored drinking water (Curtis et al., 2000).

The household tanks contained untreated water, collected from wells or boreholes, and tanks typically did not have a cover or other protection. It was quite evident from our household visits that untreated water from the main storage tank was not only used for drinking purposes but also for other domestic purposes such as bathing, washing utensils, dishes and clothes etc. In both seasons approximately 95% of water samples from the household tanks were faecally contaminated. Between 10–22% of the untreated stored water samples contained >1,000 pThC per 100 ml and were therefore highly faecally polluted. Similarly, as seen for the stored boiled drinking water, obtaining water by scooping from the main household tank by a hand-held ladle was a strong risk factor for faecal contamination in the rainy season (OR 9.5) although this practice was not significantly associated with faecal contamination in the dry season. This could be explained by people washing more frequently in the rainy season due to muddy environment, muddy roads, etc., and with frequent use the household tanks were less frequently covered (we observed this during our household visits in the rainy season). In another province in Vietnam, Phuong (2003) found that a high percentage of rural household members (84%), in particular children (65%), drank untreated water mainly from wells. The stated reasons for drinking untreated water included unavailability of boiled drinking water in the home when needed, untreated water is cooler, and the good taste of untreated water. Follow-up studies are needed on the drinking of untreated water stored in households, e.g. the conditions and quantity of consumed water and associations with diarrhoea. The finding of high faecal contamination levels in 10–22% of untreated water samples is of concern as it has been shown that consumption of highly contaminated drinking water (>1000 E. coli/100 ml) was significantly associated with diarrhoea in children (Moe et al., 1991).

The boiling of drinking water is deeply rooted in the rural populations in Vietnam and changing these practices will be difficult. Furthermore, despite its disadvantages, e.g. need and cost of firewood and time for boiling and cooling the water, boiling water can effectively kill of pathogens. Thus the introduction of alternative treatment methods and technologies, e.g. filtration methods; solar disinfection (Conroy et al., 1999); or ultraviolet disinfection or chlorination (Sobsey, 2002) should carefully be considered.

Conclusions

The faecal pollution levels of the water was as expected dependent on the type of water source, with the highest faecal contamination levels found in water from dug wells. Importantly, the water was heavily contaminated during storage in household tanks. Even though it was a common practice to treat water for drinking by boiling prior to storage in small household containers, handling by e.g. unwashed hands dipped into the water often resulted in recontamination. These observations are clear messages for programmes to improve water supplies. Provision of safe water is not a stand-alone intervention. To maximize the benefits for public health, attention should be paid to household hygiene, including the hygiene practices of children, e.g., by encouraging mothers to improve children's hygiene and the use of safe storage vessels combined with drinking water treatment at the point-of-use.

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Alternative Safe Water for Communities in the Mekong Delta and Coastal Zone: Vietnam

Tran Thi Trieu and Nguyen Lam Giang

Abstract Water quality in the Mekong Delta and coastal zones of Vietnam was suffering from pollution caused by wastewater, solid waste and pesticides discharged without treatment or management. This situation was worsened by the poor communities' habit of drinking raw water. The water treatment program SODIS (Solar Water Disinfection), introduced to some communities in the Mekong Delta (Long An, Dong Thap, Tay Ninh provinces) and in the Coastal zone (Ninh Thuan province), contributed to an improvement in drinking water quality of those communities and changed their habit of drinking raw water into drinking safe water. SODIS was introduced to 261 local promoters, 21,934 household, 976 teachers and more than 16,000 school pupils. About 70% of households in Tay Ninh province changed their habits and began drinking water as recommended by SODIS. Children in primary and secondary schools also adopted habits from SODIS. Women's unions in Dong Thap and Long An played a very important role in dissemination and promotion of SODIS in their communities. Many mass organizations such as Farmer Union, Old Soldier Association, Youth Union integrated SODIS into their own programs. SODIS become an effective alternative for safe water for many areas in Vietnam.

Key words: Coastal zone, Mekong Delta, safe drinking water, SODIS, sustainable water

Introduction

Water is possibly our most precious natural resource. Abundance and quality of water drives all human systems and those of most other organisms as well (Hathcote, 1998). Over the past ten years, people in the coastal zone and the Mekong Delta

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have exploited this resource to exhaustion. The extensive use of surface water for rice field irrigation, deforestation in the uplands and soil erosion have seriously impacted water resources. The delta and coastal areas suffer from saline water, while areas with high population density are subject to serious pollution due to domestic and industrial waste. In that context, only 55% of the total population has access to water supply systems covering basic domestic needs. Among those only 10% are supplied with water that is safe for consumption (Helvetas Annual Report, 2007). The promotion and dissemination of SODIS in Vietnam aimed to address the lack of access to potable water in very remote or difficult conditions. Moreover, information, education and communication (IEC) to promote, disseminate and sustain SODIS helped households to improve drinking water as well as their hygiene practices.

Material and Methodology

Target areas faced with difficult problems of water and sanitation were selected for SODIS introduction. In the Coastal zone, Ninh Thuan was chosen as a priority province for promotion of SODIS. In the Western area called the Mekong Delta, SODIS focused on Dong Thap and Long An. Moreover SODIS also was introduced into Tay Ninh province which belonged to the Eastern area. SODIS was launched among promoters who were staff members of such organizations as Health, Women's Union, Farmer's Union, Village and Commune Leaders, and teachers in the program called Training of Trainers. Promoters taught SODIS to end users (the villagers and children in schools). Education and communication was continuously carried out in the project areas. Big posters of SODIS were hung in places where many people would often see them (market, cross-road, T-junction, Health Clinic, Commune People Committee). Leaflets and posters containing SODIS applications were distributed to villagers and schools after they had some basic training. Communication Nights on SODIS prepared by villagers and promoters themselves, attracted audiences and gave villagers and school children much information on SODIS. Period monitoring and surveys were conducted by promoters, commune members, provincial residents, national project staff and consultants for assessment of SODIS application and people's change of behavior with respect to drinking safe water and observing other sanitation principles. Moreover, SODIS water analysis demonstrations were presented to local people in communes of project areas, to consolidate the peoples' belief in SODIS safe water.

Results and Discussion

Problem of Water Supply in the Coastal Zone and the Mekong Delta

Saline Intrusion

Saline intrusion in the area is increasing which causes difficulties of water supply in the area. During the dry season, when Mekong flow decreases, seawater flows up through a network of waterways. Of the 3.9 million hectares that make up the Mekong Delta, up to 2.1 million have been affected by salinity of seawater each year (Miller, 2000). according to a forecast of the Division of Water Resources Institute, the saline intrusion (4 g/l) will reach to 10–12 km from upstream. (Tien Giang DARD, 2004). The reasons for increasing saline intrusion are reduced upstream flow and wind from the sea during the dry season. Several development interventions have contributed to increase saline intrusion, reducing dry season flow, expanding the affected saline intrusion area where rainfall is considerably less in the dry season than in Ninh Thuan province.

Unsecure Water Quantity and Quality and Behavior of Drinking Raw Water

Access to drinking water is the first priority for the use of water. However, one quarter of the world's population is without access to safe drinking water and half of the population is without access to adequate sanitation (Danida, 2000). There are limited ground water sources. Local people collect rainwater for drinking in the dry season. Remote families always lack fresh water. Capacities of rural water supplies are too small to meet water demand. People are still very poor while the cost for constructing a water supply system is expensive. Many households directly pump water from a river, after some hours of simple treatment (flocculated by alum), and use it for domestic purposes. Potential worsening of resource competition between upstream and downstream communities in the delta results in agro-chemical pollution, further increasing the extraction of water. Downstream communities in particular would be affected by worsening water quality from acid sulphate soil and increased use of agro-chemicals upstream. The pollution of surface and ground water will increase the scarcity of fresh water throughout affected areas. A decreased availability of household water will in result disproportionate impacts on women's health due to decline of sanitation conditions (Miller, 2000). The behavior of drinking raw water increases the threat to human health. According to a survey at the end of 2007 in Ninh Thuan, Dong Thap and Tay Ninh, the number of households drinking raw water were still many with a resulting high rate of diarrhea (Table 1).

Table 1 Percentage of household drinking raw water and diarrhea cases (%) in 2007.

Province	Commune	Percentage of households to drink raw water (%)	Percentage of diarrhea cases (%)
Ninh Thuan	Hoa son	30	6.7
	Phuong Hai	65	10
Dong Thap	My Quy	11	16.83
Tay Ninh	Long Thuan	71	12.7
	Tien Thuan	87.3	7.9

SODIS as Alternative Solution for Drinking Water Improvement

The exposure of water to sunlight radiation improves the microbiological quality of water. This process could be used at household level to treat small quantities of water for drinking purposes (Wegelin, 1994). SODIS (Solar Water Micro-Organism Disinfection) is a method of water treatment suitable for households in areas faced with water polluted by micro-organisms. SODIS was developed in the laboratory and extensively tested in the field by the Federal Institute for Environmental Science and Technology (EAWAG) and its department for Water and Sanitation in Developing Countries (SANDEC). SODIS had a positive impact on diarrhea occurrence in Indonesia. The number of cases of diarrhea was reduced 73% (from 2002 to 2004) in ten villages in East Lombok, Indonesia (Aristanti, 2007). The treatment process of SODIS is easy, simple, low cost and compatible with hydrology conditions of Coastal and the Mekong Delta (high rate of solar radiation (UV-A radiation), including four basic steps:

- Preparing clear raw water with turbidity $\leq$30 NTU (Nephelometic Turbidity Unit) and free from chemical contamination.
- Filling transparent plastic bottles completely with water.
- Expose the bottles to the sun for at least 6 hours.
- Drinking treated water with cup within 2 days.

The promotion and dissemination of SODIS in Vietnam not only is the solution for the lack of access to potable water in very remote or difficult conditions, but also the key to improvement of household hygiene practices. The cooperation between Helvetas and The Center for Rural Water Supply and Environment Sanitation (CERWASS) at central level, the Women's Union in Dong Thap province, Center for Health communication, Education in Tay Ninh, the Center of Preventive Medicine in Ninh Thuan, Women's Union in Long An, facilitated the successful implementation of this low-cost technique for household water treatment. The beneficiaries are rural households in geographically difficult areas without access to potable water in the Northern mountainous region, the Central-South coastal region and the Mekong Delta. In the end, SODIS is expected to be well known and applied as an alternative household centered system for clean water in all areas facing temporary or frequent water supply difficulties.

Table 2 SODIS promoters and households introduced to SODIS.

Year	Ninh Thuan		Dong Thap		Tay Ninh		Long An		Total	
	Promoter	HH	Promoter	HH	Promoter	HH	Promoter	HH	Promoter	HH
2006	40	1,766	44	1,945	Not yet	Not yet	Not yet	Not yet	84	3711
2007	20	4,349	16	3,007	25	1,500	Not yet	Not yet	42	9,191
2008	35	1,450	30	2,500	40	3,500	30	1,582	135	9,032
Total	95	7,565	90	7,452	65	5,000	30	1,582	261	21,934

HH: households

SODIS with Community

In the communes, there was involvement of the representatives of the commune People's Committee, commune Women's Union and Health Clinic. SODIS promotion to households was carried out through a network of village promoters. Field monitoring visits among different levels were regularly carried out. Besides, provincial quarterly meetings and monthly commune meetings were organized so that involved actors in SODIS could meet together to discuss and exchange issues in SODIS implementation. In those meetings, representatives of the district authorities were also invited in order to be informed about the SODIS implementation situation and provide policy support. Besides poor villagers, better off households were included because they accept new things easier and change their behavior faster. Over the three years launching SODIS to household level, SODIS has targeted a number of local promoters and households, as shown in Table 2.

In total 21,934 households of the four provinces have been introduced to SODIS by 261 local promoters. The introduction was done with a range of activities on TOT, end user training, education and information campaigns. The provincial (and district and commune) levels received trainings on SODIS technique by the national CERWASS and then gave training to the village promoters, who later delivered training to the end households. SODIS broadcasts on local radio, newspaper, website and television also contributed to the dissemination. Mrs. Tran Thi Cuc, My Quy commune, Thap Muoi district, Dong Thap province said that, in recent years, her family drink rainwater and sometimes boiled water. When SODIS was introduced, she did not believe in it at the beginning. Gradually, she found that SODIS is simple, safe and economically useful. She used five bottles of 1.5 lt each per day. She also introduced SODIS to her relatives in an outside province (Can Tho) and they high appreciated it. The survey in March 2008 showed a prospective picture of SODIS (Table 3). The rate of households changing to drink SODIS water was quite high, 78.7% in Dong Thap, 74.5% in Long An and 70% in Tay Ninh where a high rate of households used to have the drinking raw water habit.

Fig. 1 SODIS practice by household.

Fig. 2 SODIS in school.

SODIS with School, Teachers and Children

The first secondary or primary school to apply SODIS was selected by the project commune. SODIS was launched to children via teachers who were trained by officers of CERWASS and Helvetas. The teachers attended a one-day workshop to learn how to conduct and encourage children to practice SODIS at home, then take SODIS water with them when they go to school. Each school was given a stand and bottles, both used for SODIS practice at school and at the childrens' homes. Besides learning SODIS from teachers, children receive SODIS information from media by local broadcasting with loudspeaker systems everyday, by TV and by IEC materials. Most of them know the SODIS technique and practice it effectively. At some schools, teachers prepare SODIS water for pupils having neglected or forgot to bring safe water to school for drinking, for example at Vu Bon primary school in Ninh Thuan province, Nhut Ninh and Primary school in Long An. However, at oth-

Table 3 SODIS application in provinces.

Province	Long An		Dong Thap		Tay Ninh	
	Households	Ratio (%)	Households	Ratio (%)	Households	Ratio (%)
Interviewed household	1,117		1,806		3,357	
Knowing SODIS	1,058	94.7	1,771	98.1	2,877	85.7
Drinking SODIS	832	74.5	1,421	78.7	2,379	70.9
Drinking raw water	105	9.4	27	1.5	555	16.5
Buying more bottles	536	48.0	1,213	67.2	312	9.3
SODIS applying correctly	740	66.2	1,380	76.4	2,210	65.6

Table 4 SODIS was also introduced to schools in provinces.

Year	Ninh Thuan		Dong Thap		Tay Ninh		Long An		Total	
	Teacher	Pupil	Teacher	Pupil	Teacher	Pupil	Teacher	Pupil	Teacher	Pupil
2007	152	3,950	400	5,500	46	611	Not yet	Not yet	652	11,450
2008	32	1,300			227	2,717	65	600	324	4,617
Total	184	5,250	400	5,500	273	3,328	65	600	976	16,067

ers, SODIS is not successful because of overwork of teachers or not enough stands and bottles for all pupils. So, the practice at schools is relatively sporadic, i.e. not a daily activity. The pupils were encouraged to practice SODIS at home and bring water to school. As observed, there is a relatively high number (about 50%) of school pupils bring SODIS bottles to schools for their drinking. Around 976 teachers and more than 16,000 school pupils were introduced to SODIS (Table 4).

A competition about SODIS was also organized in each school. SODIS was integrated into school activities (meeting on early Monday morning) and Teenage Association activities. SODIS is a simple technique and communicated by many channels. As observed during SODIS nights and SODIS Competitions, most of the questions relating to SODIS were correctly answered.

SODIS Cooperation with Other Projects and Organizations

SODIS was considered a proper and useful technique in accordance with the National Strategic Plan of Rural Clean Water Supply and Sanitation of Vietnam Government. The cooperation with National CERWASS – a professional partner of the project, contributed to the achievement of dissemination of SODIS in Vietnam. The wide distribution of brochures, posters, CDs and continuous broadcast of SODIS information and techniques on mass media and local loudspeakers have attracted attention of organizations and projects. Many of them asked for SODIS integration into their activities, Phu Yen Center of Health Communication and Education would like to integrate SODIS into their activities of Heath Communication at communes. Long An Women's Union supported promotion of SODIS in Nhat Ninh commune which is the central point from which to spread SODIS to other places of their province. The strong and enthusiastic involvement of provincial leaders also contributed to the success of the dissemination and the maintenance of SODIS in the project areas. The application rate in Tay Ninh, ranked the highest percentage of the targeted households that regularly apply SODIS (around 50 to 60%), could be the result of the active involvement and strong commitment of the leaders of the provincial partner. Thanks to strong organization with top-to-bottom network of Dong Thap Women's Union which can ensure frequent visits and monitoring to the communities, the percentage of households applying SODIS is regularly at around 60%.

Challenges in SODIS Implementation and Promotion

The introduction and dissemination of SODIS is closely linked with behavior change and this can not be done within a short time. Most of the areas targeted by the project either are very poor, or with limited access to water, therefore it always required greater efforts. The majority of the people do keep the habits of drinking raw water and practice very poor hygiene concerns. Moreover, their poverty also limits their practice of SODIS since water is their second priority after food security. The second challenge is the unavailability of PET bottles in the project sites. In the last years, the project operated in very poor communes, especially in Ninh Thuan and Dong Thap. In these places, local people could hardly find used PET bottles, as bottled water is a luxurious commodity there. These project sites are too far from the provincial city, and road conditions there are often very poor. As a result, it is very costly to transport bulky goods like PET bottles. Low profit is another reason that makes it difficult to do business with PET bottles, even with some commission from the project. Last but not least, there have not yet been permanent demands for PET bottles from the local communities. The third challenge is the shortage of clear water and the quality of water. In 2007, the project was carried out in some communes where people did not have suitable water to apply SODIS. For example, people in Thai An hamlet of Vinh Hai commune use well water which is highly contaminated by green algae. In the Mekong delta, water is heavily contaminated with agricultural chemicals and heavy metal. Some communes in Ninh Thuan have not enough water in the dry season.

Conclusions

SODIS is a simple technique and easily acceptable. However, the application of SODIS highly depends on weather and water resources. SODIS is only an alternative method aimed to change behavior of drinking raw water. Therefore, assessment of the project's success should not be base only on the rate of application of SODIS in households. It should be based on the increasing awareness of health improvement through water drinking (boiled water, filtered water, etc.) and sanitation behavior changes. In order to disseminate and promote SODIS, there is a need for cooperation of many organizations as well as the continuous mobilization with integration into many other programs related to health, safe water and sanitation improvement.

Acknowledgement

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Community Based Management of Traditional Water Resources in Western Himalayan Region

A Case Study from the Pilot Locations in India, South East Asia

Sushil Kumar

Abstract The state of Himachal Pradesh in the Indian Himalayan region represents a unique agro-ecological setting with dominating traditional systems of indigenous resource management. In this pursuit of resource management, highly effective community based modules of water harnessing and use were developed. The local livelihoods of the people were largely determined by the successful implementation of these traditional water management strategies. Unfortunately due to rising resource pressure and degradation over the years, these traditional models have started rupturing. The local water harvesting systems have been depleted and neglected over the years. The erratic and uneven distribution of south west monsoonal rains is further adding to the problem. Thus there is need to conserve the water through the maintenance of age old *Boulies* (traditional water sources) and other community based initiatives of water harvesting. In the year 2003, a systematic effort was attempted through a grant of 8.247 million pounds by the Department for International Development (DFID) UK to carry out water conservation activities through local institutions of people representations known as *Panchayats*. I had been closely associated with this project and implemented it in four *Panchayats*. The chapter begins with an attempt to understand the evolution of policies on water and forest management with particular reference to the state of Himachal Pradesh. It then discusses the linkages between community, forest management and its impact on water management based livelihood issues. It also examines the possibilities of strengthening local institutions through appropriate policy interventions.

Key words: Community management, local governance, traditional water resources

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Introduction

The state of Himachal Pradesh in the Indian Himalayan region represents a unique agro-ecological cultural setting with dominating traditional systems of indigenous resource management. In this pursuit of indigenous resource management, highly successful community based modules of water harnessing and use were developed. The local livelihoods of the people were accordingly determined by these traditional water management strategies. However due to rising resource pressure and degradation over the years, these traditional models have started rupturing. The local water harvesting systems have been depleted and neglected over the years. This has resulted in water scarcity for crops, animals and drinking purposes adding towards the vulnerability of the local livelihood avenues of the mountain people. The erratic and uneven distribution of south west monsoonal rains is further adding to the problem. Fortunately, the state received strategic importance in the conservation of traditional water reservoirs through the implementation of a DFID-UK funded project during the year 2003. The traditional community managed water reservoirs were successfully intervened and rejuvenated through reconciliation of local community initiatives and external technical and managerial input. The traditional wisdom and ethos of the stakeholders were effectively reflected in the village micro-plans which were implemented in the field through community participation.

Traditional Water Harvesting Systems

Throughout the state of Himachal Pradesh, several indigenous systems known as traditional water harvesting systems have been devised to catch and store rainwater along with snowmelt for future use. The practice of harvesting rainwater dates back to historical times when the need to create water sources that would remain both clean and plentiful was recognized. Zing, Kuhl, Johad, Bandh, Khatri, Boulis are the types of wells that are the common traditional systems of water harvesting. The description of these systems is given in Table 1.

Land Use and Geographical Location

The state of Himachal Pradesh is a green pearl nestled in the Western Himalayan mountain range. It extends from the perpetual snowing mountains separating it from China, Tibet in the North to Punjab plains. It is situated between 30°-22’40” and 33°12’40” North latitudes. The total area of the state is 55,673 km^2. This would give less than 1 hectare of land to every one among 6.1 million people recorded in the state. There is large scale variation in altitude, climate and geology whilst significant areas are mountainous and above the tree line, including the cold desert areas of Lahaul and Spiti. Altitude ranges from 350 to 6,975 m amsl. Nearly 10%

Table 1 Traditional water harvesting systems in the state of Himachal Pradesh, India.

Eco-zone	Traditional water harvesting system	Description	Districts* in which found
Trans Himalaya	Zing	Tanks for collecting water from melted snow/ice of glaciers	Lahaul Spiti
Western Himalaya	Kuhl	Water channel for irrigation of agricultural fields and to run flour mills and to run small hydroelectric projects to meet local requirement of electricity in Jogindernagar and Kullu	All 12 districts
	Johad	Small ponds for catching rain run-off	All 12 districts
	Bandh	Small weir erected across a stream to store water	All 12 districts
	Khatri	Chamber carved in hard rocks for storing rainwater	Hamirpur and Kangra districts
	Boulis	Groundwater aquifers and percolating water, water can be hold for longer periods	All the districts except Lahaul Spiti
Shiwaliks	Wells	Underground water	Foothills and lower belt of the state

*District is the basic administrative unit at sub-state level and also consistent with the decentralized planning process at the grass root level.

of the total area is cultivated and actual forest cover extends to 23% of the total area whereas 66% is legally classified forest area. The balance of 24% of the area is barren and uncultivable. Cattle population is also around 6.3 million which is mostly dependent on forest for grazing with very low productivity. Rural people comprise 90% of the state's population and most of them are dependent on forests. About 87% of the population is dependent on agriculture. The gross irrigation potential of the state is 0.55 million hectares while the irrigation potential created has reached only 0.2 million hectares, thus the balance of 0.35 million hectares has to be covered by irrigation schemes so that productivity of rainfed areas is improved through diversion of land towards cultivation of vegetables, horticulture and cash crops.

Precipitation, Water Resources and Water Policy

The Himachal Pradesh state is drained by six major river systems and forms the upper watershed of major tributaries and thereby has six catchment areas. Some of these are the Satluj (30.69%), the Beas (24.5%), the Chenab (14.2%), the Yamuna (10.6%), the Ravi (9.9%) and the Indus (2.6%). These catchments are further subdivided by several water divides. The major rivers are glacial-snow fed and perennial in nature. The seasonal streams of the Shiwalik foothills depend on rainwater. Water

Fig. 1

as a resource is one and indivisible: rainfall, snowfall, river waters, surface ponds, lakes and ground water are all part of one system. In the state, availability of water is highly uneven in both space and time. Precipitation is confined to only about three or four months in a year and varies from 600 mm in Lahaul Spiti to 3,200 mm in Dharamsala of Kangra District. However, in spite of heavy rain and snow during monsoon season (July, August) and winter months (December, January), the summer months are periods of water scarcity as the flow in the rivers and streams is quite low. This results in forced migration of humans and animals to the banks of rivers and streams with perennial flow. On the other hand heavy rains cause havoc due to floods and landslides. Flash floods also cause damage to life and property of the people in higher reaches of the state. The frequency of flash floods and drought has increased manifold in the recent years due to climate change and ecological disturbances. If the overflow of rivers and streams in spates could be redirected and stored, the water could be used during drought.

State Forest Policy and Watershed Development

The state of Himachal Pradesh has notified Forest Sector Policy and Strategy in 2005 outlining its forest management principles. Involvement of community in the management of forests and maintenance of forests for conservation purposes rather than commercial has been emphasized. The state's forest has impact far beyond the state in terms of downstream water supply. Watershed protection is the crucial issue

Fig. 2

to be marketed given that state rivers provide a key contribution to Delhi's dwindling water supply. The state has imposed a blanket ban on felling of green trees since 1983, keeping in view the watershed functions the forest floor plays, though the state has to forego net revenue of 50 million dollar per annum. The economic value of state forests' watershed functions has been calculated to be 18,500 million dollar.

Community Empowerment and Local Governance

The standard poverty alleviation approach based on top-down planning has not significantly impacted this situation. In this context there is an urgent need for a more effective and localized methodology for identification and funding of community priorities and reduction of the wastage of funds. To create an enabling environment for local Self-Governance, Himachal Pradesh enacted the Panchayati Raj Act in 1994, under which powers, financial as well as administrative, have been delegated to locally elected representatives of villages. *Panchayat* is an administrative unit whose members are democratically elected by the villagers. Historical experience reveals that the best mechanism for initiating local self governance is people based planning that envisages the implementation of the activities as directed by a people?s plan, in the form of a micro-plan. In preparing such a plan, villagers work through community-level public institutions to collectively identify and prioritize their problems, desire appropriate responses and implement the resulting projects. Such a governance system serves both democracy and expediency in public offices.

Government Initiatives

The construction of big dams and unplanned road construction struck a death knell for the traditional water harvesting systems. Thousands of traditional water harvesting systems fell with decline for want of proper maintenance and use. In the recently promulgated Himachal Pradesh State Water Policy it is emphasized that for each project, sustainability evaluation would be carried out to determine "Environmental discharge" which shall not be less than 15% of the available discharge at any given time. After announcement of an industrial package for the state in 2004, 33,618 small scale and 356 medium and large scale industries have come up. These require an enormous quantity of water for their processes which obviously is drawn from underground aquifers. To check and prevent the over exploitation of ground water resources, the State of Himachal Pradesh has notified Ground water (Regulation and Control of Development and Management) Act 2005, according to which every commercial user of ground water has to pay royalty Rupee 1 per 10,000 liters of water extracted. Of this amount, 1/4th will be deposited in the government treasury and 3/4th would be utilized for recharging of aquifers. This money would be spent through democratically elected local *Panchayat* (cluster of villages). Exploitation of ground water resources shall be so regulated as not to exceed the recharging possibilities.

Methodology

In 2003, Himachal Pradesh Forest Sector Reforms Project funded by DFID-UK brought together the experiences of Irrigation and Public Health Department, Horticulture Department, Agriculture Department, Forest Department and Rural Development Department for the successful preparation of village micro-plans within Himachal Pradesh and initiated trials in 85 *Panchayats* (out of 3,037 *Panchayats*). The result was the evolution of the Integrated Resource Management Plan into a methodology for villagers to make *Panchayat* level micro-plans, based on the sustainable use of their resources in mountain conditions. This grass root micro approach gave people a local basis and a platform for coming together to plan and prioritize their needs and produced a plan that government agencies could use for implementation, which had local people's involvement in implementation and management of their schemes. The case study methodology was adopted to evaluate progress using tools of interaction, personal interview, secondary data review, field, etc.

A major criterion for selection of these *Panchayats* was the population below poverty line. i.e. where the income of more than 50per cent families is less than US $900 per annum. *Panchayats* (cluster of villages), an administrative unit of local self-governance (poorest of the poor *Panchayats*) were selected for projects implementation. All the villages falling in the selected *Panchayat* were visited by the team officials drawn from departments of agriculture, horticulture, irrigation, public health, water, forest, rural development of the Government responsible for implementation of rural development schemes and were made to sit together with people of each village falling in selected *Panchayats* to discuss the developmental issues pertaining to that particular village. Thereafter a meeting is held at the *Panchayat* level by inviting people from all the villages of that *Panchayat*. By using techniques of Participatory Rural Appraisal and Rapid Rural Appraisal, natural resources avail-

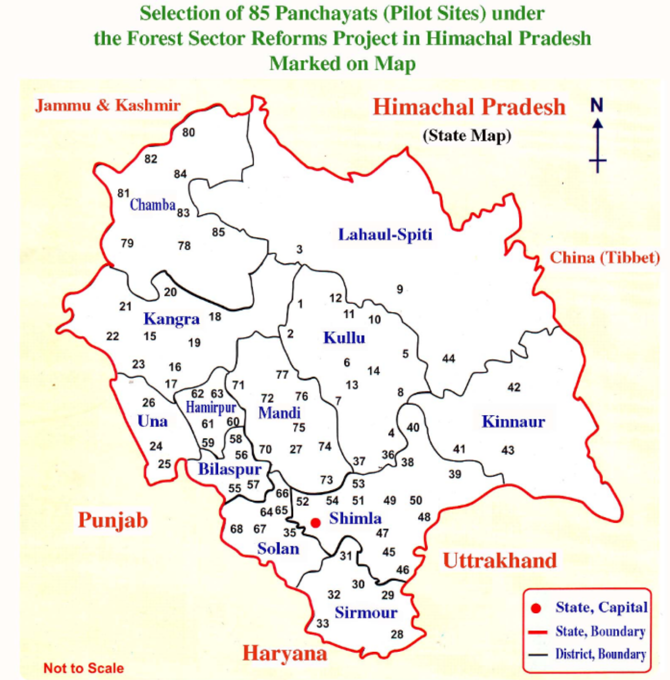

Fig. 3

Fig. 4

ability and needs of the people are identified. The detailed survey of all the households of identified poorest villagers was carried out for identification of potential user groups. People were encouraged to speak out their needs and prioritize them also. These deliberations were held four to five times before giving a final shape and then the discussed issues were approved in the general body meeting of *Panchayat*

Table 2 Distribution of *Panchayats* over the state of Himachal Pradesh, India.

No.	Name of district	Number allotted to each *Panchayat*	Name of *Panchayat*	No. of *Panchayats* in each
1.	Chamba	78, 79, 80, 81, 82, 83, 84, 85	Rajera, Kaintheli, Dand, Sahan, Mindhal, Chanju, Kudi, Gulei	8
2.	Lahaul-Spiti	3, 9, 44	Tingrit, Tindi, Geiy	3
3.	Kangra	15, 16, 17, 18, 19, 20, 21, 22, 23	Sansal, Jol, Luai, Hathidhar, Kutharna, Chaplah, Harboh, olakharyana, Amlela	9
4.	Una	24, 25, 26	Upperlohara, Bangarh, Marwari	3
5.	Hamirpur	59, 60, 61, 62, 63	Kashmir, Kalwal, Karot, Karsai, Choudu	5
6.	Bilaspur	55, 56, 57, 58	Dharot, Ghyal, Balhsina, Badgaon-galu	4
7.	Mandi	27, 69, 70, 71, 72, 73, 74, 75, 76, 77	Bobar, Gharot, Sarahan, Dhalwan, Batheri, Ropadhar, Murah, Ropidalah, Pangana, Shivabadar	10
8.	Kullu	1, 2, 4, 5, 6, 7, 8, 10, 11, 12, 13, 14, 36, 37	Mangarh, halaan, Ratocha, Pini, Kharagarh, Talra, Basturi, Mashiar, Shangad, Shilli	14
9.	Kinnaur	41, 42, 43	Sangra, Jaani Ramani, Aasrang	3
10.	Shimla	38, 39, 40, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54	Jadoon, Pabhan, Fancha, Moolkoti, Sarpara, Dhanat, Satoug, Mundoo, Gheich, Ranol, Rampuri	13
11.	Solan	35, 64, 65, 66, 67, 68	Chhosa, Nanjholi, Daunti Ghat, Sai, Jadla, Devra	6
12.	Sirmour	28, 29, 30, 31, 32, 33, 34	Pilhori, Kayari, Bharog Banedi, Nai Neti, Ridli, Kathli Bharan, Rajana	7

where all the inhabitants of the village participate. After approval of the *Panchayat*, the prioritized needs of the people are printed in the form of a booklet called micro-plans.

The activities listed in these micro-plans were implemented with funds available from the project. The village stakeholders have to contribute 5 to 20% of the budgetary requirement in the form of labour component. This component of stakeholder was made mandatory in order to create a sense of ownership in the minds of stakeholders so that once the project is over, they have to look after, maintain and use these as assets in a sustainable manner.

The central focus of the project was laid on the conservation of water through community based management of traditional water of reservoirs. Emphasis was also laid on the activities of raring biotic components (trees, shrubs, herbs, etc.) for the rejuvenation and charging of ground water aquifers. The 85 *Panchayats* (pilot sites) selected for implementation of the project basically served as research laboratories for carrying out experiments to test the strategy and approval of the project (Table 2).

Objectives

The project was strategically integrated with local livelihood opportunities and unique ecological settings for formulating sustainable resource management plans. The emerging micro-plans very successfully reflected the aspirations of local peo-

Fig. 5

ple. The empowerment of communities led to the betterment of local governance. The objectives of the project were therefore formulated as:

- Strengthening of local Community Based Organizations (CBOs) and institutions for improvement in local governance.
- Development of a cost effective model for sustainable livelihoods through conservation of fragile land and water resources.
- To conserve and rejuvenate the traditional water reservoirs through increased community initiatives and technical input.
- To develop a multi-stakeholder based forest sector policy and strategy for the state of Himachal Pradesh.

Results and Discussion

The project was successfully completed during March 2007. The objectives laid down under the project were effectively handled and fulfilled. The mid term evaluation and project appraisal reports manifestly pointed towards community empowerment, improved local governance, strengthened rural livelihoods, conserved land and water resource and effective local capacity building. The salient achievements are as follows:

- Through this project, 5.247 million pounds were judiciously spent on the field implementation of activities raised in the micro-plans of selected 85 *Panchayats*. An estimated 3 million pounds have been spent on training and capacity building of various stakeholders such as villagers, officials of Government Departments, NGOs, etc.
- On analysis of activities proposed in these micro-plans (Table 3) it was found that first priority of villagers is construction of water harvesting structures, check

Table 3 Community prioritization of local resource management.

Name of district	Plantation	Water storage structures	Soil conservation works	IGAs
Mandi	27.21	33.47	12.93	26.37
Sirmour	19.20	42.17	10.23	28.39
Solan	33.52	40.49	9.17	16.80
Una	47.50	16.08	15.98	20.43
Kangra	19.66	50.68	8.97	20.68
Chamba	33.18	21.03	10.66	35.11
Bilaspur	9.62	73.46	8.66	8.24
Hamirpur	13.16	51.45	18.99	16.38
Kinnaur	17.08	39.40	8.75	34.76
Lahaul Spiti	50.07	10.88	29.41	9.62
Kullu	33.92	34.79	11.41	19.86
Simla	31.12	42.74	16.83	9.29

dams, water ponds, percolation tanks, construction of recharging trenches, wells and *Boulies*. The second highlighted priority was related to afforestation of site specific species of trees, herbs and shrubs which meet their day to day requirement of fuel, fodder and timber besides recharging of ground water aquifers and enhanced soil moisture levels.

- The local stakeholders were found to be concerned for the creation of Income Generation Activities (IGAs). It was found that the traditional farming systems were lacking cash inflow suggesting thereby the adoption of cash generating on farm activities. The IGAs were prioritized as the third most important viable option for sustainable Village Resource Management Plans.
- It has been concluded that more than 50% of the budget was spent on purely water related activities and the remaining amount was spent on afforestation activities, which indirectly helps in recharging of water aquifers and raising of water tables.
- The selected *Panchayats* have surely moved ahead in ensuring better water services adhering to the principles of community participation. There has been huge support from the community in the water conservation programme reflected in the form of labour and cash contribution, participation in programme implementation, monitoring etc. The participation of women has been commendable.
- People of 85 selected *Panchayats* in Himachal Pradesh have revived 629 springs, ponds, tanks and *Kuhls* in their valleys with the help of this most successful Himachal Pradesh Forest Sector Reforms Project.
- There are 10,512 traditional water harvesting systems in the state. For each unit, self help groups were constituted as a withdrawal strategy so that these systems are maintained even after culmination of the project.
- This project was implemented from January 2003 to March 2007 through village *Panchayat* by involving local villagers at all stages right from planning to implementation, and monitoring and evaluation stage.

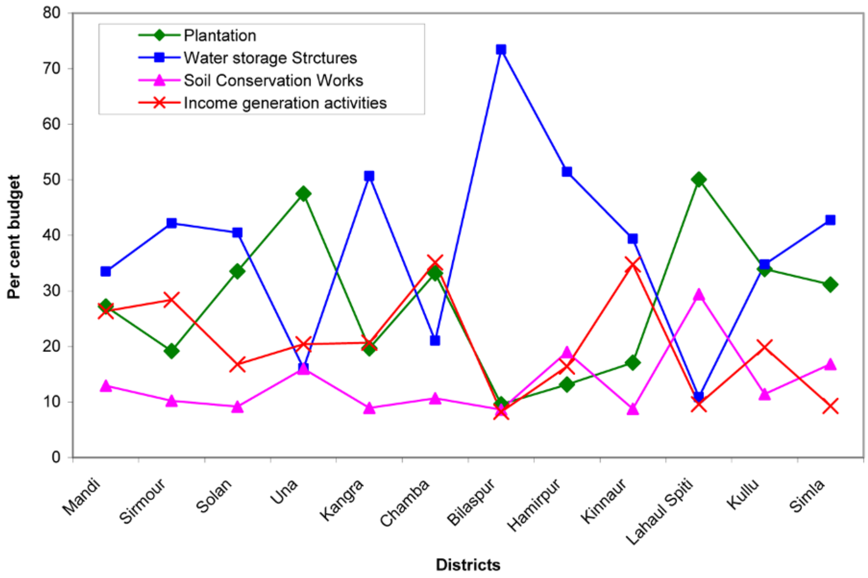

Fig. 6 Community prioritization of local resources.

- Villagers themselves tracked the origin and natural recharge zones of the streams and accordingly built rainwater harvesting structures, check dams, etc., to augment the discharge of spring and raise the ground water level in the arid valleys.
- Species of commercial trees, herbs and shrubs suitable to local conditions were planted in the catchments area to increase soil stability and help percolation.

Conclusions and Policy Recommendations

The project led to the following conclusions:

- The strategy and approach tried in 85 selected *Panchayats* in Himachal Pradesh was to understand the group dynamics. It is felt that this effort is an important step towards curbing water crises in the hilly areas, where springs are the only source of water for drinking as well as feeding the non-glacier streams. The massive afforestation programme would help combat desertification and soil degradation, would arrest global warming and shifting rainfall patterns. It will raise ground water level and increase moisture in soils and in turn increase the availability of water.
- The traditional water reservoirs systems in selected village maintained and constructed by the funds provided under DFID, UK project revealed that these not only meet the safe drinking water requirement of villagers but also help people in

growing off season vegetables and medicinal plants over land which earlier was solely dependent on rain.

- The decentralization is a lengthy project and must be adopted in phases. It has been proved by testing in the above *Panchayats* that a bottom-up approach provided an easy and immediate solution to some of the problems of centralized planning and implementation. For this to happen, a high degree of political will, commitment by the community to readily accept and use the process and decentralization for better local governance is needed.
- The experiences of designing and introducing micro-plans in Himachal Pradesh shows that it is possible for semi-literate communities in the mountains to work in a participatory mode and place ownership of the community based plans into the hands of *Panchayats*. By using indigenous technical know-how (ITK), involving affected population and adopting integrated scientific approach, we can go much ahead.
- Water management needs a tremendous amount of improvement at all levels – local, regional, national and international. Management cannot be handled singly by one actor. All the authorities and agencies and all the many sectors of the community have to act out their roles.

Acknowledgement

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PART 3

Aquatic Food Production

Quality and Safety of Aquatic Products in China

Wang Xi Chang, Tao Cen, Tao Ning Ping and Liu Yuan

Abstract The quality and safety of aquatic products have attracted more and more attention to all levels including fishery supervisor governors, aquatic products manufactures and final consumers in recent years. The countrywide establishment of HACCP and traceability system in China has gradually enhanced the security of aquatic products across the whole production chain from aquaculture, processing, distribution to consumption. Some suggestions have been initiated in this chapter.

Key words: Aquatic products, HACCP, quality, safety, traceability

Background

Supervised by Department of Fisheries under the Ministry of Agriculture, Chinese fisheries production has witnessed sustainable development. The output of Chinese aquatic products was up to 51 million tonnes in the year of 2005, which accounted for over one-third of global fisheries production, and China fishery has played an important role in aquatic product trade of the world (Wang, 2005, 2006).

It is noteworthy that the quality and safety of aquatic products became the most important issues of food supply especially in China with the consumers' increasing requirements in the 21st century which include such factors as urgency of food security, the rapid rhythm of life, inhanced nutrition and health consciousness and the diversifed consumption level and structure.

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Situation and Discussion

In order to solve the serious bottleneck problems which influenced its domestic economic and social development, China will give priority to technological development in the field of auqaculture from 2006 to 2020. According to the outline of a national program, the implementation will be focused on 11 major sectors as follows: health and disease control for aquatic production, fine-processing and deep-processing as well as modern storage and transportation for aquatic products, comprehensive exploration and utilization of biological resources of aquacultural industries, development of environment-friendly farming, food safety concerning import and export inspection and quarantine, prevention and quick response mechanism to public emergencies.

Abuse of import materials for auqaculture, especially pesticide and veterinary drugs is badly endangering the safety of aquatic products.

More attention should be paid to the five prominent food safety issues in China, which are as follows:

1. Pollution occurs when the agri-products have been produced by individual farmers during the cultivation process.
2. Small-scale, private-owned and unorganized food manufactures pose unqualified sources of pollution.
3. Lacking effective facilities and management, food distribution doesn't perform well in China.
4. Food security is relatively weak in rural areas compared with urban areas of China.
5. Food incidents occurring in China in recent years brought a bad reputation on international markets, and it even led EU, USA and other developed countries to restrict food imports from China.

To solve those bottleneck problems mentioned above encountered in fisheries production and trading, the processing and utilization of fisheries products might be the critical measure to carry out. China's aquatic product processing industry made gradual new progress in 2004. More than 10 million tonnes of aquatic products were processed or utilized as raw materials, which account for over 35% of global fisheries production. The frozen products (whole fish, block and fillet etc.) were the majority of processing products, while others included salty, canned, dressing products, surimi and surimi-based products, fish meal, fish oil, seaweed food products, seaweed chemical products, marine healthy foods, marine drugs, leather derived from fishskin, cosmetic, arts and crafts.

Chinese aquaculture product industries developed rapidly with the implementation of Chinese reform and opening up strategies, indicating a strong potential to transfer trade benefits from comparative advantage to competitive advantage on the global market.

Unstable quality of raw materials and products resulted in a gap between China and developed countries and it was hard to meet the overseas trade requirement for

China. We should pay adequate attention to explore and utilize the marine and freshwater biomass, not only increase availability of a balanced supply to the market, satisfy the needs of consumers, but also promote the quality of processing products efficiently. Thus, it is important for the China fisheries processing industry to make a great contribution to the global food supply and to promote sustainable development of methods of developing new and value-added products, enhancing product quality, insuring food safety, standardizing production, etc.

Chinese consumers have gradually become aware of the importance of food safety and quality although they are generally sensitive about the price. Nowadays, in some developed urban areas such as Beijing, Shanghai, Guangzhou and Shenzhen, consumers buy food products depending on the safety and quality first. They are willing to pay more money in order to get quality and safety guarantees. Therefore, the central government has implemented the Fangxinshipin (safety guaranteed foods) policy, and claimed that only the food manufactured by designated processing facilities are permitted to retail sales.

The trend of aquatic products processing and utilization in China comprises the following sectors: accomplish integral management for the production chain from farming, processing, storaging, transporting to ratailing; diversify the processing methods; manufacture products with good materials; standardize the product quality mechanism; promote scientific management of production, improve the processing technology, with Chinese characteristics for aquatic products processing and utilization on large scales, close network, more information and market-oriented as well.

China also should make continued efforts to diversify varieties of aquatic products as follows: convenience (seasoning before being frozen) food for supermarkets, recreational food, fast food, microwave food, baby/infant and geriatric food, functional food (healthy food), engineering food(imitation food), healthy beverage, and condiments, etc.

The advancement of modern science and technology, optimization of distribution and marketing, and globalization of economy, all these factors make it possible to combine traditional techniques with advanced technology in the future. In order to meet global market demand, it is farsighted for China to do research on health and nourishment of marine products, to provide more professional and technical training, to insure the safety and quality of aquatic products across the whole production chain, to increase utilization of aquatic products, to strengthen each product's function and characteristic, to select and breed suitable species as raw material, and to promote new products on industrial-scale, etc.

China Central Government and Department of Fishery promise to "spare no efforts" to enhance quality assessment and supervise aquatic product security as soon as possible. Nowadays, there are many aquatic product quality and safety inspecting centers located countrywide belonging to the general administration of quality supervision, inspection and quarantine, Ministry of Agriculture or local government in China, respectively. A national scheme against the residues in aquatic products was carried out in the autumn of 2006, indicating that China has already set up a complete system of aquatic product quality monitoring. Table 1 shows the adminstrative ministries related to food safety affairs in China. Aquatic product processing facto-

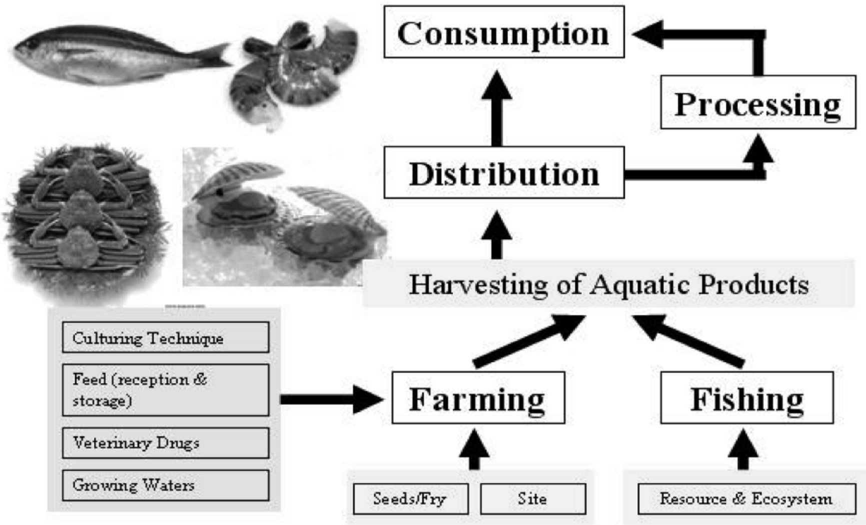

Fig. 1 Flow diagram of aquatic products from production to consumption.

ries are required to record the data of their daily production and medicine dosage. Purchase and replenishment of raw materials also should be recorded and accept strict scrutiny.

Owing to the antibiotic residue restriction of other import countries, China lost at least 7 million US dollars in the year of 2006. For example, traces of chloramphenicol were detected in the shrimp and prawn samples exported from China. So it is crucial to promote formal training courses on proper dosage of fish medicine for Chinese fishermen. Food industries in China have made considerable development on adjusting their strategies in view of a market-orientation, focusing on suitable raw materials and advanced manufacturing facilities so as to to meet consumers' demands for high quality safety.

Suggestions

Based on the statements above, it is practical and significant to make further research in the safety of aquatic product from production to circulation. Some suggestions on improving quality and safety of aquatic products in China.

Table 1 Lists of ministries related to food safety affairs in China.

No.	Ministries	Websites
1	State Food and Drug Administration	http://www.sda.gov.cn/cmsweb/webportal
2	Ministry of Public Security	http://www.mps.gov.cn/cenweb/portal/user/anon/page/policeWeb_HomePage.page
3	Ministry of Agriculture	http://www.agri.gov.cn//index.htm
4	Ministry of Commerce	http://www.mofcom.gov.cn/
5	Ministry of Health	http://www.moh.gov.cn/
6	State Administration for Industry & Commerce	http://www.saic.gov.cn/
7	General Administration of Quality Supervision, Inspection and Quarantine	http://www.aqsiq.gov.cn/
8	General Administration of Customs	http://jckspaqj.aqsiq.gov.cn/

Consolidate the Construction of HACCP, Traceability and GAP System

Safety and quality of aquatic products should be ensured from the headstream. Firstly, environmental protection should be intensified from origin, including the establishment and improvement of the inspecting network of aquatic products, and strict restriction on pollutants. More attention should be paid to formulating environmental standards for the place of origin, to develop general inspection of the environment especially on aquatic products production, to take effective measures for decontaminating the agricultural and ecological environment, and be strict with the aquatic products' quality and safety from its headstream. Secondly, we should strengthen the management of the production process. Technical training should be initiated for aquatic products producers and supervise them to obey the technical rules of safe production, and reduce the antibiotic residue as well. Thirdly, the supervision and management of aquatic products processing industry should be enhanced step by step. The enterprises should ensure their products' quality and health safety, and encourage them to take effective measures such as production permission and forcible inspection. Supervision of the law-enforcing and HACCP methods, and improvement of aquatic products safety in the chain of processing and circulation also should be actively pursued.

Strengthen the Supervision and Management of Aquatic Product Quality and Safety

Based on the construction of aquatic product quality and safety inspecting and testing centers, it is essential to enhance the professional ability of inspecting personnel, modernize the equipment and measures, implement inspecting work in producing bases, wholesale markets, agricultural trade markets, and supermarkets. The aim is to form the aquatic products self-inspection system step by step, develop all-round quality and safety monitoring mechanism. Materials and producing process could be recorded, and pollution could be supervised under control and even the whole aquatic products production could be inspected in case of any accident, so as to ensure the quality and safety of aquatic product from its headstream.

Improve the Integrity Mechanisms and Advertise the Fundamentality of Food Security

Considering the food industry on the long term, an effective method is to intensify professional faculties as well as to encourage the institution's responsible for the food industry and other food safety groups to carry out more activities on advertising. Associations of civil society organizations must play a supporting role in the management of food safety. As the 2008 Beijing Olympic Games and 2010 Shanghai World Expo draw near, it is everyone's duty to make more efforts to improve the integrity mechanisms of the society and realize sustainable development in China.

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Notes of Study on Development Strategy of Chinese Fishery to 2030

Yingqi Zhou and Xinjun Chen

Abstract The paper presents the views from the project "Study on the developmental strategy of Chinese fishery science and technology in medium and long-term". The first priority of fisheries in China is to produce sufficient aqua-products to meet the demand, which is estimated to be more than 20 million tons over current levels by 2030. The difficulties are the restrictions from resources and the environment, and poor management in marketing and administration. The strategies for fishery science and technology are classified as "Safeguard strategy, Promotion strategy, Developing and Widening strategy and Innovation strategy". The key points suggested by the strategy for raising the level of fishery science and technology and competitive power of fishery products are: formulation of policy should be based on fish consumption purposes; integration of technology through "Digital fisheries" and "Engineering fisheries"; efficiency improvement of species, feed coefficient and processing; strengthening education and training levels of fishery labor; organizational reform by promoting four types of "Complement and Combination (C&C)" systems; introduction of technology from other industries; establishing a practical action plan and goals on aquatic product security and quality management; and setting up information sharing platforms and data bases, and related service systems.

Key words: Chinese fishery, strategy, demand, resources, sustainability

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Introduction

The authors were in charge of the national project "Study on the developmental strategy of Chinese fishery science and technology in medium and long-term", which involves the forecast of demand for fish, as well as the need for fishery science and technology for 2020 and 2030 (Zhou et al., 2006). Therefore, the development targets of Chinese fishery, the characteristics of fishery science and technology and their goals have been studied. In this paper the main ideas and views on macroscopic strategy study will be described.

Background

China is a great fishery nation with a total yield of 51 million tons in 2005, which accounts for 1/3 of the total yield of the world, and is ranked number one in the world for the last 15 years. Chinese fishery structure took the leading position due to the introduction of aquaculture. Chinese aquaculture output amounts to 33.93 million tons and accounts for 2/3 of the world aquaculture output, in which 40.8% is from marine aquaculture. In addition, the Chinese fishery trade accounts for 6.8% of the world fish exports, which is ranked number 1 or 2, and is ranked number 10 for fish imports (Zhang and Rortveit, 2004). Thus it can be expected that the Chinese fishing industry will continue to play an important role in the global fisheries.

In China, the increase in economic growth rate of fishery is 9% which is higher than the GDP increment rate, and the average annual growth rate of total output is 4.1%. In 2005, the output value from marine fishery accounted for 35% of the total value created by marine industries in China. It is noted that the fishery population is 20.7 million people and the labor force is approximately 13.16 million, which is only about 2% of the agricultural population. However, the fishery provides 1/3 of the animal protein consumed by the Chinese people. Fisheries will continue to play an important role in the daily life of the Chinese people.

Priority in Chinese Fishery and Challenges

Strategy study on fisheries is different from research on natural science and technology, since a strategy study should focus on the future of fisheries including foresight, prediction of trends and goals and warnings and cautions, the mechanism and driving forces for development, for instance, the demand and supply of fish in 2030 and the limitations or risks involved. Since the study is at a national level, the following factors should be taken into consideration, viz. sustainable development, the national general strategic goals, and feasibility. It should investigate and understand the priority or importance of the factors "sufficient food supply, economic benefits and efficiency, protection of environment and resources" in the fisheries concerning national macroscopic strategy targets.

The First Priority – Demand for Fish in 2020 and 2030

The administration structure of government might indicate or reveal the main goal of a country, for instance, in China the Bureau of Fisheries comes under the Ministry of Agriculture, which is similar to the practice of most nations, i.e., food, agriculture, and fisheries, and even forests are managed by one ministry. This reveals that to provide sufficient aqua-products as food for the Chinese people is the first priority, at least in the past. This is different from the situation in USA and Australia. The fisheries sector in the USA is under the National Oceanic and Atmospheric Administration (NOAA) in the Department of Commerce while in Australia it is under the Department of Primary Industries (DPI); which reveals that the economic efficiency of resources utilization is the first priority. After China adopted a market economy system, the economic benefits and efficiency of fisheries become the second goal. Due to organizational reform of the administrative structure of government in recent years, the bureau of fisheries and the marine bureau at the provincial level have been merged together in one bureau in China. This reform might be advantageous from the viewpoint of conservation of environment and harmonious ecology. However, our investigation shows that in the near future, China will continue to set the production of sufficient fish to meet the demand of Chinese as the first priority.

By sampling, interviews and modeling, and also referring to previous studies (Chang and Zhou, 1992; Zhou, 1992, 2000; Delgado et al., 2003; Zhang and Rortveit, 2004), it is estimated that the demand for Chinese fishery products will increase by 20 or 39.5 million tons in 2020 or 2030 year respectively, or that the output value would be double that of 1997. The average fish consumed per capita in 2020 could be 35.9 kg (Figure 1). The challenge is whether the goal can be achieved and how to approach it.

Challenges Faced by Chinese Fisheries

In the present strategy study, the "bottlenecks" which might occur in the fisheries sector are predicted and analyzed, and methods are indicated how to prevent or reduce the possible appearance of bottlenecks and reduce their negative influence.

The finding from our strategy study shows the challenges that Chinese fishery will face, viz. demand on fish increasing by about 40% in 2030 must rely on self-sufficiency, mainly from aquaculture, both fresh water aquaculture and sea farming. The possible supply shortage of feed, for example, even though China imports plenty of fish meal, fish feed could be the key or "bottleneck" for aquaculture; China has to properly utilize the high seas fishery resources, however, marine fish-

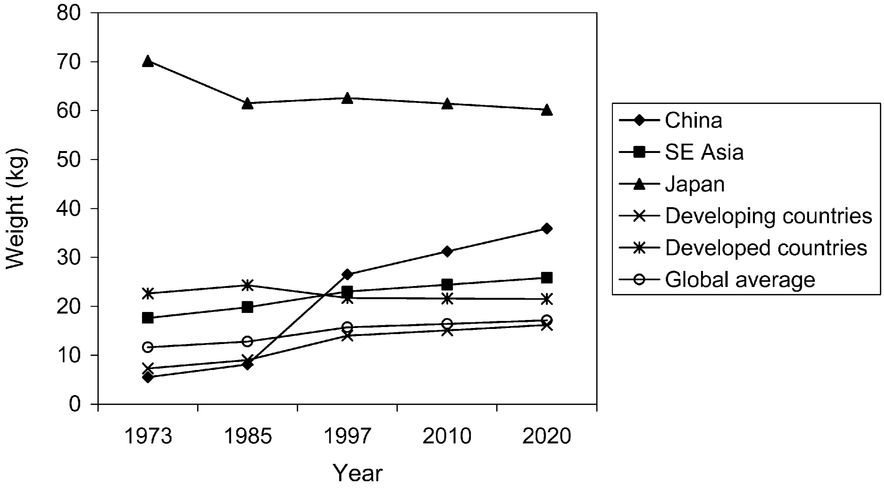

Fig. 1 Average fish consumption per capita.

ing has not much room to expand due to already declining stocks; The export of fish from China should mainly adopt the mode "import raw material and re-export after processing", hence high value added technology is required. The quality of fish will become very important as domestic and foreign consumers are requiring high quality fish.

The difficulties and restrictions involving Chinese fisheries are mainly:

- Increased industrial development has further increased the demands on resources and the environment, in fact, the current situation is that overfishing has resulted in inshore fishery resources being seriously destroyed, habitats of fishes and related aquatic environment are getting worse, and depressing biodiversity. It has been reported that the number of fishing boats are more than 480,000 in China, total fishing capacity has a surplus of 30%, and even exceed 50% in some areas (Zheng and Zhou, 2002; Zhou, 2006). "Fishing down to food web" exists anywhere according to Pauly et al. (1997). Low value species as bycatch constitutes 60%-70% of the catch. Trophic levels of species in the catch are dropping, while shrimp and small fishes becomes the main target fish. Because of environmental pollution, the output from fishing lost 500,000 tons every year in China, which is approximately RMB 3 billion Yuan.
- The development of fishery industry was restricted only by fish resources in the past; however, it has become restricted by both the resources and the market. Furthermore, because systematization of the fishery industry is poor, lack of competitive power in market economy, their survivability in risk and capability to apply new advanced technology are lower. Because of wrong guidance in the market by consuming trends, aqua-products have changed very quickly in the Chinese market, greatly increased the social opportunity costs, and as the species of market fish have changed too fast, it is not possible to carry out long term research,

Table 1 Fisheries in China.

Items	2000	2005	2010
Total output (million ton)	42.79	51.02	60.00
Aquaculture	25.78	33.93	45.50
Capture	13.91	13.09	12.00
Total value (billion Yuan)	280.8	418.0	570.0
Import & export (million ton)	4.05	6.23	
Export (million ton)	1.534	2.57	4.00
Value (billion USD)	3.83	7.89	12.0
Income per fisherman (Yuan)	4725	5869	7200
Processed products (million ton)		1.195	1.700
Value (billion Yuan)		132.1	220.0
Processed ratio	30%	34.8%	
Marine fishing vessels (1000 vessels)	248	215	192
Power (Million kw)	12.0	12.2	11.43

so the producers will find it difficult to obtain sufficient technical support. After the market system was introduced into China, the economic benefits have been paid great attention. The most high value species are selected for aquaculture, mainly to provide restaurants or hotels, however, these species which are at the top of the food chain consume more energy for growth, for instance, feed with small fish and fish meal, which places high demands on natural resources.

- Chinese fishery production methods are still coarse and un-integrated. The development of fisheries excessively relies on the input production elements, inflow of funds and resources have been massively consumed. In China, only 34.8% of aquatic products is processed (Table 1), and in the case of fresh water fish it is only 5.7%, a very low percentage in the total fresh water fish yield. In Japan, Canada, America and Peru, up to 60–90% of the fish is processed. It has to be noted that a lower processing rate affects the value added and the economic performance of fisheries.
- The essential supporting system for the fishery industry is weak. For example, research and extension service work on breeding, disease prevention and control, fish and water resources conservation and management are not sufficient. Regarding the fishery resources and the environment survey, fishery research lacks fundamental study and systematic data collection, and even lacks reliable data.
- Education and training for fishery labor is not sufficient. With the reform of the state economic structure and changes to the fishery structure, there is a massive number of fishery workers who have to transfer into other sectors; however it is difficult to shift because of lower education level (Chen and Zhou, 2000). On the one hand, this kind of shift needs the support of the entire society; obviously this is societal engineering, which involves the culture, education, exchange, and enhances the adaptive ability of fishermen to modern society. Furthermore, to create new jobs for fisheries, and then also have to maintain a continuously increasing income is another major challenge. All these are part of the challenges which Chinese fisheries face.

Recommendations for Development Strategy of Fishery Science and Technology

The outline recommended for the sustainable development of fisheries is, “To construct and create an ecologically friendly fishing industry, integrated healthy aquaculture, advanced processing industry, advanced logistic and distribution industry, varied recreation fishery and sport fishing”. The fishery science and technology development strategy may be divided into four kinds: (1) safeguard strategy, (2) promotion strategy, (3) developing and widening strategy, and (4) innovation strategy.

Safeguard Strategy

To produce sufficient aquatic products, the selection and cultivation of species for farming and their production pattern, quality control and ecological security are important issues.

Promotion Strategy

To overcome the restrictions and limitations from fisheries, water, human resources and marketing, the technology to explore new resources, cultivation and development of the market, and human resource training are required.

Developing and Widening Strategy

Refers to the “3F development” (Fishery, Fishery village and Fishermen) as a comprehensive package, it is not only to develop the fishery as an industry, but also involves society, human development, and harmonious ecological development.

Innovation Strategy

There are new areas related to fisheries, such as application of digital technology, genetic technology, aqua-biomass production as raw material, and marine medicine, which should be explored.

The key points suggested by the strategy study for raising the level of fishery science and technology and competitive power of fishery products are as follows:

- Formulation of policy should be based on fish consumption purposes. Fish utilization can be classified into groups, i.e. fish for daily food, fish for well-off life, fish for export, fish for leisure and recreation, and fish as industrial raw material. (a) Fish for general populace daily consumption and main source of protein, referred to as "people's fish", should have high priority and full support from the government including intensive research. The criteria recommended for selecting people's fish are: a low energy consumer or has broad feed scope such as herbivorous species and suitable for large scale processing, for instance, tilapia and shrimp are highly recommended. However, aquaculture of people's fish has a lower profit margin in general but huge demand. It is important to safeguard supply as the first goal in China, hence the government should organize and promote all available research institutions and universities conducting research on each link of the entire industrial chain from fish pond to table. Also providing funds to the project as a national key project to form industry on a large scale. (b) Along with improved people's living standard, the demand for different types of fish will be inevitable, including consumption of more costly fish on holidays. This type of demand makes it necessary to develop expensive and high quality variety table fish from aquaculture or fishing. To satisfy this requirement for the well-off life, the fish authority may provide appropriate support and guidance. (c) Fish for export only involves economic efficiency as the essential target. It is suggested that the policy, in principle, will guide enterprises based on market economy rules. The industry will seek and obtain R&D funds and loans from banks or the private sector. (d) Ornamental fish has a great potential market value where the buyers will be people having well-off life. However, the aquaculture of this type of species requires high tech support from research institutions. (e) Algae could be potential biofuel, an important renewable energy resource in the future.
- The integration of technology in the development of fisheries is anticipated through "Digital fisheries" and "Engineering fisheries". Aquaculture production in China relied mainly on the experience of past practices. Since there is a shortage of data from scientific research and experiments, it is difficult to adopt modern technology such as information and engineering technology. For guiding the R&D work, the new concepts "Digital fisheries" and "Engineering fisheries" are proposed. Digital fisheries in aquaculture can be called "precision fish farming". Systematic research, and the collection and analysis of all relevant data of aquaculture, can be used to give instructions and monitor the production process, control the energy flow and utilization of resources, adjust nutrition provided and metabolism of fish in precise mode, supported by computer technology. Digital fisheries also include the application of 3S technology (RS, GIS, GPS) in marine fishing and fish resources conservation and ecological system study, digital modeling of fish behavior and fishing gear performance and selectivity; also including documentation fishery or traceable fishery, professional system and intelligent fishery instrumentation, etc.

In addition, more attention should be focused on the integration of engineering technology in fish cage farming, in particular, the large-scale fish cages with supporting platforms in the open sea. Engineering fisheries means, not only application of engineering technology, but also to use systematic engineering concepts to re-organize and manage the fisheries. The results from our ecological accounting study show that land-based intensive farming is better on water, resulting in land resources saving and lower ecology cost. This is a noteworthy result (Hu and Zhou, 2005).

- Efficiency is the key of production–species, feed coefficient and processing. To meet the demand of fish in future, the products will mainly come from aquaculture, particular by sea farming. So productive species and feed coefficient become the keys to Chinese aquaculture. At present, Chinese aquaculture consumes 3 million tons of feed. If 40% of feed could improve its feed coefficient from 2.1–4.0 to 1.3–2.0, it means an additional 500,000 tons of fish can be fed. If the fish loss due to fish disease is reduced by 20%, an additional 6 million tons of fish will survive. Cultivation of well-bred species, for instance species that grow 30% faster, such as F6 salmon and F6 black beam (Pujiang No. 1), could produce considerable economic returns and fish production. The output value could be increased by means of high value added products, processing and well organized logistic management.
- Concerning the quality of human resources, while the Chinese fisheries step into modernization, the first thing is to strengthen the education and training levels of fishery labor, because, in general, fishermen are the beneficiaries and executors of sustainable development. The level of education received by fishermen received will be the key issue for sustainable fisheries. The government has to give full attention and support to this matter.
- Concerning the establishment of system and mechanism, the key lies in organizational reform. The authors suggested to promote four types of "Complement and Combination system (C&C)", also called "the three-in-one combination (3-in-1)": The first type "Enterprise-Training-Research C&C (ETR)", involves universities and scientific research institutions through this cooperation, provides the technical support for enterprise development and promotion, and is beneficial to speed up technology transfer and modernization. However, it should be noted that this type of C&C has an extremely strong utilitarian bias; it will pursue economic profit for the enterprise as the core target. It is not suitable for public welfare research. The second type of C&C is "Administration-Education-Research (AER)". This kind of 3-in-1 combination mainly carries out soft research projects by universities and research institutions, which provides policy-making guidelines and advice for the government. The third C&C is the most important in the development of fisheries, namely "Education-Research-Extension service work (ERE)". This kind of cooperation is quite common in the agricultural sector of developed countries. Education, research and extension services are the main functions of universities. Providing technical services for fishermen will guarantee the sustainable development of fisheries. The ERE system can continuously provide the knowledge and support to the persons engaging in technical extension service work, and speed up the technical transfer. At present the ERE system is not properly set up in China, in fact, the education, research and extension service are split and allocated in different sectors, which results

in the extension service being placed in a very difficult situation. The fourth one is: "Government-Institution-Enterprises (GIE)". By government instructions or guidance according to national macroscopic goals, universities transfer their scientific findings and technical achievements to enterprise directly, and rapidly, to form and create new industries to meet national or provincial goals.

- Because fisheries rely on the introduction and integration of technology from other industries, it is important to actively introduce and adopt achievements from IT, space science, bio-tech and new materials etc. and promote the integration of technology, to implement elaborate management and enhance efficiency.
- Aquatic product security and the quality are directly related to the people's welfare and health. So it is proposed to set up a practical action plan and goals on aquatic product security and quality management.
- Set up information sharing platforms and data bases, and related service systems.

Towards 2030, the important R&D works recommended in order are as follows: improve and/or optimize aquaculture production, disease prevention and control, feed development, high density aquaculture technology, fish cage farming, genetic technology, deep-sea fisheries, raises the ratio of processed fish, logistic management and distribution, intelligence fishery equipment and instrumentation, digital fisheries, engineering fisheries and resources economy and management.

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Changes in Fisheries and Water Environments of Lake Taihu, China

Zhengwen Liu, Kuanyi Li and Songquan Zhu

Abstract Lake Taihu is a large shallow lake located in the Yangtze River Delta. Over the years, 107 fish species have been recorded in this lake, and its fisheries have a long tradition of playing an important role in the local economy. However, environmental changes such as eutrophication have threatened the fisheries during the past three decades. In our recent survey, only 58 fish species were collected. Although there has been a tremendous increase in total fishery catches during the past 50 years, some traditional and important fishery species such as salangids and shrimps have shown a decrease in their catches in recent years.

Key words: Eutrophication, fisheries, Lake Taihu

Introduction

Lake Taihu is a large shallow lake located in the Yangtze River Delta, with a surface water area of 2,338 km^2 and an average water depth of 1.9 m (Qin et al., 2004). Fisheries have a long tradition and played an important role in the local economy. However, due to the rapid economic growth and population increase in its catchment, Lake Taihu has been facing water deterioration problems, particularly the problem of eutrophication, which has threatened the fisheries during the past three decades. In this paper, we analyzed the changes in fishery species and catches and discussed the relationship between fisheries and water environments in Lake Taihu.

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The Dominant Fishery Species

There are 107 fish species recorded in Lake Taihu since the beginning of the 20th century (Ni and Zhu, 2005). However, in our investigation in 2002 to 2005, there were only 58 species collected.

The loss of fish species of Lake Taihu is due to many factors (Li, 1999). Embankments and land reclamation reduced littoral zones which were the feeding and spawning grounds for many species. Dams built on the waterways between the Yangtze River and Lake Taihu have caused the extinction of anaromous and catadromous fish such as *Acipenser sinensis*, *Tenualosa reevesii*, *Mugil cephalus* and *Takifugu fasciatus*. Fish migrating between the Yangtze River and Lake Taihu including *Myxocyprinus asciaticus*, *Xenocypris microlepis* and *Ochetobius elongatus* have also not been found in recent investigation (Zhu, 2004), and the populations of some important commercial species of this group, e.g. *Mylopharyngodon piceus*, *Ctenopharyngodon iaellus*, *Hypophthalmichys molitrix* and *Aristichthys nobilis* have been maintained by artificial stocking.

However, the dominant commercial fishery species in Lake Taihu have been few: fishes such as *Coilia nasus*, salangids, *Cyprinus carpio*, *Carassius auratus*, *Hypophthalmichys molitrix* and *Aristichthys nobilis*, shrimps such as *Macrobanchium nipponensis* and *Palaemon modestus*, and bivalve mollusc *Corbicula fluminea*.

Changes in Fishery Catches

There is a tremendous increase in the total fishery catches in Lake Taihu (Table 1). The increase is particular dramatic in *Coilia*, and the proportion of *Coilia* to the total has doubled. The salangids are most valuable and famous fisheries in Lake Taihu; their catches were highest in the period of the year 1980–2000. A decrease was observed after the year 2000 and the proportion to the total catches was lowest in 2001–2003. The changes in the catches of shrimps are similar to the salangids, and the values were highest during the last 20 years of the last century and decreased after the year 2000. The percentage of shrimps to the total catches was lowest in the period of the year 2001–2003.

Water Environmental Changes and the Relationship with Fisheries

In line with the rapid economic development in the catchment, the water quality of Lake Taihu has been changed dramatically, particularly since the beginning of the 1980s (Table 2) (Qin et al., 2004). The increased nutrient input to the lake has accelerated the eutrophication process. In the 1960s, the lake was oligotrophic, and

Table 1 Annual fishery catches in Lake Taihu (values are annual means of perspective periods, original data are from the Fishery Yearbook of Jiangsu Province).

Year	Annual	Coilia		Salangids		Shrimps	
	Catches (t)	Catches (t)	%	Catches (t)	%	Catches (t)	%
1952–1955	5546.7	1281.1	23.1	983.2	17.8	664.3	12.0
1956–1960	8226.2	3361.5	40.9	506.5	6.2	607.9	7.4
1961–1965	9077.6	4947.0	54.5	489.4	5.4	589.4	6.5
1966–1970	10791.8	6422.5	59.5	624.9	5.8	962.9	8.9
1971–1975	10417.2	5913.3	56.8	766.5	7.4	787.3	7.6
1976–1980	12490.5	6766.0	54.2	703.9	5.6	824.7	6.6
1981–1985	14089.8	6090.0	43.2	1214.8	8.6	1194.2	8.5
1986–1990	15125.5	6309.9	41.7	1701.0	11.2	1022.6	6.8
1991–1995	15468.0	6838.5	44.2	1425.5	9.2	764.4	4.9
1996–2000	27348.1	9991.2	36.5	1142.9	4.2	1514.4	5.5
2001–2003	34593.4	18295.8	52.9	801.4	2.3	954.2	2.8

Table 2 The changes of the water quality of Lake Taihu (Qin et al., 2004).

Year	TIN (mg/L)	TN (mg/L)	TP (mg/L)	COD (mg/L)
1960	0.05	–	–	1.90
1981	0.89	0.90	–	2.83
1988	1.12	1.84	0.032	3.30
1994	1.14	2.05	0.086	5.77
1995	1.16	3.14	0.111	5.53
1998	1.58	2.34	0.085	5.03
1999	1.79	2.57	0.105	4.99
2004	2.67	3.44	0.133	5.33

changed to the eutrophic in 1980s and the hypereutrophic in 1990s (Chen et al., 2003a).

Eutrophication has enhanced the productivity of Lake Taihu and phytoplankton and zooplankton biomass has increased (Fan, 1996; Chen et al., 2003b; Qin et al., 2004), which was partially responsible for the increase of total fishery catches, especially the catches of planktivorous fish *Coilia*. On the other hand, eutrophication has resulted in heavy blue-green algae blooms since the beginning of the 1990s. Algal blooms have imposed numerous adverse effects on the lake ecosystems including disappearance of the macrophytes in some areas of western Lake Taihu (Qin et al., 2004) and hence the loss of the habits for fishes, molluscs and shrimps. Another mechanism of algal blooms influencing fishery species is oxygen depletion due to the decomposition of mass algae. In spite of the increase in total catches, some species showed a decrease in catches in recent years, such as salangids and shrimps, particularly *Palaemon modestus*. In addition to the effects of eutrophication on lake fisheries, overfishing might be another cause of the changes in fisheries of Lake Taihu. However, the mechanisms of the effects of both eutrophication and overfishing are complicated, and need to be further studied in order to improve the management and restoration of fisheries in Lake Taihu.

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Wastewater Management in Freshwater Pond Aquaculture in China

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Abstract This review aims to identify management strategies in freshwater pond aquaculture wastewater in China. Aquaculture activities are the major cause of the increasing level of organic waste and toxic compounds in the aquaculture industry. The main contaminants of the wastewater effluent are suspended solids, ammonium, organic nitrogen and phosphorus. Aquaculture wastewater discharges may cause many environmental problems such as eutrophication to the receiving waters. Nutrient removal is essential for aquaculture wastewater treatment to protect receiving waters and for potential reuse of the treated water. Therefore, it is apparent that appropriate wastewater treatment processes are needed for sustaining pond aquaculture development. A number of physical, chemical, and biological methods used in wastewater treatment applied in freshwater pond aquaculture systems have been presented in this review. Among which biological treatment has been considered the most feasible approach for enabling water reuse. In this chapter, the principles of the wastewater treatment systems are examined.

Key words: Freshwater pond aquaculture, treatment, wastewater, water reuse

Introduction

China has a long history in aquaculture back to 2000 years ago. Since the 1970s, under reform policies and driven by the economic benefits, the rapid development of China's aquaculture both in fresh waters and marine waters has been the focus of world attention. According to the Fishery Bureau, Chinese Ministry of Agriculture, the total production in 2005 amounted to 51.0 million metric tons, making up one quarter of the world total. Aquaculture contributes 65% to the total fishery pro-

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duction, among which inland freshwater pond aquaculture is a major part. Without doubt, China's pond aquaculture will continue to play an important role in the global supply of fish in the future.

However, along with the development, concerns are evoked about the possible effects of ever-increasing aquaculture waste both on productivity inside the aquaculture system and on the ambient aquatic ecosystem. The past obsolete technologies and incomplete arrangement of waste management systems in aquaculture contribute a lot to the deterioration of aquaculture environment, which has caused a great economic loss, destroyed the aquatic biodiversity to some extent, and hindered the sustainable development in aquiculture. It is found that only 13.9% nitrogen and 25.4% phosphorous in the fish diets are utilized by aquatic animals, while the rest accumulates in the water or deposits into the sediment (He and Wu, 2003). According to the statistics, aquaculture pollution accidents at a number of 2067 happened in 1999 and 2000, leading to an economic loss of 2 billion dollars (Yang et al., 2002). The eutrophication of water bodies for aquaculture is on a sharp rise at a rate of 2.1–3.7% per year in the Yangtze River basin and Zhujiang Delta basin compared to the last two decades.

Aimed at settling the increasingly aggravated environmental problems raised by aquaculture waste, the Chinese government has adopted a series of regulations and controls. Aquaculture systems which incorporate waste treatment and effluent reuse facilities are rapidly being developed because they have the advantage of minimal water input and wastewater discharge while allowing full control of the culture environment (Fang et al., 2004; Wang et al., 2004). The forms of aquaculture waste treatment systems may vary, but generally they can be classified into three categories: physical treatment, chemical and biological methods. Many studies have been conducted to examine the aquaculture waste treatment efficiency of different treatment system (Jin and Wu, 1998; Cheng et al., 2002; Xiao et al., 2006). However, the disadvantages of each treatment are also obvious, such as excessive sludge production, unstable performance, and nitrate accumulation. Thus, research on new methods for aquaculture wastewater treatment is under way. The purpose of this review is to analyze the sources of aquaculture waste and common waste treatment methods applied in aquaculture systems in China.

Wastewater Treatment

Wastewater treatment is a process to renovate wastewater before its reuse or discharge. The goal is to reduce or remove organic matter, solids, nutrients, disease-causing organisms and other pollutants from wastewater. A number of physical, chemical, and biological methods used in wastewater treatment have been applied in aquaculture systems. Solids removal is accomplished by physical methods such as sedimentation and mechanical filtration. Chemical methods such as effective microbes, O_3 water and ClO_2 are commonly used in the sterilization of effluent. Biological processes such as submerged biofilters, trickling filters, rotating biological contactors, and fluidized bed reactors are employed for oxidation of organic matter, nitrification, or denitrification (Van Rijn, 1996). Two parameters are of major interest: (i) the particle size distribution (PSD), which determines the treatment efficiency and (ii) the ratio of particle bound to dissolved effluent load, which defines the mechanical removal potential (Kelly et al., 1997; Dumas and Bergheim, 2001).

Physical Method

Sedimentation

There are abundant suspended solids obtained from feces and un-eaten food especially in intensive pond culture. The use of sedimentation in aquaculture has been reviewed by Lawson (1994) and Cripps and Kelly (1996). Sedimentation is the processes by which suspended solids that have a greater density or specific gravity than water, can settle out of suspension and then be separated from the main flow. It is gravity together with other confounding influences that causes particulate waste matter to sink. The settling velocity is controlled by the viscosity of the fluid (water) and the diameter of the particle (if the particle is assumed spherical). There are four types of sedimentation: discrete; flocculent; hindered or zone; and compression settling (Gregory and Zabel, 1990). The type of sedimentation is dependent on the concentration of the particles and their interaction with each other. According to natural deposition principle, settlement tanks can be set to remove most of the suspended solid wastes.

Mechanical Filtration

Mechanical filtration is also able to remove suspended solids. It includes various types such as drum filtration, screen filtration, and sand filtration. The mesh of these filters is as small as 40 um although, due to the large quantity of wash-water required, filters with a mesh of 70 um or larger are usually preferred. Despite these highly improved filtration methods, small suspended solids tend to accumulate in recirculating systems. Studies of three recirculating fish culture systems (Chen et al., 1993b) revealed that more than 95% of the suspended solids had a diameter of less than 20 um. Removal of small suspended solids can be accomplished by either chemical or biological oxidation. Sand filtration relies on certain depths of sand which is paved above the bottom of the pond as cushion for the sediment (Hopkins and Browdy, 1995). When the depth of sand reaches 15 cm or above, the releasing of half of the inorganic nitrogen and one quarter of phosphate by the sediment can be obstructed (Liu Jing et al., 1990). Besides, foam fractionation is also considered as one type of the mechanical filtration (Chen et al., 1992). Through air-stripping, it can remove and separate soluble organic substances and suspended solids inside the rising air bubbles. Foam fractionation can prevent accumulation of the toxic substances in the aquaculture wastewater.

Aeration

Aeration is commonly used in most rural areas of China, for providing oxygen to the effluent to be treated, and also to eliminate malodorous gases from bottom sediment. By causing the water to flow by gravity down an arrangement of steps, thus splashing and breaking up into films and drops; by throwing it into the air in a spray; and by blowing or drawing air bubbles through it, are some of the ways to bring the water into contact with the air (Colt et al., 1991). Pumping by air lift also has a partial aerating effect. After exchanging the surface water, rich in oxygen, with the bottom water of the pond, some sediment rich in organic matter could be decomposed effectively (Lawson, 1994).

Sediment Overturning and Removing

Too much sediment is not only detrimental to the water quality but also attributable to the changing of the bottom ecological system on which many aquatic animals rely. The pond's bottom, piled up with organic substances, is turned over and over by tillage machines to fully expose the sediment to the dissolved air. This method is aimed at creating more opportunities for contact between sediments and oxygen, meanwhile promoting the decomposition of organic substances and releasing of nutrients. In fact, the tillage of sediment usually would cause rapid decreasing of dissolved oxygen contemporarily, or alga bloom due to the large quantity of releasing nutrients. Thus, it is recommended that this method should be adopted after the drainage of a pond or at least keep a water depth at 20 cm (Losord and Westers, 1994). In addition, at the end of one culture period in China, normally in the winter, the sediment needs to be removed by human labor or machines. Removing sediment will not only improve the living environment of the fish but also increase the capacity of the pond (Metcalf and Eddy, 1991). The removed sediment, rich in various nutrients, is excellent fertilizer for horticulture or agriculture.

Chemical Methods

Liming

Materials such as agricultural limestone, basic slag, slaked lime, quick lime and liquid lime have been used to lime ponds (Boyd and Masuda, 1994). Liming has an immediate effect on water quality. It increases pH, reduces soluble phosphorus, and reduces free carbon dioxide. The pH in the upper layer of the mud and in the water will rapidly raise to 12 or higher, a level which will kill most disease agents and pests (Boyd and Masuda, 1994). The elevated pH will last for about a week, prohibiting any stocking of fish. Increasing the pH may also cause the water to become clear of suspended solids, which can promote productivity by increasing the light available to phytoplankton. However, liming a pond shortly after fertilizing may remove phosphorus from the water, which could prevent a phytoplankton bloom from developing. Culture ponds are typically fertilized in the spring with compounds containing phosphorus. Thus, it is best to apply lime in fall or winter when productivity is unlikely to be affected.

ClO_2

The stable form of chlorine dioxide (SCD) is widely considered as the most effective disinfector in wastewater treatment. SCD can eradicate pathogen, bacterium, sporangium, virus, fungus, parasites completely without any side effects. Meanwhile, as an oxidant, ClO_2 may destroy sulfureted hydrogen, hydroxybenzene, cyanide and other organic matters (Midlen and Redding, 1998). It can improve the water quality and increase the dissolved oxygen content to avoid epidemic disease exploding and infection in the cultivation process. Besides, chloride of lime is also commonly used in aquaculture. Nevertheless, high levels of chlorine may be harmful to aquatic life in receiving streams. Treatment systems often add a chlorine-neutralizing chemical to the treated wastewater before stream discharge.

Ultra-violet Filter and Ozone Water

Treated wastewater is often passed through an ultra-violet filter or treated with ozone to destroy any pathogens, parasites and diseases that may be present (Chen Shuying et al., 2001). Compared with traditional oxidants, they have the following merits: no pollution such as organic chloride; oxygen consumption is small with fast reaction rate. Yet their sterilization speed is affected by temperature, pH value and ammonia concentration (Liltved and Cripps, 1999). Chemical oxidation by ozonation can be applied to reduce the organic load in conventional waste water treatment (Metcalf and Eddy, 1991). In a recirculating system for fish culture, ozonation is effective in degradation of organic matter and is also used for sterilization (Takeda and Kiyono, 1990). For these reasons it is increasingly being used in wastewater treatment of recirculating systems (Van Rijn, 1996).

Flocculants

Chemicals are sometimes added during the treatment process to help settle out or strip out phosphorus or nitrogen. Some examples of nutrient removal systems include flocculants addition for phosphorus removal and air stripping for ammonia removal. Flocculants refer to those that contain at least one kind of monomer or polymerization aluminum salt and multi-prices carboxylic acid mixture (Tchobanoglous and Burton, 1991). They are especially good for removing algae bloom in the aquatic system. This method can purify the water body completely, yet without any harm to aquatic animals.

Biological Methods

Effective Microbes

Effective microbes, which generally include photosynthetic bacteria, lactic acid bacteria, sporangium bacillus, nitration bacteria, are utilized to decompose and absorb the sedimentary organic nitrogenous, the ammonia nitrogen, the nitrite nitrogen in the wastewater or convert them to innoxious or beneficial substances. These methods are also called suspended film systems containing suspending microorganisms in aquaculture wastewater (Midlen and Redding, 1998). As the microorganisms absorb organic matter and nutrients from the wastewater they grow in size and number. After the microorganisms have been suspended in the wastewater for several hours, they are settled out as sludge. Some of the sludge is pumped back into the incoming wastewater to reproduce "seed" microorganisms. The remainder is collected and sent to a sludge treatment process. The goals of sludge treatment are to stabilize the sludge and reduce odors, remove some of the water, decompose some of the organic matter, kill disease-causing organisms and disinfect the sludge. Untreated sludge is about 97% water. More water can be removed from sludge by using sand drying beds, vacuum filters, filter presses, and centrifuges resulting in sludge with between 80 and 50% water (Zeng et al., 2000). This dried sludge is called a sludge cake. Aerobic and anaerobic digestions are used to decompose organic matter to reduce volume. Caustic chemicals can be added to sludge or it may be heat treated to kill disease-causing organisms. Following treatment, liquid and cake sludge are usually spread on fields as fertilizes. Activated sludge, oxidation ditch, and sequential batch reactor systems are all examples of suspended film systems.

Biological Filtration

Fish produce ammonia and nitrites as metabolic waste products which are toxic. These waste products therefore need to be converted into nitrates which cause no harm to the fish. Biofilters consist of a medium with a large surface area upon which microorganisms such as nitrifying bacteria will colonize after a few weeks. Usually such as rocks, sand, plastic, gravel, pebbles and cinder are used as the medium for the growth of bacteria (Abeysinghe et al., 1996). The wastewater is spread over the substrate, allowing the wastewater to flow past the film of microorganisms fixed to the substrate. These microorganisms will convert toxic ammonia and nitrites into nontoxic nitrates via oxidation. It will usually take a few weeks to a month before microorganisms colonize and the biofilter becomes active. During this time stocking and feeding rates should be reduced (He and Wu, 2003). As organic matter and nutrients are absorbed from the wastewater, the film of microorganisms grows and thickens. Trickling filters, rotating biological contactors, and sand filters are examples of biofilters. This kind of biofiltration is recommended but current technology relies on expensive bacterial systems (Blancheton, 2000). Moreover, the disadvantages of biofilters are also obvious, including excessive sludge production, unstable performance, and nitrate accumulation (Gang Qin et al., 2005).

Botanical Filters in Integrated Aquaculture Systems

Integrated aquaculture systems are considered a promising technology. Recent efforts have been essentially devoted to macroalgae and microalgae treatment systems (Troell et al., 2003). The utilization of aquatic macrophytes and phytoplankton for the removal of nutrients in aquaculture wastewater effluents and water bodies is well documented (Redding et al., 1997). The resulting gains in vegetative biomass can provide economic returns when harvested. The principle of this method is mainly based on two approaches: the underwater roots of the aquatic macrophytes or microalgae can hold up and absorb the wastes; the aquatic macrophytes and microalgae can utilize some of the dissolved nutrients for growth (Twarowaska et al., 1997). It is verified that wastewater from intensive and semi-intensive pond culture is suitable as a nutrient source for hydroponics, and that integration with hydroponics significantly reduces the loading of dissolved nutrients to the environment. A key aspect is that by closing the water cycle, water is preserved and cleaned prior to reuse. Hitherto, it is proved that many other aquatic plants can be used for wastewater purification such as *Eichhornia crassipes*, *Alternanthera philoxeroides*, water chestnut, duckweed, morning glory, lotus and perennial ryegrass *Lolium perenne L* (Chen Min et al., 2002).

Poly-Culture

Poly-culture has also proved to be an efficient methof of waste treatment. Omnivorous fishes such as carps, tilapias and shrimp can be used to clean the leftover and remnants. In addition, utilization of bivalve mollusks such as growing giant clam (*Tridacna derasa*) in aquaculture effluent for microalgae produced on wastewater reuse systems is also a profitable option (Hastie et al., 1992). These unique bivalves possess symbiotic algae (*Symbiodinium*) that contribute a variety of photosynthetically produced compounds to the host's metabolic needs. According to Junda et al., (2001), aside from reducing the concentrations of ammonia and nitrite below detection limit, *T. derasa* had an average survivorship of 94.1% in the recirculating effluent tanks compared to 77.7% in the control tanks. It is surprisingly found that the effluent not only increased growth, but may also enhance survivorship of *T. deresa*.

Constraints and Developing Trends

The treatment of wastewater in freshwater pond aquaculture in China is still in its preliminary stages. It is maybe related to the traditional fish culture method called "fertilized water culture". The most important constraint to wastewater treatment has most often been the culturists' concern of losing fertilizers (Chen et al., 2002). Wastewater is considered as good green water which is beneficial for cost-effective fish culture. After treatment, nearly all the nutrients will be lost and new fertilizers are needed. In addition, wastewater treatment is relatively costly and beyond the technological and financial capabilities of many regions in the developing countries. Finally, the water shortage is also a major constraint for wastewater treatment. In some areas of northern parts of China, even the water for drinking is insufficient, let alone the exchanging water for aquaculture.

However, wastewater does carry pathogenic organisms and, in general, traditional treatment methods such as activated sludge were not designed to eliminate them. Organisms that can survive wastewater without treatment include bacteria, protozoa, helminthes, and viruses (Pan and Miao, 2003). Wastewater disinfection will eliminate them, but its costs are high. Most of these pathogens affect the human body by contacting the waste contaminated water and food. With the current emphasis on environmental health and water pollution issues, there is an increasing awareness of the need to dispose of these wastewaters safely and beneficially. Properly planned use of aquaculture wastewater alleviates surface water pollution problems and not only conserves valuable water resources but also takes advantage of the nutrients contained in effluent.

There are still plenty of needs for further research to improve or optimize the current methods of wastewater treatment and reuse. The result of the increased attention to this topic is expected to protect and improve the aquatic environment in relation to wastewater treatment and reuse. Further work is required to evaluate the proposed system feasibility at a larger scale and develop guidelines and standards.

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Dosing and Timing Addition of Bacterial Biomass for Improving the Water Environment in Shrimp Farming

Nguyen La Anh, Dang Thu Huong and Vu Dung

Abstract A number of bacterial biomass combinations were developed and tested at pilot scale and then applied at field scale. They consisted of bacteria capable of degrading feed residues, and mineralizing protein-rich matters. The dose and frequency of application of the bioproduct were investigated. The environmental parameters were investigated to show that the water environment of shrimp breeding ponds was improved and the pathogenic bacteria would be reduced.

Key words: Aquatic farming management, bacteria, *Bacillus*, environment

Introduction

During the past decade of aquaculture shrimp farming, due to intensive aquaculture shrimp farming management, a very high stocking density within the ponds, up from 20 to 40 shrimp post larvae per square meter of ponds, could produce tons of organic wastes from one shrimp farming crop. These organic waste compounds in aquaculture shrimp farming are quite stable, and do not have a tendency to degrade into simpler utilizable forms. The availability of leftover feed and dead phytoplankton cells created the accumulation of undesirable organic wastes and toxic gases dissolved in the aquaculture shrimp pond bottom soils. In most cases, mortality occurs when the aquaculture shrimp pond bottom is polluted and deteriorated.

One of the most common methods for ensuring a stable water environment during a shrimp farming crop is periodically using useful naturally occurring bacteria

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that produce enzymes capable of degrading the organic constituents normally found in shrimp ponds, organic wastes or organic matter, and undesirable gases in aquaculture shrimp farming and create a probiotic effect to prevent pathogenic bacterial diseases. Thus, adding useful microbial biomass resulted in reducing mortality, giving the highest survival rate with the fastest growth rate. Microorganisms used for improving the aquatic environment should satisfy the following criteria: non-pathogenic, viable in the environment, not harmful for the indigenous useful ecosystem in the pond, can improve water quality, and mineralize organic compounds. The bacteria capable of treating the aquatic breeding environment and improving the yield of aquatic animals are the following: *Bacillus*, *Lactobacillus*, *Pseudomonas*, *Micrococcus*, *Moraxella* (Fry, 1987), *Penaueus vannamei* and *Vibrio alginolyticus*. According to Logan and Bartlett (1997), the addition of a definite number of biomass of Bacillus *lentimorbus*, *Bacillus stearothermophilus* and *Bacillus cereus* into the aquatic pond from intensive farming increased the fish yield up to 25%. Foster (1991) succeeded in adding bioproduct of live bacteria to degrade the detritus mud at the bottom of lakes. Brierley et al. (1991) reported about the successful application of *Bacillus subtilis* (ATCC 6051) to recover heavy metal that contaminated water in the ponds. In this paper we conducted a study to determine the period and dosage of added bacteria at model and small scales. The findings were applied at pilot and commercial scales.

Materials and Methods

Bacterial Strains

Among 21 bacterial strains in the study, 3 strains belong to Coryneform and 11 strains belong to *Bacillus* genus (*B. subtilis*, *B. licheniformis*, *B. megaterium*) and 7 are lactic strains (*Lactobacillus*, *Pediococcus*, and *Lactococcus*). All 11 *Bacillus* strains produce a number of enzymes such as protease, amylase, cellulase (Cx). All 21 tested strains are capable of existing in water of 3–7% salinity. All selected strains were determined to be not antagonistic to shrimp *Panaeus monodon* based on study of its survival and growth rate.

Estimation of Survival Rate of Bacterial Strains

The reservoir contained 25 liters of brackish water with 90 pieces of shrimp post larvae P17 and a bacterial biomass of 10^7 CFU/L was added. Number of added *Bacillus* and Coryneform strains was determined on medium Nutrient Agar. Number of added lactic strains was determined on medium MRS. Samples were taken every three days for Bacillus and every day for Coryneform and lactic bacteria.

Determination of COD Reduction Ability of Strains

Artificial water with COD values of 100, 500 and 1000 mg/L were prepared by adding peptone 0.04, 0.1 and 0.22 g/l respectively. Bacterial biomass added was 10^6 CFU/L for 14 aerobic strains (11 *Bacillus* and 3 Coryneform).

Determination of COD

For accurate evaluation of mineralization of bacteria, at sampling time the inoculated water was centrifuged for biomass separation. The clear supernatant was used for COD measurements.

Determination of Mineralization Ability Based on Nitrate and Nitrite Reduction

Artificial water with $NO3^-$ in content $KH_2P_4 \cdot 3H_2O$-26.2 mg/l, $NaCH_3COOH \cdot 3H_2O$-17.2 mg/l, $CaCl_2$-7 mg/l, KNO_3-100 mg/l, pH 8.

Artificial water with NO_2^- in content $KH_2PO_4 \cdot 3H_2O$-26.2 mg/L, $NaCH_3COOH \cdot 3H_2O$-17.2 mg/ L, $CaCl_2$-7 mg/L, $NaNO_2$-4.5 mg/L pH 8.

Bacterial biomass added was 10^6 CFU/L for 14 aerobic strains (11 *Bacillus* and 3 Coryneform). After 24 h nitrate and nitrite contents were measured and an average reduction rate was estimated per hour.

Determination of Water Environmental Parameters

Water environmental parameters such as DO, COD, BOD_5, nitrate, nitrite, ammonium and sulfur and were determined by standard methods.

Results and Discussion

Change of Added Bacterial Biomass During Shrimp Breeding

As shown in Figure 1, bacteria belonging to *Bacillus* genus are able to exist for the longest time in the shrimp breeding media (from 9–16 days): *Bacillus megaterium* (TS1, QK12-1) were present in the aquaculture water for 16 days; *Bacillus licheniformis* D201, HA6(8), PCC04 existed for 12 days and *Bacillus subtilis* (CB3, CB15,

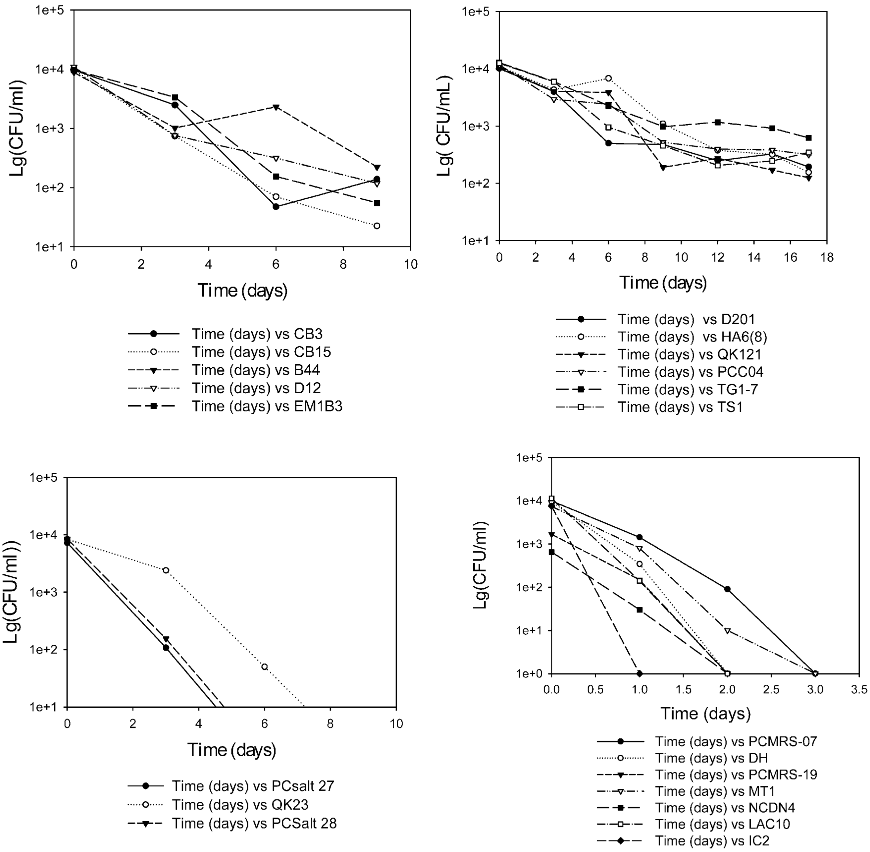

Fig. 1 Survival ability of bacterial cells in shrimp breeding condition.

B44, D12) stayed up to 9 days. Meanwhile Coryneform bacteria (QK23, PCSalt 28, PCSalt 27) survived till the fourth day and lactic bacteria (PCMRS 07, DH, PCMRS 19, MT1, NCDN4, LAC10, IC2) stayed from 1–3 days. The relatively long retention time of viable *Bacillus* cells in brackish water served as an important criterion for their selection to be used in shrimp farming.

Mineralization Ability of Bacteria Strains

Nitrate reduction is a common ability of genus *Bacillus* and Coryneform bacteria. However the rate of nitrate reduction depends on individual species and strains. In this study 14 aerobic bacterial strains were investigated for their mineralization – reduction of nitrate, nitrite (Table 1).

Table 1 Reduction rate of NO_3^- and NO_2^- by aerobic bacteria.

No	Strain index	NO_3^- reduction rate (mg/L/h)	NO_2^- reduction rate (mg/L/h)
1	CB15	Slow	0.0409
2	B44	Slow	0.0395
3	B56	Slow	0.0436
4	D12	Slow	0.0313
5	D201	Slow	0.0395
6	EM1B3	0.7273	0.0322
7	HA6(8)	0.2423	0.0372
8	PCC 04	Slow	0.0295
9	PC Salt27	Slow	0.0327
10	PC Salt28	Slow	0.0504
11	QK 23	0.7123	0.0422
12	TG 1-7	1.0910	0.0440
13	TS1	Slow	0.0327
14	QK 12-1	0.8180	0.0463

The highest nitrate reduction rate belonged to TG1-7, QK12-1, QK23, EM1B3 and HA6(8) (1.091–0.712 mg/l/h), and the nitrite reduction rates were much lower than the nitrate reduction rate. However PC Salt 28, QK12-1, TG1-7 (0.0504–0.044 mg/L/h) degrades nitrite faster than the other strains.

COD Reduction Ability of Bacterial Strains

Artificial water with COD values 100, 500 and 1000 mg/l were used for evaluating COD reduction of 14 selected strains.

Figure 2(a) shows that the strains CB15, B44, D201 , EM1B3, PCC04 were capable of reducing COD from 100 mg/l to 37–43 mg/l after 7 days, while the other strains reduced COD at a slower rate to only 60–80 mg/l (not shown). For water with COD 500 mg/l, 10 strains (EM1B3, B44, CB15, TG1-7, PCSalt 28, PCC04, TS1, QK 12-1, D12) reduced COD down to 80- 280 mg/L after 9 days (Figure 2(b)). Among these strains, TS1 and B44 showed the strongest COD reduction to 75 and 70 mg/l respectively. However the patterns of COD reduction of strains were very different. For example, CB15 and TG1-7 reduced COD gradually, while the others reduced COD significantly for 3 days, afterwards COD increased again up to the 6th day, and then decreased to the 9th day. This behavior could be explained because the water media with COD 500 mg/l was considered as nutrient for microbial development, thus for the first 3 days bacteria consumed nutrients leading to COD reduction. After this period, some extra cellular products such as enzymes (pertinacious nature) produced by bacteria together with dead and lyses cells COD caused the COD to increase up to the 6th day. The repetition of the growth cycle made COD decrease up to the 9th day. In the case of water with COD 1000 mg/l, the change

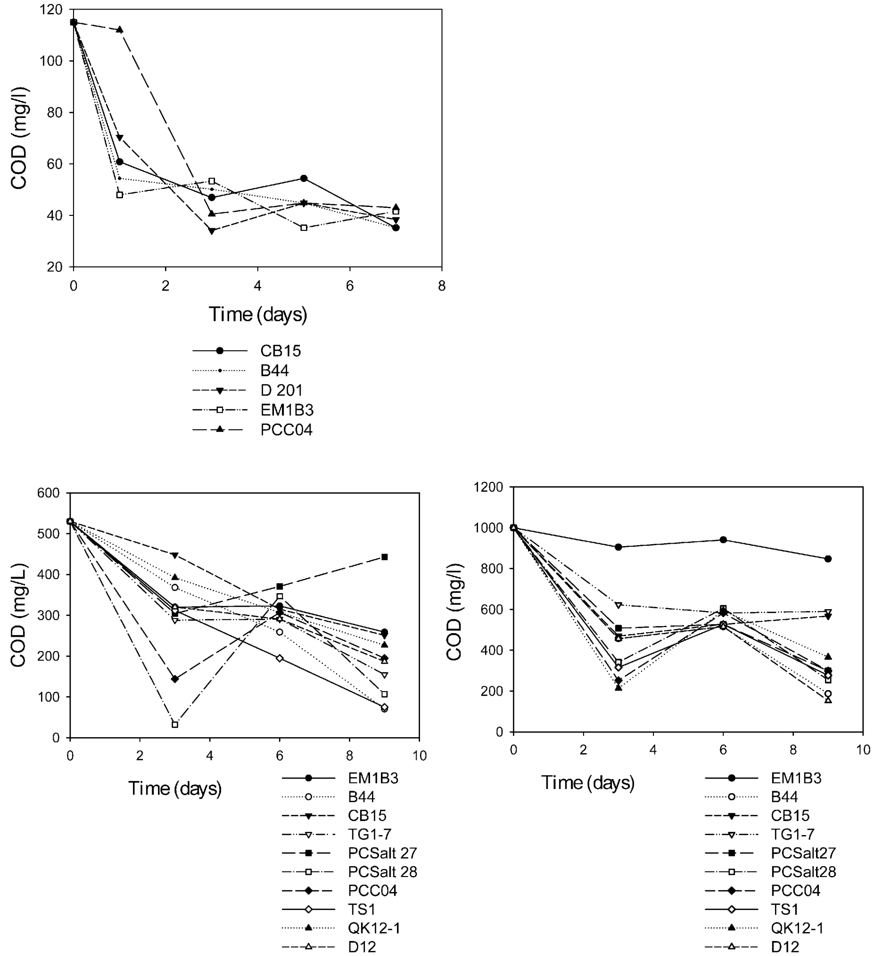

Fig. 2 Mineralization of artificial water with COD value (a) 100 mg/ L, (b) 500 mg/L and (c) 1000 mg/L.

of COD was similar in the case of COD 500 mg/l. The strain EM1B3 produced diverse exocellular enzymes (data not shown) but was weak for COD reduction. The largest COD reductions were due to strains D12 (COD to 152 mg/l) and B44 (COD to 186 mg/l) after 9 days.

Table 2 Combination of aerobic bacterial strains for testing mineralization ability.

No.	Combination	NH_4^+ (mg/l)	COD (mg/l) after 9 days
1	B 44, EM1B3, D 201, HA6(8), TG1-7	0.400	60.00
2	PCC 04, PC Salt 28	0.305	69.60
3	B 44, EM1B3, D 201, HA6(8)	0.422	63.60
4	PCC 04, B 44, EM1B3, PC Salt 28	0.460	56.80
5	B 44, EM1B3, D 201, HA6(8), TG 17, QK 12-1, QK 23	0.544	44.80
6	PCC 04, B 44, EM1B3, QK 12-1	0.635	54.40
7	EM1B3, B44, CB15, TG1-7, PCSalt 28, PCC04, TS1, QK12-1	1.047	52.80
8	EM1B3, B44, CB15, TG1-7, PCSalt 28, TS1, QK12-1	0.831	43.60
9	EM1B3, B44, CB15, TG1-7, TS1, QK12-1	0.964	41.60
10	EM1B3, B44, CB15, TG1-7, TS1	1.067	38.80
11	B44, CB15, TG1-7, TS1, QK12-1	1.449	81.60
12	B44, CB15, TG1-7, PCCO4, TS1, QK12-1	0.635	42.40
13	B44, CB15, TG1-7, PCCO4, TS1	0.130	37.33
14	B44, TG1-7, TS1	0.398	49.60
15	B44, TS1	1.346	42.00
16	TG1-7, PCSalt 28, PCC04	2.509	60.80
17	PCSalt 27, PCSalt 28, PCC04	0.244	47.60
18	EM1B3, B44, CB15, TG 17, PCC 04, TS 1	0.234	36.53
19	Pond Clear	1.636	52.40
20	Ichkhangto	3.457	43.60

NH_4^+ initial 3.54 mg/L, COD initial 105 mg/L

Selection of Bacteria for Developing a Useful Combination

Each bacterial strain had an individual spectrum of its enzyme degrading organics, mineralization, and survival in the aquatic farming condition. Thus, they should be applied in combination so that they could complement each other. In this study 18 combinations were investigated and compared with 2 commercially available products "Ichkhangto" and "Pond Clear", by adding a concentration of 106 CFU/ml into artificial water of COD 105 mg/L (Table 2). The biomass of each strain was equal in every combination.

Results show that after 9 days, at least 6 combinations reduced COD lower than "Pond Clear" (COD to 52.4 mg/L) and Ichkhangto (COD to 43.6 mg/l). Among them the combination Nos. 9, 10, 13, and 18 mineralized fastest, where the 9th day COD values were 41.60, 38.8, 37.33 and 36.53 mg/L, respectively. Concerning ammonium reduction, almost all combinations showed better results than the two reference samples, but combination Nos. 13, 17 and 18 degraded ammonium to 0.130, 0.244 and 0.234 mg/l after 9 days. Based on both results, combination No 18 containing the strains EM1B3, B44, CB15, TG 17, PCC 04, TS 1 was the most suitable for probiotic farming environment creation. In what follows, this combination is referred to as "Biodan".

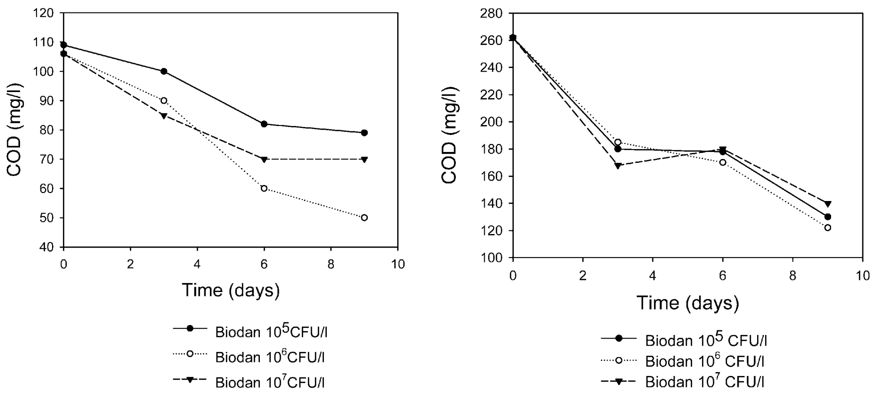

Fig. 3 Application of Biodan combination with concentrations of 10^5, 10^6, 10^7 CFU/L for artificial water with (a) COD 100 mg/L and (b) COD 200 mg/L.

Dosing Bacterial Biomass Addition for Ensuring Environment Quality

For artificial water with COD value 100 mg/L, biomass of the selected combination (Biodan) was added with concentrations of 10^5, 10^6 and 10^7 CFU/L, that gave the final COD after 9 days of 76, 45 and 63 mg/l, respectively (Figure 3a). For artificial water with COD 200 mg/l, these 3 concentrations of Biodan did not give significantly different results. The final COD values after 9 days were in the range of 125–138 mg/l (Figure 3b). Thus, for water in shrimp farming ponds, which had COD in the range of 100–200 mg/l, our combination Biodan was recommended to be used with a concentration of 10^5 CFU/l.

Application of Selected Combination of Bacterial Strains at Pilot and Commercial Scales

The experiments were conducted at pilot and commercial scales at the Teaching and Aquatic Technological Transfer of the North, Quykim, Haiphong, Vietnam.

For the pilot scale, the products with bacterial biomass concentration of 10^5 CFU/L used were CT1: the commercially available imported product YK3, CT2: the selected combination Biodan, and CT3: the reference for non-using useful bacteria. Each bioproduct was used in 9 aquariums at the same ambient conditions. The volume of brackish water of each aquarium was 50 l and the bottom sludge was 7 cm high. In every aquarium 15 shrimps of 6.1 g/piece were cultured, and samples were taken every 3 days.

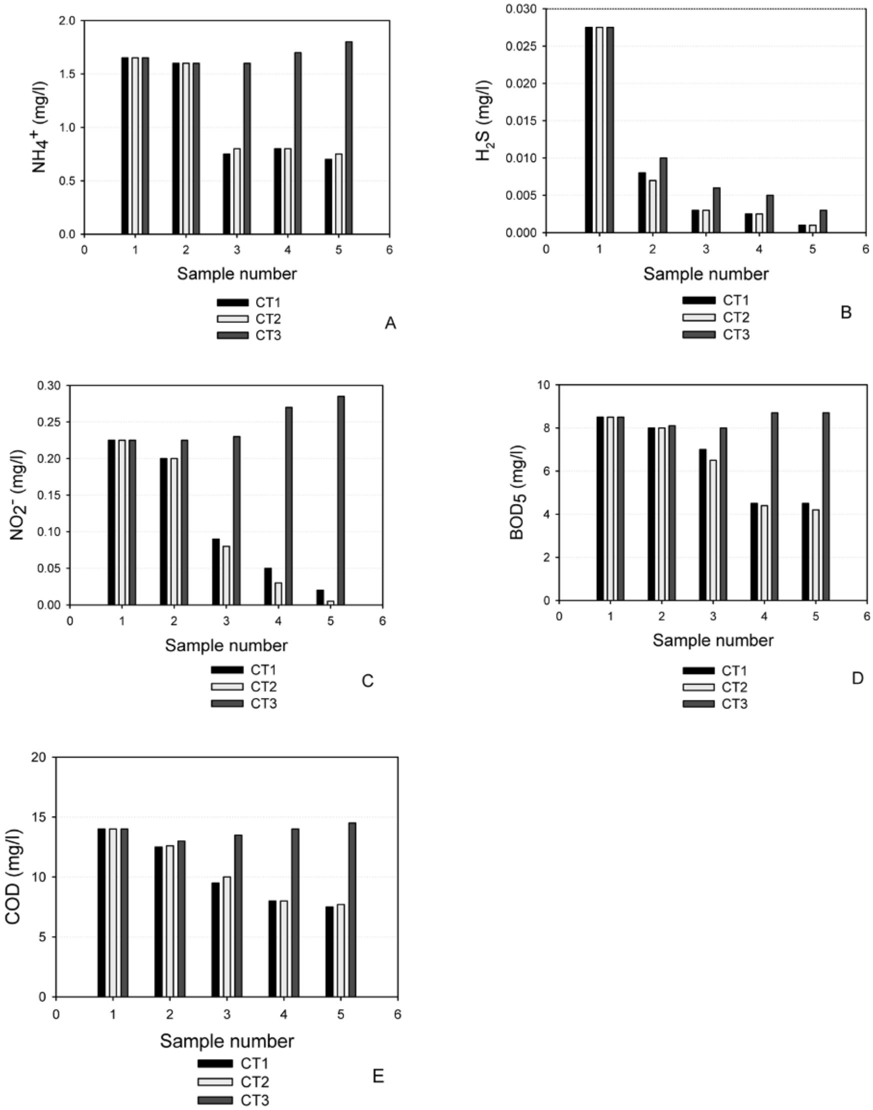

Fig. 4 Environmental parameters during 12 days breeding: (a) NH_4^+, (b) H_2S, (c) NO_2^-, (d) BOD_5, (e) COD.

The measurements showed no significant changes in the temperature (26.0–29.1°C); DO (6.0–6.5 mg/l), pH (7.8–8.1) and salinity 25‰. The environmental parameters NH_4^+, H_2S, BOD_5 and COD at bacterial biomass added aquariums for both Biodan and YK3 were much better than the non-using useful bacteria ones (Figure 4), although the weight of shrimps in all cases was almost the same (7.3–7.4 g/piece) after 10 days breeding.

For the commercial scale, the studied combinations were used with the concentration 1–5× 10^5 CFU/L or 2–3 kg/hectare of shrimp pond with the frequency of every 9 days for shrimp *Panaeus monodon*. After 3 months of application of the bioproduct, shrimp were healthy and COD value fluctuated in the range of 20–30 mg/ml. Other environmental parameters NH_4^+, NO_3^-, NO_2^- were always acceptable for shrimp breeding ($NH_4^+ < 0.1$ mg/L, $NO_3^- < 0.1$ mg/L, $NO_2^- < 0.1$ mg/L). In the reference pond, the COD values were always higher 40–50 mg/l (data not shown).

Conclusions

By using bacterial strains that were obtained in Vietnam by isolation from nature and from the Collection of Industrial Microorganism at Food Industries Research Institute, it is possible to produce a bioproduct with stable qualities and properties. The bioproduct consists of viable cells of bacterial strains belonging to genus *Bacillus*, that are capable of treating water and detritus mud of shrimp ponds by degrading feed residue and reducing contaminants from degraded food such as NH_4^+, NO_3^-, NO_2^-, and COD and BOD of water. By applying 10^5 CFU/L water with the initial COD value 100–150 mg/L, after 6–9 days, COD can be reduced and amounts to 10–50 mg/L. The concentrations of NH_3^+, NO_3^-, NO_2^- would be removed from 20–100%, depending on the initial concentrations of these compounds. Thus the water environment of shrimp breeding ponds can be improved and the pathogenic bacteria would be reduced.

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Study of Mercury Pollution at Bantarpanjang Area (Citarum River) Using Biomarker

Mahastuti H. Tjokronegoro and Dwina Roosmini

Abstract Water pollution in Citarum River located in West Java, Indonesia has worsened during the last decade due to the increase in population, agriculture and industrial development to fulfill human needs. Various monitoring methods are used to investigate surface water quality in the Citarum River. By using *Liposarcus pardalis* fish as a biomarker to monitor heavy metal water pollution in the Citarum River, Hadisantosa (2006) showed that copper (Cu), lead (Pb), and nickel (Ni) concentrations in fish were increasing along the Citarum River from upstream to downstream but a significant increase of mercury (Hg) concentration was only detected in the Bantar Panjang area. Therefore, the present study was intended to identify the source of mercury pollution in the Bantar Panjang area. In this study, nine sampling points were selected along the Citarum River in Bantar Panjang area, by considering the tributaries of the river. At each sampling point, three fish samples were taken and analyzed for Hg concentration based on Indonesian National Standard (SNI) 01-2364-1991. Land use data surrounding the sampling points was examined to identify the Hg pollution source. In this research, the land use data was obtained from EPA-West Java Province. A significant increase of Hg concentration in fish samples was identified after the inlet of Citarik and Cipamokolan Tributaries, which coincides with the Hg concentration pattern in river water based on water quality monitoring data from EPA-West Java for the period 2001–2005. Utilizing land use data, Hg pollution in the river is related to the type of industries and number of industrial plants, raw materials and processes in industries, waste water flow, and the treatment of waste water.

Key words: Biomarker, land use, *Liposarcus pardalis*, mercury, river pollution

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Introduction

Citarum River Basin with an area of 6,080 km^2 is the largest river basin in West Java and the most exploited one in Indonesia (Wardhani, 2005). The Citarum River originates from Mount Wayang, South Bandung and ends at Tanjung Karawang (Java Sea). Up to now, Citarum River has been a life source for West Java and Jakarta people. Citarum River Basin has a population of 11.3 million and more than 1,000 industrial plants which have been potential sources of pollution at Citarum River (Hadisantosa, 2006).

Along with the increase in human activities, the amount of pollution in Citarum River has also increased. Since better water quality monitoring methods need to be developed, a biomarker as an indicator of environmental degradation is a potential alternative to be developed for the environmental monitoring system. The principle behind the biomarker approach is the analysis of an organism to determine their metal content in order to monitor the excess of metal in their tissues (Rashed and Nageeb, 2004). Biomarkers are often used to assess the impact of waste-producing activities that pollute the environment leading to the biota's exposure to aquatic and terrestrial pollutants (Roosmini et al., 2006).

Hadisantosa (2006) using *Liposarcus pardalis* as the biomarker, showed that Cu, Pb, and Ni concentrations in fish are increased from Majalaya to Batujajar along the Citarum River, but that a significant increase of Hg concentration is detected in the Bantar Panjang area, which is located right after Majalaya where the textile industry is the dominant industry in the area. Further study of mercury pollution using *Liposarcus pardalis* as a biomarker on Citarum River at Bantar Panjang related to its land use is needed. The aim of this research is to identify the source of mercury pollution related to land use in the Bantar Panjang area.

Materials and Methods

Nine sampling points were selected in the research area based on the inlets of the tributaries of Citarum River at Bantar Panjang area (Figure 1). Sampling points from upstream to downstream are as follows: (I) before Citarik Tributary inlet; (II) Citarik Tributary; (III) between Citarik and Cikeruh Tributary; (IV) Cikeruh Tributary; (V) between Cikeruh Tributary to recycling industry area; (VI) after recycling industry to point before Cipamokolan Tributary inlet; (VII) before Cipamokolan Tributary inlet; (VIII) Cipamokolan Tributary; (IX) after Cipamokolan Tributary inlet. The sampling point locations were determined using Global Positioning System (GPS).

Three *Liposarcus pardalis* samples are taken at each sampling point and analyzed for Hg concentration in fish tissues, using Indonesia National Standard (SNI) 01-2364-1991. Mercury in fish tissues is extracted using nitric acid (HNO_3), and analyzed using Atomic Absorption Spectrophotometry (AAS). Mercury pollution

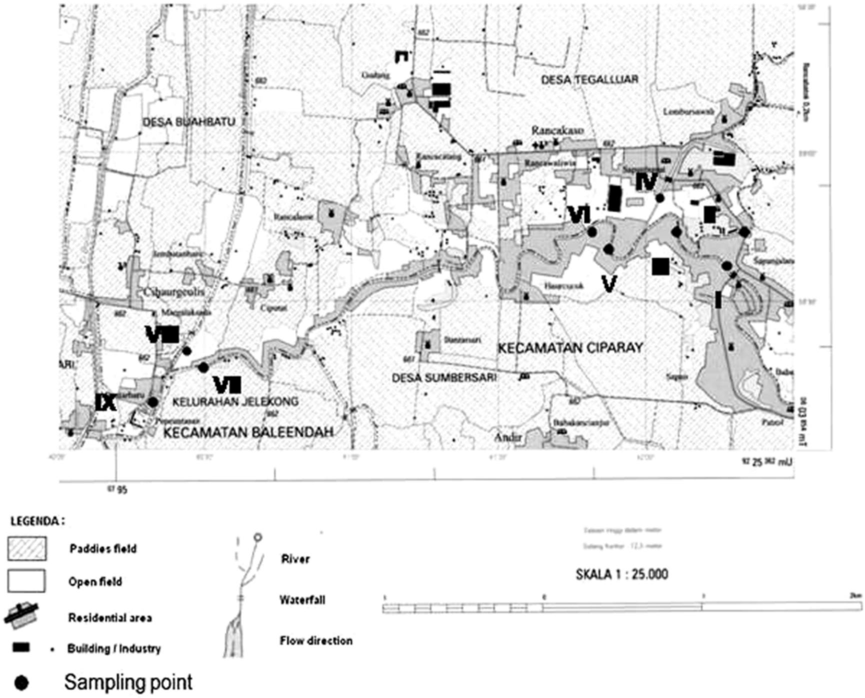

Fig. 1 Land use map in research area and sampling points.

sources are identified through field observations in the study area and the study of land use data.

Results and Discussion

The study site located in Kecamatan Ciparay has an area of 461,762 km^2 and the habitat of the population is 134,320 km^2. Agricultural activities dominate land use in Ciparay (Hadisantosa, 2006). Land use pattern in the research area is shown in Figure 1. The land use map shows that the reseach area is dominated by paddy fields and residential areas. The area of sampling points I–VI is dominated by residential areas with few agricultural activities, while paddy fields are pre-dominant in the area between sampling points VII–IX. Sampling point IX is surrounded by paddy fields and vegetable agriculture while sampling point X is surrounded by paddy fields and residential areas.

The results of Hg concentration in *Liposarcus pardalis* as biomarker for each sampling point along Citarum River and the position of the tributaries that contribute to the river are shown in Figure 2. The highest Hg concentration in *Liposarcus pardalis* is detected at sampling point IX with an average of 0.034 mg/kg. The

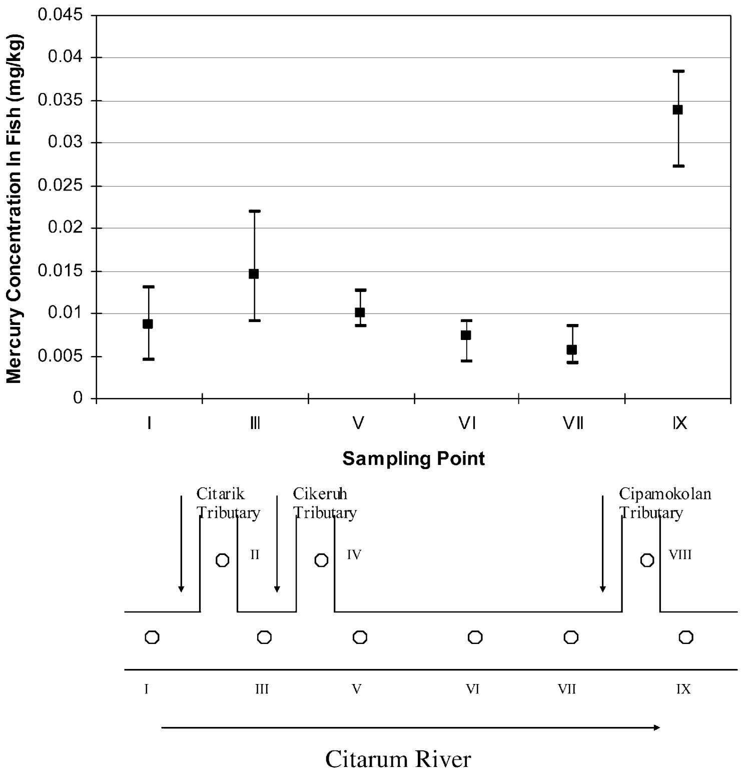

Fig. 2 Mercury (Hg) concentration in fish for each sampling point at Citarum River.

Hg concentration increases from 0.009 mg/kg to 0.015 mg/kg after Citarik Tributary and decreases to 0.0051 mg/kg at downstream before significantly increasing to 0.034 mg/kg at the sampling point after the Cipamokolan Tributary. It seems that Cikeruh Tributary does not contribute significant mercury pollution to Citarum River, as the Hg concentration at sampling point V has not increased. Based on land use data in Figure 1, a high concentration of mercury at sampling points occurred in the area surrounded by broad paddy fields compared to land use upstream. Upstream land use is dominated by residential areas and some vegetable and open fields, apart from residential areas, paddy fields become the main land use in the research area. Agricultural activities that use pesticides and fungicides could be a potential source of mercury pollution.

Mercury concentrations in each tributary are shown in Figure 3. The Hg concentration in *Liposarcus pardalis* at sampling point Citarik Tributary is high compared to Cikeruh and Cipamokolan Tributaries.

The highest Hg concentration in *Liposarcus pardalis* of 0.034 mg/kg is detected at downstream of Citarum River after the Cipamokolan Tributary (Sampling Point IX). The lowest concentration of mercury 0.005 mg/kg is measured at sampling

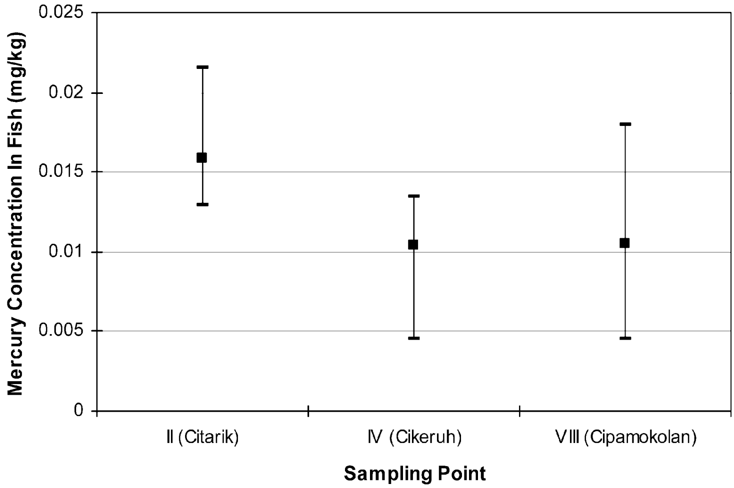

Fig. 3 Mercury (Hg) concentration in fish for each sampling point at tributaries of Citarum River.

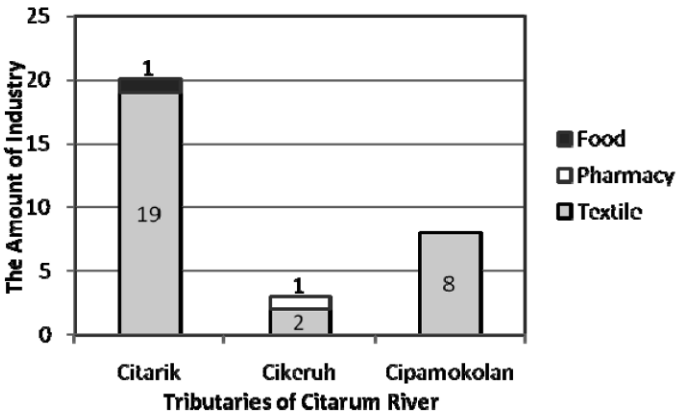

Fig. 4 The distribution of industrial plants around each tributary of Citarum River.

point VII. These two sampling points with significantly different Hg concentrations have similar patterns of land use activities, broad paddy fields with limited residential areas and open fields. Other sources of mercury pollution are various industries and other forms of solid waste. The distribution of industries around Citarum River and its tributaries is shown in Figure 4.

The dominant industry is the textile industry. Citarik Tributary has the highest number of industrial plants with nineteen textile plants and one food manufacturing plant. Cipamokolan Tributary is surrounded by eight textile plants and Cikeruh has two textile plants and one pharmaceutical plant.

By comparing the distribution of industrial plants in Figure 4 with the Hg concentration in Figure 3, it seems that Hg concentration in *Liposarcus pardalis* is related

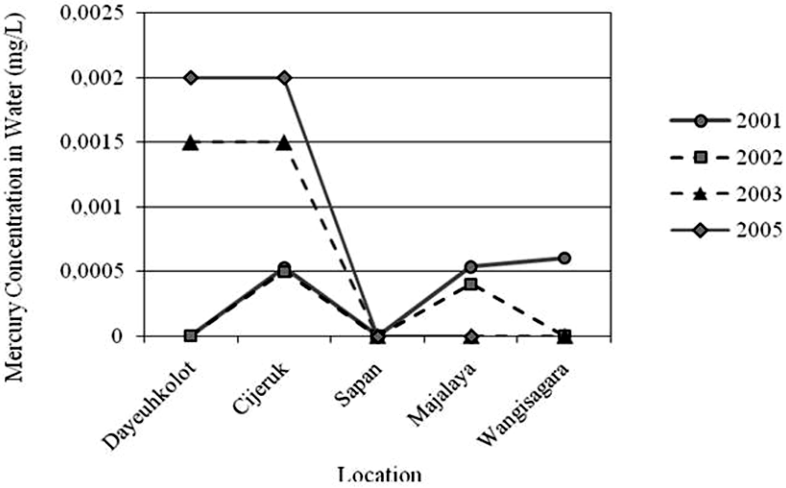

Fig. 5 Mercury concentration in Water of Citarum River (EPA-West Java Province).

to the pattern of Hg concentrations. Mercury concentration in *Liposarcus pardalis* at Citarik Tributary with twenty industrial plants is the highest compared to other sampling points with lower industrial activities at Cikeruh and Cipamokolan Tributaries. The other source of mercury pollution is domestic wastewater, "Beside industrial wastewater, domestic wastewater too contains substantial quantities of metals. The prevalence of mercury in domestic formulations, such as cosmetic or cleansing agents, is frequently overlooked. Agricultural discharge contains residual of pesticides and fertilizers which contains mercury", (Rashed and Nageeb, 2004).

The highest concentration of Mercury in *Liposarcus pardalis* was 0.034 mg/kg. This concentration is still below the permissible level 0.1–1 mg/kg wetweight for consumption according to FAO Fisheries Circular No. 825 (FAO, 1989). Mercury concentrations in water are shown in Figure 5 from 2001 to 2005. A significant increase in Hg concentration occurs in 2003 and 2005 at Dayeuhkolot and Cijeruk sampling points. From Sapan to Cijeruk sampling point, Hg concentration in water increases significantly, from not detected to 0.0015 mg/L in 2003 and even more in 2005 to 0.002 mg/L.

The location of Sapan and Cijeruk sampling points with respect to the research area is shows in Figure 6.

Figure 6 shows that the research area was located between Sapan and Cijeruk on Citarum River basin, Sapan is approximately 5 km before sampling point I while Cijeruk is approximately 2 km after sampling point IX. This study shows that the pattern of Hg concentration in *Liposarcus pardalis* coincides with the Hg concentration in water samples that are monitored by EPA West Java Province. Therefore, biomarker as a monitoring method can describe mercury pollution of the Citarum River environment.

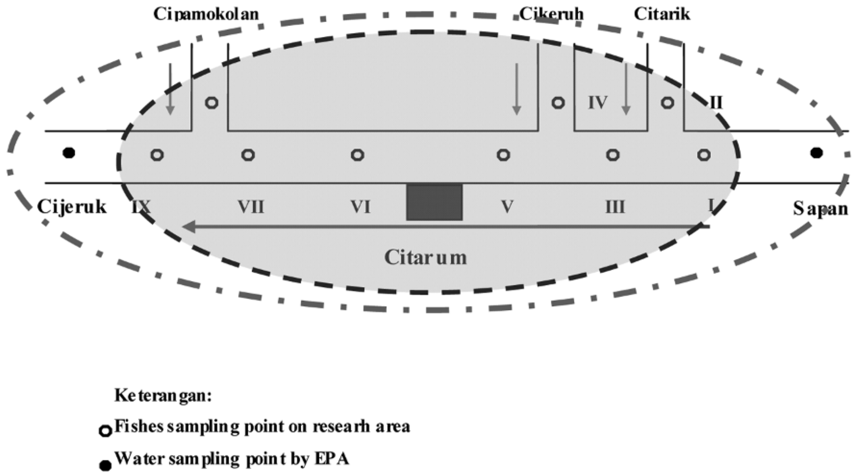

Fig. 6 Location of Sapan and Cijeruk sampling points with respect to research area.

Conclusions

- The concentration of mercury in *Liposarcus pardalis* was still below the permissible level for consumption according to FAO Fisheries Circular No. 825 (FAO 1989).
- Mercury concentration in *Liposarcus pardalis*, as a biomarker, increases along with the increase of mercury concentration in water. Therefore, biomarker, as a monitoring method, can describe mercury pollution in water environment.
- Significant increase of mercury concentration in *Liposarcus pardalis* occured in Jelekong District with dominant agriculture activities in land use.

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PART 4

Crop Production

Increased Wheat Yield by Rainwater Management: A Case Study in Arid Lands of Iran

J. Tabtabaee Yazdi, M.Y. Han, M. Ghodsi and S.A. Haghayaghi

Abstract Efficiency of rainwater utilization was evaluated for dryland farming in the North-East of Iran. Runoff collected from a plastic covered catchment was directed into a ground reservoir and used for supplementary irrigation of dryland wheat agriculture. Grain yield was increased by 70 and 87% after fulfilling 35 and 70% of crop water requirements during two successive years, respectively. The results encourage any similar planning for the vast arid zone of the country.

Key words: Dryland farming, increased grain yield, rainwater management, runoff enhancement, supplementary irrigation

Introduction

Rainwater harvesting and utilization for supplementary irrigation has been successfully employed in many dry regions as a means of collecting and storing rainwater from neighboring catchment and delivering it to planting area during dry periods (Laura, 2004; Short and Lantzke, 2006; Qiang et al., 2006). Rainwater harvesting for dryland agriculture is divided into two major categories (Oweis et al., 1999). The more conventional rainwater utilization method is based on direct use of collected runoff for plant irrigation, where as the more promising systems involve an external reservoir to collect runoff (in excess of immediate plant use) for the subsequent dry period or before the next rain happens. Previous studies have indicated that direct use of rainwater has not been successful in regions where the rainy season does not coincide with irrigation time since it is virtually impossible to store water in the soil

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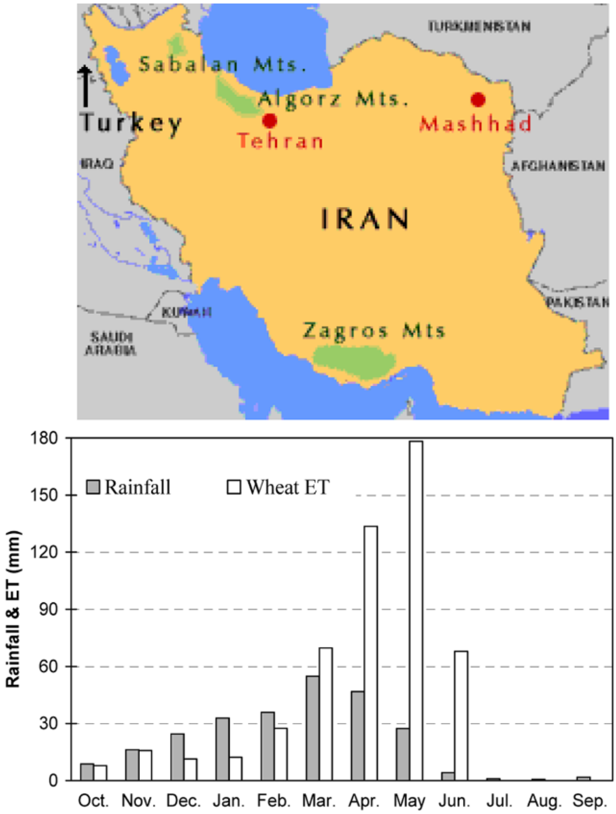

Fig. 1 Map of Iran with long term average rainfall distribution for demonstration site.

from one wet season to the next and there will be crop failures if only soil is used for storage (Cluff, 1980). The present study demonstrates the effect of rainwater utilization using external reservoirs to provide supplementary irrigation for wheat cultivation in the N-E of Iran (Agriculture and Natural Resource Research Station, Torogh, Mashhad). Yield growth of a native wheat grain was compared for a rainwater harvesting method and traditional dryland farming during two successive years.

Demonstration Site

The project site is positioned in the N-E of Iran (Mashhad) with average annual precipitation of less than 250 mm, mainly occurring during late winter and early spring times. The role of supplementary irrigation using rainwater could be very crucial since the critical crop growing periods do not coincide with natural rainfall discrepancies. Figure 1 shows a map of Iran and a comparison between rainfall distribution with native wheat water requirements at the project site.

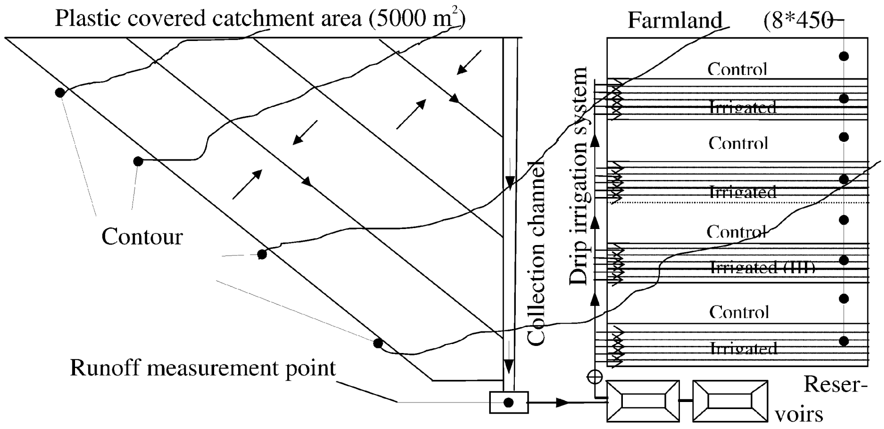

Fig. 2 Schematic diagram of demonstration RWH system.

In order to examine the effectiveness of rainwater utilization, a 5,000 m^2 flat area (sloping 1%) was rippled, cleaned and shaped as a series of sloping roads so that the runoff could be directed from side slops and flow longitudinally towards an end collecting channel (Figure 2). The whole catchment was covered by 10 m wide plastic strip sheets to acquire maximum runoff efficiency. Runoff collected by the end channel was discharged downstream into a 500 m^3 ground storage via a sediment trap. A sharp crested rectangular weir along with a recording water level data logger was installed at the end of the collecting channel for runoff measurements with 15 minute intervals. Rainfall distribution was simultaneously recorded in the nearby local meteorological station.

The experimental farmland was located next to the runoff catchment and consisted of a series of eight scaled plots with a dimension of 6×85 m^2. Following a randomized completely block design, four plots were considered for supplementary irrigation and the remaining four replications were accounted as control (without irrigation). In an effort to conserve more water, a drip irrigation system was used with 4 l/hr/m discharge capacity. Collected rainwater was pumped from the reservoir into the 50 mm diameter distribution pipe, after passing through a filter and metering device. The main distribution pipe was connected to the irrigation tapes at the upstream side of cultivated plots (Figure 2).

Physical and chemical soil properties were measured using samples taken from 0–30 cm and 30–60 cm depth at different places and the results are shown in Tables 1 and 2. It was observed that the soil texture is loamy and has no salinity or acidity problem. The water holding capacity of local soil along the 60 cm root zone depth was equal to 72 mm.

Table 1 Physical characteristics of the local soil.

Depth (cm)	Soil Texture	Bulk Density (g/cm^3)	Field Capacity (gravimetric percent)	Wilting Point (gravimetric percent)
0–30	Loam	1.57	18.7	11.2
30–60	Loam	1.42	21.4	12.9

Table 2 Chemical characteristics of the local soil.

Depth (cm)	pH	Electrical Conductivity (dS/m)	Sodium Absorption Ratio (SAR)
0–30	7.55	2.66	0.53
30–60	7.50	3.20	2.1

Wheat Cultivation Using Rainwater Irrigation

Rainwater irrigation farming started in the year 2005 with the planting of a commercial wheat seed (Azar 2 cultivar) using 120 kg/ha seed right after the first rainfall in November 2005. A complete process of farming preparation and controls including disinfection and fertilization was undertaken. In order to evaluate the efficiency of rainwater management for dryland farming, a supplementary irrigation program (defined as application of a limited amount of water to the crop when rainfall fails to provide sufficient water for plant growth to increase and stabilize yields; Oweis et al., 1999) was planned. Rainfall data during the wheat growing period for two successive years (2005–2007), along with the monthly wheat evapotranspiration (obtained from Farshi et al., 1997) are shown in Figure 3. From a total of 420 mm wheat water requirement, 116 mm were provided from direct rainfall. If the remaining part of plant water potential had been harvested from the surrounding catchment, the maximum yield could have been obtained.

Taking into account the total irrigation time, applied during two critical growing periods (29 April 2006 at the wheat booting stage with an equivalent of 80 mm and on 18 May 2006 at grain filling time with an equivalent of 25 mm) a total of 215 m^3 of water was allocated for plant growth (35% of extra water required in excess of natural rainfall). Compared to the conventional dryland farming which was undertaken in control plots, grain yield was increased by 70% (from 978 kg/ha in the dryland plots to 1,651 kg/ha for irrigated plots) (Table 3).

A second trial for supplementary irrigation practice was conducted during the next year (2006–2007). Rainfall record was compared with wheat evapotranspiration in Figure 4. It was observed that in this year a total of 159 mm (from total 420 mm crop water requirement) was produced from natural rain. Three supplementary irrigations were carried out at critical crop growing stages with total volume of 310 m^3 (5, 24 and 31 May 2007, in booting stage, milky and doughy stages of grain filling period with irrigation height measured as 35, 55 and 60 mm, respectively). It

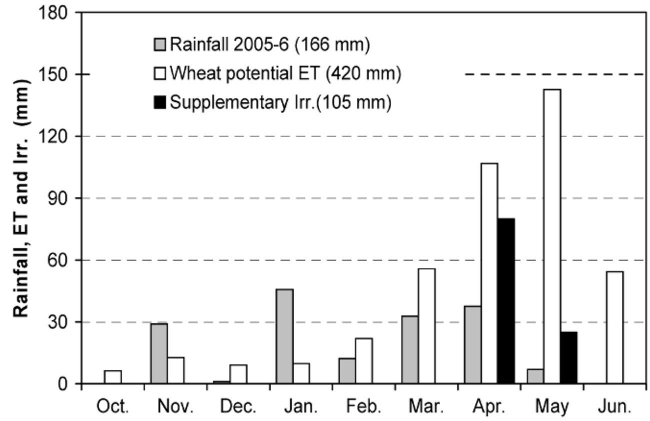

Fig. 3 Rain, ET and irrigation height (2005–2006).

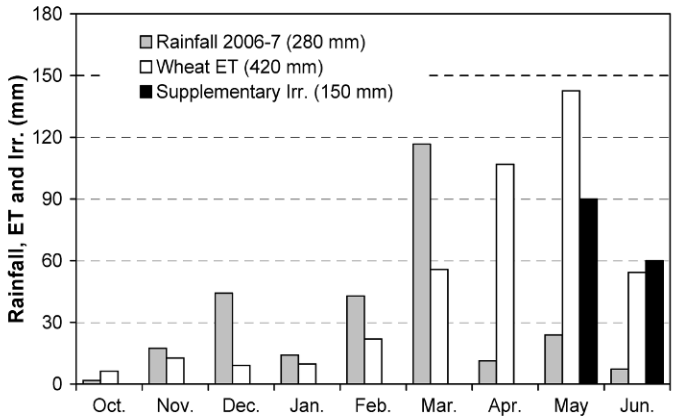

Fig. 4 Rain, ET and irrigation height (2006–2007).

means that around 58% of the required excess water was acquired by the current water harvesting system. Compared to the control dryland farming, wheat grain yield increased in the second year by an average of 87% (i.e. from 744 kg/ha in control plots to 1,394 kg/ha in the irrigated areas) (Table 3). Such a production growth is certainly encouraging since it is beyond the normal within the neighboring area and more importantly because dryland wheat cultivation is very competitive farming in arid and semi-arid regions of the country.

It can be proved that the increasing grain yield in the irrigated treatments have been mainly due to increasing mean grain weight and mean grain number per unit area in comparison with control plots.

Table 3 Response of grain yield to supplementary irrigation.

Year	Dryland (Control) (kg/ha)	Supplementary Irr. (kg/ha)	Response (%)
2005–2006	975	1651	70
2006–2007	744	1394	87

Conclusions

Water shortage and consequent decrease of food production has seriously endangered people living in arid part of the world. This problem has been partially addressed by the concept of rainwater management which implies a decentralized and participatory approach for rainwater utilization, taking advantage of vastly available unused land in targeted areas. A crop's required water in excess of natural rain can be harvested from a neighboring area and reserved for subsequent dry periods or between occurrences of rain. This practice has led to dependence on conventional dryland farming that increases a specific crop's productivity, but which is not otherwise beneficial. The present research was one of the first systematic attempts to examine the effect of some of the case dependent parameters such as climate and soil type in a real scale rainwater utilization system in the N-E of Iran.

Following installation of the project's components (including 5,000 m^2 plastic cover catchment, 500 m^3 ground reservoir, conveying channel, drip irrigation system and 4,000 m^2 farming area) supplementary irrigation was conducted over alternative wheat cultivated scaled plots and grain yield was compared with control dryland plots for two successive years.

The results give indication of how to cope with two important dryland problems of rainfall shortage and the mismatch of rainy seasons with plant requirements. It is in agreement with other research results in the fact that, if the minimum water required for the critical time of a crop growing period can be harvested from preceding rainfalls, the overall grain yield can be increased considerably. The research outcomes give hope to many local farmers who cannot recoup their expenses following conventional dryland farming processes.

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Water – An Emerging Critical Factor in Chinese Rice Production and Trade

Funing Zhong and Shunfei Liu

Abstract China's rice exports have been large and volatile in the world market with the quantities of exports basically determined by excess supply in their domestic market. The restructuring following fast economic growth has reduced the importance of rice production in terms of sown area, and gradually shifted rice production from south to north. As a result, rice production in China is likely to be more dependent on yield growth, more constrained by water shortage in the north, and volatile in yield and output.

Key words: Restructuring of agriculture, rice production, water constraints

Introduction

China is a major rice trader in the international market. According to FAO trade statistics, the total volume of Chinese rice exports was 52.8 million metric tons from 1961 to 2002 and accounted for 7.6% of the world's total imports of 691.7 million metric tons in the same time period (see Figure 1 for details). However, the annual rice export from China fluctuated quite significantly during those 40 years. It reached a high of 3.7 million metric tons in the peak year of 1998, compared with only 32,000 metric tons in 1995 (5,000 tons in Chinese statistics). The share of Chinese exports in world rice trade was also volatile: from 27.7% in 1973 to 0.1% or less in 1994 (see Figure 2).

Because of the large share and the volatile fluctuations in Chinese rice exports in the world market, it is important to understand what factors determine the behavior of the Chinese rice trade, and what kind of constraints the Chinese sector is facing. It is believed that China's rice exports are a kind of "residual", or excess supply, in a

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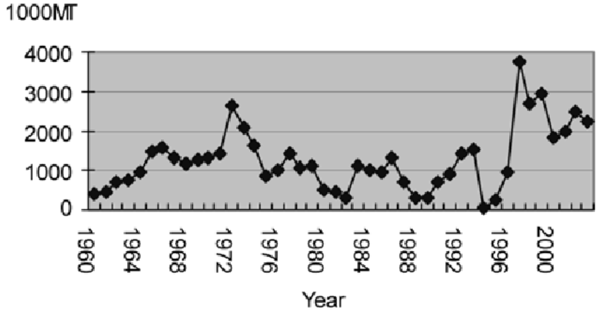

Fig. 1 China's exports of milled rice. Source: FAO.

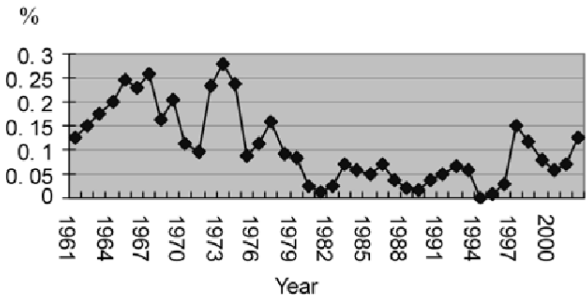

Fig. 2 Share of Chinese rice exports in world total imports. Source: FAO.

domestic market with volumes determined by balance in the domestic market with some time lags. Following fast economic and income growth, farmland has been lost to urbanization, agricultural production has been shifted to high-value products, and the relative importance of rice is declining even with the grain sector. At the same time, grain, especially rice, production is gradually moving from traditional southern regions to the north due to the changing economic environment. However, such a shifting may add not only greater fluctuations in rice yield and output, but also heavier pressure on water resources which is already sounding an alarm bell in the north.

This chapter tries to describe the relationship between China's rice trade and the balance in its domestic market first, and then to analyze the impact of changing structure in Chinese grain production on the domestic rice market, followed by a discussion of the interrelations between changing rice production and stressed water constraints. A brief summary will be presented with a discussion of the implication to world rice trade in the future. As rice is the most important food crop produced and consumed in China, findings of this study are also relevant to domestic producers, consumers, and policy makers.[1]

[1] A part of this chapter is drawn from Zhong and Liu (2006).

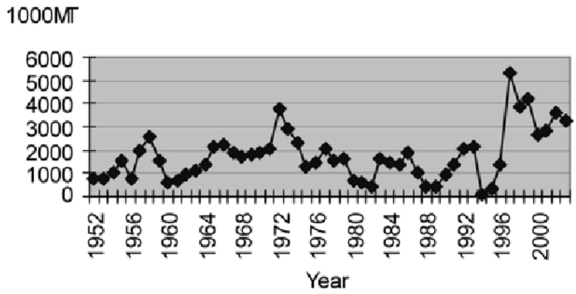

Fig. 3 China's rice exports (paddy rice). Source: Agricultural Yearbook Compilation Committee.

Determinants of Chinese Rice Exports

China is both the largest rice producer and consumer in the world. With a huge population and associated domestic market, rice exports from China are not so significant a component in total disposal as they are in the world market. From 1952 to 2004, the total volume of rice exports was 62.4 million metric tons, accounting for 1.3% of total domestic production of 7,080.3 million metric tons and fluctuating from 3.7% to almost zero (Figure 3). Having struggled with shortages in food supply for many years, China does not have the luxury of using rice production as an export-oriented commercial business pursuing profit. The primary objective of rice produc- tion in China is to feed her domestic population, with the differences between annual production and domestic consumption, probably with some lags, to be exported.

As such exports could be used as a source of foreign exchange earnings, relatively larger volumes of rice were exported from 1952 to 1977 in order to finance industrialization under the central planning scheme at the cost of depressed domestic consumption. However, since the reform started, it has been more and more difficult to export basic food by controlling domestic supply, so the volumes of rice exports have been reduced since 1978, even as production increases continuously. That is why annual rice exports averaged 1.8% or domestic production between 1952 and 1977 against 91.2 million metric tons of average annual production, while the exports' percentage were reduced to just 1% of annual domestic production during the 1978–2004 time period with average production reaching 174.4 million metric tons (Figure 4).

From the mid-1980s, the volumes of China's rice exports could be roughly explained by over-supply in the domestic market. If annual rice production increased significantly above the trend for a few years, then the exports could increase as well, with some time lags. Taking the 1978–2004 production trend as a baseline, it could be found that when annual rice production was up by 3 to 14 million metric tons during 1983–1987, exports were between 0.7 and 1.2 million metric tons for 1984–1988, much higher than periods both before and after. Again, when annual production was 12 to 17 million metric tons above the trend in the 1996–1999 time

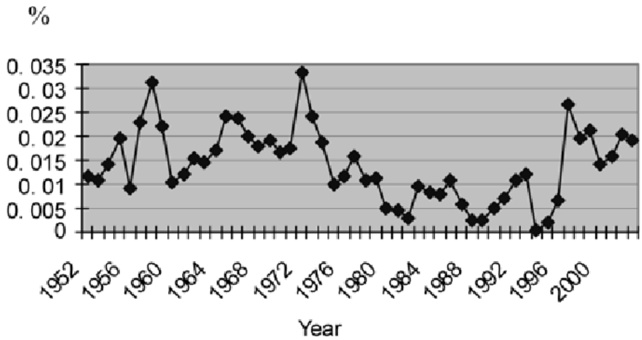

Fig. 4 Share of China's rice exports in total production. Source: Agricultural Yearbook Compilation Committee.

period, rice exports reached the range between 0.9 and 3.7 million metric tons between 1997 and 2000. Rice exports continued to be at high levels, between 1.9 and 2.6 million metric tons during 2001–2003 although annual production was below the trend for those three years. This could be explained by the possible existence of accumulated stocks from previous years. One piece of evidence was that the market price was kept at a constant low level while production continued to decrease quite significantly from 2000 to 2003, implying market demand was likely to have been met by gradual release of stocks, especially those that remained on the farms and thus were not taken into account.

Trends in Rice and Major Grain Crop Production

As demonstrated above, to a large extent, rice exports are residuals from the domestic market. It is reasonable to assume that consumption of rice as a basic food is relatively stable or increases smoothly with population and income growth, so the behavior of rice exports is more likely to be explained by production. In addition to year-to-year fluctuations in rice production, which is unpredictable, the general trends of rice production are characterized as (1) growth depends on yield gains; (2) relative share in major grain crops tends to decline in terms of sown areas; and (3) production gradually shifts to northern regions under less favorable natural conditions.

From 1978 to 2003, rice sown area declined from 34.4 million hectares to 26.5 million hectares, roughly 1% each year in the 25 years. It bounced back to 28.4 million hectares in 2004, but still 17.4% below the 1978 level. On the contrary, the average yield per hectare continued to increase, from 3,978 kg in 1978 to 6,366 kg in 1998, and kept at a high level of 6,310 kg by 2004. As a result, the total production of rice showed an upward trend during the 26 year period, from 136.9 million metric

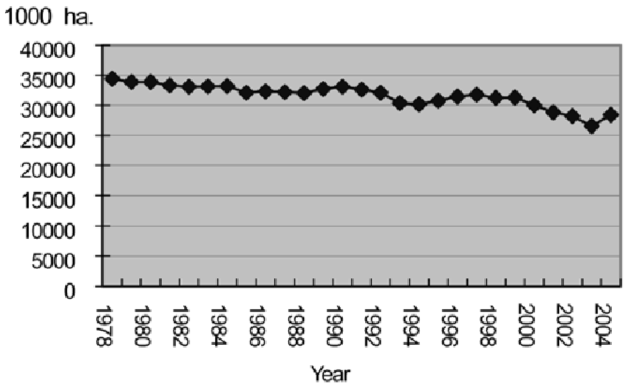

Fig. 5 China's rice sown areas. Source: National Statistical Bureau.

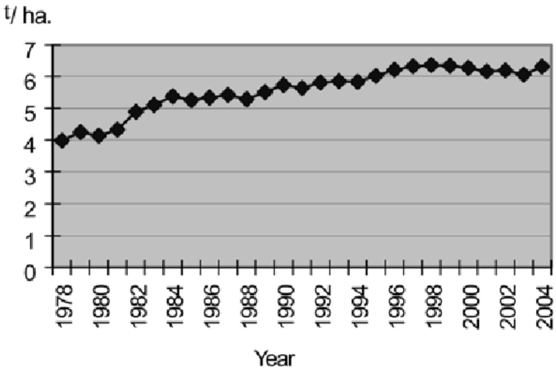

Fig. 6 China's rice yield. Source: National Statistical Bureau.

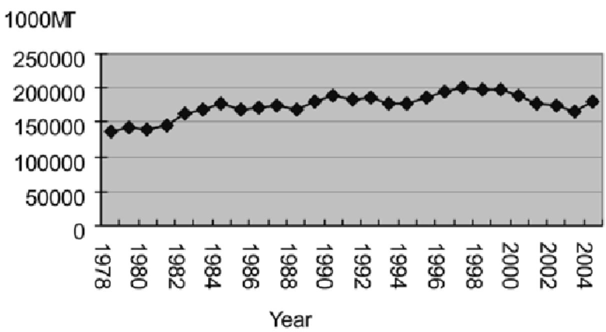

Fig. 7 China's rice production (paddy). Source: National Statistical Bureau.

tons in 1978 to 200.7 metric tons in 1997, and stayed at 179.1 million metric tons by 2004 (see Figures 5–7).

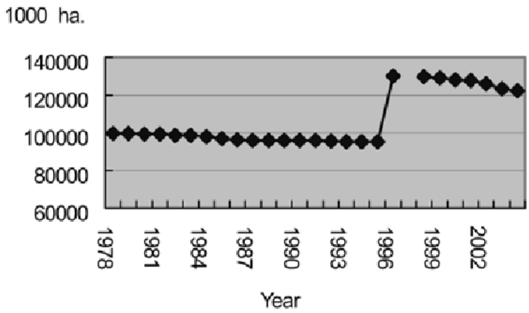

Fig. 8 Cultivated land in China. Source: National Statistical Bureau.

The actual growth in rice yield is greater than indicated by Figures 5–7. Firstly, a substitution of high quality varieties for the low quality but higher yield varieties has been witnessed following the changing demand corresponding to income growth. Secondly, rice production is gradually moving to the north, where natural conditions are not as favorable as those in the south, which is to be discussed in more detail later, resulting in a decline in overall average yield without growth brought by new varieties and technology, as well as increased inputs. It is believed that modern biotechnology has contributed a great deal to the growth of yields and production of almost all crops. As the most important crop in China, rice certainly benefits more than most other crops, for example, the famous hybrid rice since the late 1970s. And this trend is likely to continue in the future, such as research on the so-called super-rice and GM rice. The losses in rice areas are attributable to three factors: (1) the decline of cultivated land due to urbanization; (2) the decline of grain sown areas due to restructuring of agriculture towards high-value products; and (3) the decline of rice's share in total grain sown areas due to relocation of rice production that revealed a different comparative advantage in rice production among regions.

The cultivated land was reduced from 99.4 million hectares in 1978 to 95.0 million hectares in 1995, or 4.4% in 17 years. The statistics of cultivated land was revised upward to 130.0 million hectares in 1996, in order to correct the figure due to long-time under-reporting. However, it again declined to 122.4 million hectares by 2004, exhibited another 5.8% decrease over eight years, much faster than that during the previous 17 years (Figure 8). Apparently most of the cultivated land had been lost to industrialization and urbanization during the rapid economic growth.

Structural change inside the agricultural sector probably claimed more of the farmland from grain production. From 1978 to 2004, the total areas sown with grain crops declined from 120.6 million hectares to 101.6 million hectares, with its share in total crop areas declining from 80.3 to 66.2% in 26 years (see Figures 9 and 10 for details). This decline is not only stimulated by changing demand towards high value farm products following economic and income growth, but also facilitated by achievement in agricultural R&D which supported such a decline with countervailing increases in yields. At the same time, the share of rice in total grain sown areas declined as well.

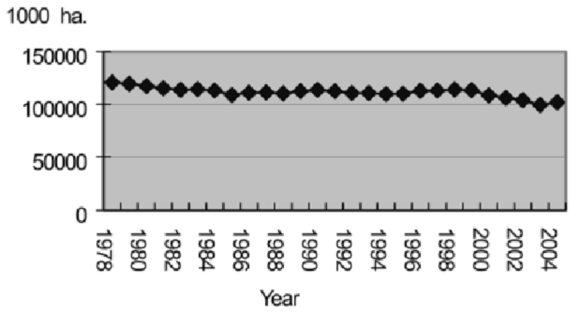

Fig. 9 Chinese grain sown areas. Source: National Statistical Bureau.

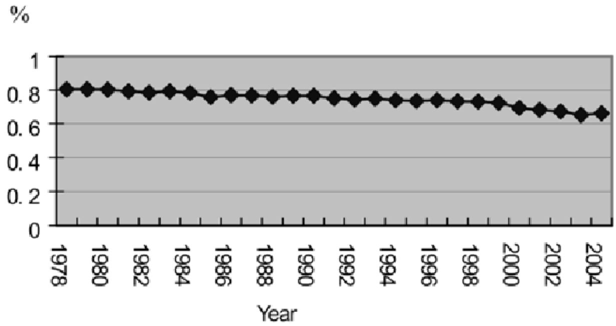

Fig. 10 Share of grain in total sown area. Source: National Statistical Bureau.

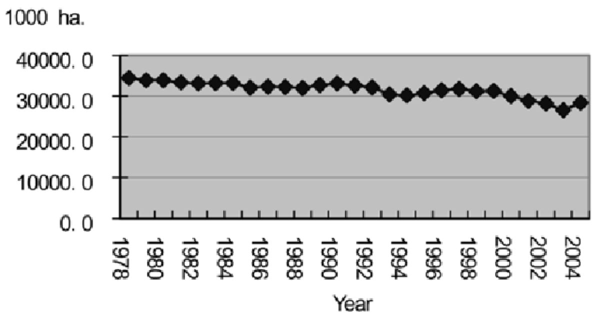

Fig. 11 Rice sown areas. Source: National Statistical Bureau.

The restructuring of grain production reduced rice sown areas too. As mentioned before, the rice sown area was 34.4 million hectares in 1978, accounting for 28.5% of the total grain areas. However, it declined to 26.5 million hectares, accounting for 26.6% of the total grain sown areas in 2003. Even if it bounced back to 28.4 million hectares in 2004, it was still below the 1978 level, at just under 28% (see Figures 11 and 12). Among other major grain crops, only corn benefited from the losses in rice sown areas. Its sown areas increased from roughly 20 million hectares in 1978 to

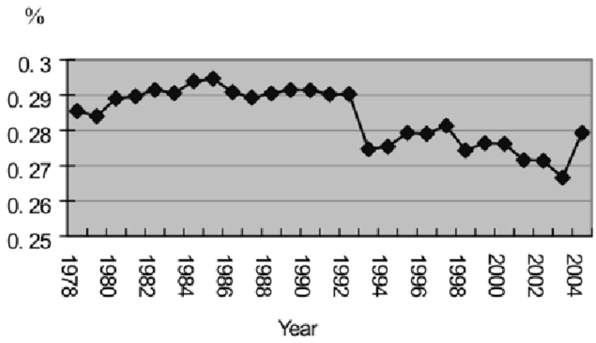

Fig. 12 Share of rice in grain sown areas. Source: National Statistical Bureau.

25.4 million hectares in 2004 (the peak year was 1999 with 25.9 million hectares), with its share in total grain sown areas increasing even more, from 16.5 to 25.5% (Figures 13 and 14). At the same time, the relative decline in wheat sown areas was a little bit greater than that in rice areas. Wheat sown area was 29.2 million hectares in 1978, but declined to 21.6 million hectares in 2004, with its share in total grain sown areas declining from 24.2 to 21.3% (see Figures 15 and 16).

Such a change in the shares of major grain crops resulted partly from relocation of grain production among regions. As economic growth has been faster in the south along the coastal regions, farm land has been lost and grain has been shifted to high value products faster there compared with other regions. Co-incidentally, the economically fast growing region includes major rice producing areas. As grain production moves towards northern inland regions, the share of rice production tends to decline, except in the northeast provinces where rice production finds suitable and water-sufficient areas (Figure 17).

As a result, the importance of southern regions in rice production declined during the 26 years, which implied changes in rice varieties too. For example, the rice sown area of the southern double-rice region, where rice production was dominated by Indica varieties, accounted for 56% of the national total in 1978, but this figure declined to 48% by 2004. At the same time, the region along the mid- and low-reaches of the Yangtze River, where both Indica and Japonica varieties were grown, also showed a loss in rice production, from 24% of national total to 22% during the same time period. On the contrary, the northeast region, where rice production was dominated by Japonica varieties, gained significantly in rice production, from 3% of the national total in 1978 to 10% by 2004.

Due to climate differences China is divided into three major rice production regions: Indica varieties growing in the south, Japonica varieties growing in the north, with central provinces along the Yangtze River growing both varieties. As rice production is gradually moving from south to north, it is reasonable to assume that the share of Japonica varieties has increased in rice production at the cost of Indica varieties and this may have an impact on China's rice trade.

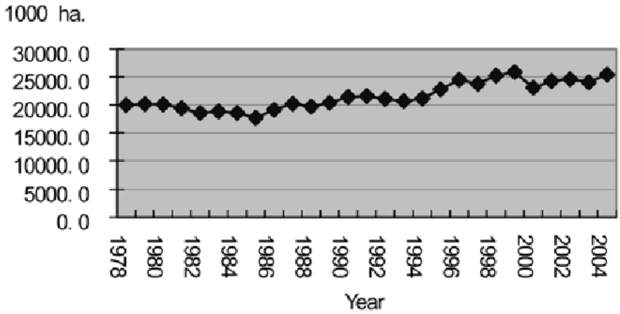

Fig. 13 Corn sown areas. Source: National Statistical Bureau.

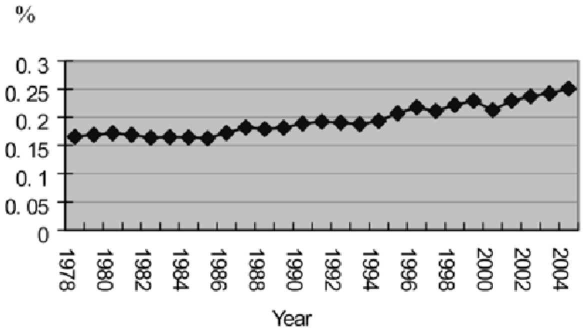

Fig. 14 Share of corn in grain sown areas. Source: National Statistical Bureau.

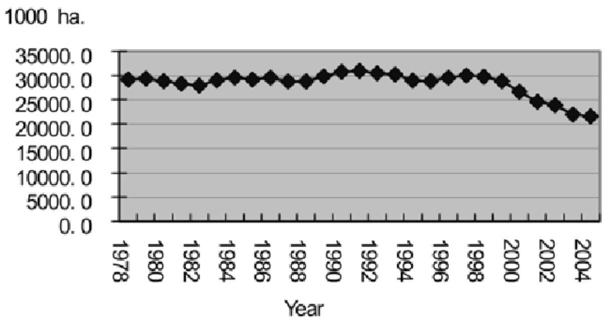

Fig. 15 Wheat sown areas. Source: National Statistical Bureau.

Interrelation between Rice Production and Water Supply

The gradual relocation of China's rice production certainly has a more important impact on the sustainability of water resource, and in turn, on the future production of rice itself. China is a country facing water scarcity, with the severity increasing

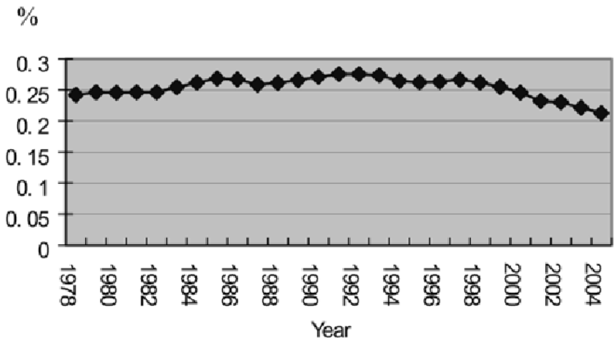

Fig. 16 Share of wheat in grain sown areas. Source: National Statistical Bureau.

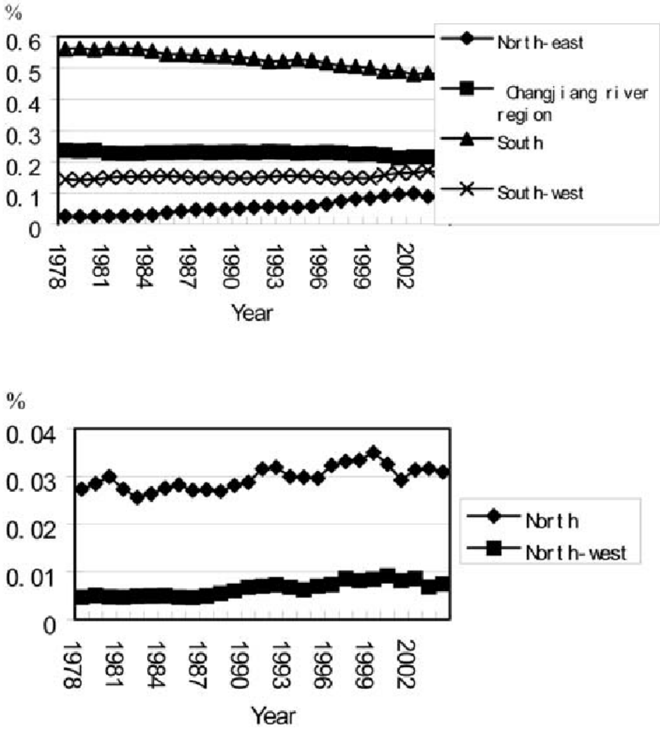

Fig. 17 Changing share of each region in total rice sown areas. Source: National Statistical Bureau.

from south to north, and from east to west. As in many developing countries, the agricultural sector consumes a lions' share of the water resource in China, currently more than 80% of national total, and rice requires by far the highest utilization rate of water resource per unit of land. Therefore, following the gradual shift of rice production from south to north, the stress on water resources in the north will be increased as a result, which is likely not only to hurt the local economy growth but also prevent future expansion of rice production in the region.

According to Cai and Rosegrant (2004), the national average per capita renewable water in China is only about one-fourth of the world average (about 8,500 m^3). The situation is especially worse in the north: the figure falls below the threshold for severe water scarcity of 1,000 m^3 in the North China Plain, and the average annual precipitation is 530 and 235 mm in northeast and northwest regions, respectively, that are about 50 and 23% of average annual evapotranspiration, and the regions are short of river flows. On the contrary, the average annual precipitation is 1,236 and 1,513 mm in the Yangtze River and Pearl River regions, respectively, that are about 30 to 40% higher than the average annual evapotranspiration, and there are rich river flows as well.

Under such conditions, it is reasonable to assume that the expansion of rice production in the north is likely to be a short-time phenomenon, as it will eventually turn out to be a less preferred production in water shortage areas. Fast industrialization and urbanization will claim more and more water resource, and the resulting demand for high-value farm produce will lead to rice and other grain crops to be replaced as well. It is also reasonable to assume that even in the short-run the expansion of rice production might slow down, if not entirely stop, and the water scarcity gets more and more severe.

In addition to the low long-run annual averages in measuring water resource, the reliability of the water supply is also low in the north, ranging from 78–85% against 92–99% in the south. It implies that the annual fluctuation in rice yield and output will increase, leading to uneven domestic supply and even greater fluctuation in trade volumes.

Summary and Implication for Trade

It could be concluded from the above analysis that China's rice exports are residuals from the domestic market, i.e., the quantity is basically determined by excess supply with some time lags. It is reasonable to expect a continuous decline in China's rice sown areas resulting from rapid income growth, associated fast industrialization and urbanization, and future increases in rice output will rely more on yield gains. As rice production is moving toward less favorable northern regions, the pressures on yield gains will increase further, while the yield and output will exhibit greater fluctuations and the expansion of rice production in the north will soon face serious constraints such as water shortage.

Such a situation may have an important impact on China's domestic rice market. As exports are a residual of the domestic market, its fluctuation will be much greater in the future. China's long-run ability to export rice may decrease if the yield gains can not offset the loss in sown areas and the negative effect of relocation. In addition to potential reduction in average quantity in the long-run, the annual fluctuation of rice exports is likely to increase as production moves to new and less favorable regions. Finally, the composition of rice supply, Japonica vs. Indica varieties, may also influence China's rice exports in terms of destination, and probably quantity as well.

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Sustainability of Water-Use and Food Production in the Haihe Catchment

Yonghui Yang, Jing Fan, Yukun Hu and Juana Moiwo

Abstract The Haihe River Catchment is one of the seven biggest catchments in China. It is important also because of the fact that two mega cities, Beijing and Tianjin, are located in the catchment. With the rapid development of agriculture, local economy, and population, the area has changed from a once dominant flood plain to a draught plain with acute water shortages exacerbated by quick declines of surface and sub-surface water levels. Each year, about 8 billion m^3 of water is withdrawn from the aquifer systems of the catchment. Our analysis shows that water use in food production, especially in recent decades, is one of the major causes of water shortage. However, the contribution of food production to the regional GDP is on the decline; for instance only 8.6% in 2005 as against 17.6% in 1990. Further analysis reveals that in the short term, food production and supply at the national level may not be serious since most areas in the south, which formerly produced an important portion of the nation's food, now do so on a lesser scale. Thus, a slight decrease in food production through policy adjustments in the Haihe Catchment may be a good strategy to ensure long-term sustainability of water-use, agricultural production, regional economic growth, and above all, a healthy environment.

Key words: Food production and supply, Haihe Catchment, water-use, local economy, sustainability

Introduction

The International Water Management Institute Report shows that serious water shortages in most regions of the world are caused by over-use of water by the agricultural sector. Similarly, though agriculture has been recognized as the dominant

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cause of water crisis, it remains the major sustaining force of regional development in North China. As environmental and water problems continue to deepen in time and space, China's central government pays great attention to the sustainable use of the limited water resources. For instance, water has become the second important environmental issue, next only to energy, such as oil and coal, in the national five-year report and the mid-term (2006–2020) science and technology development agenda. It is therefore urgent and appropriate to embark upon strategies that will ensure sustainability of water resources, water-use and the local economy of North China.

The Haihe Catchment is one of the most important catchments in China. Two mega cities Beijing and Tianjin are located in the region. With an annual water resource of 293 m^3 per capita, 10% of the national population, and 10.3% of the national cultivated land, it faces the highest water pressure and shortage in China (Liu and He, 1996).

However, the situation was totally different 40 years ago. During the 1960s, phreatic water levels were within a few meters, even centimeters of the land surface. With frequent flooding from the strong runoff, flood damage control was the biggest challenge of the time. Meanwhile high soil salinity from high groundwater levels in the plain and coastal regions strongly hindered agricultural development. In 1970, the situation started changing to what it is today. In a bid to conserve water, dams were constructed in the upstream regions of the Taihang and Yanshan Mountains. The development of irrigation agriculture over the entire catchment improved agricultural productivity. Pumping was introduced in the coastal region to lower groundwater level as a means of abating soil salinity. All actions seemed appropriate and in the right direction. However, at the beginning of 1980, a series of water shortages had already constituted a formidable threat to earlier achievements. Currently, the region continues to experience a widening groundwater table decline in over 40,000 km^2 of landscape at a rate of 3 m/yr in the coastal region and about 1 m/yr in the piedmonts of the Taihang Mountains. Total annual water shortage in the catchment has been estimated at about 8 billion m^3.

Agriculture has been recognized as the major contributor to water shortages as it accounts for 69.3% of total water use. Another three important water users are: industry, domestic, and animal husbandry, respectively accounting for 15.9, 11.6, and 3.2% of the total water use. Although the first phase of the South-North Water Transfer is scheduled to be completed by 2010, the cost of portable water, however, remains prohibitive in irrigated agriculture. The cost of a ton of portable water is at least half the price of the food it can produce.

Achieving a sustainable use of available water resources is a great challenge at both national and regional levels (Hebei Department of Water Conservancy, 1999). Since agriculture is the biggest user of water and a major factor influencing regional water balance and economic sustainability, this paper reconsiders development of agriculture in the Haihe Catchment by analyzing water use, agricultural production, and macro economic sustainability. Relevant suggestions are advanced on improving the local environmental and economic conditions, thus fostering sustainable water-use and food production.

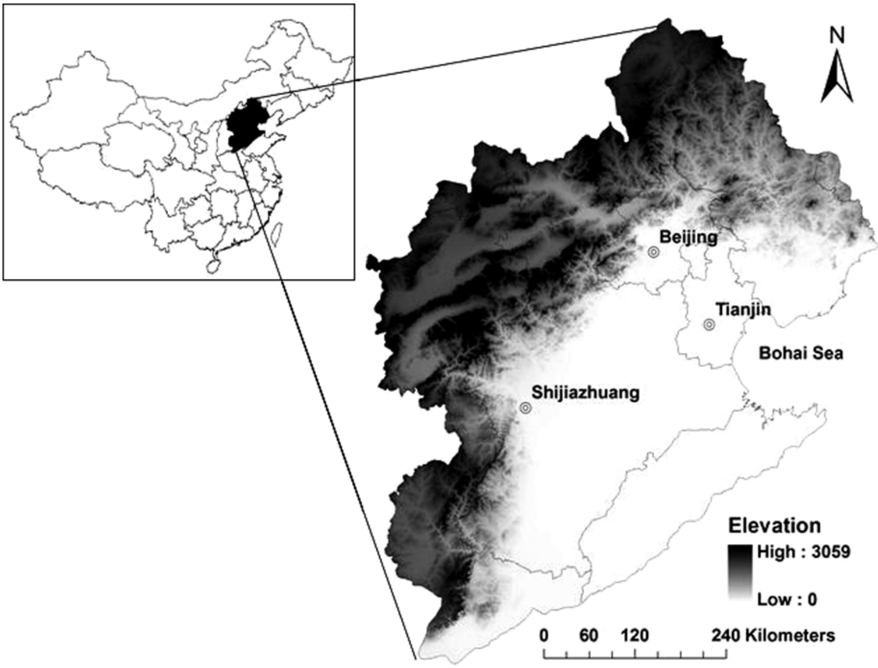

Fig. 1 Location and topography of the Haihe Catchment.

Study Site

The study site selected was located at the central part of the Haihe Catchment. Figure 1 shows the location of the catchment in China. It is a region surrounded by the Bohai Sea, Inner Mongolia in the north, Shanxi Province in the west, Henan Province, and Shandong Province. For convenience of analysis, only data from the central three administrative areas Beijing, Tianjin, and Hebei Province were collected and analyzed.

Results

Sustainability Problems of Regional Water Resources

Recent trends of groundwater level and runoff owing to groundwater and surface water over-use suggest the difficulties of regional sustainability of this life-supporting resource. In Figure 2, the examples show that runoff in the Haihe Catchment is decreasing dramatically. In the Hutuo River at the upstream of Shijiazhuang City, mountain annual runoff is only about 1/3 of what it was in the 1960s and the

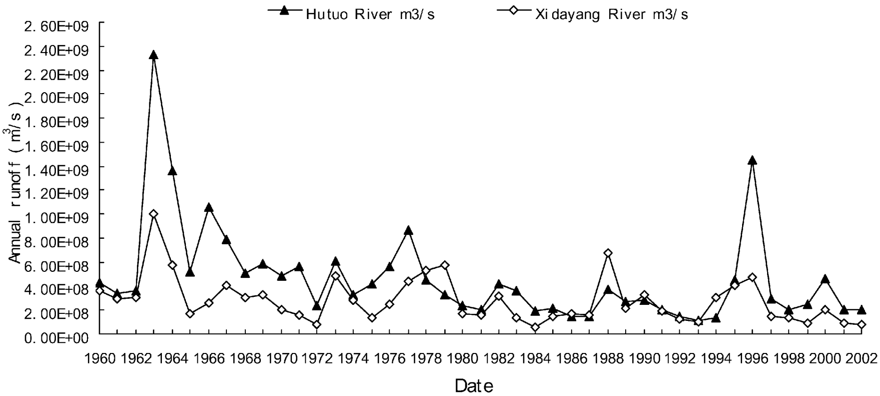

Fig. 2 Trend of annual runoff in the Hutuo and Xidayang Rivers (two big rivers that supply water to Shijiazhuang and Baoding Cities in the Haihe Catchment).

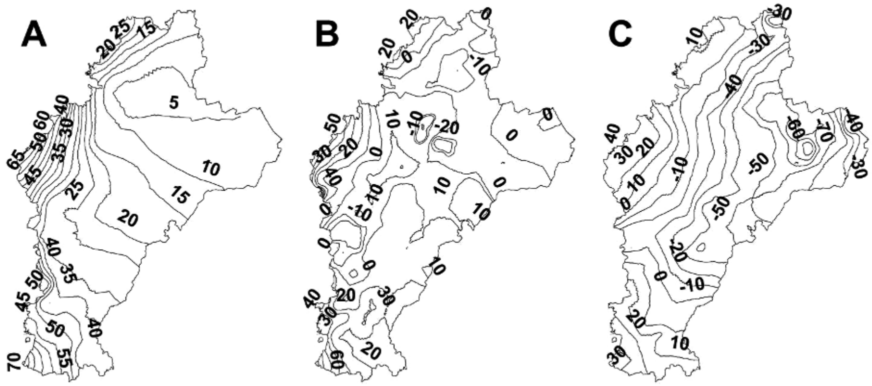

Fig. 3 Changes in groundwater level in Hebei Plain. (A: Groundwater level in 1974. B: Phreatic water level in 2004. C: Piezometric head in 2004. Negative value shows that groundwater level is below sea level).

Xidayang River, which is at the upstream of Baoding City experiences a similar phenomenon.

Figure 3 shows a groundwater level decline since 1974. In the 1970s, groundwater flew naturally from the mountainous region to the coastal region. However, in 2004, the situation totally changed. At present, the phreatic water level lies below sea level in nearly 1/2 of the catchment. And nearly 80% of the deep groundwater aquifer lies below sea level with the deepest piezometric head at 80 m below sea level. In areas near the coast, land subsidence over three meters is not uncommon anymore. Water pollution too has worsened, since most of the rivers hardly reach the sea for most parts of the year to discharge waste waters loaded in the upstream zones. All these phenomena clearly suggest that the present use of water is unsustainable.

Table 1 Percentage area, population and cultivated land of Beijing–Tianjin–Hebei relative to China's, GDP.

	Beijing–Tianjin–Hebei	China	Percentage (%)
Area (10^4 km^2)	21.9	960	2.3
Population (billion)	94	1307	7.2
Cultivated land $\times 10^6$ ha	7.71	130.03	5.9
GDP (10^9 Yuan)	2068	18308	11.3
GDP agriculture (10^9 Yuan)	171	2307	7.4
GDP industry (10^9 Yuan)	826	7691	10.7
Grain production (million ton)	28.31	484.02	5.8

The Role of Agriculture in the Regional and National Economy

With two mega cities, Beijing and Tianjin, directly under the jurisdiction of the Central Government, the vitality of the region in China is obvious. Basic information on the three administrative zones is given in Table 1. The region accounts for 11.3% of the total national GDP. The contribution of agriculture to the GDP is about 1/5 of that from the industrial sector. Thus the role of agriculture in the regional economy is somewhat weak. However, with about 5.9% of the total cultivated land of the nation, the region produces 5.8% of the nation's grain, suggesting that the region is producing a national average grain yield under relatively poor climatic conditions with regards to solar energy, temperature and, especially annual precipitation (450–650 mm). This high yield production mainly relies on intensive water inputs with large amounts of the water pumped from the aquifer systems.

Aside from high grain yields, the region's fruit and meat productions are higher than the national average. Although there is a lack of comprehensive national statistics on vegetable production, Hebei Province is listed as the second highest vegetable production region in China, next only to Shandong (Xia, 2005). Our analysis on per capita grain, vegetable, meat, and fruit productions suggests that the region is over-self-sufficient in meat, vegetable, and fruit, with only a slightly below national average food supply with only 400–500 mm of annual precipitation.

Agricultural Water-Use and Contribution to GDP

Table 2 shows percentage change of agricultural water-use over the last 15 years in Beijing, Tian, and Hebei Region. According to the statistics, agricultural water-use has been largely consistent. Thus, the major reason for the cut-back in agricultural water-use has been increased total water-use resulting mainly from expanding domestic water-use from its original 1.52 billion m^3 in 1990 to 4.21 billion m^3 in 2005. Industrial water-use shows a clear sign of decrease since 2000. However, agricultural water-use in terms of the contribution of agriculture to total regional GDP has

Table 2 Ratio of agricultural water-use and GDP to regional water-use and GDP of the Beijing, Tianjin and Hebei Region.

Year	Water-use (billion m^3)			GDP (billion Yuan)		
	Total water-use	Agricultural water-use	% ratio of agriculture to total	Total	Agriculture	% ratio of agriculture to total
1990	24.16	18.21	75.4	169.91	29.91	17.6
1995	25.82	19.35	74.9	516.45	77.59	15.0
2000	27.53	19.03	69.1	920.71	98.81	10.7
2005	25.56	17.65	69.1	2068.00	171.34	8.3

declined from 17.6% in 1990 to 8.3% in 2005, suggesting that less water-use in the agricultural sec- tor is worthwhile.

Crop Water-Use

As can be seen from Table 3, wheat and corn, the two major crops, account for over 90.2% of the local grain production. Table 4 shows an increase in planting area in 2005, which should bring about an increased crop water requirement. The planting area of each of the crops in 2005 is also compared with that in 1985. According to the statistics, it is surprising that in 2005, the area under grain production was nearly the same as that occupied by fruit trees and vegetables, given the fact that wheat and corn are always cultivated on rotational basis. If present statistics of water-use are anything to go by, then during the last 20 years, water-use efficiency had witnessed great improvement in that the same amount of water has been used to produce more food, fruit, vegetable, and meat. Unfortunately, there is still a lack of a comprehensive experiment that will estimate non-irrigation and irrigation water-use in vegetable and fruit production. However, available data on fruit tree water-use shows that vegetable ET in most years is around 950–1000 mm, about 100 mm higher than estimated ET in wheat-corn rotation fields by Liu et al. (2002). Zhang (2006) estimated vegetable water-use for the whole growing season to be 922–1,057 mm, slightly higher than for crop fields. Cotton is the only crop, whose annual ET, around 540 mm (Yang 2006), is nearest to our regional annual precipitation. However, crop planting area is decreasing due to high labor cost. In other words, considering the planting area and water-use (annual ET) by crop type, the effect of fruit trees and vegetables on agricultural water-use is similar to water-use by rotation of wheat-corn. A rough estimation will be that wheat-corn rotation accounts for about 40% of the total water-use (8.8 billion m^3, calculations based on plentiful irrigation), and fruit trees together with vegetables accounts for another 50% of the total water-use (10.4 billion m^3, calculations based on plentiful irrigation), while oil crops, cotton, and so on use about 10% of the total water. The calculation of water-use is slightly higher than the annual water-use (17.7 billion m^3), since some land may not be ef-

Table 3 Agricultural production of common products in Beijing, Tianjin, and Hebei.

Products (10^4 ton)	1980	1985	1990	1995	2000	2005
Grain	1846.5	2326.8	2730.4	3206.3	2819.4	2831.0
Wheat		860.9	1093.5	1226.1	1334.4	1224.4
Corn		840.7	1033.9	1396.9	1094.2	1329.6
Fruit		184.8	212.0	497.1	764.2	1578.0
Vegetable		N/A	2111.4	2979.9	5473.7	7434.2
Meat		101.7	151.8	360.5	504.2	696.4
Pork		95.4	135.2	223.5	289.2	404.3
Beef		2.1	6.9	10.2	71.4	97.5
Lamb		4.2	9.7	19.5	28.2	40.7
Milk		28.1	43.6	70.6	143.1	467.9
Egg		58.1	95.7	257.9	398.6	498.5

Table 4 Cultivated area of different crops, vegetables, and fruit trees (in 1,000 ha).

	Total	Wheat	Corn	Vegetable	Fruit	Cotton
1985	7450	2693	2103	355	397	884
2005	9602	2529	2936	1322	1228	636

ficiently irrigated. Fruit trees and vegetables have overtaken wheat-corn rotation to become the biggest water users.

Since agricultural water-use in 2005 and 1990 is very similar, agricultural water-saving must have been augmented a lot. The biggest achievement of agricultural water-saving lies in increased yield over the years.

Discussion

According to the above analysis, efficient agricultural water-use is increasing from unchanged total water-use. However, agricultural water-use still accounts for 69.1% of the total water-use. Since the South-North Water Diversion is aimed mainly at solving water shortages in the big municipalities owing to high transfer costs, water shortage cannot be expected to be greatly eased in the short term in the agricultural sector. For instance, domestic water-use in rural areas is expected to rise dramatically. According to our farmer-level survey in 2006, farmers need to change from single showers per one to three months in winter to multiple showers per month; and from clothes washing every 7–10 days to every 2–3 days when 24-hour water supply is available. For the long-term, as local water resources become more and more difficult to support the present agricultural production, it is necessary to think about cutting down current agricultural production level.

In fact, it is often suggested that the current food production should be cut down. However, these suggestions are generally ignored in order to guarantee adequate food supply to feed China's population, which is the highest in the world. In Fig-

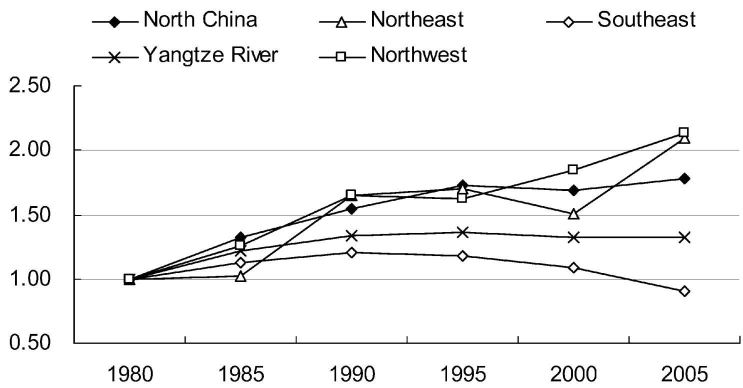

Fig. 4 Agricultural production trend since 1980. Data shows ratio of present agricultural production to production in 1980 (1980 treated as reference production base).

ure 4, the trend of food production in different parts of China since 1980 is shown. Surprisingly enough, all the areas with increasing food production are located in the north, where climatic conditions are hostile. On the other hand, the Yangtze River Catchment and Southeast China, the two areas that produced 46% of China's total food in 1985 had not seen much increase in food production. In fact on the contrary, Southeast China had witnessed decreased production despite the better prevailing climatic conditions. A possible reason behind the production down turn is that people in Southeast China are more affluent, and benefit less from agricultural farming. For instance, in Hebei Province, not counting the cost of land and labor, farmers earn 5397 and 5396 Yuan per hectare of wheat and corn respectively, which is unbelievably low. The decreasing trend in food production in southeast China can be found in statistical data. For example, the cultivated area for grain in 2005 was 11.05 million ha compared to 16.50 million ha in 1985.

The above analyses suggest that China still has a big potential to increase grain production, if suitable policies are enacted to encourage food production in the south. Therefore, a beneficial decrease of food production in the North China Plain, especially Beijing, Tianjin and the Hebei Province can slow down groundwater decline, which is crucial in the context of the environment, local economy and food supply. Moreover, preservation of water will increase the level of food production in the long-run as mandated under China's population goals. Thus the only undone portion of water-use and food production is the policy decision to shape better income for farmers.

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Exploring Land Use Planning Options: Experiences and Challenges for Food and Water Security

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Abstract Most of THE Southeast Asian countries have natural and managed ecosystems that HAVE experienced major challenges from a range of technological, environmental, socioeconomic and political forces; and these regions have been subjected to pressure of land use change, environmental degradation, water shortage, and loss of biodiversity. Food production has continued to be threatened by the scarcity of natural resources through conversion of agricultural lands caused by rapid urbanization, exploitation and competition for the use of limited resources, such as water. A study was conducted (1) to develop a scientific technical methodology for exploring land use options; and (2) to operationalize such methodology for supporting a network of multi-disciplinary teams and stakeholders in the ecosystem. An exploratory land use planning and analysis system (LUPAS) was developed and its component models is presented here as a case study. Optimization of the model showed a great scope for system-wide water sharing on rice-based cropping systems, generation of labor employment in agriculture, considerable increase in farmers' income, and the possibility of reducing soil erosion, biocides and pesticides use without adversely affecting the agricultural production in the area. LUPAS can be applied to other ecosystem areas in China, Japan and elsewhere for strategic land use planning and environmental assessment to attain food and water security.

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Key words: Decision support systems, food and water security, land use, sustainability

Introduction

Loss of agricultural land, increasing urbanization of populations, climate change, and competition for land and water resources are among the "mega trends" that may drive national development of any country in Southeast Asia. Most of these areas face common issues related to the ecological sustainability that is required to maintain economic development. These issues concern what alternative crops can be grown given water, labor, and land constraints, how to increase efficiency and productivity of current food crop production, and how to arrest the negative effects on the natural resource base due to agricultural practices. Due to their complexity and interrelatedness, these issues require a system approach to support decisions. Land use driven by market forces has affected large parts of the humid tropical toposequence, from uplands to rain fed and irrigated lowlands (Pascual, 1995). Farmers have responded by diversifying into cash-generating enterprises, often at the expense of staple crops such as rice and corn. Common enterprises are the production of high value vegetables, aquaculture and floriculture. Bilateral and multilateral agreements to do research into and generate technologies for these diversified land use systems, led to launching of the "Systems Research Network for Ecoregional Land Use Planning in Support of Natural Resource Management in Tropical Asia", or Sysnet, in four case study regions, namely India, Malaysia, Philippines and Vietnam (Roetter et al., 2000; Lansigan et al., 2000). The Sysnet Philippines team is composed of scientists and researchers from research institutions and the academe (MMSU and UPLB) to develop and apply an operational land use planning and analysis systems for the province of Ilocos Norte. An assembly of Sysnet systems analysis research tools developed computer-based decision support systems for multi-disciplinary research and development geared towards agricultural land use planning and natural resources management (Laborte, 2006). This paper describes the DSS methodology of LUPAS and its application to spatial land evaluation and exploration of the agricultural land use options for the province of Ilocos Norte, Philippines.

Materials and Methods

The development of decision support systems in this study utilizes database management systems, geographical information systems, optimization techniques such as an interactive multiple goal linear programming (IMGLP) method, simulation and land evaluation modeling (Pascual, 1995; Lansigan et al., 2000). This method comprises the use of a computer-based input-output model, a set of goal variables, and an interactive multiple criteria decision procedure. The input-output model constructed for the study is composed of the technical coefficients that describe the range of production activities assumed to be relevant to the region. These include production activities currently practiced (farmer's practice) and possible future production activities that would be technically feasible under prevailing agroecological conditions if higher levels of external inputs were applied. Each production activity is defined by its relevant outputs (production) and inputs (means of production) – coefficients that relate to a well-defined way of producing a certain product. The technical coefficients for the current production activities are derived from surveys in the areas where they are practiced. For potential yield production techniques, the technical coefficients are derived by using the available crop simulation models, such as ORYZA1 and WOFOST 7 (Roetter et al., 2000). For land evaluation, the quantitative approach for explanatory land use analysis requires the delineation of land areas with more or less homogeneous land characteristics. Land units form the basis for quantifying input-output relations pertaining to agricultural production activities. As a first step in defining land units for land use planning, zoning of the physical environment is required, based on the most relevant properties such as climatic, soil and hydrological characteristics, and defined agroecological units. Data on some crucial land characteristics or qualities may be inadequate, or may not be available for larger areas. In such a case, transfer functions and interpolation techniques can be applied. In the digitizing and transformation of maps, the universal traverse mercator projection was applied. In defining agroecological land units for Ilocos Norte, five land characteristics were considered such as: (a) Total annual rainfall – this range of values was grouped into two classes: $>$2,000 and $<$2,000 mm yr^{-1}; (b) Rainfall distribution – three subzones throughout the year were distinguished: areas with 2–4 dry months; areas with 5–6 dry months; and areas with at least 7 dry months; (c) Irrigated areas – this corresponds to areas under irrigation systems (national, communal, and water impoundments) delineated by NIA and BSWM; (d) Slope – areas are classified as either level to gently sloping ($<$18%) or moderately sloping ($>$18%). Areas with steep slopes are considered unsuitable for crop production and are excluded from possible agricultural development areas; and (e) Soil texture – three broad soil textures are distinguished, namely, fine, medium, and coarse.

Furthermore, the areas that are clearly not suitable for agricultural use were excluded. Such areas include unsuitable soils, water bodies, forest, and built-up areas. The overlays, reclassifications and spatial displays of the afore-mentioned thematic maps and agro-ecological units were performed using GIS software. Input-output tables required as technical coefficients for optimization analysis were developed based on primary data surveys and secondary information from various sources (Lansigan et al., 2000). The procedures followed for estimating availability of resources and input-output relations are:

- Size of land units in each municipality was calculated using GIS;
- Water Supply (WS) available monthly or annually for each municipality:

$$\text{WS} = \text{average rainfall} \times \text{Area} \times (1 - \text{fraction due to evaporation} - \text{fraction due to storage});$$

- Water demand (WD) monthly or annually for each municipality:

$$\mathrm{WD} = [(\text{urban population} \times \mathrm{DU} + (\text{rural population} \times \mathrm{DR})] \times \mathrm{T},$$

  where DU and DR are per capita water demand for urban and rural users, being 0.19 and 0.4 $m^3\ d^{-1}$, respectively; and T is the number of days during the calculation period, 30 days in a month or 365 days in a year;
- Water available for crops (WC):

$$\mathrm{WC} = \mathrm{WS} - \mathrm{WD}.$$

  Crop water requirements were estimated based on local data and expert knowledge. The water balance was analyzed monthly, and also annually assuming that reservoirs for water regulations are built;
- Labor or manpower available (in man-days) was estimated by assuming that 45% of the rural population of the municipality contributes to the labor force;
- Labor requirements, either family or hired labor, for different crop production activities are based on survey data in the province.

Other pertinent data were gathered with assistance of the municipal agricultural officers and agricultural technicians in the province. These data together with estimates of target yields and other technical coefficients, such as costs of material inputs, were combined in input-output tables serving as input for land use optimization. A linear programming model is generally used to optimize a single objective function (Pascual, 1985; Laborte, 2006). However, for the study, interactive multiple goal linear programming or IMGLP was developed. This methodology makes it possible to optimize a set of objective functions in an iterative process. This reveals trade-off between different goals that are modeled by the objective functions (Alocilja and Ritchie, 1993). In the IMGLP model developed, the following items were declared: the major land evaluation units (LEUs) taken as 23 units (22 towns and 1 city); 3 sub-LEUs covering rained lowland, rainfed upland and irrigated areas; and 25 rice-based land use, totaling to 1,725 variables. The goal variables incorporated in the model were derived from various consultation meetings conducted at MMSU, Batac, Ilocos Norte with major stakeholders in the development of the province, i.e., municipal planners and agricultural officers, provincial government officers, farmer leaders and research and development agencies in the province. The current model constructed from the province of Ilocos Norte and its municipalities consist of seven objective functions: (a) Maximize rice production; (b) Maximize non-rice production; (c) Maximize labor employment in agriculture; (d) Maximize farmers' income; (e) Maximize soil erosion; (f) Minimize the use of biocides; and (g) Minimize fertilizer use. The IMGLP model for Ilocos Norte was analyzed using the XPRESS optimization software (Dash Associates, 1997). Within the model, constraints on land area, labor, and water availability for the entire province were imposed. In addition, three alternative scenarios were considered: (1) without water-sharing among municipalities; (2) with water-sharing, the latter assuming existence of an efficient irrigation network connecting all the municipalities allowing more efficient use of available water for agricultural production; and (3) with bounds for rice production efficiency. The resulting database output of land allocation of various cropping systems was linked in a base map of Ilocos Norte using GIS. The scenarios that were conceived were compared with the present conditions in the case study area.

Results and Discussion

Ilocos Norte is geographically located at 17°48” to 18°29”N and 120°25” to 120°58”E, occupying the coastal plain in the northwestern portion of northern Luzon. It has a total area of 3,339.3 km^2 composed of one city and 22 municipalities which are further subdivided into 557 villages (barangays). The centrally located Laoag City at the western portion of the province is the provincial capital. Laoag City is 485 north-northwest of Manila and 15 km from MMSU. The existing land use map of Ilocos Norte was prepared from the combined data of the Bureau of Soils and Water Management (BSWM) and the Department of Environment and Natural Resources, substantiated with the local planning and agricultural officers of the province (BSWM, 1985; PPDO. 1998). Reported data revealed that about 221,909 ha were intensively used for agricultural production; forests, 51,361 ha; extensive area for perennial and pasture lands, 63,142 ha; riverbeds and lakes, 6,177 ha; and built-up areas, 1,146 ha. Rice-based agriculture has remained the main source of livelihood in the province. Other crops grown include garlic, tomato, corn, mungbean, cotton, tobacco, sweet pepper, onion, and other vegetables.

From the quantitative land evaluation of five land characteristics, a total of 47 agroecological units suitable for agricultural use were defined. The overlay of the aforementioned 47 agro-ecological units with the municipal boundaries using GIS software resulted in 200 land units or equivalent to a total agricultural area of 12,650 ha were reclassified for the province . Size distribution of these land units ranges from 200 ha (smallest) to 4,550 ha (largest).

The general framework of the decision support systems on land use planning analysis system or LUPAS is presented in Figure 1. These include crop simulation models, expert systems, GIS, and multiple goal linear programming (MGLP) models for land evaluation and optimization. LUPAS is aimed at exploration of potential and alternative land use options at regional or provincial scale (Lansigan et al., 2000; Laborte, 2006). LUPAS, which was developed to improve the scientific basis for land use planning, is a decision support system (DSS) for strategic planning, based on the interactive multiple goal linear programming (IMGLP) technique. In the IMGLP model, some computer runs were made covering 23 municipalities, 200 LUs, 3 ecoregions (irrigated, rainfed, and upland) and about 25 cropping systems as land use types. The results of the optimization of the seven different objective functions at three scenarios as compared to the present situation in Ilocos Norte are presented in Figure 2.

These results are model runs in optimizing goals individually without imposing restrictions set by requirements for other goals. Also, the use of scenarios is a way

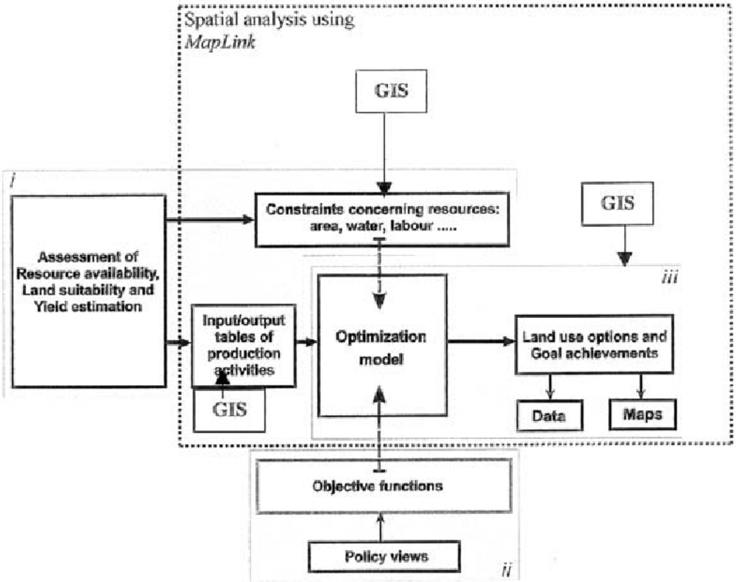

Fig. 1 General framework of the decision support systems on (i) land evaluation; (ii) scenario construction; and (iii) land use optimization (Roetter et al., 2000).

to cope with uncertainties and a way to imply development pathways. The foregoing results showed that maximizing Goals 1, 2, 3, and 4 on three scenarios (A, B, and C) were optimally feasible and maximally higher as compared to the current situation (TODAY) except for Goal 1. Under Goal 1, there is an estimated current rice surplus of 1.43 times more than the targeted self-sufficiency level of 153,823 tons. The model further revealed that maximizing non-rice production (Goal 2, Figure 2) gave the best beneficial option to the province coupled with the highly feasible labor employment generated (Goal 3, Figure 2). The indicated benefits which farmers can derive on increased income may come from the production of more profitable dry season crops such as garlic, tomato, onion and vegetables (Goal 4, Figure 2). However, if the province opts to maximize rice production, the generated production under the water-sharing scenario is twice more than the no water-sharing scenario (Goal 1, Figure 2). This further assumes that the land units belonging to the same irrigation system can share water resources such that water use efficiency can be improved. This would mean more income for the farmers, and a suitable food supply at lower prices for the consuming public. Under the environmental concerns of the land use plan, minimizing soil erosion (Goals 5), biocide use (Goal 6) and fertilizer use (Goal 7) were optimally feasible and minimally lower than the current situation (Figure 2). This connotes the technical possibilities of reducing soil erosion, biocides and pesticides use without adversely affecting the agricultural production in the province. The afore-mentioned results showed that there is a vast and wide scope for policy geared to develop all current agricultural land for rice-based cropping sys-

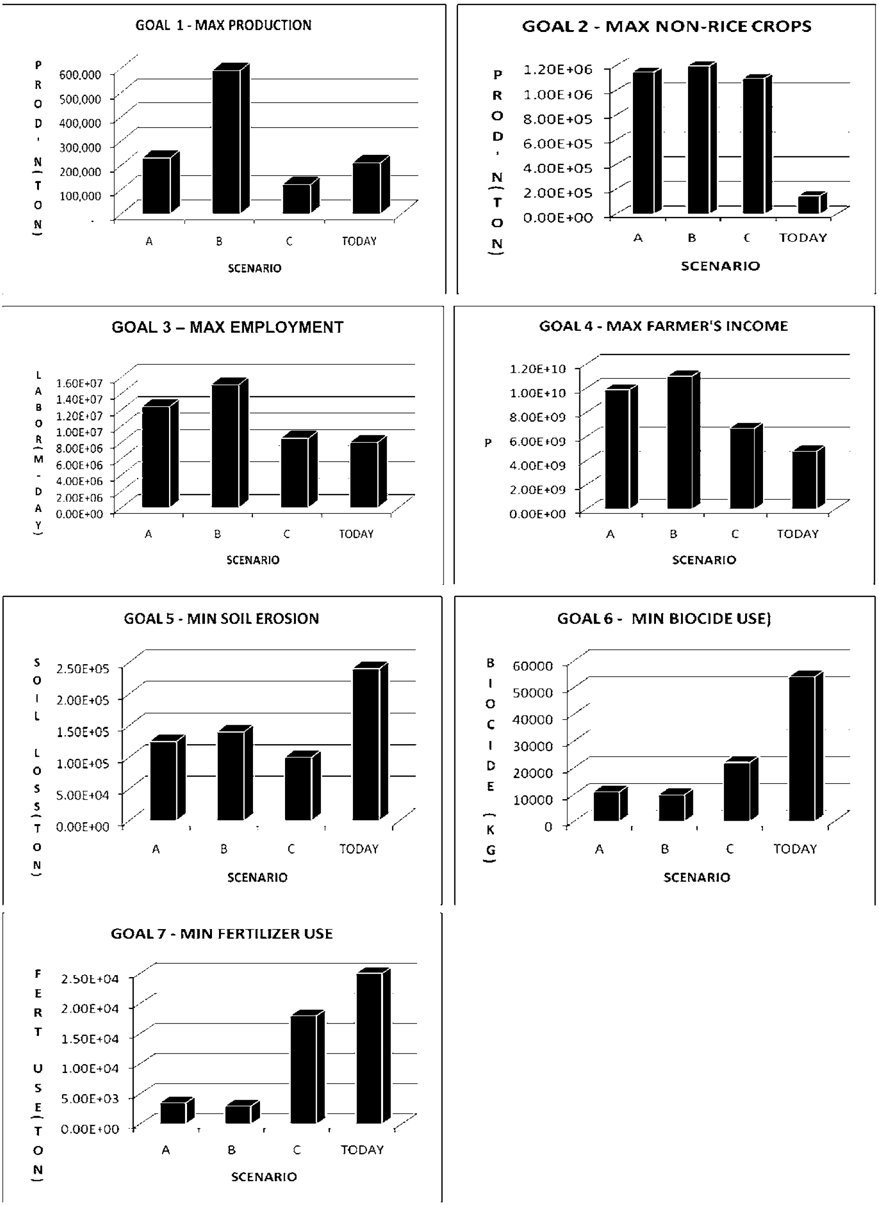

Fig. 2 Optimum scenarios (A – without sharing water, B – with water sharing, C – with bounds for rice production) compared to current situation (TODAY) at seven objective functions.

tems in the area. These results can be looked upon as evitable, and government might want to mitigate some of the effects. The scenarios are all extreme and as such may not be pursued, but they indicate directions that might be stimulated with the aid of policy instruments. Active participation created rapport and valuable exchange of information, feedback and knowledge-sharing. Adoption of the DSS methodology to scale-down from the provincial to municipal or barangay levels was suggested by major stakeholders. Therefore, it is worth to pursue institutionalization of such research and development on DSS methodology in the comprehensive land use plan in the local government units (LGUs) of the country. Likewise, precision agriculture demonstrated in this study could be applied to delineate the strategic agriculture and fishery development zones (SAFDZ), the "modern nucleus" under the Agriculture and Fishery Modernization Act of 1997 among LGUs.

Conclusions

Food security is critically dependent upon optimizing the use of land and water. Food availability is a necessary, but not a sufficient, condition for food security. Food security at the aggregate level may not necessarily translate into food security at the family level. The key challenge of growing more food with less water has both science-based and people-based dimensions. The research methodology development of LUPAS has showed an innovative DSS for strategic agricultural land use planning and resource management with emphasis on food and water security. Designed for and tailored to the specific questions of planners and policymakers in a given study area (such as in Ilocos Norte Province), it offers improved accessibility of information in support of: (a) trade-off analysis of multiple goals (such as production, income, employment) in complex decisions situations; (b) fine-tuning of resource management systems; and (c) comparison of resource use intensity and environmental costs of alternative production activities (Lansigan et al., 2000; Laborte, 2006). Initial optimization results show that when water is shared among land units in each irrigation system, the province benefits a lot. When rice production is maximized, only 39% of total available land is allocated, compared to 53% otherwise. Maximizing farmers' income resulted in total allocation of land, with root crops allocated to 59% and the rest to rice-tomato and rice-onion. Almost all of the maximizing goals under the water-sharing scenario considered yielded higher values than the no water-sharing scenario, more so under present conditions. The exploratory analysis suggests that with efficient distribution of water, more income for the province and the farmers would be realized, and this would ensure a steady supply of food crops for the province at lower prices. While the scientific-technical component may come up with optimal agricultural land use options in the case study area, their acceptability by stakeholders may still be an issue. However, the DSS provides a rational basis for addressing such differences in goals and priorities taking into account the available resources. The IMGLP model does not produce forecasts but rather shows scenarios of feasible land use options subject to well-defined conditions. The scenarios are a survey of technical possibilities based on series of well-founded assumptions and presuppositions.

The DSS methodology of LUPAS, though developed to serve a specific aim, could be applied in other provinces and regions in Southeast Asia (China, Japan, etc.), especially those conditions where integration of biophysical, socioeconomic, and environmental factors are considered. Coupled with this, to assure food security and improve farmer's income, the following strategies should be adopted and institutionalized by the government: (a) implement a policy framework to ensure that the food and water security program is carried out in the long term; (b) prioritize infrastructure projects such as irrigation systems, post-harvest and marketing facilities, farm-to-market roads and information technology-based infrastructure systems; (c) improve the capabilities of extension workers in the LGUs by training them to improve their technical and extension skills; and (d) integrate R&D, training, people participation, agronomic practices, economic instruments, and administrative policies. The DSS includes reviewed contributions by global experts in the field, who elaborate on the governance of food security, the biophysical dimensions of more food per crop, as well as on the socioeconomic dimensions of food and water security.

Some opportunities and challenges for LUPAS methodology include: (a) spatial analysis of resources at various scales; (b) more quantitative tools for technology coefficients of production technologies; (c) optimization at multi-scale; and (d) institutionalization of LUPAS as a beneficial land use planning system to its stakeholders (Laborte, 2006).

Acknowledgements

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The Impact of the Bio-Ethanol Production to the World Grain Market: A Case Study of World Maize Market

Hideaki Takagi, Nobuhiro Suzuki and Hirotaka Matsuda

Abstract The world food supply has been expected to undergo a serious shortage because of the extremely rapid development of a number of countries, especially BRICs (Brazil, Russia, India and China). In addition, it has also been predicted that an expansion in production of biofuels will not only intensify that shortage but also increase the price of food. However, the price effects on farming activity and the contribution of technological progress to increase the yield are issues that have not been considered in current papers. The aim of this study is to simulate the impact of productions on the international grain market, including the effect of price and the contribution of technological progress to agricultural production, mainly focusing on the international maize market from 2005 to 2020, by establishing a simultaneous equation model. It is shown in this study that the international price of maize has not been increasing, although it fluctuates every year. The reason is that the time trend variable as the proxy variable of technological progress, indicates that technological progress increases production even though the harvested area of maize remains at its usual level or decreases. The results indicate that the food crisis that was widely anticipated has not occurred and that the technological progress is an important reason.

Key words: Bio-ethanol, price of grains, technological progress, world grain market, world maize market, yield

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Introduction

The world food supply has been expected to undergo a serious shortage because of the extremely rapid development of a number of countries, especially BRICs (Brazil, Russia, India and China). The general increase in income has made it possible for a larger number of people to eat more meat. More grains for animal feed is needed in order to produce more meat. However, there is a limited, and relatively small, amount of arable land all over the world and small potential to expand that land. Therefore, the total amount of grain produced in the future will not be able to feed the whole world. This is the basis for the prediction of a world food shortage. In addition, it is also said that the expansion in production of biofuels such as bioethanol, made from sugarcane and corn, will intensify the world food shortage and increase its price.

However, the price effects on farming activity and the contribution of technological progress to an increasing yield are not considered in some current papers. The increase of demand for grain cannot be avoided but the results of these contributions can produce enough food for a rapidly expanding population, even though the arable land cannot be expanded any more.

The aim of this study is to simulate the impact of bio-ethanol productions on the international grain market, including the effect of price and the contribution of technological progress to agricultural production, mainly focusing on the international maize market, from 2005 to 2020 by establishing a simultaneous equation model. The structure of this study is as follows. The simulation model of this study is set in the second section. The result of the simulation and the discussion can be found in the third section. Finally, the conclusion of this study is presented in the fourth section.

The Simulation Model

The Estimation of Price Elasticity of Yield of Maize

Although farmers generally respond to the fluctuations of prices, almost none existing simulation models of the world cereal market include this factor. A price increase lets the farmer produce more and vice versa. Those responses to price by farmers can buffer the impact of the price on the world cereal market. An assumption of the existing models implies that the efforts of farmers to their production, in other words, yield to an increasing effect by responding to the price, are ignored in spite of high demand. In this study, the relationship between the yield of maize and the world price of maize is estimated by using a Cobb–Douglas type function for establishing the world maize market simulation model:

$$\log Y_t = C + \alpha T + \beta \log Pm_{t-1} + \gamma D \qquad (1)$$

Table 1 Estimates for price elasticity of yields of maize.

	Argentina	Brazil	China	EU	US
constant	–85.0	–82.0	–19.3	–50.3	–23.7
	(–15.0)	(–8.0)	(–4.9)	(–6.2)	(–4.7)
T	0.043	0.043	0.009	0.025	0.013
	(15.3)	(9.3)	(5.1)	(6.4)	(5.1)
$\log Pm(-1)$	0.307	–	0.417	0.305	–
	(2.7)	–	(4.4)	(2.4)	–
R^2 adjusted	0.92	0.86	0.72	0.73	0.85
D.W.	1.52	2.15	2.38	3.05	2.95

Notes: 1. t-values are in parentheses.
2. – means unable to obtain significant results.

Y, Pm and T indicate the yield (per ha) of maize, the price of maize and time trend, respectively. C and D is constant and a dummy variable for the extremely decreasing yield. Because the planting decided by farmers depend heavily on the price in the previous year, that price is used in the equation. Moreover, the equation is a double logarithm formula and so the parameter β is the price elasticity of yield of maize. The expected estimation result of β is positive significant. Argentina, Brazil, China, the EU and the US are estimated as the major maize production nations and region. Table 1 shows the result of the estimation of price elasticity of yield of maize. The estimation method is OLS.

In the cases of Brazil and the US, the estimation results are not significant. Otherwise, the results for other nations and regions are positive significant. These results indicate that a high price in a given year allows the in the following year to increase.

The Estimation of the Relationship between Ethanol Price and Maize Price

In this subsection, the relationship between ethanol price and maize price is estimated. The following is our chosen equation for that estimation:

$$\log ETH_t = C + \beta \log\left(\frac{Pp_t}{Pm_t}\right) \tag{2}$$

ETH is the demand for ethanol. C is a constant. The assumption of this equation is that the demand for ethanol is affected by its price it through the maize price as the cost of the ethanol from maize; therefore the demand for ethanol is decided by the ratio of the international crude oil price (Pp) to the international maize price (Pm). This equation is estimated by using the data of the US because the US is the main producer of maize for ethanol in the world. The estimation method is OLS and the expected value of the coefficient β is positive significant.

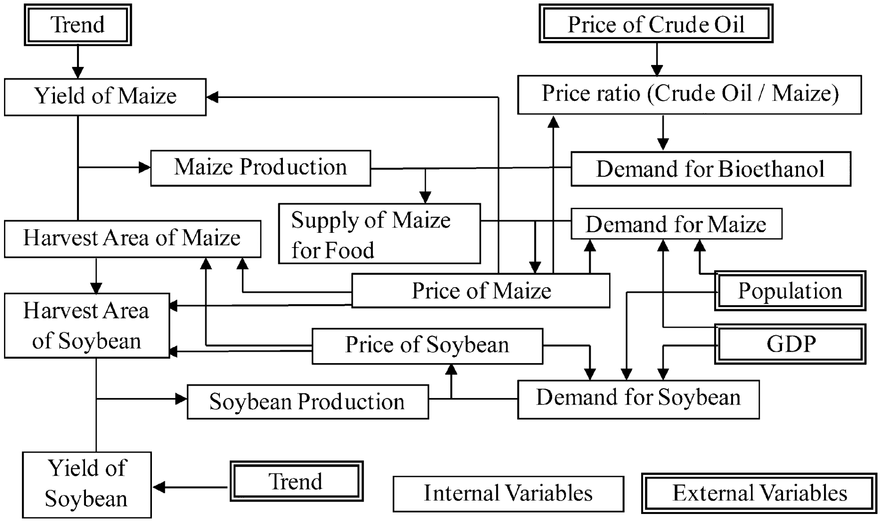

Fig. 1 Concept chart of simulation model.

The estimation result of coefficient is positive significant as expected. The coefficient is the price ratio elasticity of ethanol because the equation is formulated in double logarithm form. The elasticity is nearly 1. This means that the ratio of international crude oil price to the international maize price has a relative large impact on the ethanol demand.

Simulation of the Simultaneous Equation Model of the World Maize Market

Figure 1 shows the conceptual frame work of simultaneous equation model of this study. The simultaneous simulation model of this study integrated three international markets, which are maize, soybeans as a substitution of maize for cultivation and ethanol. It should be noticed that the ethanol market in the US is only considered. The specific simultaneous simulation models are shown below.

The yield of maize

$$Y_a = \exp(-85.0 + 0.0425 * T + 0.307 * \log(Pm(-1))) \tag{3}$$

$$Y_b = \exp(-72.7 + 0.0370 * T) \tag{4}$$

$$Y_c = \exp(-19.6 + 0.00929 * T + 0.417 * \log(Pm(-1))) \tag{5}$$

$$Y_e = \exp(-50.3 + 0.0253 * T + 0.305 * \log(Pm(-1))) \tag{6}$$

$$Y_u = \exp(-23.7 + 0.0129 * T) \tag{7}$$

These are drawn from the estimated equation from (2), a, b, c, e and u mean Argentina, Brazil, China, EU, and the US, respectively.

The harvested area of maize

$$S_a = S_a(-1) * (Pm(-1)/Pm(-2))^{0.627} * (Ps(-1)/Ps(-2))^{(-0.162)} \tag{8}$$

$$S_b = S_b(-1) * (Pm(-1)/Pm(-2))^{0.400} * (Ps(-1)/Ps(-2))^{(-0.131)} \tag{9}$$

$$S_c = S_c(-1) * (Pm(-1)/Pm(-2))^{0.1710} \tag{10}$$

$$S_e = S_e(-1) * (Pm(-1)/Pm(-2))^{0.200} \tag{11}$$

$$S_u = S_u(-1) * (Pm(-1)/Pm(-2))^{0.176} * (Ps(-1)/Ps(-2))^{(-0.0410)} \tag{12}$$

The international soybean price is indicated by Ps. These equations are set up as below. The equation of harvested area in Cobb–Douglass form is

$$S = C * Pm(-1)^{\alpha} * Ps(-1)^{\beta} * R \tag{13}$$

It is assumed in this study that the main factors in deciding on a harvesting area are prices and supplies of maize. Other factors are assumed to be constant and indicated by R. The constant C and the parameters α and β are estimated from previous data. The final estimation equations are set up as the present estimations divided by previous estimations and then both sides are multiplied by the magnitude of the previously harvested area.

The amount of maize production each countries and region

$$Q_a = Ya * Sa \tag{14}$$

$$Q_b = Yb * Sb \tag{15}$$

$$Q_c = Yc * Sc \tag{16}$$

$$Q_e = Ye * Se \tag{17}$$

The case of the US is estimated differently from those countries and regions because the maize production in the US is only related to the ethanol market in this model.

The demand of ethanol

$$ETH = \exp(12.0 + 0.993 * \log(Pp/Pm)) \tag{18}$$

$$Pp = 1.02 * Pp(-1) \tag{19}$$

Table 2 The population growth rate (%).

	Argentina	Brazil	China	EU	US	Japan
2005–2010	1.0	1.3	0.6	0.1	0.9	0.1
2010–2020	0.9	1.3	0.5	0.1	0.8	–0.1

The first equation is from the previous section. The second one is the equation of oil price as an exogenous variable. In this case, it is assumed that its price is increased by an increment of 2%. The ethanol demand is in the US, which is required to deduct maize for animal feed from the total production amout of maize. In other words, the maize for animal feed in the US is shown as below.

$$Q_u = Y_u * S_u - ETH \tag{20}$$

The demand of maize including the maize for animal

$$D_a = 16274 * pop_a * (Pm/210)^{(-0.3)} * (GDP_a)^{0.0202} \tag{21}$$

$$D_b = 35113 * pop_b * (Pm/210)^{(-0.3)} * (GDP_b)^{0.016} \tag{22}$$

$$D_c = 138706 * pop_c * (Pm/210)^{(-0.1)} * (GDP_c)^{0.0588} \tag{23}$$

$$D_e = 63243 * pop_e * (P?/210)^{(-0.5)} * (GDP_e)^{0.0119} \tag{24}$$

$$D_u = 247804 * pop_u * (P?/210)^{(-0.4)} * (GDP_u)^{0.0079} \tag{25}$$

$$D_j = 16530 * pop_j * (P?/210)^{(-0.6)} * (GDP_j)^{0.1952} \tag{26}$$

The subscript j means Japan.The equations are similarly defined by way of the harvested area of maize.

$$D = D_{-5} * (pop/pop_{0.5}) * (Pm/Pm_{05})^{\alpha} * (GDP/GDP_{05})^{\beta} \tag{27}$$

GDP is included as a factor of economic growth. Moreover, all equations are multiplied by population in order to estimate the total amount of the demand. The subscript j means Japan. “05” indicates the year 2005. Parameters α and β are from previous data. The price of maize in 2005 was 210 (cent/bushel). The population and GDP in 2005 are fixed at 1. In addition, population growth rates of each country and region are shown in Table 2.

The economic growth in each countries and region

$$GDP_a = 1.04 * GDP_a(-1) \tag{28}$$

$$GDP_b = 1.05 * GDP_b(-1) \tag{29}$$

$$GDP_c = 1.11 * GDP_c(-1) \tag{30}$$

$$GDP_e = 1.03 * GDP_e(-1) \tag{31}$$

$$GDP_u = 1.03 * GDP_u(-1) \tag{32}$$

$$GDP_j = 1.02 * GDP_j(-1) \tag{33}$$

It should be noted that the maize demand in Japan is defined by exporting of maize from Argentina, Brazil, China, EU and the US. Moreover, the consumption of maize in each country and region except Japan are defined by subtracting of its exports to Japan, although these countries and regions export it to countries and regions other than Japan.

Finally, the international market's equitable condition is set up as below.

$$Pm = (D_a + D_b + D_c + D_e + D_u + D_j)/(Q_a + Q_b + Q_c + Q_e + Q_u) * Pm \tag{34}$$

The next setup builds a simulation model of the international soybean market.

The harvested area of soybean

$$Ss_a = 17544 - S_a \tag{35}$$

$$Ss_b = 34609 - S_b \tag{36}$$

$$Ss_c = 36243 - S_c \tag{37}$$

$$Ss_e = 90546 - S_e \tag{38}$$

$$Ss_u = 57574 - S_u \tag{39}$$

The total amount of harvested maize area and soybean area was constant in 2005 because there were many controversies about whether the cultivated area could be expanded. The total harvested area of maize and soybean in each countries and region is the first term of the equation. The production amount of soybean is obtained by subtracting the harvested maize area from the total harvested area. The yield of soybean is fixed in 2005.

The amount of soybean production in each country and region

$$Qs_a = 2.68 * Ss_a \tag{40}$$

$$Qs_b = 1.61 * Ss_b \tag{41}$$

$$Qs_c = 1.7 * Ss_c \tag{42}$$

$$Qs_e = 3 * Ss_e \tag{43}$$

$$Qs_u = 3.02 * Ss_u \tag{44}$$

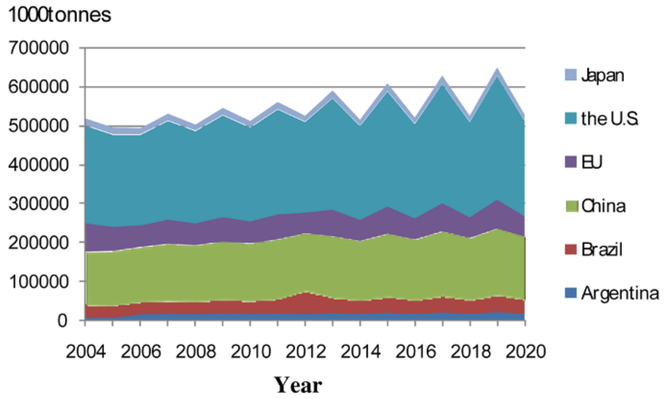

Fig. 2 Maize demand for food.

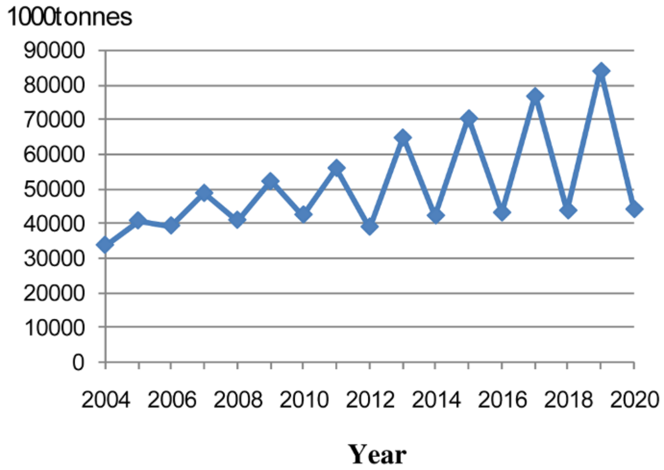

Fig. 3 Maize demand for ethanol.

The demand for soybean

$$Ds_a = 38300 * pop_a * (GDP_a)^{0.6} * (Ps/238)^{(-0.39)} \tag{45}$$

$$Ds_b = 50619 * pop_b * (GDP_b)^{0.96} * (Ps/238)^{(-0.42)} \tag{46}$$

$$Ds_c = 16619 * pop_c * (GDP_c)^{1.04} * (Ps/238)^{(-0.24)} \tag{47}$$

$$Ds_e = 1194 * pop_e * (GDP_e)^{0.05} * (Ps/238)^{(-0.39)} \tag{48}$$

$$Ds_u = 81909 * pop_u * (GDP_u)^{0.08} * (Ps/238)^{(-0.42)} \tag{49}$$

$$Ds_j = 3872 * pop_j * (GDP_j)^{0.11} * (Ps/238)^{(-0.34)} \tag{50}$$

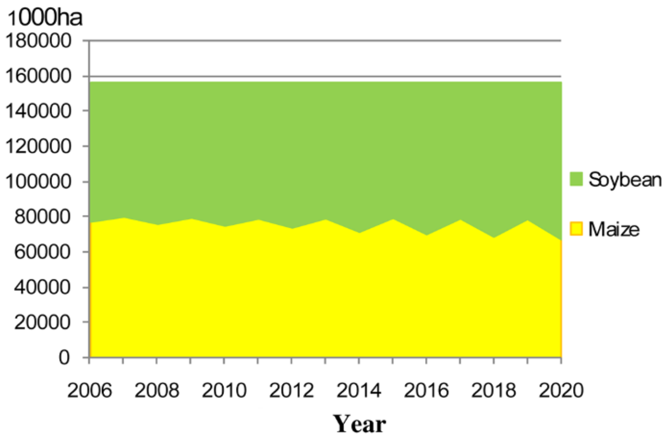

Fig. 4 Total harvest area.

The estimation methods of these equations are similar with the demand for maize. The market clearing condition of maize is as follows:

$$Ps = Ps * (Ds_a + Ds_b + Ds_c + Ds_e + Ds_u + Ds_j)/(Qs_a + Qs_b + Qs_c + Qs_e + Qs_u) \tag{51}$$

Results of Simulation and Discussion

The simulations by the simultaneous equation model set previously are carried over from 2005 to 2020. Figure 2 shows the projection of maize demand including animal feed. According to our simulation, the total demand for maize is increased by 76 million tons in increments of 15% by 2020. The trend of maize demand for ethanol is shown in Figure 3. The maize demand for ethanol reaches 17 million tons in increments of 40% by 2020. In total, the demand fo maize is projected to be 93 million tons by 2020.

The supply side projections of maize are indicated in Figures 4 and 5. It is shown in Figure 4 that the harvested areas of maize in each country and region are constant or on decreasing trend. The projective yield of each country and region are shown in Figure 5. All yields except the case of China are on the path of increasing trend. Therefore, the increase of maize production in the world is caused more by yield rather than harvested areas of it becoming decreased. The factors of increasing yield in the simulation model are its international price and the time trend, which is the variable of technological progress. Figure 6 shows the projection of maize price. As the figure shows, the projected international price trend of maize does not increase in spite of fluctuating every year. That is due to the increase of yield by time trend, in other words technological progress. Of course, the price stimulates the farming

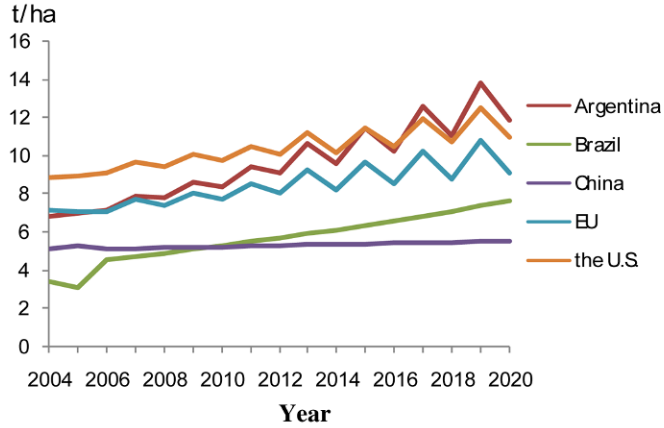

Fig. 5 Yield of maize.

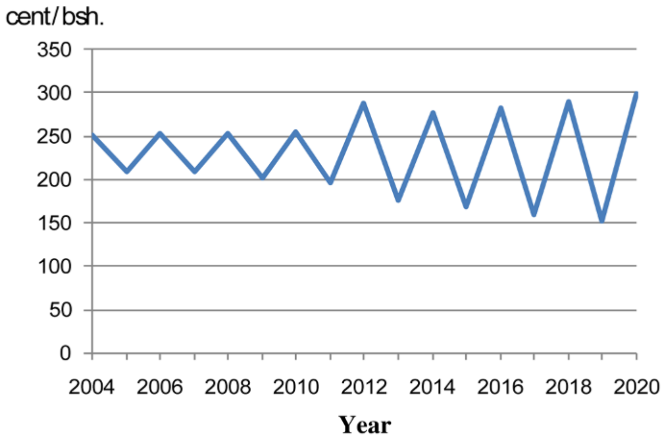

Fig. 6 Price of maize.

as well as technological progress but, generally, the impact of the technological progress in agricultural production is much more than that of the price in the long term. The technological progress on maize production is able to increase the yield and keep the price stable even though it fluctuates every year.

The case of the world soybean price trend is indicated in Figure 7. The figure shows a remarkable increasing of price. The main reason for this obtained projection is the assumption of a fixed yield of soybeans in 2005. As Figure 4 shows, the harvested areas of soybean in each country and region are constant or increase because those of maize are constant or decrease. Therefore, there is no competition between the world maize production and the world soybean production in our model.

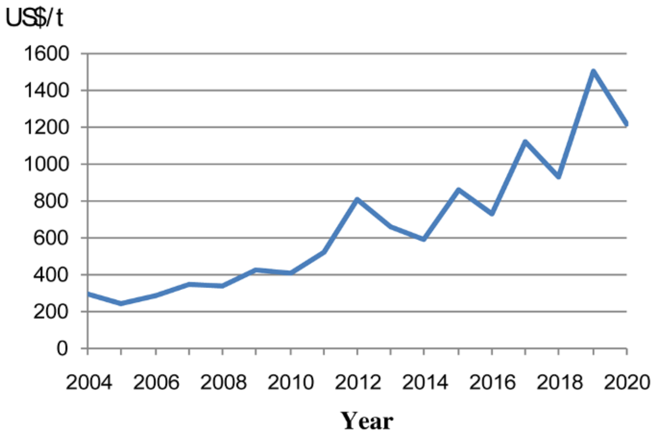

Fig. 7 Price of soybean.

Conclusions

The aim of this study is to simulate the impact of bio-ethanol productions on the international grain market, mainly focusing on the international maize market, from 2005 to 2020 by establishing a simultaneous equation model. The main feature of this study is including the effect of the price to the farmer and to technological progress. It is shown in this study that the international price of maize does not increase although it fluctuates every year. The reason is that the time trend variable as the proxy variable of technological progress, indicates that technological progress increases production even though the harvested area of maize remains or decreases. The results of this study indicate that the widely alleged food crisis has not come and that the technological progress is very important. Meanwhile, the price of soybean has increased remarkably in the whole period. The assumption of no technological progress and fixing the harvested area from 2005 cause the situation.

There are three issues that remain to be addressed in this study. First one considers the fluctuation of the international maize price. It seems that the assumption of the yield and harvested area for a given year depends only on the previous year's price. Generally, the agricultural production is affected by multi-periods. The multi-log models are candidate for solving this problem. The second issue is that the technological progress should be broken down into its factors and expressed in equations by the observed factors. Finally, in the case of soybean, explicitly-defined technological progress in production should be considered.

Acknowledgement

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Optimization of Rice Supply Chain in Thailand: A Case Study of Two Rice Mills

S. Wilasinee, A. Imran and N. Athapol

Abstract Two rice supply chains in Thailand were analyzed: (1) a rice mill located in the harvesting area (Northeast), and (2) a rice mill in the marketing area (Central Thailand). Parameters such as cost minimization while the paddy was on the farm and in-transport were taken into account. The high production cost and logistic cost were the weak points of the rice supply chain in Thailand. The rice mill in the marketing area was high in cost of transportation and inventory. Higher income from by-products was found in the marketing area. Therefore, the net revenue of rice mills in the marketing area was higher than in the harvesting area. Quality indicators such as moisture content were used to relate to the transportation cost. The transportation cost increased with the high moisture content of paddies which depends on volume, type of vehicle and distance of transportation. The best operating condition was drying at 60°C for 2 hours that gave a head rice yield of about 38.5% for Thai aromatic rice (KDML105). The optimum model showed highest net revenue from farms that use direct seeding cultivation, a combine harvester and sun drying. The optimization model for rice purchasing for a rice mill showed that high moisture and a dry paddy was beneficial for the rice mill in the harvesting and marketing areas, respectively. The optimized model proposed a traceability system using a radio frequency identification (RFID) system to track information such as source of production, cultivation practice, logistic system, quality of paddy and milled rice in compliance with the Good Agricultural Practice (GAP) regulations in Thailand.

Key words: Rice, supply chain, traceability, transportation cost

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Introduction

There is a paucity of technical literature about the value chains in agrifood, especially in the developing world. With the opening of global markets in barrier-free environments, there we expect that five to six multi-national retailers will eventually dominate the world food supply (Blackburn, 2000). If developing countries like Thailand are to be part of these value chains, their agrifood industries need to adapt to this change (Cunningham, 2001). In this context we have analyzed the value chain for Thai rice. There are various stakeholders including farmers, middlemen/paddy merchants, rice mills, rice merchants, wholesalers, retailers, exporters, and consumers; moreover, there are state agencies that control the prices of paddy following their individual governmental policies.

Thailand has been the world's largest rice exporter for more than a decade; however, with increasing cost in the domestic market, Thailand is losing international market share. The prime reasons for this are adulteration, risk of damage, higher labor cost, increasing logistics cost (i.e., 19% of Thai rice GDP) (Center for Logistics Excellence, 2006).

However, the quantity and the quality of rice in the supply chain still need to be improved. The quantity of paddy depends on cultivation practice from farm production. Many cultivation methods depend on irrigation and incur labor and production costs for applying such methods as transplanting or broadcasting. The qualities of rice as % impurity, % moisture content, and milling yield, are effected by harvesting and drying methods and storage conditions, respectively. Furthermore, each stage of a supply chain must be connected by logistics, the management of the movement, storage, and processing of materials and information in the chain. The logistics costs include transportation, inventory holding, risk and damage, and administration. In Thailand, transportation of paddy or rice has only one course, road transportation using different modes such as pick-up, 4-wheel truck, 6-wheel truck, 10-wheel truck and trailer truck.

Given the complication of the rice supply chain, an optimization model that combines rice mill model and a transportation model could serve as a useful tool to advise stakeholders regarding the choice of production and transportation strategy and to develop general recommendations. Changes in quality, quantity, conditions, and costs affect the choice of production and transportation strategy as well as the net revenue result, and an optimization model gives the possibility to capture these simultaneously. The RFID technology can be implemented at any stage of the value chain.

The aim of this study is to develop an overview of the Thai rice supply chain and to develop optimization models for transportation and milling/processing. The study focused on developing transportation and rice mill models based on maximum net revenue and cost minimization and improving GAP, marketing and transportation system, and quality of paddy inputs to the mills.

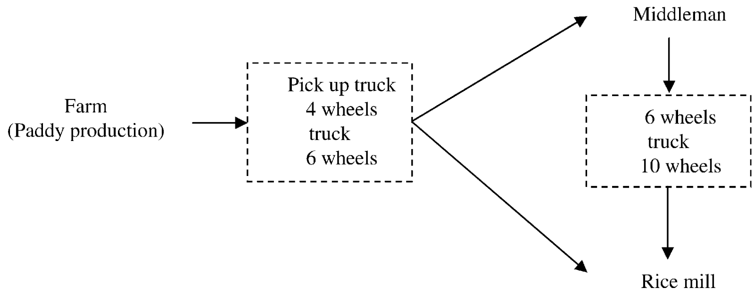

Fig. 1 Paddy transportation from farm to middleman and rice mill.

Materials and Methods

The study is a continuation of the rice farming optimization model (Sangsom, 2008); therefore, we will not discuss that model here. We only intend to give the model used and the results (in the third section). The optimization model of farm production was developed to achieve maximum net revenue from low cost and high income:

Max. net revenue = Income (Quantity, Price) − Cost (Cultivation, Harvesting, Drying)

Overall model structure:

$$\text{Max. net revenue} = \text{Income} - \text{Cost} = Q_a \times P_{ac} - (C_a + H_b + D_c)$$

where a is the cultivation mode (transplanting, direct seeding), b is the harvesting method, and c is the level of moisture content (<14, 14–16, 17–20 and >20% MC).

Transportation Model

Paddy transportation from farm to middleman and rice mill is shown in Figure 1. For this transportation, most vehicles used were pick-up, 4-wheel, 6-wheel and 10-wheel trucks. Transportation costs varied according to quantity and distance. For paddy transportation from middleman to rice mill, the middleman collected the paddy and transported it to the rice mill in large quantities using 6-wheel, 10-wheel and trailer trucks with power tiller.

Transportation cost consisted of fuel consumption, driver's salary, maintenance and depreciation, weighing and unloading charges (which depended on vehicle mode, distance and amount of paddy). The paddy transportation model was divided into two parts as a transportation model of farm to middleman/rice mill and middleman to rice mill. Optimization of vehicle use was selected using the "Solver" in Microsoft Excel 2003.

Farm to Middleman/Rice Mill

Farm production was divided into four sizes <10, 10–20, 20–30, and 40–60 rais/household which was estimated to be a paddy output equal to 400 kg paddy/rai and the average distance from farm to middleman or rice mill was 20 km. The optimization model was built on a vehicle mode and amounts of paddy per trip for transportation from each farm size, based on cost minimization.

$$\begin{aligned}\text{Min. transportation cost} &= \text{(Weight of paddy from four farm sizes (ton))}\\ &\times \text{(Cost baht/km/ton/trip) of vehicle mode, m)}\\ &\times \text{(Trip)} \times \text{(Distance (km))}\end{aligned}$$

Thus,

$$\text{Min Transportation Cost} = n(X_m \cdot C_m \cdot N_m \cdot d)$$

where X_m was the quantity (ton) of paddy per trip of transportation mode, m (pick up, 4-wheel, 6-wheel and 10-wheel trucks). C_m is transportation cost (baht/km/ton/trip) by mode of transportation, m. N_m is the number of trips of transportation mode, m. d is distance (km).

Constraints of the model:

- Maximum load of vehicles as pick-up truck, 4-wheel truck, 6-wheel truck and 10-wheel truck were 2, 6, 10 and 15 tons, respectively.
- Sum total amount of paddy equaled paddy output of each farm.
- Number of trips was not less than 0.
- Total number of trip/day not exceeding 5.
- Calculation of transportation cost based on empty return trips.

Middleman to Rice Mill

The amount of paddy transported from a middleman was divided into two scales as 50 and 100 tons/day with different distances such as 50, 100, 200, 300, 400 and 500 km, respectively. The optimization model was vehicle mode and amount of trip for transportation under each condition (amount of paddy and distance) of a middleman based on minimum cost.

$$\begin{aligned}\text{Min. transportation cost} &= \text{(Weight of paddy from middleman (ton))}\\ &\times \text{(Cost baht/km/ton/trip) of vehicle mode,} n)\\ &\times \text{(Trip)} \times \text{(Distance (km))}\end{aligned}$$

Thus,

$$\text{Min. transportation cost} = n(X_n \cdot C_n \cdot N_n \cdot d)$$

where X_n is the quantity (ton) of paddy per trip of transportation mode, n (4-wheel, 6-wheel, 10-wheel and trailer truck). C_n denotes transportation cost (baht/km/ton/trip) by mode of transportation, n. N_n is the number of trips of transportation mode, n. d is the distance in km.

Constraints of the model:

- Maximum load of vehicle as 4-wheel truck, 6-wheel truck, 10-wheel truck and trailer truck were 6, 10, 15 and 21 tons, respectively.
- Sum total amount of paddy equaled paddy output of each farm.
- Number of trips was not less than 0.
- Total number of trip/day not exceeding 10.
- Calculation of transportation cost based on empty return trips.

Rice Mill Model

A rice mill receives a paddy from a supplier such as a middleman or a farmer. The paddy is sampled using an automatic or manual probe and checked for moisture content, impurity and head rice yield. After that, the paddy is priced. The wet paddy is dried and stored in a warehouse or silo. Then the paddy is milled using the following steps: pre-cleaning, husking, husk aspiration, paddy separation, destoning, whitening, polishing, sifting, length grading, blending and weighing. The milled rice is packed and sent to a customer. This step in rice mill process is shown in Figure 2.

Max. net revenu = Income (Quantity, Price) – Cost (Paddy, Drying, storage)

Income = [(Quantity of milled rice × Price) + (Quantity of by-product × Price)]

Cost = [Paddy cost + Processing cost + Transportation cost]

$$\text{Max. net revenue} = n[(Q_r \cdot p_1 + B \cdot p_2) - X_r(C_r + H_r + T_r)]$$

where Q_r is the quantity of milled rice from moisture content of paddy, r (<14, 14–16, 17–20 and >20% MC). B is the quantity of by-product as husk and bran rice. p_1 and p_2 denote the price of milled rice and by-product, respectively. X_r is the quantity of paddy from moisture content, r. C_r is paddy cost which depends on moisture content, r. H_r presents processing cost per ton which consists of drying, storage, milling and packing cost at paddy moisture content, r. T_r are transportation costs per ton which consist of paddy, milled rice and packed rice transportation costs.

Constraints of model:

- Total quantity of paddy (ton) divided by drying time (hr) ≤ milling capacity (ton/hr).
- Total quantity of dried paddy (ton) ≤ maximum capacity storage (ton).

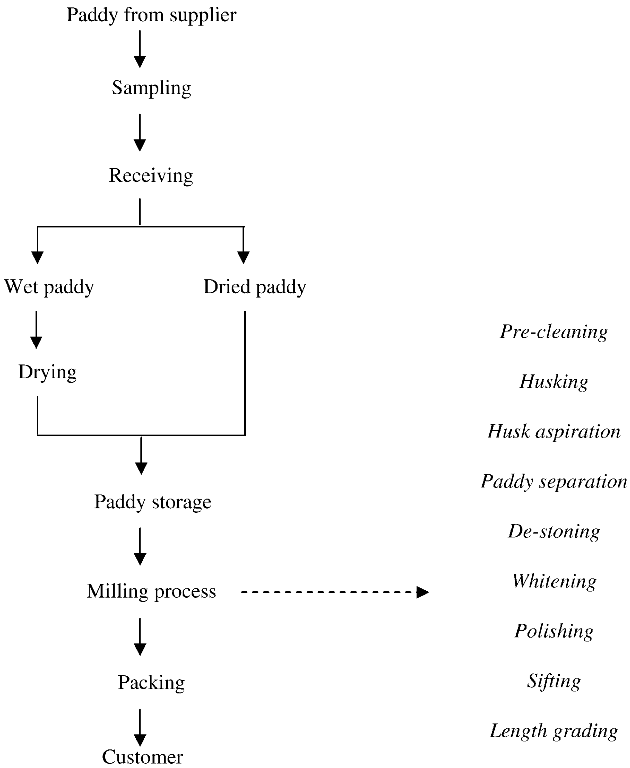

Fig. 2 Milled rice processing in rice mill.

- Quantity of paddy is not less than 0 ($X_r \geq 0$).
- Total drying capacity (ton/day) $\leq$ maximum capacity of dryer (ton/day).

Results and Discussion

Supply Chain of Company A Located in Harvesting Area (North East of Thailand)

This rice mill plant is located in a production area of aromatic rice, which is the most produced type in the Northeast of Thailand. The company produced milled rice both for local and overseas markets including by-products from rice milling processes such as rice bran and husk.

The paddy was supplied from a pool of 4,000 to 5,000 farmers in the province within 30 km perimeter around the company and 10 middlemen. There were two types of middlemen, one local and the other from a neighboring province. From the farm, wet paddy was transferred immediately from the field to a rice mill and some was sun-dried at farm level. The mode of transport was by road with different types of vehicles such as pick-up truck, 6-wheel truck and 10-wheel truck depending on the volume of the paddy and the availability of the vehicle. For the local middleman, the paddy was collected from farmers in the province and brought to the rice mill by a 6-wheel or a 10-wheel truck. For the middleman from some other province, they bought a large scale of paddy. The paddy was collected from farmers and graded according to requirements of customers. Then the paddy was transported by a 10-wheel truck or trailer to the mill.

Two types of middleman which supplied KDML105 paddy were village merchant and non-village merchant. Both follow a similar pattern of receiving, storage and selling to consumers. The *Transportation* model had again two types: (1) *farmer to middleman*: the farmer transported the paddy by pick-up truck, 4-wheel truck and 6-wheel truck. The transportation cost was 250–300 baht/ton. (2) *Middleman to rice mill (60 km)*: the paddy was transported by a 10-wheels truck. The transportation cost was about 200 baht/ton.

Paddy Receiving by Rice Mill

The paddy was sampled using a probe for quality checking and price determination. The paddy qualities were checked in terms of moisture content, purity of rice, yield, and variety. Paddy grains were separated into five levels of paddy moisture content (<14, 14–16, 16–18, 18–20, >20% MC) for suitable drying conditions and stored in the warehouse by piling up to 200 tons. There was air ventilation into the paddy pile for reducing warm temperature.

Mill Rice Processing

The mill had a modern machine in its processing line. Milled rice processing comprised of four main steps: paddy cleaning, drying, milling and packing. For paddy cleaning, the impurities such as weeds, gravels, soil, immature grains or other impurities were removed from this stage by a cleaning machine. The moist paddy was dried to 14% moisture content using modern dryers like a fluidized bed dryer or a mixed column LSU (Louisiana State University) dryer. They were dried in series. Drying temperature ranged from 45–50°C and drying time depended on initial moisture content of the paddy. After that, the dried paddy was kept in silos with total capacity of 6,000 tons and storage time about 18–20 days. The milling capacity was 6,000 tons of paddy per month. The milling process consisted of husk removing from the paddy, whitening and polishing for bran removal and then passing through a grading machine to separate the head rice and broken rice into different grades. Then, the milled rice was passed to a color sorting machine to remove impurities such as red rice, yellow rice, and white belly rice before packing. Finally, milled rice was stored in silos which were divided into whole grains and five levels of broken rice from No. 1 to No. 5. The storage time was not more than 1.5 months. Then, the milled rice from silos was transferred and packed into large bags (jumbo size, 100 kg) and stored in a warehouse with 3,000 tons of milled rice. A fumigation treatment was used every week to kill insects. The milled rice in jumbo size was transported to a packing plant at the central branch. There are various kinds of packing materials and sizes according to customer's requirements and many sizes of packaging as follows: domestic as 70 g, 5, 10, 15, 25, 50 kg and export as 70 g, 0.5, 1, 2, 5, 10, 15, 22, 25, 50 kg.

Distribution of Products and By-Products

Rice products from packing plants, such as aromatic rice (KDML105), normal white rice, brown rice, red rice, rice germ and parboiled rice were distributed to domestic and export markets. For the domestic market, milled rice was sold to 20–30 wholesalers, and modern trade organizations such as Big C, Tesco Lotus and Tops supermarket. For the export market, milled rice was transported overseas to ports at Sichang and Leamchabang. By-products from milling processes were rice bran and husk. Rice bran was sold to rice bran oil industries near the plant. The husk was sold to power plant and paper industries near the plant.

Supply Chain of Company B in Central Thailand

The plant was located in the central area which was the largest area for growing of the second rice crop. The company sold the milled rice both locally and overseas including by-products such as broken rice, crude bran oil, extracted bran, and ash.

Aromatic rice was supplied from different sources in the Northeast province. They were middlemen, cooperatives of individual farmers and other agricultural cooperatives of farmers participating in agricultural banks. The paddy was collected from farmers and evaluated for quality according to customer's requirements. In order to maintain quality and decrease spoilage during transportation, the moist paddy was dried by the sun or by dryers belonging to the middlemen. Then, the paddy was transported by 10-wheel trucks or by trailer to a rice mill.

KDML105 paddy was supplied from the Northeast from two types of suppliers. There were non-village merchants and a cooperative of farmers with the Bank of Agriculture and Agricultural Cooperatives (BAAC). Losses during transportation by truck from the starting point amounted to about 1%, consisting of weight loss due to decrease in moisture content and breakage of the paddies. The next significant loss of paddy during transportation was also about 1% due to spillage.

Paddy Receiving by Rice Mill

The paddy was sampled by a probe for checking of quality and price estimation. The paddy was checked for moisture content, purity of rice, yield, and variety. Paddy grains were separated based on paddy moisture content into five levels: <14, 14–16, 16–18, 18–20 and $>20\%$ for suitable drying condition and % head rice (<30, 30–33, 33–35%). Then, the paddy was stored in silos that had ventilation systems to keep the quality of moist paddy before the drying stage.

Mill Rice Processing

The rice mill had modern machines. Milled rice processing comprised four main steps as follows: paddy cleaning, drying, milling and packing. For paddy cleaning, impurities such as weeds, gravels, soil, immature grains or other impurities were removed during this stage. The moist paddy was dried to 14% moisture content using a mixed column dryer of LSU (Louisiana State University) model. Drying temperature did not exceed 60°C and drying time depended on initial moisture content of the paddy. After that, the dried paddy was kept in silos having a capacity of 66,350 tons and stored for 1–6 months. The milling capacity was 1,000 tons of paddies per day. Husk was removed by a husker to obtain brown rice, whitening and polishing for removing bran and embryo from brown rice and was graded to obtain head rice and broken rice. Milled rice was sorted to remove all impurities such as red rice, yellow rice, and white belly rice by using a color sorting machine before packing.

Milled rice was stored in silos after separation according to variety and type of rice (100, 5, 10, and 25%). The total capacity was 12,000 tons of milled rice, and the storage time not over one month. Silos with ventilation systems cooled down the rice's temperature. The milled rice was transported to a packing plant. There were various kinds of packing materials and sizes according to customer's requirements. Many sizes of packaging were used: for domestic shipment to 5 kg and for export up to 50 kg.

Distribution

Rice products such as Thai aromatic rice (KDML105), white rice, brown rice/cargo rice and broken rice were distributed to domestic and export markets. For domestic markets, the milled rice was sold to wholesalers and modern trade organizations. For export markets, the milled rice was transported overseas to the ports of Sichang and Leamchabang. By-products from milling processes were rice bran and husk. From the rice bran, crude bran oil was extracted at a rice bran oil plant (capacity 100 tons/day). Crude bran oil was distributed to overseas markets; moreover, extracted bran was sold to animal feed mills. Paddy husks were used as an alternative energy source to produce superheated steam to drive electric turbines (capacity 9.24 MW). The ash was exported to Europe to be used as insulation in cast iron foundries.

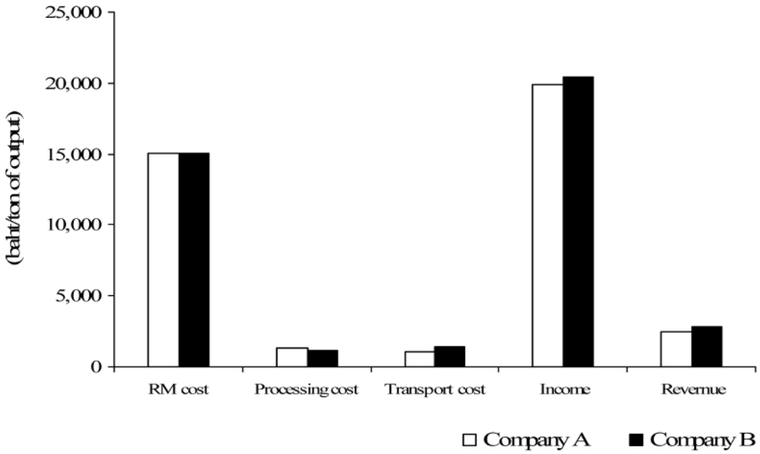

Fig. 3 Comparison of the cost, income and net revenue of rice production in Company A and B.

Comparison of Supply Chain between Two Companies at Different Locations

Figure 3 presents the cost, income and net revenue of rice production in two rice mills from the Northeast and the Central area and the details are shown in Table 1.

The total cost included cost of paddy, processing, and transportation. The paddy cost of both rice mills was the same because the price of paddy was referenced to DIT (Department of Internal Trade) which averaged from 14 to 20% moisture content on 30 January 2008. Processing cost of Company A was more than Company B which included drying, storage, milling and packing. The drying cost and milling cost of Company A were more than Company B. However, Company A had less storage cost than Company B which was situated far away from the planting area; Company B stocked more paddy and stored it for a longer time than Company A. Company A had lower transportation cost than Company B whose paddy was supplied from the Northeast area by middlemen.

Income from product and by-product of Company B was more than Company A because by-products in the Central area were priced higher than in the Northeast. Therefore, the net revenue of Company B in the Central area was higher than Company A in the Northeast by about 356 baht/ton output.

Optimization of the farming model based on maximization of net revenue is shown in Table 2. The production cost of the models ranged from 5,173.72 to 6,005.81 baht/rai, from which the Office of Agricultural Economics reported an average production cost for a first rice crop in 2007 to be 5,941.47 baht/rai and the net revenue to be 4,058.53 baht/rai with the price of paddy equal 10,000 baht/ton.

The optimizations of the farming model were three orders from maximum to minimum of net revenue at farm production as follows:

Table 1 Comparison of the cost, income and net revenue of rice production in Company A and B.

	Detail	Unit	Company A	Company B
Input	Moisture content of paddy	(%)	14–20	14–20
	Quantity of paddy input	(ton)	100	100
	Quantity of dried paddy	(ton)	96	96
Output	Head rice	(ton)	36	36
	Broken rice	(ton)	28	28
	Husk	(ton)	21	21
	Bran	(ton)	10	10
Processing cost	Raw material	(baht)	952,000	952,000
	Drying	(baht)	6,201	5,200
	Storage	(baht)	3,833	22,995
	Milling	(baht)	52,698	23,953
	Packing	(baht)	18,971	18,971
Transportation load	Paddy transportation	(ton)	100	100
	Milled rice transportation	(ton)	63	63
	Packed rice transportation	(ton)	63	63
Transportation cost	Paddy transportation	(baht)	0	55,000
	Milled rice transportation	(baht)	34,780	0
	Packed rice transportation	(baht)	34,780	31,619
Income	Milled rice	(baht)	1,180,738	1,180,738
	By product	(baht)	78,951	107,982
Total	Income	(baht)	1,259,689	1,288,720
	Cost	(baht)	1,103,264	1,109,739
	Revenue	(baht)	156,425	178,982
Total	Income	(baht/ton output)	19,925	20,385
	Cost	(baht/ton output)	17,432	17,535
	– RM cost	(baht/ton output)	15,037	15,037
	– Processing cost	(baht/ton output)	1,294	1,126
	– Transport cost	(baht/ton output)	1,100	1,371
	Revenue	(baht/ton output)	2,494	2,850

- The model No. 4 was maximum net revenue which consisted of direct seeding cultivation, combine harvester, and sun drying to 13.39% MC and its average income, expenditure and net revenue were 9,720.00, 5,323.72 and 4,396.28 baht/rai, respectively.
- The model No. 12 consisted of transplanting cultivation, manual harvesting, and sun drying to 13.39% MC and its average income, expenditure and net revenue were 9,995.00, 5,656.35 and 4,338.65 baht/rai, respectively.
- The model No. 3 consisted of direct seeding cultivation, combine harvester, and sun drying to 15.66% MC and its average income, expenditure and net revenue were 9,620.63, 5,296.29 and 4,324.34 baht/rai, respectively.

The worst model was No. 7 which consisted of transplanting cultivation, combine harvester and wet paddy and its average income, expenditure and net revenue were

Table 2 The farming model based on maximum net revenue.

Model	Cultivation method	Harvesting mode	Sun dry (day)	% MC	Total cost (baht/ton)	Price (baht/ton)	Net revenue (baht/ton)
1	Direct seeding	Combine harvester	0	25.83	5,173.72	8,096.25	2,922.53
2	Direct seeding	Combine harvester	2	17.88	5,269.60	9,288.75	4,019.15
3	Direct seeding	Combine harvester	3	15.66	5,296.29	9,620.63	4,324.34
4	Direct seeding	Combine harvester	4	13.39	5,323.72	9,720.00	4,396.28
5	Direct seeding	Manual harvesting	0	17.46	5,503.75	9,350.88	3,847.12
6	Direct seeding	Manual harvesting	2	13.39	5,552.88	9,720.00	4,167.12
7	Transplanting	Combine harvester	0	25.83	5,855.81	8,371.25	2,515.44
8	Transplanting	Combine harvester	2	17.88	5,951.69	9,563.75	3,612.06
9	Transplanting	Combine harvester	3	15.66	5,978.37	9,895.63	3,917.25
10	Transplanting	Combine harvester	4	13.39	6,005.81	9,995.00	3,989.19
11	Transplanting	Manual harvesting	0	17.46	5,607.23	9,625.88	4,018.65
12	Transplanting	Manual harvesting	2	13.39	5,656.35	9,995.00	4,338.65

8,371.25, 5,855.81 and 2,515.44 baht/rai, respectively. From the results, the recommendation on the model application should be based on:

- The paddy moisture content was the most important effect on cost of paddy. Farmer should dry the paddy before selling to rice mill or middleman.
- Combine harvester is mostly used because of it is high capacity and more efficiency than manual harvesting. The dryer is needed to dry the wet paddy after using the harvester due to high moisture paddy. The drying facility should be available in the area. The mobile dryer is one part of the solution.
- Due to poor trafficability for powered harvesting equipment and lack of access roads to the fields, the farmers have to harvest manually. The farmer should select transplanting cultivation because the rate of manual harvesting was higher than direct seeding cultivation.

Transportation Model

The transportation mode used most often for transferring paddy in Thailand is road by truck. Transportation costs consisted of fuel consumption, driver salaries, main-

Table 3 The data of transportation cost of different vehicles.

Vehicle mode	Engine (cc)	Volume (m^3)	Max. load (ton)	Transportation cost (baht/trip) $a+b*W+(c+d)*2D+[(e*D*W+f*2D)*F]$					
				a	b	c	d	e	f
Pick up	2,500	3.57	2	20	15	1.77	0.31	0.0167	0.0667
4-wheel truck	4,000	8.86	6	25	15	1.77	0.31	0.0069	0.0833
6-wheel truck	6,000	14.36	10	30	15	2.00	0.31	0.0033	0.1667
10-wheel truck	7,900	34.31	15	35	15	3.60	0.31	0.0027	0.1818
Trailer	>8,000	68.62	21	125	15	3.40	0.31	0.0018	0.2326

tenance & depreciation, weighing, and unloading charges by using transport modes including pick-up, 4-wheel, 6-wheel and 10-wheel trucks. The data for transport calculation are shown in Table 3.

Transportation Model between Farm and Rice Mill/Middleman

In surveying, the land size of a rice farmer was 21.77 rais/household on the average (min: 5 rai/household, max: 60 rais/household) and the average distance was 20 km (min: 10 km, max: 35 km). For model development, the farm size was divided into four sizes: <10, 11–20, 21–40, and 41–60 rais/household with an average paddy output of 400 kg paddy/rai. Therefore, the loads of paddy of four land sizes were 3.32, 6.88, 13.49 and 21.33 kg paddy.

$$\text{Transportation cost (baht)} = [a+b*W+(c+d)*2D+((e*D*W+f*2D)*F)]*n$$

where a is the weighing charge (baht/trip), b is the unloading charge (baht/ton), c is maintenance and depreciation (baht/km), d present the driver's salary (baht/km), e is the fuel consumption (liter/km/ton), f is the fuel consumption (liter/km), W is weight (ton), D is distance (km), F is fuel price (baht/liter): 28 baht/liter, n denotes the number of trips.

The optimization of vehicle usage based on minimization cost at average distance 20 km of four farm sizes by the "Solver" (in Microsoft Excel 2003) is shown in Table 4. The vehicle optimization of farm size <10, 11–20 and 21–40 rais/household were 4-wheel, 6-wheel and 10-wheel trucks, respectively and transportation cost were 79.56, 61.78 and 45.79 baht/ton, respectively. Moreover, the vehicle optimization of farm size 41–60 rais/household were 6 and 10-wheel trucks whose transportation cost were 49.62 baht/ton. Farmers with different farm sizes <10, 11–20, 21–40, and 41–60 rais/household used mostly pick-up trucks for transportation. Transportation costs were 120.68, 117.32, 107.31 and 106.81 baht/ton, respectively. The economic value was not beneficial.

Table 4 The transportation cost from farm to rice mill/middleman.

Farm	Area (rai)	Paddy (ton)	Transportation cost (baht/ton) Pick-up	4-wheel truck	6-wheel truck	10-wheel truck	Optimization model Vehicle mode	Trip	Cost (baht/ton)
A	<10	3.32	120.68	79.55	109.95	135.49	4-wheel truck	1	79.56
B	11–20	6.88	117.32	77.44	61.78	73.93	6-wheel truck	1	61.78
C	21–40	13.49	107.31	63.66	62.67	45.79	10-wheel truck	1	45.79
D	41–60	21.33	106.81	56.64	60.32	53.55	6-wheel truck	1	49.62
							10-wheel truck	1	49.62

Remark: Average distance = 20 km.

Transportation Model between Middleman and Rice Mill

The middleman collects the paddy and sends to a rice mill using 6-, 10-wheel and trailer trucks depending on paddy quantity, volume, and available vehicles. For transportation, the model for the middleman was divided by paddy quantity into 50 tons paddy and 100 tons paddy and separated the distance to 50, 100, 200, 300, 400 and 500 km. The optimization model was developed by the "Solver" in Microsoft Excel 2003. Case study according to the optimization of transportation, for 50 tons of paddy, was transported from the middleman to the rice mill by two trips of a trailer truck and one trip of a 6-wheel truck. The transportation cost of distances 50, 100, 200, 300, 400 and 500 km were 78.30, 136.00, 251.41, 366.81, 482.22 and 597.62 baht/ton, respectively.

One hundred tons of paddy was transported from middleman to rice mill by a trailer truck in five trips. The transportation cost of distances 50, 100, 200, 300, 400 and 500 km were 74.88, 128.52, 235.79, 343.05, 450.32 and 557.59 baht/ton, respectively (Table 5).

Rice Mill Model

The rice mill model was a model of optimization of paddy moisture content on raw material cost, head rice yield, drying cost, and transportation cost. The rice mill model was divided into two rice mills, under separate managment, at different locations in the Northeast and the Central area.

The model was optimized for the choice of paddy moisture content which was supplied based on a maximum of net revenue of rice mills in the Northeast and in the Central areas as shown in Figure 4 and Table 6.

Tab. 5 The transportation cost from middleman to rice mill at different loads and distances.

Paddy (ton)	Distance (km)	Transportation cost (baht/ton)				Optimization model		
		4-wheel truck	6-wheel truck	10-wheel truck	Trailer-truck	Vehicle mode	Trip	Cost (baht/ton)
50	50	108.58	92.40	93.58	86.36	Trailer	2	78.30
						6-wheel truck	1	
	100	197.67	166.79	169.37	150.21	Trailer	2	136.00
						6-wheel truck	1	
	200	375.83	315.58	320.93	277.93	Trailer	2	251.41
						6-wheel truck	1	
	300	554.00	464.38	472.50	405.64	Trailer	2	366.81
						6-wheel truck	1	
	400	732.17	613.17	624.07	533.35	Trailer	2	482.22
						6-wheel truck	1	
	500	910.33	761.96	775.63	661.07	Trailer	2	597.62
						6-wheel truck	1	
100	50	103.92	92.40	84.23	74.88	Trailer	5	74.88
	100	188.59	166.79	151.02	128.52	Trailer	5	128.52
	200	357.93	315.58	284.58	235.79	Trailer	5	235.79
	300	527.27	464.38	418.15	343.05	Trailer	5	343.05
	400	696.62	613.17	551.71	450.32	Trailer	5	450.32
	500	865.96	761.96	685.28	557.59	Trailer	5	557.59

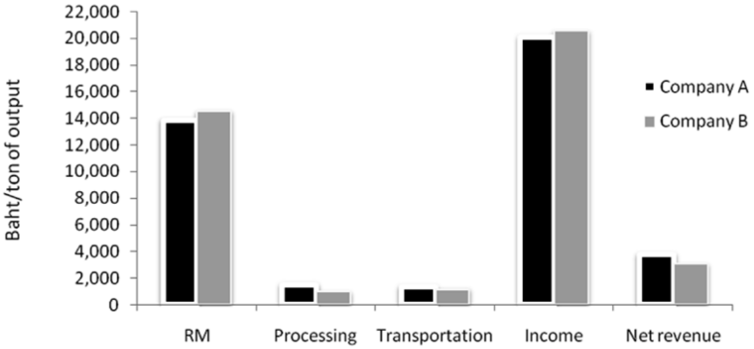

Fig. 4 Comparison cost of Company A and Company B.

Rice Mill in the Northeast

Running the model based on maximum net revenue, the model's optimized choice of paddy moisture content, which was supplied from farmer or middleman was more than 20% MC. Although there was a drying cost for wet paddy, the price of wet paddy at 8,200 baht/ton and drying cost at 116.08 baht/ton was lower than dried paddy in the market (10,000 baht/ton). Moreover, a rice mill modernized with a dryer gave a higher yield than with sun drying from the farm level.

Rice Mill in the Central Area

The model's optimized choice of paddy moisture content that was bought from a farmer or a middleman was less than 14% moisture content under constraint of time delivery. The cost of paddy at <14% moisture content was 10,000 baht/ton. The rice mill in the Central area bought KDML105 paddy from a large middleman who dried the paddy by dryer. Therefore, the effect of head rice yield was not different with drying in a rice mill. Moreover, transportation cost of dried paddy was lower than wet paddy.

The result shown in Table 6 is an optimization model which consists of a farming model, a transportation model and a rice mill model for maximum net revenue in a supply chain. Moreover, the quality and safety of a food supply chain were important and traceable.

Traceability System

Tracking grain is a quite difficult and complicated task due to its size and quantity. To facilitate traceability, a trail of information must be recorded at every level in the production system to ensure food safety and trace back to the origin if problems

Table 6 The optimization model of Company A and B.

	Detail	Unit	Company A	Company B
	Storage capacity	(ton/day)	240	400
	Drying capacity	(ton/day)	200	400
Input	Moisture content of paddy	(%)	>20	¡14%
	Quantity of paddy input	(ton)	268	400
	Quantity of dried paddy	(ton)	240	400
Output	Head rice	(ton)	94	157
	Broken rice	(ton)	64	107
	Husk	(ton)	53	88
	Bran	(ton)	24	41
Processing	Raw material	(baht)	2,198,026	4,000,000
cost	Drying	(baht)	31,116	0
	Storage	(baht)	9,600	96,000
	Milling	(baht)	132,000	100,000
	Packing	(baht)	47,520	79,200
Transport	Paddy transportation	(ton)	0	400
load	Milled rice transportation	(ton)	158	0
	Packed rice transportation	(ton)	158	264
Transport	Paddy transportation	(baht)	0	220,000
cost	Milled rice transportation	(baht)	87,120	0
	Packed rice transportation	(baht)	87,120	132,000
Income	Milled rice	(baht)	2,995,298	4,992,164
	By product	(baht)	197,760	450,800
Total	Income	(baht)	3,193,058	5,442,964
	Cost	(baht)	2,592,502	4,627,200
	Revenue	(baht)	600,556	815,764
	Income	(baht/ton output)	20,158	20,617
	Cost	(baht/ton output)	16,367	17,527
	Revenue	(baht/ton output)	3,791	3,090

occur at the end of the chain. The traceability system consisted of a logical chain of events that can be connected as seed source/seed company, producer, elevator/paddy merchant and rice mill. A process for each element can be managed and can supply credible information. Moreover, there was credible independent verification of the process such as GAP (Good Agricultural Practice) and GMP (Good Manufacturing Practices). In this study, a traceability system using RFID (Reader/Writer), application software, middleware, and tags was implemented on a trial basis. For industry application, investment in hardware was about 100,000 baht/set (distance 4 m), 25–30 baht/sticker type of tag and 60 baht/card type.

Conclusions

The model of minimized cost for paddy transportation for a farmer who had a land size as <10, 11–20, 21–40, and 41–60 rais/household called for 4-wheel trucks, 6-wheel trucks, 10- and 6-wheel trucks, and 10-wheel trucks, respectively. For a middleman, the optimized vehicle for transporting paddy of 50 tons was a trailer and a 6-wheel truck. Furthermore, the optimized vehicle for 100 tons was a trailer truck. The model's optimized choice for supplying paddy to a rice mill is: (1) for a rice mill in the harvesting area, wet paddy and (2) for a rice mill in the marketing area, dried paddy. The study provides a basis for GAP and GMP protocols for a traceability system. The rice mill management should be able to implement segregation and documentation systems that trace information back to a group of producers or to a production region using RFID systems.

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Exploring Behavioral Changes towards Chemical-Safe Agriculture: The Case of Thai Vegetable Farmers

Varaporn Punyawadee

Abstract A case study of vegetable production was employed to investigate the relevant factors that influenced the adoption of chemical-safe technology in Thai agriculture. The study was based on survey data on vegetable production in crop year 2005/06 of 300 farmers in Chiang Mai province. The farmers were divided into two main groups, i.e., those who produced chemical-safe vegetables and the others who produced vegetables with the use of traditional chemical pest management on a conventional basis. The results, using logistic regression analysis, showed that the factors affecting the increase in adoption of chemical-safe technology included the farmer being in a group that had a marketing function, being trained on chemical-safe technology, number of full-time household agricultural labor, age and education. The probability of adoption of such technology was likely to decrease with the area planted to vegetable and the need for hired labor. The promotion of chemical-safe agriculture should primarily focus on marketing functions including reduction of revenue and price risks. Research and development of new alternative technology that could substitute current intensive uses of labor should be put on the agenda. Training and other self-learning methods on how to apply food-safety production practices should be continuously implemented nationwide. On the consumer side, campaigns to promote demand for food-safety are needed in accelerating farmers' adoption of chemical-safe practices.

Key words: Chemical-safe vegetables, food safety, sustainable agriculture, Thailand

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Introduction

Agricultural development in Thailand has shifted from traditional agriculture to modernization following the world's trend with the introduction of modern technology, mechanization and widespread use of agrochemicals. Like many other developing countries, pesticides have been commonly and intensively used in Thai agriculture to obtain higher yield and the enhanced appearance of the products appealed to domestic consumers and export markets. Imports of pesticides rose about three times or 212.7% between 1998 and 2006 while imports of chemical fertilizer increased about 28.2% during the same period (www.oae.go.th/imp-exp.htm). Excessive uses of agrochemicals have apparently marked Thailand as one of the top countries with intensive agrochemical application.

Food safety targeting in organic agriculture and other forms of chemical-safe agriculture has recently been listed among Thailand's top priorities in agricultural development. Several programs that have offered farmers alternative methods for chemical crop protection have been implemented nationwide since 1986; however, the outcomes have been disappointing. After two decades of efforts, less than 5% of Thai farmers have permanently switched to the practice of chemical-safe agriculture. Clearly, there is a need to identify the problems and factors underlying the farmers' decision to abstain from these methods. The results drawn from the study could be used to identify target groups of farmers that could be encouraged to at least experiment with a chemical-safe scheme. Plans of action and the incentives needed should also be appropriately directed in order to help facilitate and accelerate the adoption of chemical-safe technology, which would help us to achieve an acceptable level of "food safety". As a consequence, this would generate external benefits not only in terms of mitigation of harmful effects on health and environment but also an increase of competitiveness in export markets where trade barriers regarding food safety and environmental quality are now enforced more rigorously.

This study aimed at identifying the problems of slow growth in chemical-safe agriculture in Thailand and more importantly to investigate the factors that influenced the adoption of chemical-safe technology with particular attention to vegetable production in Chiang Mai province.

Materials and Methods

To analyze the major factors relating to the adoption of chemical-safe technology in vegetable production, this study divides the population into two main groups, i.e., the farmers who employ chemical-safe techniques in their vegetable production and those who employ chemical pest management on a conventional basis without any restriction or control over chemical uses, which will be referred to as typical vegetable production. The sample of 300 vegetable farmers in Chiang Mai was taken from the two groups of farmers by purposive sampling; while within each group, the samples were drawn using a random sampling technique. This study was conducted in district areas where both chemical-safe and typical vegetables were produced in crop year 2005/2006. The analysis of the adoption of chemical-safe farming technology employed a logistic regression model in order to determine the different factors that might influence the adoption of such technology. In this study, the variables that might affect the decision making of the farmers (independent variables) were divided into three groups: personal characteristics, socio-economic forces, and institutional factors.

The logistic regression model employed in this study consisted of a dependent variable that was qualitative with two values: 1 and 0, indicating that farmers would adopt chemical-safe technology or not adopt, respectively. The logistic regression model employs a maximum likelihood method to analyze the probability of the event to take place by assuming a cumulative logistic probability function. The logistic regression model can be expressed as follows:

$$P_i = E(Y_i/X_i) = f(X,\beta) = \frac{1}{1+e^{-\beta X}} = \frac{e^{\beta X}}{1+e^{\beta X}} \tag{1}$$

where P_i is the probability of the event i taking place, $F(\cdot)$ is the cumulative logistic probability distribution function, X are independent variables, and β denotes coefficients of independent variables. From (1) we obtain

$$1 - P_i = \frac{1}{1+e^{\beta X}} \tag{2}$$

Dividing (1) by (2)

$$\frac{P_1}{1-P_i} = \frac{1+e^{\beta X}}{1+e^{-\beta X}} = e^{\beta X} \tag{3}$$

where $P_i/1-P_i$ is the odds ratio. In this study, the odds ratio indicates the proportion between the probability that the farmers would adopt chemical-safe technology and the probability that the farmers would not adopt it.

From (3) taking *Ln*

$$L_i = Ln\left(\frac{P_i}{1-P_i}\right) = Y_i = \beta_i X_i + U_i \tag{4}$$

where L is the natural logarithm (*Ln*) of the odds ratio.

From Equation (4), in this study Y_i is the observed value ($Y_i = 1$ when the farmer adopted chemical-safe technology in his vegetable production during crop year 2005/2006 and $Y_i = 0$ otherwise).

The independent variables that were hypothesized to affect a farmer's decision whether to adopt the chemical-safe technology in vegetable production are given in Equation (5).

$$\begin{aligned} Y = {} & b_0 + b_1 AGE + b_2 EDU + b_3 LAND + b_4 VLAND + b_5 VPI + b_6 LAB + b_7 SUF \\ & + b_8 HEALTH + b_9 G\text{-}MKT + b_{10} TRAIN + b_{11} TOUR + b_{12} K \end{aligned} \tag{5}$$

where Y is the observed value representing the decision to adopt or not adopt chemical-safe technology in his vegetable production during crop year 2005/2006 ($Y_i = 1$ when the farmer adopt chemical-safe and $Y_i = 0$ otherwise), AGE is the age of the farmer or the household's decision maker (year), EDU is the formal education level of the farmer or the household's decision maker, LAND represents the agricultural land holdings (rai, where 1 hectare = 6.25 rais), VLAND denotes the areas planted to vegetable crops (rai), VPI is the net revenue over monetary variable cost in vegetable production, crop year 2005/2006 (baht, where 1 US dollar was about 33 baht as of July 2008), LAB is the full-time household labor devoted to agriculture (man-day), SUF is the need for hired labor (SUF = 1 if hired labor was needed and SUF = 0 otherwise) HEALTH represents the health impact from agrochemical uses (HEALTH = 1 for those with problems and HEALTH = 0 otherwise), G-MKT denotes the interactive variable between being member of a farmer group (G = 1 if was a member) and whether the group performed marketing function (MKT = 1 if the group performed marketing function during the study period), TRAIN is the training in chemical-safe technology or participating in the farmer field school during the past three years (TRAIN = 1 if received the training and TRAIN = 0 otherwise), TOUR denotes the study trip to the demonstration plot of chemical-safe farming practice during the past three years (TOUR = 1 if the farmer had experience and TOUR = 0 otherwise), and K is the knowledge about the chemical-safe agricultural farming (score of 0–10).

In this study, the estimated coefficient b_i represents the variation of *Ln* of odds ratio in the adoption of chemical-safe farming technology with regards to the change in one unit of the independent variable considered (e.g. age of farmers) holding other independent variables in the model constant. Normally, analysis using a logistic regression model does not interpret the estimated coefficient b_i as indicated but instead considers the relationship of variables in the form of the odds ratio (e^{bi}). In this case, it represents the ratio between the probability of the event taking place, which is that the farmer grows chemical-safe vegetables, and the probability that the farmer instead grows typical vegetables. The results in terms of the odds could indicate the independent variables that affected the probability of the adoption of chemical-safe technology in vegetable production including the direction of the relationships.

Results and Discussions

Estimation of the model as expressed in Equation (5) is shown in Table 1. In considering the Wald Statistic value, it was found that variables that did not exert any effect towards the adoption of chemical-safe vegetable production technology with significant level of 0.10, were as follows: owned land for agricultural use (LAND), health impact (HEALTH), study trip to the demonstration plot of chemical-safe farming practice (TOUR), and level of knowledge on chemical-safe vegetable farming (K).

The reason that health impact was statistically insignificant might be because the impacts from agricultural chemicals would be accumulated over the longer-run and

Table 1 Statistical results of factors underlying the adoption of chemical-safe technology in vegetable production.

Variables	B	S.E.	Wald	df	Sig.	Exp (B)
AGE	0.052	0.024	4.840	1	0.028	1.053
EDU	0.322	0.172	3.520	1	0.061	1.380
LAB	0.533	0.191	7.752	1	0.005	1.704
SUF	–1.320	0.376	12.311	1	0.000	0.267
VLAND	–0.576	0.145	15.801	1	0.000	0.562
TRAIN	1.048	0.522	4.023	1	0.045	2.852
G-MKT	2.639	0.428	38.101	1	0.000	14.001
VPI	0.000	0.000	3.142	1	0.076	1.000
LAND	0.009	0.034	0.063	1	0.802	1.009
HEALTH	0.314	0.510	0.379	1	0.538	1.369
TOUR	0.760	0.518	2.156	1	0.142	2.139
K	0.206	0.171	1.450	1	0.229	1.229
Constant	–6.924	2.144	10.427	1	0.001	0.001

Note: Model Chi-Square = 192.282 Sig. = 0.000
$-2\log\text{likelihood} = 208.077$
Nagelkerke R Square = 0.648
Hosmer and Lemeshow Chi-Square = 4.574 Sig. = 0.802

the farmers might have not realized the problems. On statistical grounds, the factors affecting the adoption of chemical-safe technology in vegetable production can be summarized as follows:

- Age (AGE) was found to have a positive effect on such adoption, as indicated by the positive coefficient and exponential value of greater than 1, which meant that as age increased, the odd ratio or chance of the farmers to adopt chemical-safe vegetables also increased at a significant level of 0.05.
- Level of education (EDU) also positively affected such adoption, similar to age but with higher coefficient value, which meant that if the level of education of farmers increased, the probability for the farmers to plant chemical-safe vegetables also became higher at a significant level of 0.10.
- Number of full-time household labor in agriculture (LAB) had a similar relationship with such adoption at a significant level of 0.01, which meant that if farmers had high full-time household labor, the opportunity for farmers to adopt chemical-safe technology in vegetable farming was also high.
- Need for hired farm labor (SUF) was found to have an inverse effect on farmers' adoption of such technology because of the negative coefficient value and exponential value of less than 1, which meant that if farm household had the need to hire farm labor, the chance for farmers to grow chemical-safe vegetables then decreased at a significant level of 0.001. The result seemed to be consistent with the current experience that chemical-safe production particularly of vegetables, requires intensive labor for care and management of the plants. The results of the analysis indicated that if there was a need to hire extra labor, the inclination for

farmers to accept such technology decreased as the farmers encountered a higher cost of labor.

- Area planted with vegetables (V_LAND) was found to have an inverse effect on adoption of such technology because of the negative coefficient value and exponential value of less than 1 with a significant level of 0.001. The result meant that if the size of area planted with vegetables was large, the chance for the farmers to grow chemical-safe vegetables would decrease. This is consistent with the current practice of growing chemical-safe vegetables in Thailand where dependence was placed primarily on labor. Prevention of plant pests and diseases relied mainly on man-labor where the use of natural substances to replace chemicals was less effective. This was considered an important limitation in the adoption of the technology at the present time.
- Training on chemical-safe farming during the past three years (TRAIN) was found to exert a positive effect on the adoption of such technology at a significant level of 0.05. Farmers who had undergone training showed a higher tendency to adopt the technology than those who have not joined any training program. The coefficient value was positive and high, which was second only to the marketing factor. This indicated the importance of training towards the adoption of such technology.
- Membership in marketing groups (G-MKT) was shown to have positive effect towards the adoption of the technology. The coefficient value was positive and of the highest value with a significant level of 0.001, indicating that it served as the most important factor affecting the adoption of chemical-safe vegetable production in this study.
- The net revenue over the monetary variable cost in vegetable production (VPI) was found to affect adoption of the technology at a significant level of 0.10 but with little impact, because the coefficient value was approximately 0 and the exponential value was 1.

Conclusions

Based on the results of the study, among the factors that had positive impacts on the adoption of chemical-safe technology in vegetable production, the presence of marketing groups was considered as the most important variable. This was followed by participation in training programs related to the technology on chemical-safe agricultural production. As for the labor factor, if there is high household labor, there is a higher tendency for farmers to practice chemical-safe vegetable farming as they could substitute chemicals with increasing labor for care and management of crops. Other factors that positively affect the adoption of chemical-safe technology on farming included age, education and net revenue from growing vegetables.

On the other hand, factors that exerted a negative effect towards adoption of chemical-safe technology on vegetable farming included area planted with vegetables and the need to hire farm labor. If the area planted with vegetables increased, the opportunity for farmers to plant chemical-safe vegetables tended to decrease. Similarly, if farm households needed to hire additional farm labor, the adoption of such technology also tended to decrease because this would lead to an increase in cash expenses. Based on the results of this study, the guidelines for the development of chemical-safe agriculture, particularly vegetable production, could be summarized as follows:

- Market requirements are considered a very important factor for farmers to consider in growing vegetables and accepting the chemical-safe technology. From the survey in this study, the market for vegetables where farmers were able to sell their products, was characterized as a specific market where consumers knew that the products were of high quality and were safe from any chemicals thus allowing the products to be sold at a higher price than ordinary vegetables. However, that specific market could either sell only a few products or the market was located in a much farther place from the farm thus increasing extra transportation cost especially when compared with the low value of vegetable products.

Therefore, in increasing the probability that farmers will adopt chemical-safe technology in vegetable production, a marketing group with management capabilities should be developed. Establishment of a market in the community, especially where the products are mainly produced (a permanent alternative market or a type of weekend market) could also be considered. Public campaigns should be targeted to consumers within the area including those from neighboring villages so that it could serve as a place for buying and selling thus allowing producers or farmers to reduce their transport expenses besides ensuring the consumers the availability of a wider array of quality products for consumption.

- A training program or farmers' school should be conducted to provide knowledge on alternative farming in order to reduce the use of chemicals. In addition, knowledge about the impact from the use of farm chemicals on the public's health and environment in the long run should also be emphasized. This activity must be supported by the government or other agencies involved and be continuously promoted in order to produce sustainability. It is unfortunate that, in some cases, farmers who wanted to try or to test the technology after training, were given no knowledge of whom to ask or where to seek advice. As a result, many farmers simply revert back to their old practice of growing typical vegetables.
- The problem of labor is another major factor that affects the adoption of technology in chemical-safe vegetable farming because there is a great need to use labor to provide care and management of the farm. Some farmers mentioned that "the practice of planting chemical-safe vegetables may be worth the cash expenses but not their own labor", a characterization that makes it different from typical chemical farming. Clearly, it can be seen that care and management of chemical-safe vegetables greatly requires intensive labor throughout the production area, thus the area of land needs to be small (for effective care) and as a result becomes a limitation to the practice of commercial farming that emphasizes crop yield for the market.

The solution to the problem as indicated previously, calls for the promotion and encouragement of research on the technology of chemical-safe farming in order to identify natural substances that can effectively substitute for farm chemicals. There should be studies on these types of technology at the international level which can be applied to a larger area in the Thai society where scarcity of farm labor has become increasingly more important. Besides looking for a technology, or for natural substances that can replace chemicals, there must be support to produce this change in dynamics, at a lower cost. At present, even though there is a decrease in the use of chemical substances or fertilizers in chemical-safe farm production, the cost for substitutes is relatively high when compared at the utilization level with similar effects.

- Finally, an increase in the spread of knowledge to food consumers through various means of communications, e.g. television, newspaper, internet, etc., can promote a behavioral change in consumption. As a consequence, farmers will be motivated to increasingly grow safe products or to reduce the use of farm chemicals, thus providing a positive impact on the health of all members of society and improving the quality of the environment that forms a crucial basis of sustainable development in the future.

Acknowledgement

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Supply-Demand Balance of Compost between Urban and Agricultural Sectors According to Peri-Urban Development in an Urban-Rural Fringe Area in Asia: A Case Study in Nonthaburi, Thailand

R. Honda, A. Hiramatsu, Y. Hara and M. Sekiyama

Abstract We investigated the current situation of supply and demand potential of compost and illustrated the shift of supply-demand balance of compost between urban and agricultural sectors according to peri-urban development in an urban-rural fringe area of Bangkok. In the study area in Bang Maenang, Nonthaburi, Thailand, 42% of the supply potential is estimated to exceed the demand balance in 2007. The population density where supply and demand potential balance was estimated as approximately 1,300–1,400 persons/km^2. Since the nitrogen supply potential in the study area exceeded the estimated demand potential, proper collection and treatment of surplus nitrogen was required to protect the canal water environment.

Key words: Resources circulation, compost, peri-urban development

Introduction

Many developing Asian countries face serious environmental problems associated with rapid economic growth. Although there is an urgent need to learn from the experience of industrialized countries that have solved serious pollution problems, existing pollution-control measures must be applied in a manner appropriate to the target region (Takiguchi et al., 2007). Bangkok Metropolitan in Thailand is one of the largest expanding cities in Asia. Increase of middle-income citizens promotes their migration from the urban center to the wider suburban area, where they can own their houses (Hiramatsu et al., 2008). Responding to their demand, there is robust development of new residential communities found in the urban fringe of Bangkok.

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In Asia, built-up areas tend to expand in such a way that areas of urban-rural mixed land use are created. This tendency is rooted in socio-cultural conventions such as long-standing and speculative private land ownership and the absence of appropriate land-use planning (Evers, 1984). Existing land-use plans may seem ineffective, according to Western urban planning theory that negatively regards mixed land uses. However, urban-rural mixed areas in the urban fringe offer the potential for resource circulation and for the development of sustainable societies through the harmonization of human beings and the environment (Yokohari et al., 2000).

In this study, we supposed nitrogen resources circulation by utilization of compost generated from municipal solid waste in the neighboring agricultural fields. We investigated the current situation of supply and demand potential of compost, and those estimated from land-use change in variation of population density, in order to illustrate the shift of supply-demand balance of compost between urban and agricultural sectors according to peri-urban development in an urban-rural fringe area of Bangkok.

Materials and Methods

Study Area

We targeted Bang Maenang District in Nonthaburi Province as a study area, and conducted the study focusing on the area along the two canals in the district, Bang-Kho Canal (Canal 1) and Bang-Kra-Boo Canal (Canal 2). We chose these canals because development of a new residential area was active along the canals, and because there is a certain difference in robustness of the developments, although they are neighbors. Basins of Bang-Kho Canal and Bang-Kra-Boo Canal were divided for descriptive purposes as C1-1 to C1-4 and C2-1 to C2-2, respectively (Figure 1). The area of basins of Canal 1 and 2 was 1.95 km^2 and 1.10 km^2. The total area of the target site was 3.05 km^2.

Land-Use Change and Population

Land-use change due to urban development in the target area between 2003 and 2007 was spatially investigated using GIS software (ArcGIS, ESRI). The 2003 urban plan- ning base map in vector format with a scale of 1:4000 (Department of Public Works and Town & Country Planning, Ministry of Interior, Thailand) was obtained and used for GIS analysis. The map for 2007 was constructed by editing a 2003 vector map through on-screen visual interpretation of ALOS PRISM satellite imagery observed in 2007. An area of a residential land use, the number of houses, an area of rice fields and vegetable fields in each year and their changes were calcu-

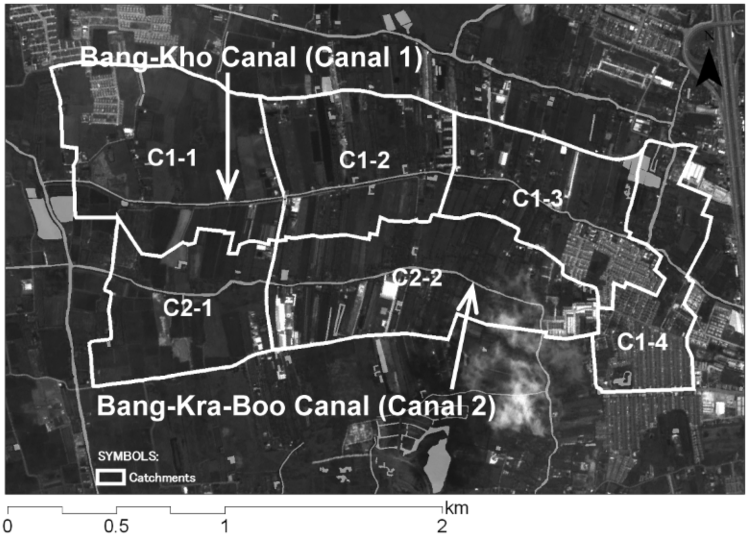

Fig. 1 Target area in Bang Maenang, Nonthaburi, Thailand.

lated by overlaying the 2003 and the 2007 maps. Population was extrapolated from the average household size: 3.4 persons/household (Thai Census, 2000).

Nitrogen Demand in Agricultural Sectors

Demand for nitrogen in agriculture fields in the target area was estimated based on field surveys. The amount of applied nitrogen in rice and vegetable fields was 9.61 and 6.67 g/m^2/year, respectively, which was estimated from the amount of applied fertilizer and nitrogen contents in the fertilizer according to the results of interview surveys of the farmers.

Nitrogen Discharge from Urban Sectors

The amount of municipal solid waste generation and nutrient contents in the waste were obtained by field surveys. We investigated solid waste generated by 24 randomly selected households in Bang Maenang (Hiramatsu et al., 2008). The amount of municipal solid waste generation was 346 kg/household/year, and the average nitrogen content was 4.02%. Wastewater discharge was assumed to be equal to the amount of water usage, 279 L/person/year, which was obtained at Water Management Association in Nonthaburi. A nitrogen concentration in wastewater was assumed as 50 mgN/L (Lee and Wong, 2003). Amount of nitrogen discharge from a residence was estimated as 47.5 g/household/year (Honda et al., 2010).

Estimation of Supply-Demand Balance in Variation of Population Density

The residential area was estimated from population as an independent variable. All residents in the target area were assumed to live in detached houses. The average space per household was 240 m^2/household, which was obtained by analysis of the GIS data. Land for rice fields, vegetable fields, and other uses were allocated to the remaining area with the same ratio as in 2007, which was 2:1:1 along Canal 1 and 4:5:1 along Canal 2.

Nitrogen supply potential in compost was estimated from the amount of municipal solid waste. The amount of municipal solid waste generated with a nitrogen basis was calculated from a given population value and the number of households. Nitrogen discharge from wastewater was also estimated from the number of households. Nitrogen loss by composting was estimated as 43.2% by N-loss equation (Equation 1) (Kirchmann, 1985). The C/N ratio of the solid waste was 11.48 according to the result of field surveys.

$$\text{N loss ratio} = 0.559031 - 0.01108 * \text{C/N ratio} \tag{1}$$

Nitrogen demand potential was estimated from the amount of applied nitrogen in fertilizer and total area of rice and vegetable fields. We assumed that demand for nitrogen in compost was half of that in fertilizers.

Results and Discussion

The Current Situation of Balance of Supply and Demand Potential

Population in the target area was estimated to increase 50% from 5,100 in 2003 to 7,600 in 2007, approximately. Rate of land-use change were faster along Canal 1 than Canal 2, and in the downstream area, which is closer to the urban center, than in the upstream area (Figure 2). Along Canal 1, agricultural area decreased 12 % and residential area in- creased 25% from 2003 until 2007. Along Canal 2, agricultural area decreased 10 % and residential area increased 9% (Table 1).

Nitrogen demand in fertilizers in agricultural sectors was estimated to decrease 14 and 12%, while generation of municipal solid waste increased by 52 and 4% along Canal 1 and 2, respectively. Compost supply was redundant along Canal 1, while it was deficient along Canal 2. In total, though supply and demand balance almost matched in 2003, 42% was estimated to remain redundant in 2007, according

Table 1 Land-use change of the target area from 2003 until 2007 in Bang Maenang, Nonthaburi, Thailand. The values in parentheses are ratios in total area.

	Population	Population density [persons/km^2]	Built-up area [km^2]	Rice fields [km^2]	Vegetable fields [km^2]	Other use [km^2]
Canal 1						
2003	4,719	2,426	0.381 (20%)	0.775 (39%)	0.406 (21%)	0.383 (20%)
2007	7,184	3,694	0.490 (25%)	0.643 (34%)	0.378 (19%)	0.434 (22%)
Canal 2						
2003	394	358	0.127 (12%)	0.420 (38%)	0.515 (46%)	0.039 (4%)
2007	408	370	0.233 (21%)	0.383 (35%)	0.430 (39%)	0.055 (5%)
Total						
2003	5,114	1,678	0.508 (17%)	1.195 (39%)	0.921 (30%)	0.422 (14%)
2007	7,592	2,492	0.724 (24%)	1.026 (34%)	0.808 (27%)	0.489 (16%)

Table 2 Supply and demand potential of nitrogen.

[t/year]

	Municipal solid waste	Fertilizer use	Compost supply potential (1)	Compost demand potential (2)	Balance (1)-(2)	Surplus ratio
Canal 1						
2003	19.28	10.16	10.96	6.17	4.79	(44%)
2007	29.35	8.70	16.68	5.43	11.25	(67%)
Canal 2						
2003	1.61	7.47	0.92	5.65	-4.73	
2007	1.67	6.55	0.95	4.84	-3.89	
Total						
2003	20.89	17.63	11.88	11.82	0.06	(5%)
2007	31.02	15.25	17.63	10.27	7.36	(42%)

to reports of an increase of supply from urban sectors and decrease of demand in agricultural sectors.

Municipal solid waste in this area was basically collected and brought to the waste disposal site located in the northern part of Nonthaburi province. According to the interview survey to the farmers, most of the farmers did not use compost or manure, or they used only small amount of compost in personal basis.

Estimation of Supply-Demand Balance in Variation of Population Density

The supply and demand potential of compost in variation of population density is shown in Figure 3. The estimated lines are probably reasonable because most of plots corresponding to observed data in Nonthaburi are almost on the line. The lines of supply and demand potential meet when population densities are approximately 1,270 and 1,390 along Canal 1 and 2, respectively. Ratios of residential area corresponding to these points are 9 and 10%, respectively. The population density where

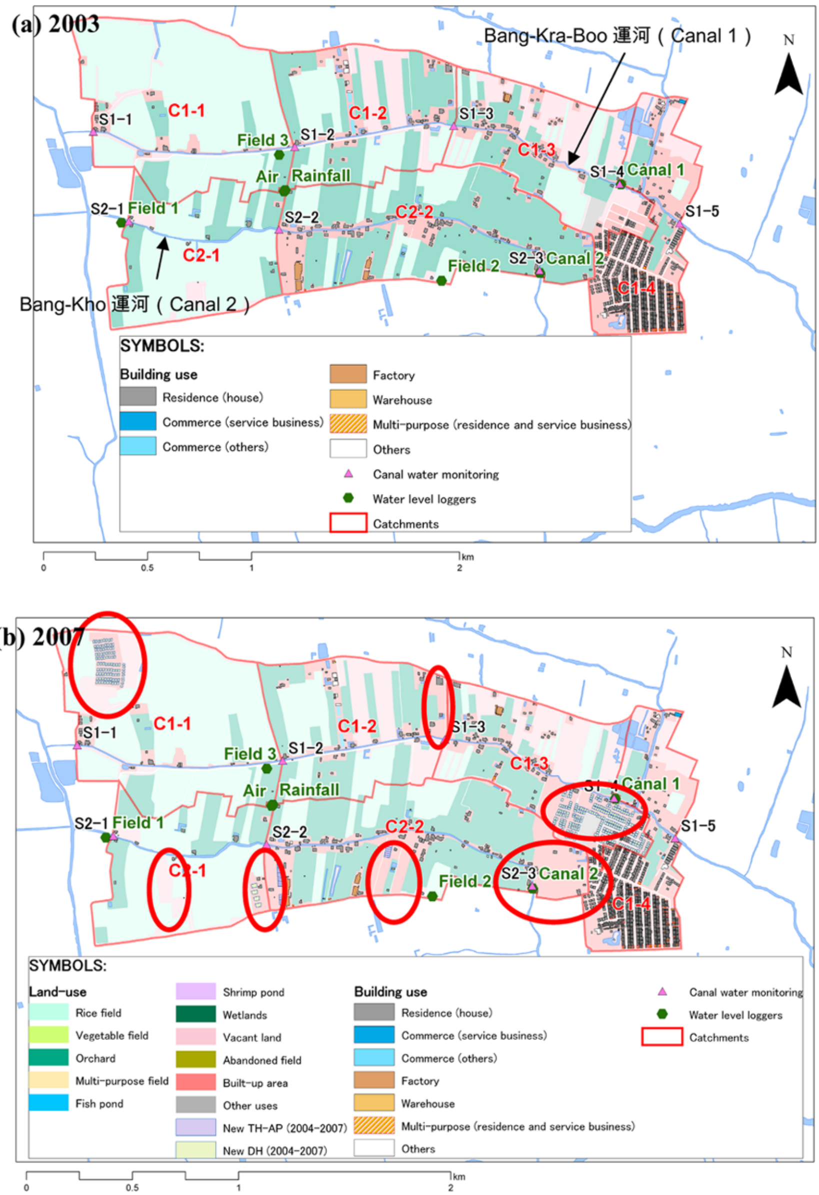

Fig. 2 (a) Land-use change from 2003 until 2007 in the target area in Bang Maenang, Nonthaburi, Thailand. The circled area shows a newly developed area. (b) Land-use change from 2003 until 2007 in the target area in Bang Maenang, Nonthaburi, Thailand. The circled area shows a newly developed area.

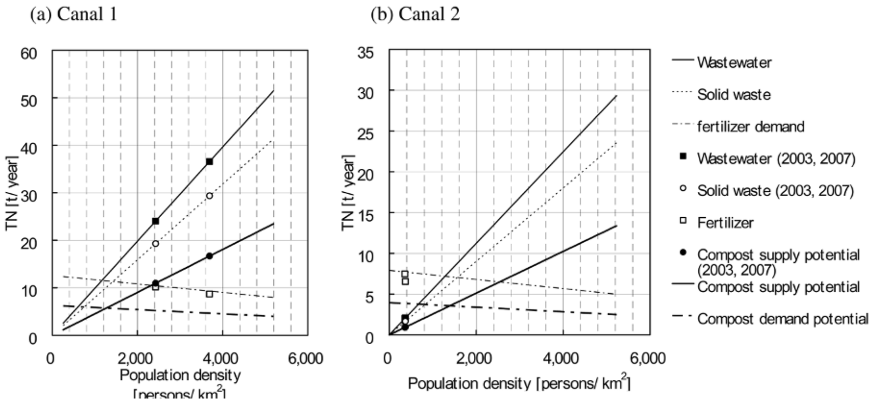

Fig. 3 Estimated supply-demand balance of compost in relation to population density. The plots shows the estimation from GIS data in 2003 and 2007.

supply and demand potentials meet has a similar value although the ratio of rice fields to vegetable fields is significantly different between Canal 1 and Canal 2. Impacts of transportation cost on compost circulation are probably limited because total area of the target area was as small as 3 km^2. However, the values obtained in this study should be evaluated carefully especially in application to larger area, because they were focused only on balance of amount of supply and demand potential.

Not only municipal solid waste but also domestic wastewater has a significant amount of nitrogen discharge. If utilization of nitrogen in wastewater is possible, supply and demand potential equals in lower population density. However, nitrogen circulation from wastewater, such as utilization of composted activated sludge was probably difficult in the current situation in the target area, because most of the wastewater was discharged directly to the canals without proper treatment.

It was difficult to utilize a large part of the discharged nitrogen in the study area since nitrogen discharge was much larger than nitrogen demand in the area. Instead, the proper collection and treatment of surplus nitrogen was necessary in order to prevent it from discharging into the canal and from burdening the canal water environment.

Conclusions

We could observe increase of residential area and decrease of agricultural area according to population increase induced by the peri-urban development. As a result, supply potential of compost from municipal solid waste increased, while demand potential in the agricultural fields decrease. In the study area in Bang Maenang, Nonthaburi, Thailand, 42% of supply potential estimated to exceed demand balance in 2007, while they almost equaled in 2003. The population density where supply and demand potential balance was estimated as approximately 1,300–1,400 persons/km^2. Since the population density in the study area exceeded the estimated value and a significant amount of nitrogen was also discharged from wastewater, the proper collection and treatment of surplus nitrogen was required to protect the canal water environment.

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PART 5

Food and Water Security in Climate Changes

Water Resources in the Hexi Corridor and Its Cycle

Q. Feng

Abstract The Qilian Mountains are the cradle of all inland rivers in the Hexi arid region. The mountain glaciers are important water resources for this region. Changes in the mountain runoffs resulting from global climate warming will have important impacts on the development of human society and economy in the region. In this paper, the river runoffs from the Qilian Mountains and their dynamic changes are analyzed on the basis of instrumental data of precipitation, air temperature, and discharge from the weather and hydrological stations in the study area. The results show that the annual change in mountain runoffs is affected mainly by precipitation in the east of the region, but also by temperatures in the west of the region. There are some obvious regional differences in the influence of climatic change on surface runoffs in the Hexi region. River runoffs in the western part of the Hexi region have been increasing, whereas those in the eastern part have been decreasing. River runoffs in the central part, such as the Heihe River, present a slowly increasing trend, although it is not quite visible.

Key words: Water resources, Hexi corridor, mountain runoffs, river runoffs

Introduction

The Hexi region, situated between N 37°17′ 42°18′ and E 92°23′ 104°12′ with a total area of 215×10^5 km^2 (Cheng and Qu, 1992), is an important region of economic development in Gansu Province, China. Owing to the influences of different landforms, physiognomy and hydro-meteorological conditions, the region can be partitioned into two kinds of runoff zones, i.e. the runoff forming zone and the runoff consuming zone (Cheng and Qu, 1992), based on their characteristics from

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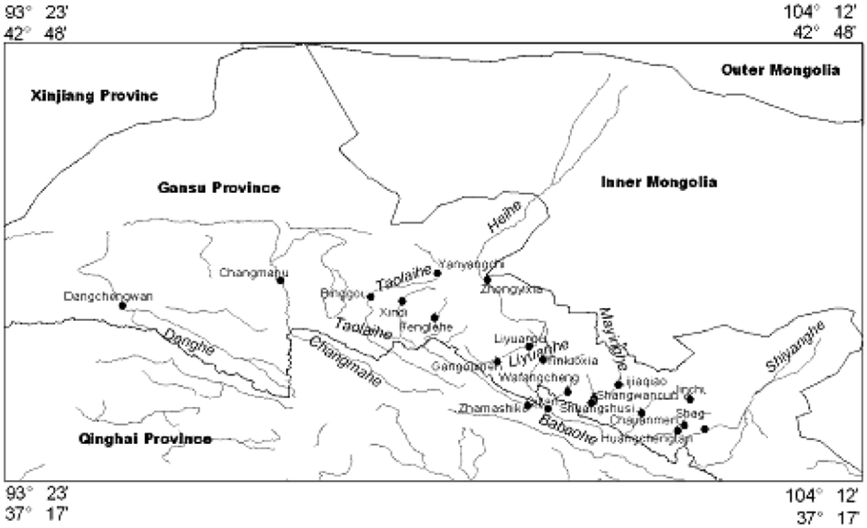

Fig. 1 Sketch map of the main river in the Hexi Inland Arid Region.

headstream to mouth. The area of the Qilian Mountains – located in the southern part of the region and in the northeastern edge of the Qinghai-Tibetan Plateau, is the runoff forming zone and the source of all rivers in the region. The vast deluvial and alluvial plain at the front of the Qilian Mountains is the runoff consuming zone. Because the subsistence space of a plain oasis is determined by surface runoff from a mountain area, it has very practical significance to research the characteristics of its variability and forecast the trend of change in the runoff from the Qilian Mountains. Figure 1 is a sketch map of the main river in the Hexi Inland Region.

Studied Area

The rivers from east to west in the region belong to three great river systems, that is, the Shiyang River System, the Heihe Water System and the Shule River System, respectively. In total, there are 57 inland rivers of different size, in which 23 rivers were set up as hydrometric stations (8-river in the Shiyang River Catchments, 9-river in the Heihe River Catchments and 6-river in the Shule River Catchments), and most of them have for more than 40 years kept instrumental records that are the basis for accurately calculating water resources. Owing to terrain, precipitation and underlying surface of catchments, the flow is very short and the runoff is very small in most of the above rivers. There are only ten rivers of which the runoffs are more than 1.0×10^8 m^3, and there are only three rivers of which the runoffs are more than 5×10^8 m^3 (the main stream of the Heihe River of the Heihe River System, the

Table 1 Glacier water resources and mountain runoff in the Hexi Region.

Water systems	Glacier number	Glacier areas (km^2)	Water resources ($10^8 m^3$)	Glacier melt runoff (GR) ($10^8 m^3$)	Mountainous runoff (MR) ($10^8 m^3$)	GR/MR (%)
Shiyang River	141	64.82	21.434	0.5797	15.73	3.7
Heihe River	1078	420.55	136.7	2.979	36.44	8.2
Shule River	1225	1171.84	643.176	6.4304	20.22	31.8
Sum	2444	1657.21	801.31	9.9891	72.39	13.8

Taole River of the Heihe River System, and the Changma River of the Shule River System (Lan, 2000; Gao and Yang, 1995).

Glacier Water Resources

According to statistics compiled from the relevant data (Liu and Kang, 2001), there are 2,444 pieces of glaciers in the area of the Qilian Mountains in the Hexi Region of Gansu Province, in which 250 of those pieces are included in the Harerteng River basin flowing into the Sugan Lake with an ice surface area of 1657.21 km^2 and an ice volume of 801.3×10^8 m^3, which is equal to a water volume of 721.2×10^8 m^3 that is about ten times the annual total quantity of runoff water from the mountainous area. Therefore, glacier ice provides an enormous solid reservoir of water, in which abundant fresh water resources are deposited and it plays an important role in adjusting river runoff. The glacier water resources and the quantity of water of runoff from the mountainous area in the three great rivers basin in the Hexi Region were calculated in Table 1 (Chang and Qu, 1992). The Shulehe River basin holds the main glacier water resources that are distributed into the area of the Hexi Region, consisting of a proportion of 50% of the quantity of glaciers, 71% of the ice surface area, and 80% of the reserves of glacier water resources. The Heihe River basin is the second main source of glacier water resources in the area, consisting of a proportion of 44% of the quantity of glaciers, 25% of the ice surface area, and 17% of the reserves of glacier water resources. The quantity of glaciers in the Shiyang River basin is the lowest, consisting of a proportion of 6% of the quantity of glaciers, 4% of the ice surface area, and only 3% of the reserves of glacier water resources.

On average, glacier melt runoff provides 13.8% of the total mountainous runoff in the three great water systems. Thereunto, the proportion from the Shule River basin is most with 31.8% of the annual runoff; that of the Heihe River basin is second at 8.2%; that of the Shiyang River basin is least, a proportion of 3.7%. As an enormous solid reservoir, the glaciers play an important role in adjusting river runoff. In the arid years, glaciers melt more and supply more glacier-melt runoff; on the contrary, in the humid years, glacier-melt lowers and the supply of glacier water to rivers decreases, but the supply of glacier ice increases because snowfall in the Alpen area increases and accordingly the water reserves of glaciers increases.

Table 2 Change in glaciers in the Hexi inland river basins since 100-year.

Rivers	Mountains	S_1 (km^2)*	S_2 (km^2)**	ΔS (km^2)***	$\Delta S/S_1$ (%)
Shiyang	Qilianshan	64.82	103.49	–38.67	–37.4
Heihe	Qilianshan	420.55	500.84	–80.29	–16.0
Shule	Qilianshan	849.38	949.07	–99.69	–10.5
Total		1334.75	1553.4	–218.65	–14.1

*S_1: the modern glacier area; **S_2: the maximum glacier area period of the 100-year; ***ΔS: change in glacier area during the period from 1000-year to 1956.

Variations in the Water Resources of Glaciers

The "Little Ice Age" is the name given to a cold period of the earth's climate on a century time-scale during about the 17th to 19th centuries. Global mountain glaciers all advanced in this period. Obviously there are three pieces of the terminal moraine ridges near the end of the modern Alp glaciers. Because the "Little Ice Age" moraine ridges were saved perfectly, there are obvious differences between the external shape characteristics, extent, weathering degree and vegetation status of them and that of the moraine ridges formed in earlier periods. Thus the relic signs of the "Little Ice Age" moraine ridges were used for estimating the size of glaciers and reconstructing the circumstances at that time (Liu and Kang, 2001) (Table 2).

The glacier area in the Hexi inland river basins, which occupies about 14% of the total area of glaciers in the period, has decreased 219 km^2 since the "Little Ice Age", to about 1553 km^2, whereas the quantities of decreasing glaciers in various regions are different. The extent of variations in glaciers is bigger in the fringe mountainous regions and the humid areas. Hereinto the variation of the glacier of the Lenglongling Mountain Range, situated in the eastern section of the Qilian Mountains, is the most at –37.5%. The ratio of glacier change decreases gradually along with a decrease in humidity degree and an increase of distance to an ocean. For example, the ratio of glacier change in the mountainous region of the Heihe River basin, situated in the middle section of the Qilian Mountains, is –16%. The ratio of glacier change in the Shule River basin, situated in the western section of the Qilian Mountains, is the lowest at –10.5%. The representative glaciers in the eastern, middle and western sections of the Qilian Mountains respectively were researched and semi-directionally observed in the middle periods of the 1970s and 1980s, providing data from when the area was researched in force by CAS (Chinese Academy of Science) in 1958. Some data of glacier variation were obtained (Liu and Kang, 2001) (Table 3).

The number of glaciers that have been monitored over a long period is small and some methods of monitoring glacier variation by use of repeated aviation and satellite photos cannot be carried out in other areas because of local condition restrictions. The obtained data on glacier variation are few and lack representation at present. At the same time, strict comparisons of the glacier variation data are quite difficult because of the differences in the periods of the obtained data. Therefore, it

Table 3 Variation in representative glaciers in Qilian Mt. since 1958.

Glacier name	Position	Length (km)	Area (km2)	Observation period (year)	Glacier End Changes			Glacier area variations	
					m	m/ a	%/a	km^2	%/a
No.4 Glacier	Upper of Shiyang River	2.1	1.86	1956~1976	-320	16.0	-0.76	-0.265	-0.71
				1976~1984	-69.7	-8.7	-0.41	-0.0142	-0.10
"1, July" Glacier	Upper of Heihe River	3.8	3.04	1956~1975	-40	-2.1	-0.055	-0.0240	-0.042
				1975~1984	-10	-1.1	-0.029	-0.0047	-0.017
No.12 Glacier	Upper of Shule River	10.0	21.91	1962~1976	-71.8	-5.1	-0.051	-0.1305	-0.042
				1976 ~1985	-11.7	-1.3	-0.013	-0.0066	-0.003

Table 4 Glacier changes during the period from 1960 to 1995.

Basins	Glacier area (S, km^2)	Glacier area variations (ΔS, km^2)	ΔS/S (%)
Shiyang River	64.82	–12.93	–19.9
Heihe River	420.56	–29.18	–6.9
Shule River (Main stream region)	849.38	–35.67	–4.2
Sum	1334.75	–77.78	–5.8

is necessary to find a method of calculating the large-scale glacier variations. The results show that, as a rule, the rate of change of a glacier area decreases along with the grade of glacier area augmentation, whether the change occurred during recent decades or during the "Little Ice Age". Thus the relationship between the ratio of change in glacier area and the grade of glacier area in various representative basins in the mountainous area in the latest decades can be established. Hereby, the quantity of glacier reduction in the Qilian Mt. area is calculated and listed in Table 4.

Runoff Variations

Changes in river runoff are determined mostly by the change in temperature and precipitation in the mountainous area. The rising of temperature in the mountainous area leads to not only increasing evaporation and glacier melt runoff but also rising of the snow line and retreat of the glacier. The increase of precipitation leads to an increase not only in runoff but also in supplying glacier-water reserves in the form of snowfall in the Alpen zones. Consequently, glacier retreats are restrained. The trend of variation in temperature and precipitation in the mountainous area since the mid-1950s is examined from the annual sequences of the temperature and precipitation at the Tuole meteorological station located in the western section (N 38°48′, E 98°25′; altitude 3368 m), the Qilian meteorological station located in the middle (N 38°11′, E 100°15′; altitude 2789 m), and the Wushaoling meteorological station located in the eastern section of the Qilian Mountains (N 37°12′, E 102°52′; altitude 3044). Since the global climate is warming due to the content of CO_2 and other greenhouse

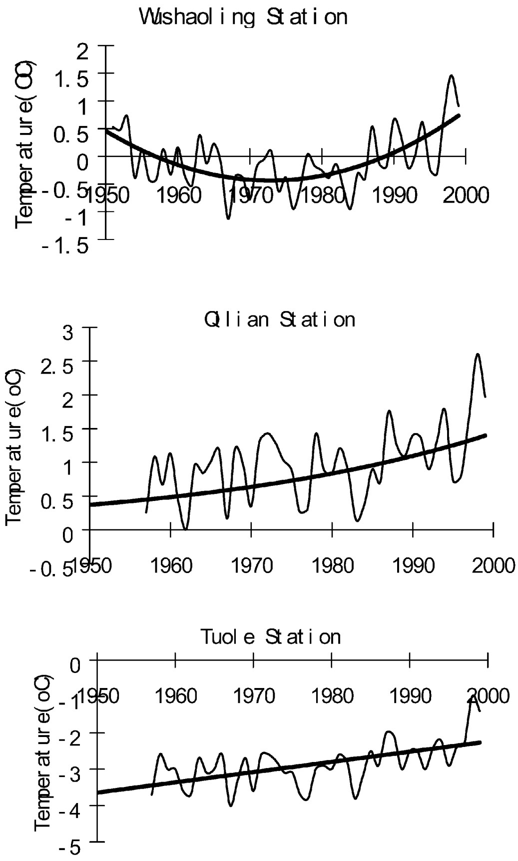

Fig. 2 Change in yearly mean temperature at the eastern (Wushaoling Station), middle (Qilian Station) and western section (Tuole Station) of the Qilian Mountains.

gases are increasing in the atmosphere, this brings a fluctuant rise in air temperature and the aggrandizement of dry climate in the inland regions of northwestern China. Although the variation possesses a catholicity, there are many differences in various areas (Shi, 2000). The results show that the temperature presents a rising trend in the whole mountainous area, and the variation in the precipitation is balanced basically in the eastern section, and that increases slightly at the middle and eastern sections (Figures 1 and 2). Temperature and precipitation variability and other measurements involving some characteristics of every weather station in the Qilian Mountain area, the runoff formation region of the Hexi Inland Region, can be seen in Table 5.

Table 5 Characteristics of temperature and precipitation variability of every weather station in the Qilian Mountain area.

Stations	Longitude	Latitude	Altitude (m)		Decadal averages 1950s	1960s	1970s	1980s	1990s	Mean (1950s–1990s)
Wushaoling	37°12′	102°52′	3044	T (°C)	0.09	–0.265	–0.356	–0.278	0.086	–0.163
				P (mm)	485.2	361.3	383.9	417.4	383.4	406.2
Qilian	38°25′	199°35′	2789	T (°C)	0.67	0.641	0.738	0.751	1.049	0.77
				P (mm)	400	401	37.2	411	419.5	401
Tuole	34°48′	98°25′	3368	T (°C)	–3.09	–3.13	–2.79	–2.18	–2.18	–2.86
				P (mm)	269.4	263.3	284.7	313.4	283.1	269.1

Changes in River Runoff

The process of long-term variation in river runoff is controlled by the hydro-meteorological condition of the mountainous area in the Hexi inland region. According to the consistency of long-term variation processes with the difference of the high–low extents on the water quantity of the river, the rivers in the region can be partitioned into two kinds of synchronous change zones of runoff, with the Liyuan River as a bound. The rivers located east of the Liyuan River originate from the eastern section of the Qilian Mt., of which the landforms lean to the northeast and river runoff is mainly supplied by rainfall. The rivers all possess some resemblances, that is, there is some zonal Alpen woodland in the underlying surfaces and the occupied proportions of glacier-snow melt water in annual runoff are very small. Therefore the variations in the rivers are obviously synchronous. The rivers located west of the Liyuan River mostly originate from longitudinal valleys in which the landforms all lean west or northwest. The big fluctuations of the rivers' runoff are, however, similar to the rivers in the east because they are all affected by moisture coming from the east, but the proportion of water melt from glacier snow and supplied to the rivers increases because precipitation and underlying surface conditions have great differences from the rivers in the east. The dynamic processes of the rivers in the west are affected not only by precipitation, but also obviously by the long-term fluctuating changes in heating power conditions such as alpine air temperature etc. Long-term characteristics in runoff variability of the rivers located in the east and the west can all be represented by the variation in the runoff of the Heihe River runoff, as its upriver is the longitudinal valley and its runoff forming condition is at the middle between the rivers in the east and the rivers in the west. The long-term processes on runoff normally present in a tooth-pattern fluctuation. Weakening in the short-term and high frequency fluctuation in runoff sequences can be averaged by a running mean method and the trend of change in runoff can be displayed if it exists (Lan and Kang, 2001a). The high, the normal and the low flow year can be determined and classified according to the frequency factor of annual runoff in some years, K_p, (K_p = the annual runoff in a certain year / the long-term average runoff) (Lan and Kang, 2001b). The frequency factors and the classification of the elevation, the normal and

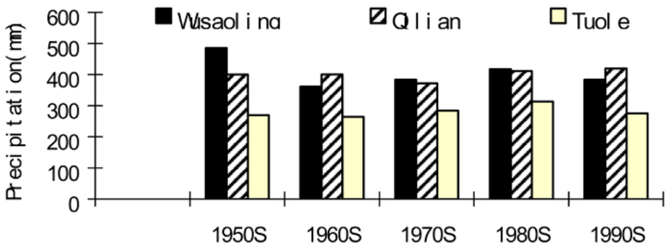

Fig. 3 Decadal precipitation change at the eastern (Wushaoling Station), middle (Qilian Station) and western sections (Tuole Station) of the Qilian Mountains.

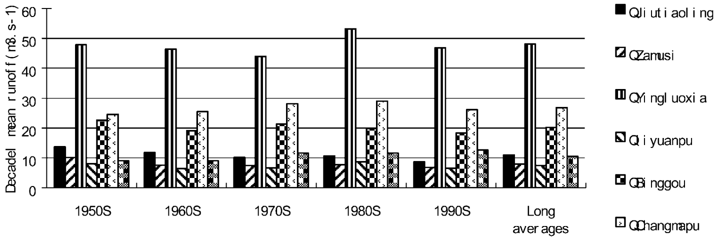

Fig. 4 Decadal change on mountainous runoff at the eastern (Jiutiaoling Station on Xinying River, Zamusi Station on the Zomu River), the middle (Qilian Station on the Heihe River, Liyuanpu Station on the Liyuan River and Tuole Stationon on the Taolai River) and the western sect (Chamapu Station on the Changma River and Dangchengwan Station and Dangchengwan Station on the Dang River).

Table 6 Frequency factors (K_p)* of the mountain runoff in the main rivers in Hexi Region.

Rivers	Stations	HFY	PHFY	NFY	LFY	
			GFHY		GLFY	PFLY
Xiyin	Jiutiaoling	> 1.31	1.31–1.07	1.07–0.88	0.88–0.78	< 0.78
Zamu	Zamusi	> 1.29	1.29–1.02	1.02–0.91	0.91–0.81	< 0.81
Heihe	Yingluoxia	> 1.10	1.10–1.02	1.02–0.98	0.96–0.84	< 0.84
Liyuan	Liyuanpu	> 1.26	1.26–1.03	1.03–0.96	0.96–0.71	< 0.71
Taole	Binggou	> 1.25	1.25–0.98	0.98–0.89	0.89–0.82	< 0.82
Changma	Changmapu	> 1.70	1.27–1.00	1.00–0.93	0.93–0.83	< 0.84
Danghe	Dangchengwan	> 1.29	1.29–1.02	1.02–0.91	0.91–0.84	< 0.84

*K_p = the annual runoff in a certain year / the long-term average runoff (Lan and Kang, 2001b)

the low flow year of the mountainous runoff in the main rivers in Hexi region are presented in Tables 6 and 7. Decadal variations in the temperature, the precipitation and the mountain runoff in the east, the middle and the west part of the Qilian mountains area can be seen in Figures 2–4).

Table 7 Classification of the high, the normal and the low flow of the mountain runoff in the main rivers in the Hexi Region.

Frequency, *P*	High, normal and low flow years classification	
≤12.5%	Particularly high flow year (PHFY)	High flow year (HFY)
12.5%< *P* ≤37.5%	Normal high flow year (GHFY)	
37.5%< *P* ≤62.5%	Normal flow year (NFY)	
62.5%< *P* ≤87.5%	Normal low flow year (GLFY)	Low flow year (LFY)
>87.5%	Particularly low flow year (PLFY)	

Variation Trends of Mountain Runoff

Our climate has been warming because of the change in heat conditions and atmosphere circumfluence, which have led to changes in regional distribution of precipitation and runoff, and the changes in idiographic representations consequently are as follows (Shi, 1995): (i) bringing alpine glacier and snow to melt; (ii) affecting total evaporation quantity in the basin; (iii) changing precipitation form in alpine regions; (iv) changing the temperature difference between alpine glacier zones and the whole basin's underlying surface with the air on the near ground layer, and more affecting the small climate of mountain watershed. Because air temperature is the output term affecting water balance, the rising air temperature in the mountainous area will reduce the mountain runoff on the same precipitation condition. Results of global climate models show that the most firsthand effect resulting from the air temperature rising is the intensity of water cycle increasing. Response of the mountain runoff in the main rivers in Hexi inland region to climate change were researched by analyzing the relationship between annual runoff at the Jiutiaoling, the Yingluoxia and the Changmapu hydrometric station with annual average air temperature and precipitation at the Wushaoling, the Qilian and the Tuole weather stations in the Qilian mountainous area. Results of correlation analysis show there is a consanguineous correlativity between the mountain runoff with the precipitation in the mountainous area (Lan and Kang, 2001c; Lan, 1993). It can be expressly observed from Figure 5 that the mountain runoff in the river at the east, middle and west of the Qilian Mt. presented different change trends. The mountain runoff at the east of the Qilian Mt presented obvious down trends because air temperature descended and precipitation reduced. However the runoff at the middle and west part all presented up-trends because of air temperature and precipitation quantity in mountainous area rising in-phase.

The glaciers on the Qilian Mt. belong to the continental glaciers, which develop at the alpine mountain zones, and whose changes are steady correspondingly under global warming up conditions. Glaciers melting will increase, snow line will rise and glaciers will shrink along with weather warming and air temperature rising. Buildup of glacier melting will bring on the increases of ice-melt runoff and generating runoff at the unit glaciers area on the one hand, glaciers shrinking and

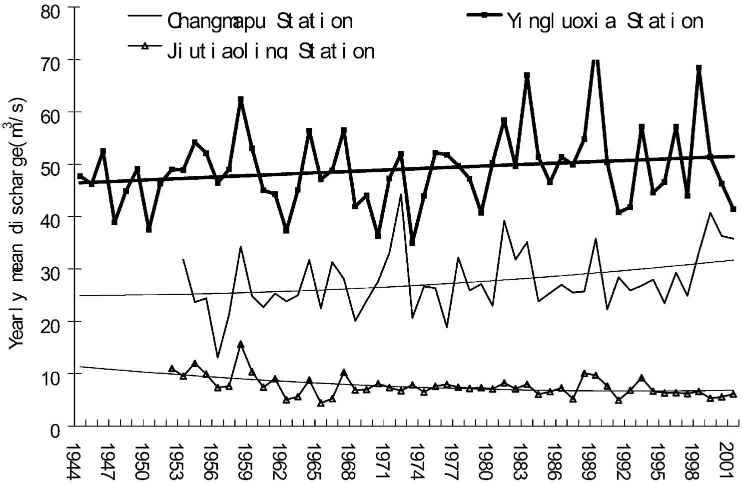

Fig. 5 Trends of change in river runoffs at the eastern, middle and western part of the Qilian Mountains area.

decrease of glaciers area will bring on the reducing of glaciers melting runoff on the other hand. When the effect of buildup of glacier melting increasing glacier-melt runoff is larger than that reducing the glacier-melt runoff, the function of glacier melting runoff supplying rivers will increase. So there is a critical period of glacier melt-runoff from increasing to reducing along with weather warming and glaciers shrinking. The primary research results show the glaciers in the Shiyang River basin, as a whole, belong to the active glaciers region in the continental glaciers in China, and its critical period is about in 2035 under the present weather change trend conditions and that the critical periods of the Heihe River basin and the Shule River basin are after 2050 (Kang, 1999; Kang and Cheng, 2001; Lai, 1992; Prost and Tarody, 1994).

Conclusions

Glaciers are important water resources, in the form of solid reservoirs, whose changes exert a great effect on mountain runoff. The alpine mountain zones in the arid area in Northwestern China belong to the comparatively steady glacier region, all under the influence of continental weather conditions. Glaciers basically shrink continuously within areas of rising air temperature and increasing precipitation. However the shrinking quantity of glaciers is different in various mountain systems and basins, and the range of shrinking is less as a whole. The glacier-melt runoff has presented an increasing trend during recent decades under weather warming. The leading trend of the glacier-melt runoff still is an increase because of weather continually warming up during the coming 30 to 50 years, which will help stave off reduction of the mountain runoff brought on by that warming.

Affected by precipitation, the yearly changing processes of mountain runoff are basically steady, yet there are some differences among the rivers located in the eastern, middle and western parts of the Qilian Mt. Area; that is, the mountain runoff in the eastern parts presents an obvious down-trend owing to air temperature rising and precipitation quantity reducing, the mountain runoff at the middle part increases slightly because precipitation quantity increases slightly and melt-water increases, bringing in a rising air temperature; the mountain runoff located in the western part presents an obvious up-trend owing to air temperature rising and precipitation quantity increasing. It can be expected in the near future that in some years the mountain runoff in the eastern part of the Qilian Mountains will sequentially slowly reduce, that in the middle part will slightly increase or keep a steady state, and that in the western part will sequentially increase.

Yearly changes in the range of mountain runoff will be relatively less, though the precipitation quantities will increase along with air temperature rising as a whole. Therefore the influence on future climate warming of surface water resources in the mountainous area is not quite remarkable and the influence is certainly smaller than that in the surrounding plain areas; even so, the influence of the special geography environment can be expected to be larger than the influence of global weather warming on the mountain runoff in the Hexi Region.

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Adaptive Capacity to Changes in the Water Cycle: A Case Study of Northern China

Shiming Ma, Jianyun Zhang, Silong Zhang, Jinhe Jiang and Yinlong Xu

Abstract Water scarcity and its impacts on agricultural production and food security are growing concerns worldwide. As the most populous country with a rapidly expanding demand for water and food, China's situation in many aspects exemplifies the global picture. Northern China has long been a populous area and an industrial and agricultural base in the country. It is the most serious area of water shortage in China. The total amount of water use increased from 243.7 billion m^3 in 1994 to 254.2 billion m^3 in 2002. Lack of water has become a big constraint to the development of agricultural production and social economy. Many areas in Northern China have average water resources below 500 m^3 per person. With the growing demand for water from agriculture, as well as industries and municipalities, water resources have been exploited excessively. Pollution and environmental degradation, in particular soil and water erosion, have compounded the situation by reducing the availability of usable fresh water. With more frequent droughts enhanced by the changing climate, the potential for additional water supply would decrease.

This study intends to reveal the water shortage issues, changes in water cycle and

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impacts of climate change on the hydrological cycle in Northern China. Firstly, the natural and socio-economic conditions related to the changes in the water cycle as background in Northern China are briefly introduced. The Variable Infiltration Capacity model (VIC-3L) is applied to project the possible changes in water resources, including water supply and demand for the different areas in Northern China under the projected climate change scenarios by Hadley Center's regional climate model system-PRECIS. Then, the adaptive capacity to changes in the water cycle is analyzed by assessing the vulnerability of water resources to the climate change under different climatic and socio-economic scenarios. Finally, it is discussed the possible adaptive options related to the sustainable development and utilization of water resources in Northern China, such as optimizing the distribution of water resources, improving the efficiency of water use, enhancing the saving of water use as well as protection and rehabilitation of ecosystems.

Key words: Adaptive capacity, climate change, Northern China, vulnerability, water cycle, water resources

Introduction

Water scarcity and its impacts on agricultural production and food security are growing concerns worldwide. As the most populous country with the rapid expanding demand for water and food, China's situation in many aspects exemplifies the global picture (CEA, 2000). Northern China has long been a populous area and an industrial and agricultural base in the country. It is the most serious area of water shortage in China. The total amount of water use increased from 243.7 billion m^3 in 1994 to 254.2 billion m^3 in 2002. Lack of water has become a big constraint to the development of agricultural production and social economy. Many areas in Northern China have the average water resources below 500 m^3 per person (MWR, 2003). With the growing demand for water from agriculture, as well as industries and municipalities, water resources have been exploited excessively. Pollution and environmental degradation, in particular soil and water erosion, have compounded the situation by reducing the availability of usable fresh water. With more frequent droughts enhanced by the changing climate, the potential for additional water supply would decrease. This study intends to reveal the water shortage issues, changes in water cycle and impacts of climate change on the hydrological cycle in the Northern China. On the basis of analysis of adaptive capacity to change in water cycle, the possible adaptive options related to the sustainable development and utilization of water resources in the Northern China will be discussed.

Material and Methods

Study Region

Northern China encompasses five provinces (Inner Mongolia, Hebei, Henan, Shandong, Shanxi) and the two major cities of Beijing and Tianjin. It is one of the most important agricultural regions and recognized as one of the most important food pools in China. Dominated by a continental monsoon climate, precipitation in Northern China is generally low and concentrated in a few months for the year. Annual rainfall gradually decreases from about 600 mm in the North China Plain to 440 mm in the Loess Plateau to less than 300 mm in the west of Inner Mongolia. About 70% of the annual precipitation is in the form of storms in the four months of June, July, August and September.

Northern China is one of the most water deficient areas in the world, according to official statistics. China is one of the 13 water deficient countries in the world, with per-capita water resources available standing at 2,200 cubic meters, one quarter of the world's average (MWR, 2003). The regional distribution of China's water resources is extremely uneven, with the possession of water per person in the northern region accounting for only one third of the nation's average. The per-capita possession of water resources in the Beijing-Tianjin-Hebei area, one of the most densely populated areas and a well-developed area in China, is less than one-sixth of China's average, ranging from 150 to 320 cubic meters (MWR, 2002). Prolonged drought in northern China over the past few years has caused water shortages in many cities, forced some enterprises to suspend operations, and led to lower grain production.

It is predicted that when China's population peaks at 1.6 billion in 2030, the per-capita possession of water resources will plummet by 25%, with that in the Beijing-Tianjin-Hebei area plunging to 110 to 240 cubic meters (Zhang et al., 2004). The water shortages will seriously affect China's economic and social development. The relation between water supply and water consumption has been worsening in recent years. The groundwater level in large parts of the North China plain has fallen due to overextraction of water for irrigation and urban supply. Extraction of water for industrial and urban uses is rising rapidly. Many rivers in the North typically run dry during several months of the year. Depending on the region, China also has both drought- and flood-related water problems. Frequent flooding along the Yellow River, ultimately caused by massive sediment deposition in its middle and lower reaches, is a major threat to China's agricultural sector. Water pollution is increasing.

Building of Climate Change Scenarios

To project the future anthropogenic climate change under a range of greenhouse gases (GHG) and aerosol emissions, global climate models (GCMs) are the most

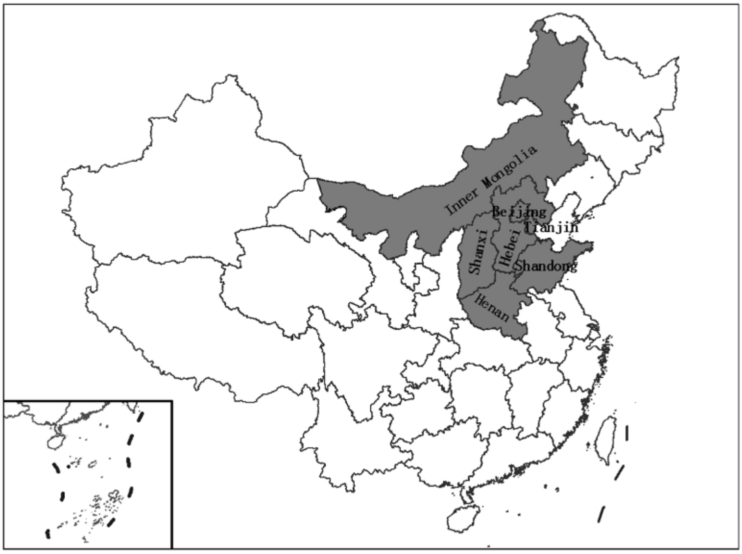

Fig. 1 Study region.

effective way as they are comprehensive mathematical descriptions of the important physical elements and processes in the atmosphere, oceans and land surface which comprise the climate system. However, as the coarse resolution of a few hundred kilometers of GCMs, it is necessary to downscale the climate change projection from coarser scale of GCMs into smaller scales for impacts assessments work. It has been proven that RCM is the most effective and physically reasonable way to downscale the information of climate change projected by GCM from coarse-scale to small-scale for potential impacts assessments of climate change. Hadley Centre RCM system-Providing Regional Climates for Impacts Studies (PRECIS) (Met Office, 2002; Jones, 2004) is under the developing stage towards this purpose all over China, which has been set up to develop the climate scenarios (Xu and Jones, 2004) for assessing the impacts of climate change on Chinese agriculture (Xiong et al., 2003). The large-scale fields are provided from HadAM3H (which is a higher resolution and improved version of the atmospheric component of the Hadley Centre's global coupled model HadCM3) at the lateral boundaries to drive PRECIS. PRECIS was designed to contain: one job of simulated ECMWF reanalysis data, which is taken as an offline experiment to test the PRECIS capacity itself for simulating the historic climatology; 3 jobs of climate baseline scenario (1961–1990), 3 jobs of SRES A2 scenario (2071–2100), and one job for SRES B2 scenario (2071–2100). Except the ECMWF job, there is also a selection of interactive sulphur cycles for all the scenario simulations (Xu and Jones, 2004).

Building of Socio-Economic Scenarios

The medium-long China socio-economic integration model (CEIM) was developed using system dynamics and input-output theory. The main socio-economic indicators and its relation, such as population, urbanization, gross domestic production (GDP), industry structure, etc., were predicted for 2000–2050–2080. The property of system dynamics is medium-long run forecast and strategy programming, and policy analysis, and input-output method can describe in detail the complicated relation between sectors in an economic system. The demand sub-model in our model integrates input-output method (Jiang and Yao, 2004). The model consists of several sub-models, such as production, population, capital (fixed asset investment of sectors and investment demand) and technology advancement, and environment et al. In the production sub-model the economic system includes 10 industries: agriculture, coal, oil and natural gas, other mining, food, chemistry, machine and electron, electricity gas and water, other manufacture, construction, post and transportation, trade and services. Every industry has its production function. The model simulation result mainly includes: GDP, industry value-added, economic growth rate, GDP per capita, industry structure, population, labor structure, urbanization, primary consumption, arable land area, grain demand and supply. The modeling goal is the future socio-economic system development, and the uncertain factors are too much, so we model two scenarios: high and low. Analyzing the two results helps to estimate the future socio-economic development trend. The difference between two scenarios is to set different exogenous technology advancement rates for economic development and different birthrates for population growth.

Projection to Water Supply and Demand

In this study, water supply and demand for the different areas in Northern China were one part of the results simulated by applying the Three-layer Variable Infiltration Capacity (VIC-3L) model under the projected climate change scenarios by Hadley Center's regional climate model system-PRECIS (Zhang et al., 2004). The Variable Infiltration Capacity – Three Layer (VIC-3L) Model is a macroscale hydrologic model that solves a full energy and water balance. It has been used previously to model the hydrology of large river basins such as the Ohio (LSA-E) and the Arkansas-Red (LSA-SW), as well as at a global scale. The basic components of the VIC-3L model: infiltration and runoff are controlled using a Variable Infiltration Curve (VIC); baseflow is controlled by a non-linear function for high moisture content; three soil moisture layers; and variable vegetation coverage (1 through N-1) plus bare soil (N). Soil, vegetation and forcing data sets with a 50 km $\times$ 50 km grid resolution over China are produced. Soil parameters needed are derived from the soil classification information of global 5-min data provided by the NOAA hydrology office, the vegetation parameters are derived based on AVHRR (Advanced Very High Resolution Radiometer) and LDAS (Land Data Assimilation System)

Table 1 Average climate change under SRES A2 & B2 scenarios over China from PRECIS relative to baselines simulation (1961–1990), plus corresponding CO_2 concentrations.

	A2 (medium-high emissions)			B2 (medium-low emissions)		
Time period	Temperature increase (°C)	Precipitation increase (%)	CO_2 (ppmv*)	Temperature increase (°C)	Precipitation increase (%)	CO_2 (ppmv*)
2011∼2020	1.00	3.3	440	1.16	3.7	429
2041∼2050	2.11	7.0	559	2.20	7.0	492
2071∼2080	3.89	12.9	721	3.20	10.2	561

*Parts per million by volume

Table 2 Seasonal changes of mean precipitation (%) in 2071–2100 to baseline (1960–1990) in Northern China and China under B2 scenario projected by PRECIS.

Region	Annual	Spring	Summer	Autumn	Winter
China	9.6	13.1	6.3	2.8	8.7
North China	14.2	28.1	2.1	8.6	62.9

information and the forcing data are obtained through interpolation methods based on 699 meteorological stations. Daily forcing data from 699 stations for the period 1980–1990 are mapped to each grid through the interpolation methods. The VIC-3L model is applied to each of the 4355 grids for the period 1980–1990.

Results and Discussion

Climate Change Scenarios for 2020s, 2050s and 2080s

The average temperature increase projected by PRECIS will be between 3 and 4°C by the end of the 21st century in China, depending on the level of future emissions. The change of precipitation shows an increased trend generally as well. The projected climate change scenarios of three decades for the emissions scenarios A2 and B2 are summarized in Table 1.

The temperature and precipitation changes under A2 and B2 scenarios in 2071–2090 in Northern China are shown in Table 3.

Socio-economic Scenarios for 2020s, 2050s and 2080s

The population and GDP are the main driving forces for the building of socio-economic scenarios. Based on the SRES scenarios, the medium-long China socio-

Table 3 Temperature and precipitation changes to baselines simulation (1961–1990) under A2 and B2 scenarios in 2071–2090 in Northern China.

Location	A2 (medium-high emissions)		B2 (medium-low emissions)	
	Temperature increase (°C)	Precipitation increase (%)	Temperature increase (°C)	Precipitation increase (%)
Beijing	3.8	16	3.3	20
Tianjin	3.8	20	3.2	22
Hebei	3.8	12	3.2	17
Henan	3.6	10	2.8	14
Shandong	3.6	12	3.0	8
Shanxi	4.1	4	3.4	9
Inner Mongolia	4.3	17	3.6	15

Table 4 Population changes under A1 scenario.

A1 Population (million)	2000	2020	2050	2100
Beijing	13.8	14.7	14.1	8.4
Tianjin	10.0	10.7	10.2	6.1
Hebei	67.4	71.8	68.7	40.8
Henan	92.6	98.5	94.3	56.0
Shandong	90.8	96.6	92.4	55.0
Shanxi	33.0	35.1	33.6	20.0
Inner Mongolia	23.8	25.3	24.2	14.4

Table 5 Population changes under A2 scenario.

A2 Population (million)	2000	2020	2050	2100
Beijing	13.8	17.5	22.9	28.6
Tianjin	10.0	12.7	16.6	20.7
Hebei	67.4	85.4	111.8	139.5
Henan	92.6	117.2	153.5	191.5
Shandong	90.8	115.0	150.6	187.9
Shanxi	33.0	41.8	54.7	68.2
Inner Mongolia	23.8	30.1	39.4	49.2

economic integration model (CEIM) is used to predict population and GDP development in the 21st century under A1, A2, B1 and B2 scenarios (Tables 4–11).

The growth ratios of population and GDP are designed based on the statistical data in 2000, with different ratios at the different time series. The trends of population and GDP changes under four different scenarios in Beijing are shown in Figure 2.

Table 6 Population changes under B1 scenario.

B1 Population (million)	2000	2020	2050	2100
Beijing	13.8	14.7	14.1	8.4
Tianjin	10.0	10.7	10.2	6.1
Hebei	67.4	71.8	68.8	40.8
Henan	92.6	98.5	94.3	56.0
Shandong	90.8	96.6	92.4	55.0
Shanxi	33.0	35.1	33.6	20.0
Inner Mongolia	23.8	25.3	24.2	14.4

Table 7 Population changes under B2 scenario.

B2 Population (million)	2000	2020	2050	2100
Beijing	13.8	15.7	17.0	17.3
Tianjin	10.0	11.3	12.3	12.6
Hebei	67.4	76.4	82.7	84.6
Henan	92.6	104.8	113.6	116.1
Shandong	90.8	102.8	111.4	113.8
Shanxi	33.0	37.3	40.5	41.4
Inner Mongolia	23.8	26.9	29.2	29.8

Table 8 GDP changes under A1 scenario.

A1 GDP (billion yuan)	2000	2020	2050	2100
Beijing	247.9	1324.7	7124.2	18098.7
Tianjin	163.9	876.1	4711.7	11969.8
Hebei	508.9	2719.6	14626.2	37157.0
Henan	513.7	2745.6	14766.1	37512.6
Shandong	854.2	4565.1	24551.8	62372.6
Shanxi	164.4	878.5	4724.5	12002.3
Inner Mongolia	140.1	748.7	4026.6	10229.5

Changes of Water Supplies and Demands

The total water consumption in China will keep a low increase in the future. Based on the projected changes of water supplies and demands, the annual increase rate of total water consumption will be 0.59% or less than 0.30% between 2000 and 2050, with water consumption around 8000 billion m^3/a. From 2050 to 2100, the zero increase rate of total water consumption could realize (Tables 12 and 13). The general trend of water supplies and demands in Northern China is similar to total China, with the exception of Inner Mongolia, where the water deficit will continue to 2100 (Table 14).

One of the significant changes in water consumption in China is that the total water consumption fluctuates around 550 billion m^3/a between 1997 and 2000. The

Table 9 GDP changes under A2 scenario.

A2 GDP (billion yuan)	2000	2020	2050	2100
Beijing	247.9	570.3	1668.3	7380.6
Tianjin	163.9	377.1	1103.4	4881.3
Hebei	508.9	1170.7	3425.1	15152.6
Henan	513.7	1181.9	3457.9	15297.6
Shandong	854.2	1965.2	5749.5	25435.5
Shanxi	164.4	378.2	1106.4	4894.5
Inner Mongolia	140.1	322.3	943.0	4171.6

Table 10 GDP changes under B1 scenario.

B1 GDP (billion yuan)	2000	2020	2050	2100
Beijing	247.9	817.7	3237.2	8163.9
Tianjin	163.9	540.8	2140.9	5399.3
Hebei	508.9	1678.7	6646.0	16760.6
Henan	513.7	1694.8	6709.6	16921.0
Shandong	854.2	2817.9	11156.1	28134.8
Shanxi	164.4	542.3	2146.8	5413.9
Inner Mongolia	140.1	462.2	1829.7	4614.3

Table 11 GDP changes under B2 scenario.

B2 GDP (billion yuan)	2000	2020	2050	2100
Beijing	247.9	1035.6	3898.4	8792.1
Tianjin	163.9	685.0	2578.3	5814.8
Hebei	508.9	2126.3	8003.5	18050.4
Henan	513.7	2146.7	8080.1	18223.2
Shandong	854.2	3569.3	13434.9	30299.8
Shanxi	164.4	686.8	2585.3	5830.6
Inner Mongolia	140.1	585.4	2203.4	4969.3

most significant increase in water consumption is for industry use with an increase of 25% in 2.8% rate per year between 1993 and 2000. Water consumption for households both in cities and towns, and in rural areas increased 32.2% in 6.0% rate per year at the same time. The water consumption for agriculture did not increase. Water supply will increase due to the increase of precipitation in the next 50 years. The projected results were shown in Table 3. The critical changes in water cycle is that the run-off per capita decreases significantly both in A2 and B2 scenario and in no climate change condition with the increasing population in 2075 in Northern China (Figure 3).

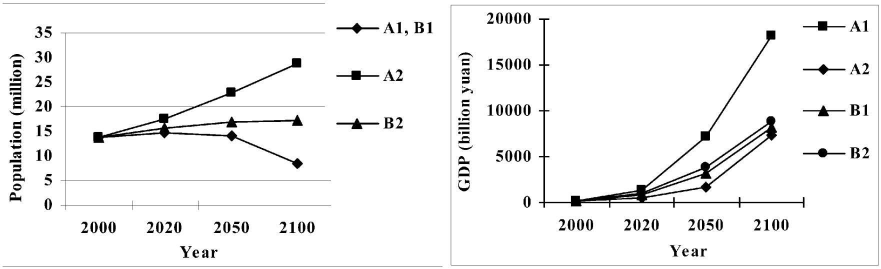

Fig. 2 Population and GDP changes under four different scenarios in Beijing.

Table 12 Prediction of possible total water supply in Northern China (billion m^3).

	2000 (actual water supply)	2050	2100
Beijing	4.0	6.9	7.9
Tianjin	2.3	3.4	3.6
Hebei	21.2	28.3	30.6
Henan	20.5	27.4	29.9
Shandong	24.9	30.9	32.3
Shanxi	5.7	8.7	9.4
Inner Mongolia	17.2	27.5	35.0
North China	95.8	134.1	148.7
China total	553.1	780.2	825.0

Table 13 Prediction of possible total water demand in Northern China (billion m^3).

	2000 (actual water consumption)	2050	2100
Beijing	4.0	6.9	7.9
Tianjin	2.3	3.4	3.6
Hebei	21.2	28.3	30.6
Henan	20.5	27.4	29.9
Shandong	24.4	30.9	32.3
Shanxi	5.6	8.7	9.4
Inner Mongolia	17.2	29.4	37.2
North China	95.2	136.0	150.8
China total	619.5	786.3	831.8

Adaptive Capacity Analysis

Northern China is identified as one of the most vulnerable regions in water resources in China. The available water resources access per capita per year in most provinces and cities are below China's average exception of Inner Mongolia (Table 15).

The vulnerability of the water resources in Northern China will not change a lot in the future. With increasing population, the run-off per capita will decrease sig-

Table 14 Water balance between predicted supply and demand in Northern China (billion m^3).

	2000 (actual water consumption)	2050	2100
Beijing	0	0	0
Tianjin	0	0	0
Hebei	0	0	0
Henan	0	0	0
Shandong	0.5	0	0
Shanxi	0.1	0	0
Inner Mongolia	0	–1.9	–2.2
North China	0.6	–1.9	–2.2
China total	–66.4	–6.1	–6.8

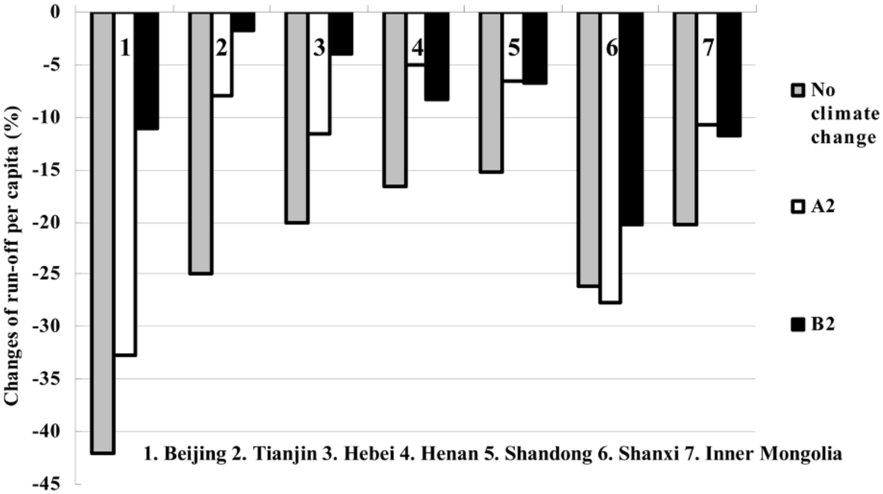

Fig. 3 Changes of run-off per capita under A2 and B2 scenarios and without considering climate change in 2075 in Northern China.

Table 15 Available water resources per capita in 2000 in Northern China (in m^3 per capita per year).

Beijing	Tianjin	Hebei	Henan	Shandong	Shanxi	Inner Mongolia	North China	China
289.9	230.0	314.5	221.4	274.2	172.7	722.7	317.9	438.2

nificantly. Without considering climate change, the run-off per capita will averagely drop 23% with 1069 m^3 in 2075 compared to the baseline (1960–1990) in China and with 30% decreasing rate in North China (Figure 3). Under A2 scenario, the run-off per capita will on average drop 13% with 618 m^3 in 2075 compared to the baseline (1960–1990) in China and with 18% decreasing rate in Northern China. Under B2 scenario, the run-off per capita will on average drop 13.5% with 621 m^3 in 2075 compared to the baseline (1960–1990) in China and with 20 to 40% decreasing rate in Northern China. The run-off per capita in Beijing and Shanxi Province will drop 40%. Adaptive capacity is the ability of a system to evolve in order to accommodate climate changes or to expand the range of variability with which it can cope (Jones, 2001; Yohe and Tol, 2002). Adaptive capacity varies widely between different temporal and spatial scales. The differences between scales are determined by environmental factors as well as the various demographic, social, economic, political and cultural features of different human systems (Burton et al., 1998).

The capacity to adapt to climate change is closely linked to the capacity to cope with and respond to climate variability and extreme events. The economic, institutional, political, social factors are likely to play an important role in enabling the society to adapt to climate change. By analysis of adaptive capacity to water cycle changes in Northern China, the factors, such as population, GDP and gross output value of industry, related to levels of development, are identified as determinants of adaptive capacity (Table 16). The adaptive capacity in Northern China is therefore divided into three groups. The first group contains Beijing and Tianjin cities with strong adaptive capacity. The second group belongs to moderate adaptive capacity which includes Hebei, Henan, Shandong Provinces. And the third group is with weak adaptive capacity, including Shanxi Province and Inner Mongolia Autonomous Region. As the "Water Transfer Schemes South to North" starts to actualize and the process around the Bohai economic Cycle is accelerated, the adaptive capacity of water resources in Beijing, Tianjin, Hebei and Shandong will be enhanced.

Adaptive Options for Sustainable Development and Utilization of Water Resources

Although the uncertainties of the potential impacts of water cycle changes on ecosystems and national economy makes decision making in adaptation difficult, the possible adaptive options related to the sustainable development and utilization of water resources will help enhance the adaptive capacity in Northern China. The adaptive options to reduce vulnerability and enhance the adaptive capacity in water resources could be taken in the following areas:

- Based on the national long-term development plan, a long-term development plan to build modernized water management systems both at the regional and provincial levels needs to be drawn up.
- To improve the management of exiting infrastructure to promote water-saving work in the whole society should be taken as one of many strategic options.
- The new water-saving techniques, in particular in the industrial and urban sectors, should be actively adopted, as water uses for industrial and urban use is rising rapidly.

Table 16 Glacier water resources and mountain runoff in the Hexi Region.

Key economic indicator in Northern China (2002)	Beijing	Tianjin	Hebei	Henan	Shanxi	Shandong	Inner Mongolia	North China	Share of China %
Population million	14.2	10.1	67.4	96.1	32.9	90.8	23.8	335.3	26.1
Area $\times 10^3$ km^2	16.8	11.9	188.0	167.0	156.0	156.7	1183.0	1879.5	19.6
Arab Land $\times 10^3$ ha	343.9	485.6	6683.3	7262.8	4588.6	7334.7	8201.0	34899.9	26.8
GDP billion(1000 m)	321.3	205.1	612.3	616.9	201.8	1055.2	173.4	3185.9	30.4
Gross output value of industry billion(1000 m)	317.4	332.3	429.5	430.4	171.8	560.3	99.5	2341.1	21.1
Gross output value of agriculture billion(1000 m)	23.0	18.1	172.9	219.5	35.2	11645.0	58.8	780.0	28.5
GDP per capita Yuan	28449.0	22380.0	9115.00	6436.5	6146.0	11645.0	7241.0	91412.5*	159.6**
Wheat output 1000 t	243.0	441.0	10099.1	22483.0	2432.0	15470.6	1215.0	52384.6	58.0
Maize output 1000 t	461.0	771.0	10350.0	11897.6	4353.0	13160.3	8215.0	49207.9	40.6

Source: National Bureau of Statistics of China (NBSC), 2003;
*The average value in the region.
**The equilibrium of regional value to the national average value.

- In order to improve the response ability in the water supply, the building and rebuilding of small and medium size reservoirs in the region could significantly optimize the distribution of water resources in the region. Furthermore, the Water Transfer Schemes South to North will alleviate potential water shortages to a great extent in Northern China.
- Enhance water and soil conservation, watershed administration and construction of environmental protection engineering which aim to improve the protection and rehabilitation of ecosystems should be taken as one of the long-term tasks.
- The control of the use of groundwater should be in a move to prevent the sinking of the ground and sea water erosion. The efficient use and quality control of the water resources transferred by the "Water Transfer Schemes South to North" are both the challenges we face and the adaptive options, if ever the schemes start.

Generally, adaptation is one of the effective ways to respond to water cycle change. While some adaptation options might alleviate present and potential water shortages, other options, such as irrigation, will directly affect the demand. The implementation of adaptive options could reduce the adverse impacts of climate change on water resources, but with quite huge investments. The extra investments needed for the implementation of adaptation options are a huge burden for the economic development of China, in particular, for some of the less developed provinces in Northern China.

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Measuring Climate Change Risk on Supply Chain of Rice in Bangladesh

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Abstract Climate change may cause abrupt fluctuations in weather and it is a potential threat to rice production of Bangladesh. Existence of the causal relation between the state of weather and rice production sets the objective of this paper to measure the probable risk on supply chain of rice due to climate change. Applying the risk analysis techniques for stock-market portfolio analysis, risk and return of climate induced fluctuation of rice production is estimated. The yield of three different types of rice varies in different weather conditions like drought, flood etc. In an unfavourable weather condition, yield of rice is lower than the expected yield. A 30% increase of probability of drought, flood and joint occurrence of drought and flood may reduce annual expected rice production by 95.4, 65.2 and 76.3 thousand metric tons respectively on average in the long-run. In an actual year of drought, the production of rice may be 1.92 million metric tons less than normal expected production. The risk of fluctuation in rice production increases with higher probabilities of bad weather. Fluctuation of rice production may make the supply chain of rice vulnerable. Hence, climate change should increase the risk of supply chain instability for rice in Bangladesh.

Key words: Rice production, supply chain, climate change, risk analysis

Introduction

Bangladesh is one of those countries that may suffer from adverse weather conditions due to climate change. Adverse weather may affect the agricultural system of this country causing ups and downs in agricultural yields. Rice is the main crop of this country and its supply chain may become unstable because of weather related fluctuations in production. This supply chain is a complex process involving three

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phases of activities. First phase is the collection and distribution of necessary inputs like fertilizer, seeds etc. Second phase is the production of rice in fields that encompass interaction between human labour and acts of nature in addition to other inputs. The last phase is distribution of produced rice. It is possible to control the first and third phases of supply chain through managerial interventions but the second phase of producing rice is, to a great extent, out of managerial control. Fluctuation of weather may have a strong impact on level of production of rice. The state of weather is dependent on climate change. The second phase of a supply chain has inherent risk of production fluctuations due to climatic changes.

Climate change brings changes in the state of weather and may be the source of new risks to our agricultural production system. Climate refers to the average weather experienced over a period of thirty years. The term climate change usually refers to changes in weather that have occurred since the early 1900s. In 1999, the United Nations Framework Convention on Climate Change defined climate change to mean a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods. Some scientists have suggested that droughts, floods, and hurricanes will become more common with climate change. Despite tremendous technological advances in agriculture, weather is still a key factor in agricultural productivity and excess rain, flood and drought are risk factors for production of rice.

According to experts' opinion, Bangladesh is subject to high risk of climate change induced fluctuating weather. Already climate change is affecting agriculture of this country through prolonged inundation, increased drought, salinity and loss of land due to erosion (Rashid and Islam, 2007). Increased evapotranspiration has been resulting in more water demand and exploitation of groundwater leading to water shortage for agriculture (Selvaraju et al., 2006). The climate is one of the biggest risk factors impacting on agricultural systems performance in Bangladesh because climate variability contributes to the vulnerability of agricultural yield. Agriculture is the main occupation of the people in Bangladesh that employs about 60% of the active labour force and contributes around 30% to Gross Domestic Product (GDP). Rice is a major crop in the country. It accounts for about 70% of total cropped area and about two-third of value added in crop production. Fluctuation in rice production must have adverse impact on the macro-economic stability of the country.

There are three different types of rice in Bangladesh – the direct seeded pre-monsoon Aus in upland; irrigated mainly dry season Boro and rain-fed lowland Aman. Each type of rice has two varieties, local and modern high yield. Boro is the main crop in the country and it was about 55% of total rice production in 2005. The three types of rice have three different harvesting times; Aus in July–August, Aman in November–December and Boro in April–May. They are subject to different types of weather risks because of differences in cropping times. For example, Boro is subject to risk of drought while Aus may face risk of flood.

The objective of this paper is to analyse the risk in supply chain of rice measured in terms of variability of rice production within the framework of interactions among climate, weather and agriculture. It specifically measures probable risk of variation in rice production due to climate change induced increased frequency of floods and droughts in Bangladesh. In specific there are three objectives. First, estimating level of risks associated with three different types of rice production under the existing state of weather. Second, to understand whether the risk of producing rice may be diversified or reduced by changing proportion of local and high yielding varieties of rice. Finally, analysis of potential impacts of weather changes on the production of rice of three types.

This paper uses risk and return measurement methods of portfolio analysis in stock markets to measure climate related risk on supply chain of rice. This methodology of risk analysis helps to include probability of weather change situations for measuring the risk of rice production.

Materials and Methods

The sources of data for this paper are the Bangladesh Bureau of Statistics (BBS) and Bangladesh Meteorological Department. Using secondary data available from the stated source, the acreage and production of rice by types are analysed for 31 years between 1974 and 2005 with respect to weather conditions of the same period. The probabilities of normal weather, drought, flood and joint occurrence of drought and flood in the same year are estimated from the meteorological data of the years between 1974 and 2005. Each type of rice is considered as a portfolio of two different varieties, local traditional rice and modern high yield variety (HYV) rice. The harmonic mean of each variety of rice of all types is calculated for different weather conditions. The expected yield and standard deviation (SD) of each type of rice for all varieties are calculated as follows. Expected yield is the average yield and standard deviation is the measure of risk.

$$E(Y^{tv}) = \sum_{w=1}^{n} P_w Y_w^{tv} \tag{1}$$

$$\sigma^{tv} = \sqrt{\sum_{w=1}^{n} [Y_w^{tv} - E(Y^{tv})]^2 \times P_w} \tag{2}$$

Here, t is type of rice and v is variety within each type of rice, w is weather condition, Y is yield, P is probability, σ is standard deviation, and $E(Y)$ is expected yield. The elements of sets of t, v and w are the following:

$$t = \{\text{Aus, Aman, Boro}\}$$

$$v = \{\text{local, HYV}\}$$

$$w = \{\text{normal, drought, flood, drought \& flood}\}$$

As mentioned earlier, each type of rice is a portfolio of two varieties and expected yield of the portfolio is calculated as following where L_1 and L_2 are proportions of land used for local variety and HYV of rice production respectively. This portfolio yield is the expected yield from a combination of two varieties of rice.

$$E(Y^t) = L_1 \times E(Y^t_{local}) + L_2 \times E(Y^t_{HYV}) \tag{3}$$

The covariance of yields of two varieties of a type of rice measures their comovement. It helps to understand if it is possible to reduce risk by changing combinations of varieties in a portfolio. A positive covariance indicates no possibility of risk reduction through combination of different items in the portfolio while a negative covariance indicates the opposite. In addition, the correlation between two elements is the indication of strength of association between the two and the sign of correlation is the direction of the relation. The calculation procedure of covariance and correlation for a portfolio of two members is the following:

$$Cov^t_{local,HYV} = \sum_{w=1}^{n} [Y_w^{t,\,local} - E(Y^{t,\,local})] \times [Y_w^{t,\,HYV} - E(Y^{t,\,HYV})] \times P_w \tag{4}$$

$$Cor^t_{local,\,HYV} = \frac{Cov^t_{local,HYV}}{\sigma^t_{local} \times \sigma^t_{HYV}} \tag{5}$$

The portfolio standard deviation is the measure of risk from the combination of all elements of a portfolio. In case of a negative correlation between elements of a portfolio, the portfolio SD becomes smaller than the individual SD of the elements and indicates reduction of risk. The procedure for calculation of portfolio standard deviation is:

$$\sigma^t = \sqrt{(\sigma^t_{local})^2 L_1^2 + (\sigma^t_{HYV})^2 L_2^2 + 2L_1 L_2 Cov_{local,\,HYV}} \tag{6}$$

The last stage of the analysis is simulation of risk scenario and assessing impact on the production of rice in Bangladesh. The changes in expected risk and return parameters are analysed at 10% and 30% increase in the probability drought, flood and joint occurrence of drought and flood in same year. Probability of a single weather condition has been changed at a time resulting in decrease in normal weather holding other risk conditions of weather unchanged. The rice production and acreage data of the year 2004–05 is the base of analysis. All changes and impacts are compared with the expected values of existing weather condition.

Results and Discussion

All three varieties of rice have yield fluctuation subject to state of weather. In general, normal weather helps to produce higher output in all cases except high yielding variety of Aus. Table 1 shows rice yields in different states of the weather. This vari-

Table 1 State of weather and respective yield of different types of rice in Bangladesh.

Climate		Average production of rice (metric ton per acre)					
State	Probability	Aman		Aus		Boro	
		Local	HYV	Local	HYV	Local	HYV
Normal	0.387	0.526	0.928	0.384	0.749	0.613	1.145
Flood	0.323	0.492	0.873	0.363	0.791	0.618	1.147
Drought	0.161	0.458	0.788	0.348	0.808	0.587	1.086
Drought and flood	0.129	0.468	0.866	0.332	0.838	0.533	1.018

ety of rice showed higher yield in adverse weather conditions. According to harvesting pattern, Boro and Aman are exposed to the risk of drought. The per acre yield loss is the higher of these two types of rice during drought. Aman is also exposed to risk of flood and shows lower yield in case of flood. Aus is exposed to risk of flood but at the same time it is a flood friendly crop. Its yield fluctuation is low across different states of weather. However, Boro and Aman are primary rice harvests in Bangladesh and drought is a major risk for the rice supply chain in this country.

Table 2 presents measurement of risk and expected return for three different types of rice when they are exposed to existing weather conditions. The yield of HYV Boro is the highest followed by HYV Aman. These two varieties also have a high level of standard deviations or risks. All HYV of rice have high risk compared to local varieties. Local Aus variety has lowest risk, only 0.0180 and HYV Aman has highest risk 0.0478. Bangladeshi farmers harvest both local and HYV rice and the risk factor is dependent on the proportion of land allocated among two varieties. As a portfolio, expected yield of Boro is 1.096 metric ton per acre compared to 0.707 and 0.549 metric tons respectively for Aman and Aus. Boro portfolio has highest risk 0.0442 because farmers allocated 95.4% of total cultivated land for this type of rice to HYV.

Among the portfolios, Aus has a negative covariance and strong negative correlation coefficient between two local and HYV varieties. It indicates the opportunity to reduce risk of portfolio by combination of two varieties. Local and HYV of Aus are not equally exposed to risks of weather rather they have opposite tendencies. So, the combination of two varieties may not increase expected yield but certainly reduces risk of production. Aman and Boro portfolios have positive covariance and also strong positive correlation coefficients. In a favourable weather these two portfolios should produce more rice than expected yield. In unfavourable weather the yield of these two types of rice should be below the expected yield. In normal weather, yield of Boro portfolio may be as high as 1.183 metric ton per acre, higher than individual yield of HYV Boro. In an unfavourable year, most likely in a year of drought, yield of Boro portfolio may be as low as 1.001 metric tons, 8.67% less than the expected yield. Similarly, Aman yield may vary between 0.781 and 0.634 metric tons per acre depending on weather conditions. Aus yield is very robust and yield variations may be between 0.556 and 0.542 metric ton per acre.

Table 2 Expected risk and return parameters of different types of rice.

	Parameters	Aman		Aus		Boro	
		Local	HYV	Local	HYV	Local	HYV
Independent	Expected Yield (M. Tons per Acre)	0.497	0.880	0.365	0.784	0.600	1.120
	Standard Deviation	0.0261	0.0478	0.0180	0.0308	0.0279	0.0450
	Share of Land (Reference Year 2004–05)	45.0%	55.0%	56.0%	44.0%	4.6%	95.4%
Portfolio	Expected Yield (M. Tons per Acre)	0.707		0.549		1.096	
	Covariance	0.0012		–0.0006		0.0012	
	Correlation	0.938		–0.995		0.991	
	Standard Deviation	0.0375		0.0037		0.0441	
	Interval Estimate of Expected Yield at 95% Confidence Level (a = 0.05)	0.707 ± 0.074		0.549 ± 0.007		1.096 ± 0.087	

Climate change is expected to have impact on the state of weather through changing frequency of droughts and above normal floods in Bangladesh. Table 3 presents expected yield and risk when there are 10 and 30% changes in probabilities of drought, flood and joint occurrence of drought and flood. At 10% increase in probability of drought, expected yield of Aman and Boro may fall by 0.14 and 0.09% respectively. The standard deviation or risk of Aman and Boro may increase by 0.16 and 0.23%, respectively. If the probability of drought increases by 30%, the expected yield of Aman and Boro may decrease by 0.71 and 0.27%, respectively. Risks also increase for these two types of rise. The increase in probability of drought may not have any impact on the yield of Aus. In fact, it may reduce the risk of Aus yield by 2.70% at a 30% increase in probability. Aus is the type of rice that may negate impact of drought if there is a normal level of flood.

Increase in probability of flood does not have much impact on yield of Aus and Boro. The yield of Aman may be affected by increase in flood probability. A 10 and 30% increase of flood may decrease Aman yield by 0.14 and 0.71%, respectively. It is very similar to the fluctuations as it is in drought. Though, the expected yield of Boro is not affected by increase in probability of flood, but fluctuation of yield increases. The risk of fluctuation of yield of Aus decreases with increase in probability of flood in Bangladesh. Aus yield is robust compared to the other two varieties of rice in both flood and drought situations.

The combined impact, when flood and drought occurs in the same year, may be highest on the Boro. Annual yield may be reduced by 0.46% and risk of yield fluctuation may be increased by 8.62% at a 30% increase probability. Aus yield remains unaffected again though the yield fluctuation may increase. However, yield

Table 3 Expected return and risk of rice yield and higher probability of bad weather.

State of weather	Parameters	10% increase			30% increase		
		Aman	Aus	Boro	Aman	Aus	Boro
Drought	Expected yield metric ton per acre	0.706	0.549	1.095	0.702	0.549	1.093
	Standard deviation	0.0381	0.0037	0.0442	0.0391	0.0036	0.0443
	Change compared to existing weather condition						
	Expected yield	–0.14%	0%	–0.09%	–0.71%	0%	–0.27%
	Standard deviation	0.16%	0%	0.23%	4.27%	–2.70%	0.45%
Flood	Expected yield metric ton per acre	0.706	0.549	1.096	0.702	0.549	1.096
	Standard deviation	0.0368	0.0036	0.0442	0.0352	0.0035	0.0443
	Change compared to existing weather condition						
	Expected yield	–0.14%	0.00%	0.00%	–0.71%	0.00%	0.00%
	Standard deviation	–1.87%	–2.70%	0.23%	–6.13%	–5.41%	0.45%
Flood & drought	Expected yield metric ton per acre	0.707	0.549	1.094	0.705	0.549	1.091
	Standard deviation	0.0373	0.0037	0.0455	0.0368	0.0038	0.0479
	Change compared to existing weather condition						
	Expected yield	0.00%	0.00%	–0.18%	–0.28%	0.00%	–0.46%
	Standard deviation	–0.53%	0.00%	3.17%	–1.87%	2.70%	8.62%

fluctuation of Aman may reduce in combined impact years, but yield itself may reduce by 0.28% if probability increases by 30%.

At the 30% increase in probabilities of flood, drought and flood & drought may have a long-run impact on the annual yield of rice. Table 4 shows the estimated potential impacts of climate change on rice production in Bangladesh. Average yield loss for 30% probability increase in drought and flood should be 95.4 and 65.2 thousands metric tons every year respectively. The same level of probability increase in joint occurrence of flood and drought should have an average annual yield loss of 76.3 thousand metric tons. So, climate change induced bad weather may reduce availability of rice in the supply chain.

Analyzing the expected yield at the level of land use of year 2004–05, it is estimated that in an actual year of drought, flood and joint flood and drought year the aggregate rice yield should be 92.14%, 98.28% and 90.57% of the expected aggregate yield of a normal year. In an actual drought year the production loss of rice may be about 1.92 million metric tons and the same for an above normal flood year should be 0.042 millions tons of rice. In a year of joint occurrence of flood and drought total production loss may be about 2.30 million metric tons.

Table 4 Long-term total yield loss of rice for climate change and 30% increase in probability of different state of weather.

Type of rice	Land use at level of 2004–2005 (‘000 acres)	Expected production (’000 metric tons)			
		Existing weather condition	30 % Probability increase		
			Drought	Flood	Flood & drought
Aman	13047	9224.2	9159.0	9159.0	9198.1
Aus	2532	1390.1	1390.1	1390.1	1390.1
Boro	10042	11006.0	10975.9	11006.0	10955.8
Total		21620.3	21525.0	21555.1	21544.0
Change			–95.4	–65.2	–76.3

Conclusions

The macroeconomic stability, poverty level and economic growth of Bangladesh are dependent on the normal production of rice in the country. Fluctuation in rice production may create vulnerability in the supply chain of the country and may affect all economic variables. Unfortunately, the climate change induced changes in weather is a genuine risk factor for rice yield of this country. More critical is that its two main types of rice, Aman and Boro, are more exposed to weather fluctuations and it is not possible to reduce this risk by altering proportion of land allocation to local and HYV varieties. It is expected that Bangladesh has to face frequent uncertainty in supply chain of rice in coming years because climate change will cause significant changes in weather of this country. Probably the country will become more incapable to ensure a stable supply chain of rice in coming years. In a year of unfavourable weather, Bangladesh may need to import a large quantity of food grains to supplement supply chain deficits in rice due to internal loss of production. In existing situation of declining food production all over the world, import of food may become very difficult. The country should start formulating strategic contingency plans to face supply chain uncertainty of rice immediately. Failure to do so may result in unbearable human and social calamities in the country.

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The Multi-Functional Role of Rice Paddy Area for Food and Water Sustainability – Lessons Learned from Korean Tradition

Mooyoung Han and Jaesoo Shim

Abstract Korea has always suffered from frequent flooding and drought because of its unfavorable climate and geological conditions. In order to survive the worst conditions and maintain food and water sustainability, some technology and wisdom might have been developed and melted into the Korean tradition and culture. Some of important wisdoms might be the selection of rice as the major crop, respecting farmers, developing rain gauge and record keeping of a nation wide rain gauge network and making regulations encouraging reservoirs. The multifunctional role of rice paddy areas such as to control flooding, draught, erosion, etc are reevaluated. From the lessons learned from Korean tradition, a new water management paradigm is suggested, which is to manage with many small reservoirs controlling both water quality and quantity at the source. The decentralized rainwater management at the whole watershed by all the stakeholders might be a good strategy for climate change adaptation.

Key words: Food sustainability, Korean tradition, new paradigm, rainwater management, rice paddy area, water sustainability

Introduction

Korea has always suffered from frequent flooding and drought because it is located in a monsoon area. The annual average rainfall is 1,300 mm, however, the dispersion of rainfall is about 12,000 mm, which is one of the highest in the world (Figure 1).

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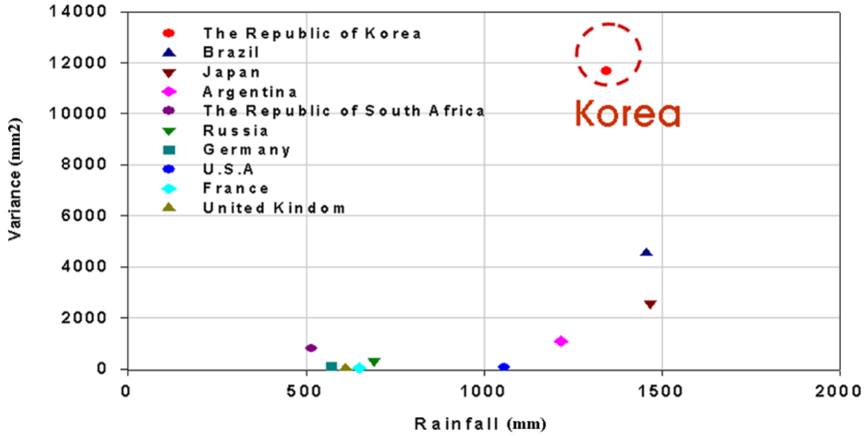

Fig. 1 Average and dispersion of rainfall in Asian countries.

Furthermore, about 70% of Korean peninsular is mountainous area. Therefore, it is very difficult to manage water.

Because water management is directly related to food production, economy and society, not only the leaders but also ordinary citizens of old Korean nations must understand the important relationship between water and food management. The ruling philosophy of GhoChosun (the first nation which was founded in BC2333) was toward the sustainable water management showing the importance of rainwater management. The whole society made a consensus for the sustainable management of water, and this has been melded into the tradition and culture of Korea directly and indirectly.

Traditionally in Korea, growing rice is recommended probably because the periods of water demand for rice growing coincide with the rainfall pattern (Figure 2). Although rice growing takes a lot of different steps from the seeding to the harvesting (88 processes, which made the symbolic character of rice; 米), farmers are considered as the most important persons in the world (農者天下之大本). Farmers in Korea are respected not only for the role of food producer, but also for water management. This kind of wisdom is inevitable to survive the worst climate and geographical condition in Korea. As a result the first rainwater gauge was invented (1441) in Korea by King Sejong, the Great, who started collection and record keeping of rainfall data from a nation-wide network since 1448. Numerous small reservoirs were built all around the country based on the law and government organization to make reservoirs. Such technologies to make reservoirs are transferred to other neighboring countries. In the future, such wisdom coupled with advanced technology will be a good preparation for climate change adaptation.

The purposes of this chapter are: (1) to reevaluate the multi-functional role of rice paddy area for both food and water sustainability in Korea, and (2) suggest a new paradigm of water management from the lessons learned from Korean tradition that might be helpful for climate change adaptation strategy.

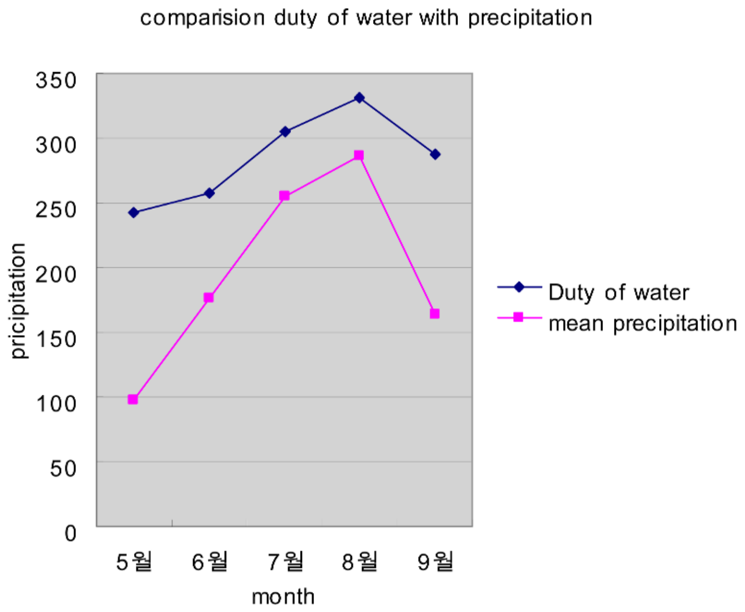

Fig. 2 Monthly rainfall and water demand for rice growing.

Multifunctional Role of Rice Paddy Area in Water Management

The rice paddy area has multiple roles for both food and water security. Especially, maintaining the slopes within rice paddy areas reduces soil erosion (Figure 3).

Flood Control

A paddy field could control a flood as storage retaining much rainwater. Banks of a paddy field would play a role as green dam because the banks are designed to store water for cultivating supply.

Raising Groundwater Level

Water in a paddy field would infiltrate through the bottom of the area and join groundwater. 45% of total infiltrated water would contribute to raise groundwater level, and others are retained in the soil. The amount of water contributed to increase the level is more than about 2 times the amount of supplied water to the Korean people.

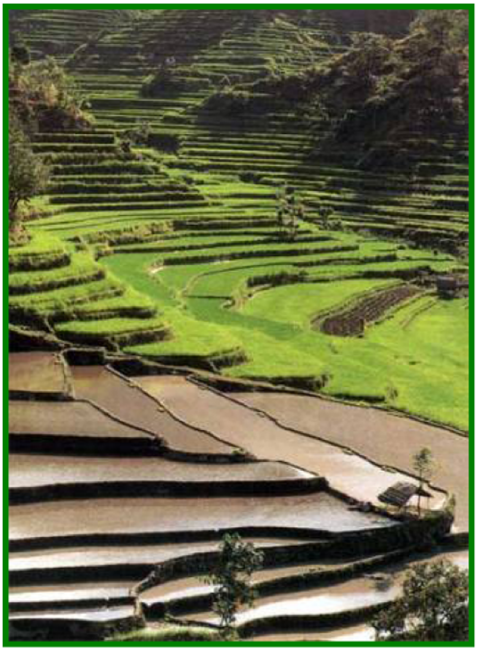

Fig. 3 A rice paddy area at the slope area.

Cooling Atmosphere

Latent heat of water evaporated from paddy fields would increase less the temperature of the atmosphere during summer season.

Erosion Control

Paddy fields accept soils eroded away from the field with a slope of more than 7°. The more the paddy field conserves the eroded soil, the less the soil moves into a stream or reservoir.

Cleaning Environment System

There is much carbon dioxide that we are producing. A paddy adsorbs the carbon dioxide in the atmosphere, and the amount of the adsorbed carbon dioxide by only paddies in Korea would be 6,165 ton annually.

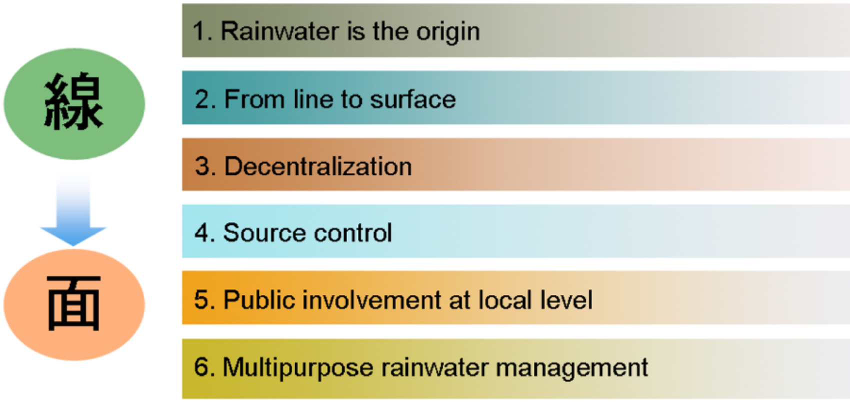

Fig. 4 New paradigm of rainwater management suggested for climate change adaptation strategy.

Water Purification

The water for irrigation is supplied from a river, being less clean. While being used in a paddy field, the water is cleaned by bacteria, or other biological organisms. In other words, the water in a paddy field would be changed to more clean water with time.

Others

There are other benefits of paddy fields such as organic matter conservation, soil acidification control, natural weeding effect, bio-diversity, etc.

Suggestion of a New Paradigm of Rainwater Management

The most difficult problems in water management occur in monsoon areas, because they suffer from flooding after a severe drought period. Climate change is expected to make this problem even more severe, and a new paradigm in the management of rainwater is required (Figure 4). Although these paradigms are developed in the context of a monsoon area, similar concepts can be applied to other dry or wet areas, such as Mediterranean climates. Eventually it will help countries to meet the MDG, and efficient use of water will require less energy and ensure sustainability.

Rainwater Is the Source of All Water

All of our water sources, surface water and groundwater originate from rainwater. Direct collection and use of rainwater can not only save the energy required for water treatment and transportation, but also increase safety factors against damage by flooding, water shortage, pollution or fire. Rainwater harvesting should be considered the first option for water supply for existing and new water supply system.

Management by Area

Changes in the permeability of the land surface induced by development or heavy rainfall due to the climate change may greatly increase runoff. Current measures to deal with this have been at the nearest stream, and include rainwater pump stations, dams, and elevated dikes. These measures deal with runoff in a chain of structures (management by line). It may be better to create a number of detention ponds or storages on a small scale over the entire area on which the rain falls. This would not only prevent flooding, but also reduce the effect of drought. Saved water can be used to create small lakes or wetlands for better environment.

Decentralized Management

Traditionally, water supply systems have been based on a centralized system, where water is taken from a dam, treated and distributed on a large scale. Although there may be merit in such large-scale systems, they are significant users of energy for water treatment and transportation. Instead, a decentralized system coupled with proper management will reduce the costs and energy requirements. If we implement the RWH system at an existing large-scale water supply system, we will create a more flexible and secure water management structure.

Source Control

Raw water taken from a river may contain turbidity, pathogens or soluble contaminants collected from over the entire catchment. These need to be reduced by treatment, which requires additional energy and money. However, if we collect rainwater near where it has fallen, we can maintain good water quality with relatively little treatment. An additional benefit of reducing the volume of runoff by direct storage or ground infiltration is the reduced threat of flooding at a local level. After collection, the saved water can be used for various purposes near where it is required.

Involvement of Local Action

Rainwater harvesting involves many small-scale projects at the local level, instead of one large, remote project, and so involves a lot of stakeholders. Since the involvement and support of local people is very important, education and public awareness are crucial.

Conclusion

In Korea, rice growing means not only the sustainability of food but also the sustainability of water because of the multifunctional role of rice paddy area in order to survive the harsh environmental conditions. In order to adapt the climate change, a new paradigm which is learned from old tradition should be included which is decentralized and source control. The tradition coupled with the recent advancement of technology will show a clue to the climate change adaptation in the world.

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Promoting Plant Residue Utilization for Food Security and Climate Change Mitigation in Thailand

Janya Sang-Arun, Eiji Yamaji and Jureerat Boonwan

Abstract Burning is the most simple and cheap method for small-scale farmers to manage plant residue. This practice does provide immediate benefits to farmers, but the wider immediate and long-term negative impacts are much larger. The objective of this study is to elaborate an alternative model for environmental and economically sound plant residue management that benefits all stakeholders particularly in terms of food security, income generation and climate change mitigation. The study found that there are several factors disrupting the adoption of non-burning practices in the study district such as land and labour scarcity, costs and the risk of wildfire. The study revealed that elementary schools and students have the capacity to manage certain amounts of plant residues and to produce vegetables and compost for the communities. Considering the weaknesses, threats and opportunities of existing policies, the study proposed a new model to manage plant residues involving local partnership and participation. This model would benefit relevant stakeholders: government, farmers, private sector actors, schools, students and the communities. Food security and income generation in the district would be the visible benefits attracting the interest of all stakeholders. Reduced greenhouse gas emissions and improved air quality would be benefits for the region and the globe.

Key words: Burning practice, climate change, food security, income generation, plant residues, student participation

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Introduction

Thailand is a large exporter of agricultural products, but food insecurity remains significant in northeastern and northern parts of the country (FIVIMS Thailand, 2005). Small-scale farmers in rural areas are more susceptible to food insecurity and the impacts of climate change because they conduct rainfed farming. In 2005, a severe drought damaged 809,000 ha of crops (NASA Earth Observatory, 2005) seriously affecting food security and the livelihoods of small-scale farmers who basically rely on their agricultural products.

Thai farmers undertake a number of agricultural practices that impact negatively on the environment, for instance, deforestation to expand agricultural land, burning of farm plant residues, excessive use of agrochemicals and intensive farming on hill slopes. These practices affect productivity, human security, livelihoods and health over the long-term. For instance, burning of plant residues in the northern part of Thailand generates smog of small particles that has induced respiratory problems in Chaing Mai and Chiang Rai provinces since 2006. The problem has adversely affected tourism in the provinces. Therefore, the government prohibited the burning of plant residues and has enforced this policy rigorously.

Burning is the most simple and cheap method to dispose of plant residues on farmland. It assists with land clearance and contributes to pest and disease control. However, this practice generates various greenhouse gases (GHGs), destroys available organic matter for soil amendment and decreases potential nutrient recovery from the residues. One study found that avoiding the burning of rice straw and using them for organic fertilizer would reduce methane emissions from the field (Pransin, 2007). Further, the composition of the rice straw includes nitrogen (0.6%), phosphorus (0.1%), potassium (1.4%) and other minerals. Therefore, farmers can reduce the cost of using chemical fertilizer by around 20.5US$/ha by applying plant residues for soil fertilization (Sripongpangul, 2007; 1 US$ = 32 Baht).

The 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gases Inventories accounts non-CO_2 emissions from the burning of crop residues as GHG emissions (IPCC, 2006). Thailand's initial national communication under the United Nations Framework Convention on Climate Change (UNFCCC) did not include GHG emissions from crop residue burning in the agricultural sector (ONEP, 2000). Later, however, several investigations on emissions from the burning of crop residues were undertaken. Kim Oanh (2006) found that the non-CO_2 emissions from the burning of rice straw in paddy fields was comprised of 18 kg/ha of methane, 0.5 kg/ha of nitrous oxide, 800 kg/ha of carbon monoxide and 400 kg/ha of volatile organic compounds. Kittiyopas (2008) calculated that the burning of rice straw in Thailand would produce 0.25 million tons of non-CO_2 greenhouse gases annually.

The aims of the research described in this paper were (i) to analyze government policy on the practice of burning crop residues, (ii) to investigate existing management of plant residues on farmland in the study area, (iii) to identify the potential to involve schools and students in the management of plant residues, and (iv) to identify effective policies to promote the management of plant residues on farmland that benefits relevant stakeholders and conserves the environment.

Study Area and Research Methods

Study Area

Action research was conducted in Wiang Kaen District, Chiang Rai province. Wiang Kaen is a landlocked district located at the border of Thailand and Myanmar (Figure 1). It has a total area of 526 km^2. National reserved forest covers 80% of the district; however encroachment has occurred in over 40% of the reserved forest for settlement and farming (Sang-Arun et al., 2006). The district is populated by nine ethnic groups who reside in the mountainous area and who previously practiced shifting cultivation using "slash-and-burn" methods for their subsistence. The average income of the district's residents is lower than the national average.

Research Methods

The research methods consisted of four processes. First, a field survey was conducted in May 2006 to observe crop and weed residue management practices on farmland. Second, the national and district policies related to the management of crop residues, non-burning practices and good agricultural practices were reviewed. The study assessed the strengths, weaknesses, threats, and opportunities of the policies. Third, a capacity development program was organized for elementary school students. Fourth, the study proposed a new model to manage plant residues for food security, income generation and climate change mitigation in the district.

For the capacity development program, representatives of elementary school students from 19 schools (out of a total of 22 in the district) (Figure 1) and two junior-high schools participated in a workshop and drawing contest in August 2006. The junior-high schools proposed that they should participate in the program which they expected would be useful for students and their education programs. The workshop presented the results of the field survey to students to educate them on the impact of current farming practice in the district. Alternative farming practices for sustainable agriculture were introduced to them by slide and video presentation and through a visit to a model farm of Somthawin Chintamai Border Police School. Next, the students were assigned to design the model of sustainable farming that they felt was appropriate for application by their schools or in their village. For post-activities, the participating students were encouraged to establish a model farm in their school using local material and the technology that they found appealing. A post evaluation was conducted half a year later in February 2007.

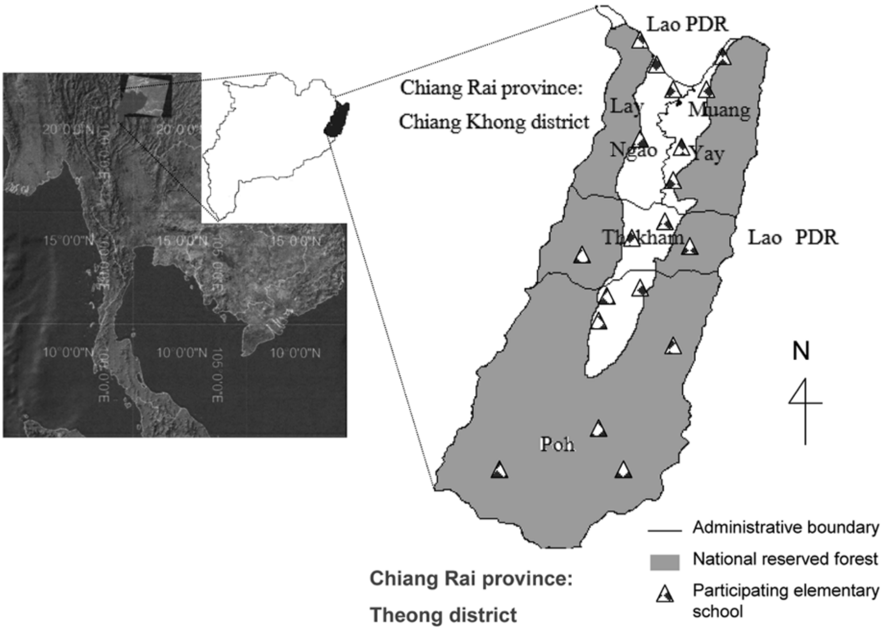

Fig. 1 Study area in Wiang Kaen district, Chiang Rai province, Thailand.

Results and Discussion

Policy Analysis and Gap Identification

There are several policies related to the management of farmland plant residues. At national level, the government prohibits burning of farmland plant residues to avoid forest fires and reduce air pollution. Active enforcement occurs in upper northern Thailand, particularly Chiang Rai, Chiang Mai, and Mae Hong Son provinces. Further, the Department of Land Development promotes organic farming and the use of organic fertilizer. Extension officers conduct many training programs for farmers on composting and how to produce biological pesticide to use on farmland. Additionally, in 2008, the Prime Minister announced his intention to continuously promote the use of organic fertilizer to increase land productivity and reduce the environmental impacts of synthetic chemical fertilizer.

The Governor of Chiang Rai province has translated the non-burning policies of the national government into action at the local level. When burning is observed, after land ownership is ascertained, social and legal punishment will be applied to the landowner. The District-Chief Officer of Wiang Kaen in cooperation with the Chiang Rai Land Development Station registered the main policies to reduce burning practice and promote sustainable agriculture as: (i) promoting mulch plowing after harvesting to reduce smog, (ii) promoting the use of organic fertilizer for environmental conservation and reducing the use of chemicals, (iii) promoting the use of food and manure for composting to reduce waste, and (iv) promoting sustainable agricultural development for health. The district subsidizes the mulch plowing of paddy fields with compensation of 48.8 US$/ha to assist farmers in meeting the costs of plowing. However, in 2008 the subsidies are applied only to 16 hectares of paddy field which is very small compared with the total paddy field area of the district.

The analysis of strengths, weaknesses, threats and opportunities of each policy revealed that they have focused directly on farmers with less involvement of other stakeholders. The policies also lacked mechanisms for income generation for farmers and marketing, and did not clearly elaborate benefit sharing arrangements. Therefore, the adoption of technology was limited to the promotion areas and the sustainability of its use is questionable. Further, the training programs provided to farmers mainly focused on technology. There was less effort to provide a clear picture of the environmental impact of farmers' practices particularly to describe the nexus between environmental impacts and income. Therefore, farmers may not make a great effort to apply the technology they received training on. As long as their first priority is income, they will reject alternative practices with less immediate financial returns.

Existing Management Practices of Plant Residues in Farmland

The field survey in 2006 found that farmers burnt plant residues as a common practice, even though the local government tries to prohibit this. The burning practice is generally applied for the cultivation of annual crops such as rice and corn. Farmers did not burn residues in orchards, but instead spread the residues for ground cover. The following specific practices were observed: (i) farmers attempted to pile weed residues before ignition (Figure 2), which makes it easier for them to control the fire, (ii) farmers burnt rice stems and corn stalks without piling, and (iii) piling and

Fig. 2 Collection of plant residues and burning in Wiang Kaen.

burning was applied to corn cobs and rice straw. Approximately 8,600 tons of rice straw, 15,500 tons of corn stalks and cobs, and an unmeasured amount of weeds in Wiang Kaen were burnt annually.

The results of the field survey and informal discussion with the local farmers revealed that there are several pragmatic reasons why farmers burn residues instead of composting them. First, farmers use burning to clear land and eliminate pathogens and pests. Second, they burn to reduce the risk of uncontrolled fire which may happen during the dry season. Third, most of the farmers are smallholders (holdings can be as small as one hectare or less) and they do not want to take the risk of investing in new practices which they view as uncertain and less profitable. Fourth, composting of plant residues on farmland uses land that could be cultivated, requires labor, and provides no direct income. Even though the government subsidized the construction of composting centers for farmers, at least one is unused. As there is no development of a compost market, the price of synthetic chemical fertilizer has continuously increased. Small-scale farmers have few resources to purchase chemical fertilizers. Therefore, some do not apply any fertilizer which then results in low land productivity.

Potential to Involve Elementary Schools and Students for Management of Farmland Plant Residues

Farmers are confronted with many obstacles to the composting of crop residues. Alternative avenues to introducing composting that do not directly focus on farmers have to be explored. One group of stakeholders that could influence farming practices because of their societal status and physical closeness to farms are elementary schools. There are 22 schools located across the district. Through the capacity building program, which covered 19 of these schools, the participating students are very active in learning about the impact of current agricultural practices and are very keen to learn how to make compost from residues. The results of the drawing contest and model farm practices provided evidence that the students understood composting techniques and had the capacity to manage plant residues. The teachers and students shared their knowledge with other students through the exhibition of student activities and actively applied this knowledge in the schools and communities.

Examples of post-workshop activities (Figure 3) are (i) the development of model farms on uncultivated land such as a rocky area, a river bank and arid soil for vegetable and herb production using rice straw, corn cobs and longan seeds and peels, (ii) production of compost for cultivation and sale, (iii) production of vegetables for school lunches, household consumption, and sale, (iv) dissemination of the knowledge from the workshop for a school program in science education, and (v) discussion on building up a school network for environmental conservation among the participating teachers.

Efforts to use plant residues in the schools clearly increased after the capacity development program. Participating students, some of who are from quite poor house-

(a) (b) (c)

Fig. 3 (a) Use of crop residues for soil amendment; (b) vegetable production; and (c) compost.

holds, were able to cultivate vegetables for home consumption and some were able to earn income from the sale of compost and vegetables. Communities in the district benefited from the increased availability of vegetables grown without chemicals for purchase.

Policy Recommendation: Integrated Management of Plant Residues for Food Security, Income Generation, and Climate Change Mitigation

The existing government policies on farmland plant residues focus on enforcement and promoting non-burning practice directly to farmers with less involvement of other stakeholders. This study proposes a new model of plant residue management that consists of policies that generate benefits for relevant stakeholders (Figure 4). The model stresses local partnership and the active participation of local stakeholders for the benefits of food security, income generation, and climate change mitigation.

As both national and local governments are mainly interested in reducing burning practices and using plant residues for soil amendment to conserve the environment, they would play the central role in providing economic incentives, finding suitable technology and providing assistance to develop and improve the proposed stakeholder functions to ensure effective plant residue management and benefit sharing. Unused public land could be made available for school composting, vegetable production and demonstration farms.

Farmers are primarily interested in the practical management of plant residues and income generation. They may not be able to manage the waste by themselves due to the constraints they face, as described above. Farmers would play the main role as providers (waste, compost, and organic foods) and users (compost). In support of the school activities, the farmers would be expected to inform students of residue availability and to allow them access to the residues.

Schools are mainly interested in developing their education curriculum as well as ensuring food security and creating a bright future for their students. The schools can

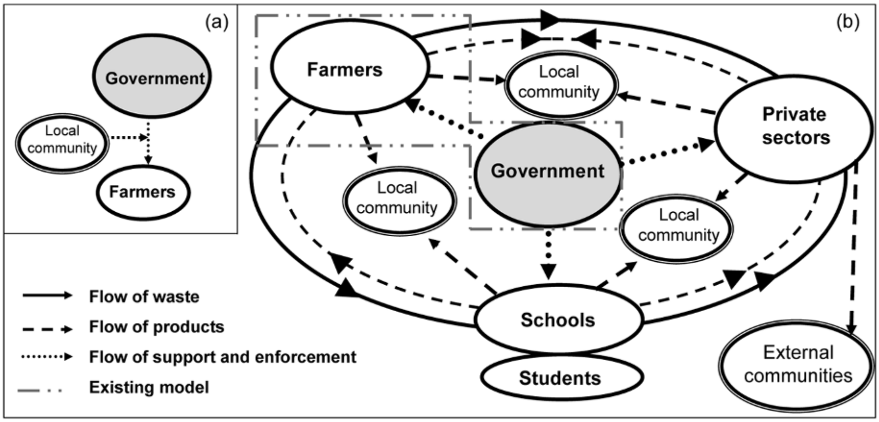

Fig. 4 (a) Stakeholder relations in the existing plant residue management model and (b) the proposed integrated, multi-stakeholder plant residue management model for food security, income generation, and climate change mitigation in Thailand.

accommodate environmentally sound management of plant residues in their education program as well as encourage students to apply plant residues for composting and vegetable cultivation. The school would assist students to produce compost and vegetables for sale in the communities. Moreover, farmers and communities respect teachers as an important community resource. The teachers could establish learning centers for farmland plant residue management (composting system and model farm) as a public education service.

Many students do not have sufficient food for lunch and it is difficult for them to afford higher education. They could participate in the composting and vegetable production of the school for both food and income. For students who do not go on to higher education, they may apply the knowledge they have gained for their farming and commerce.

The model just described is based on the premise that the farmers would stop burning plant residue if there is a good economic return for composting and a strong supporting system for alternative waste management. Organic production would also increase if the farmers can buy the compost and biological liquid fertilizer produced from plant residues. Further, this model would provide a broad range of benefits: income generation for schools, students, farmers and private sector actors, food security for students and the community, and reduced emissions of greenhouse gases and particles from burning.

Conclusions

Burning of plant residues is the most simple and cheap method for dealing with residues that small-scale farmers can afford. This practice does provide immediate benefits to farmers, but the wider immediate and long-term negative impacts are much larger. In parallel with the prohibition of burning practice, the government should promote environmentally and economically sound management of plant residues and provide support to relevant stakeholders as proposed in the model of integrated management of plant residues elaborated in this paper. The new model would assign roles to government, farmers, schools, students, the private sector and the communities, according to their interests and the benefits would be shared between them. The benefits to district stakeholders that would attract their participation are food security and income generation. Reduced greenhouse gas emissions and improved air quality would be benefits for the region and the globe.

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No-Regret Adaptation Strategies to Cope with Potential Impacts of Climate Change on Groundwater Resources of Asian Cities

Sangam Shrestha, Yatsuka Kataoka and Tetsuo Kuyama

Abstract This chapter focuses on assessment of current groundwater resource conditions and the potential impact of climate change on groundwater resources and its use and availability in Asian cities. Land subsidence, depletion in the groundwater table, groundwater contamination (e.g. from arsenic, fluoride and ammonium), and saline water intrusion have been identified as major problems as a result of over-extraction of groundwater in Asian cities. The potential impacts of climate change have been discussed with reference to current groundwater resources condition and its management in selected cities of Asia. Several adaptation options such as engineering measures and institutional measures are discussed as no-regret adaptation strategies to reduce the vulnerability and cope with these impacts caused by climate change.

Key words: Adaptation, Asia, climate change, groundwater

Introduction

Groundwater plays a very important role in sustainable development of many Asian cities. However it has not always been properly managed, which often has resulted in depletion and degradation of the resource. In addition to the existing challenges, groundwater management now confronts a brand new challenge: how to adapt to

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the potentially negative impacts of climate change on groundwater availability and its use?

Climate change impacts may add to existing pressures on groundwater resources by (i) impeding recharge capacities in some areas; and (ii) being called on to fill eventual gaps in surface water availability due to increased variability of precipitation. Groundwater contamination is also expected in low elevation coastal zones due to sea level rise. In some vulnerable areas, such impacts on groundwater resources may render the only available freshwater reserve unavailable or unsuitable for use in the near future (IPCC, 2007).

To maintain groundwater as an important resource for sustainable development and also as a reserve freshwater resource for current and future generations, groundwater management should be more strategic and proactive to cope with potential impacts of climate change. However, groundwater has received little attention from climate change impact assessments compared to surface water resources (Kundzewicz et al., 2007) and most countries in Asia have not yet been ready to respond to the effects of climate change on their water management plans.

This paper provides an overview of current groundwater issues and examines the potential and negative effects of climate change on the groundwater resources in selected Asian cities. It also explores opportunities for adaptation to the potential impacts of climate change on groundwater use and its availability.

Materials and Methods

The Institute for Global Environmental Strategies (IGES), has conducted a study on "Sustainable Water Resource Management Policy (SWMP)" since 2004, with the cooperation of research partners in the following case study cities, namely Tianjin (China), Bandung (Indonesia), Colombo and Kandy (Sri Lanka), Bangkok (Thailand), and Ho Chi Minh City (Vietnam).

All selected case study cities have common socio-economic and hydro-climatic features such as rapid increase of population and monsoon climate. For example all cities have very high population density i.e. the population density ranges from 3,944 persons/km^2 in Kandy to 926 persons/km^2 in Tianjin. The average annual rainfall ranges from 650 mm in Tianjin to 2376 mm in Colombo. All cities have similar hydro-geological settings of semi- or unconsolidated alluvial sediments except for Colombo and Kandy which have metamorphic rock formation. In addition to the case study, the status of groundwater resources in some other Asian cities were gathered from extensive literature review.

Fig. 1 Selected Asian cities for the study.

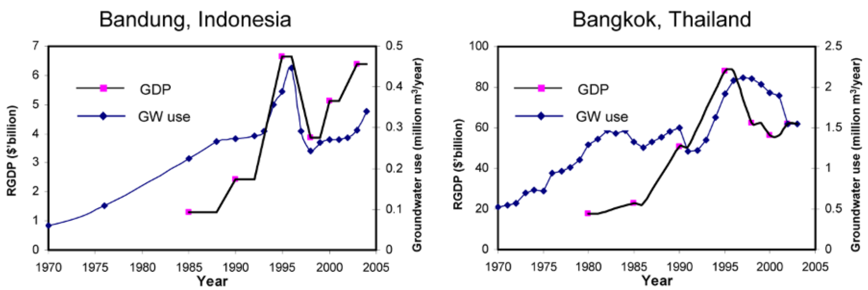

Fig. 2 Groundwater abstraction and correlation with city-level GDP. Source: Kataoka et al., 2006

Results and Discussion

Groundwater Use

The purpose and trend of groundwater use varies from city to city. It is observed that HCMC, Kandy and Tianjin have higher dependency on groundwater as compared to other cities. In Bandung, Bangkok and HCMC groundwater is mostly used for industrial and commercial sectors whereas domestic sectors are the major users of groundwater in Colombo and Kandy and the agriculture sector is the major user in Tianjin. Industrial use in total groundwater abstraction accounts for 80% in Bandung and 60% in Bangkok and also there is a strong correlation between groundwater use and gross domestic product (GDP) in these cities (Figure 2). Groundwater supports dynamic agricultural systems in India, Northern Sri Lanka, Pakistan Punjab and the Northern China plains. In India, groundwater provides about 60% of the total agricultural water use accounting for more than 50% of the total irrigated area. Similarly, groundwater contributes 50%, 50%, 65% and 70% of total agriculture water supply in Shangdong, Henan, Beijing and Hebei provinces of China respectively (Ministry of Water Resources of China, 2000). In Pakistan Punjab, more than 40% of crop water requirement comes from groundwater, producing the majority of food in Pakistan (Qureshi and Barrett-Lennard, 1998).

Problems Related to Groundwater

As an easily accessible and cheap water resource, groundwater is often abstracted beyond its natural recharging capacity, which results in depletion of the resource and/or degradation of its quality. Major problems identified as a result of over-extraction of groundwater in some areas of Asian cities include:

- Land subsidence.
- Depletion in groundwater table.
- Groundwater contamination (e.g. from arsenic, fluoride and ammonium).
- Saline water intrusion.

In China, groundwater level has declined in 30% of 194 key cities and regions monitored (WEPA, 2007). Other Asian cities like Bangkok have experienced excessive drawdown of water tables and suffer from land subsidence due to intensive use of groundwater (Figure 3) (IGES, 2007). In 2003, the degree of land subsidence for each metre drop in the water table was found to be 15 mm, 18 mm and 31 mm in Bangkok, Bandung, and Tianjin respectively. Land subsidence can affect buildings and structures such as water and sewerage networks and increase groundwater salinity, as observed in Bangkok.

Deterioration of groundwater quality and its impact on human health has been observed in many cases. A survey in Lamphun Province, Northern Thailand showed that concentration of fluoride in drinking water was up to 15.0 mg/L, while the national drinking water standard for fluoride is 0.7 mg/L. It also revealed that use of fluoride rich water for soaking rice could be a major source of fluoride intake in the surveyed area (Takeda et al., 2007). Similarly in Tianjin, where groundwater also contains a high fluoride concentration, the dental fluorosis rate of local residents was reported to be far higher than national survey results – 41% in Tianjin urban area compared to 5.21% national average in city areas (Xu et al., 2008).

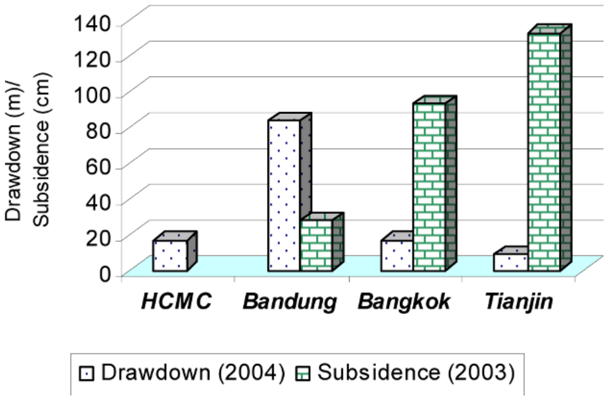

Fig. 3 Cumulative drop in water level and land subsidence in some Asian cities.

Potential Impacts of Climate Change on Groundwater Resources

The potential impacts of climate change on water resources in general have been recognised for some time, although there has been comparatively little research relating to groundwater (IPCC, 2001). Below a brief overview of potential impact of climate change on groundwater resources of Asia is given.

Potential Impacts on Groundwater Due to Change of Temperature and Precipitation

Spatial and temporal changes in temperature and precipitation may modify the surface hydraulic boundary conditions of, and ultimately cause a shift in the water balance of, an aquifer. Changes in the amount of precipitation are expected to decrease mean runoff by 1 mm/day in Central Asia and to increase mean runoff by a similar amount in South Asia. Due to the change in the variability of precipitation, surface water resources are likely to become more unreliable, thus precipitating a shift to development of more "reliable" groundwater resources, as has been observed in Taiwan (Hiscock and Tanaka, 2006). Similarly, the changing frequency of droughts or heavy precipitation can also be expected to impact on water levels in aquifers. Droughts result in declining water levels not only because of reduction in rainfall, but also due to increased evaporation and a reduction in infiltration that may accompany the development of dry topsoils. Paradoxically, extreme precipitation events may lead to less recharge to groundwater in upland areas because more of the precipitation is lost as runoff.

Degradation of Groundwater Quality by Sea Level Rise

As global temperatures rise, sea level rise is also expected due to the melting of ice sheets and glaciers. Rising sea levels would allow saltwater to penetrate farther inland and upstream in low lying river deltas (IPCC, 1998). The salinization of aquifers has been detected in many areas of Asian cities located in coastal areas. The chloride concentration exceeds the allowable limit of 250 mg/L in some monitoring locations of Bangkok (IGES, 2007). In some monitoring stations like in Samut Prakan and in Samut Sakhon that are located adjacent to the coast, salinity levels are likely to be increased as a result of sea level rise. Similarly, in HCMC, saltwater intrusion has been observed in some districts and this phenomenon seems to have been escalating, with continuing drawdown of the water table due to excessive groundwater abstraction to meet the growing water demands in the city (IGES, 2007). In Manila, tidal inflow of seawater during high tide into the Pasig River contributes to the high salinity of groundwater in Pasig City and vicinity (Philippines National Water Resource Board, 2004). Sea level rise due to climate change may increase seawater inflow into freshwater aquifers in parts of these coastal cities where hydraulic connections to aquifer beds are exposed at the sea floor.

Potential Impacts of Land Use Change Caused by Climate Change

Climate change studies suggest that some Asia-Pacific forests and vegetation may experience some initially beneficial effects from climate change and enhanced atmospheric CO_2 concentrations. Any vegetation change scenarios will have direct and indirect impacts on groundwater recharge. For example, the projected decline of steppe and desert biomes on the Tibetan Plateau may be accompanied by an expansion of conifer, broad-leaved, and evergreen forests and shrubland. Expanded forest cover may increase groundwater recharge in the Tibetan Plateau, with consequent changes in downstream river flows. In addition, studies suggest significant shifts in the distribution of tree species in China in response to warming of 2–4°C, including the migration of forest communities into non-forested areas of East China (CSIRO, 2006). The increase in forest area may increase the groundwater recharge in East China.

Potential Degradation of Groundwater by Afforestation and Carbon Sequestration

The IPCC recognises that sustainable forestry offers reduction in emissions from deforestation and forest degradation (REDD), afforestation, increasing sequestration in existing forests, supplying biomass for bio-energy and providing wood as a substitute for more energy intensive products such as concrete, aluminium, steel and plastics, as potential carbon mitigation options. The heightened global interest in providing incentives for forest conservation by valuing standing forests as carbon sinks and reservoirs is encouraging. However, increased forest cover will have impacts on groundwater recharge, through increased evapotranspiration, that may require on-site research before proceeding with specific projects. Some research has revealed that groundwater recharge is generally lower in forested areas than non-forested areas (Scanlon et al., 2006). Carbon sequestration in aquifers may have unforeseen impacts on human health due to groundwater contamination (Jackson et al., 2005). When carbon dioxide enters the groundwater it can increase its acidity, potentially leaching toxic chemicals, such as lead, from rocks into the water, making groundwater unsuitable for use.

Increase of Groundwater Dependency Due to Changes in Water Use

In the future, dependence on groundwater may increase due to the increasing unreliability of using surface water. It is projected that in many areas the quantity of surface water will vary and its quality will be degraded because of increased drought and flood events as a result of climate change (Kundzewicz et al., 2007). IPCC summary reports indicate that there is a very high likelihood that current water management practices will be inadequate to reduce the negative impacts of climate change on water supply reliability.

Adaptation Measures and Strategies

There is no panacea to minimise the risk of climate change to groundwater. The first step is to mainstream adaptation into water management plans, strengthening the existing management systems and measures to cope with both current and potential impacts. Groundwater volumes in aquifers need to be increased in order to conserve groundwater, maintaining groundwater ecosystems and storing reserve water supplies underground. Second, water sources should be diversified and water conservation should be promoted to minimise the risk of water shortages especially in droughts. Third, institutional arrangements to promote adaptation options are needed, which may require a paradigm shift in groundwater management. A mixture of engineering measures and institutional measures are discussed in this section.

Integrating Adaptation Strategies into National Policy and Planning

Adaptation measures need to be addressed in the context of development policies on poverty reduction, agricultural development, water resources development and disaster prevention. Integrating adaptation concerns into sustainable development planning processes is a necessary strategy for long term groundwater protection. In many developing countries it is difficult to integrate adaptation concerns into national policy due to (i) low staff capacity for planning, monitoring and evaluation; (ii) poor data on adaptation options and weak information sharing across sectors; and (iii) limited awareness of adaptation among stakeholders. Since agricultural and industrial sectors depend heavily on groundwater, so policies dealing with agriculture and industrial development must try to incorporate the impacts of climate change on groundwater resources.

Promoting Water Harvesting and Conservation Technologies

Rainwater harvesting is a simple and low cost technique that involves the capture and storage of rainwater from roofs and ground catchments for domestic, agricultural, industrial and environmental purposes. Some traditional and innovative techniques are available to collect rainfall and runoff that can serve as alternative water sources in drought prone areas to minimise the stress on groundwater and in low elevation coastal zones where contaminated aquifers are a problem. Allocating 1–5% of catchment areas to water harvesting can meet the needs of water deficit communities (Sharma and Smakhtin, 2006).

Rainwater Harvesting for Domestic Use

In Asia, rainwater harvesting for domestic use is common. Rainwater harvesting from roof top areas is also beneficial in low elevation coastal zones where groundwater recharge is not useful due to saline contamination of aquifers. In addition to domestic use, rainwater harvesting can also be used for groundwater recharge with some recharge technologies. Recharging aquifers by rainwater in coastal areas can dilute to some extent the elevated salinity concentration, making marginal supplies usable.

Rainwater and Run-off Water Harvesting for Agriculture

As agriculture is the largest user of groundwater in Asia, the anticipated stress on groundwater due to climate change can be minimised by promoting farming based on rainwater and runoff harvesting. Micro-catchment based cropping with field bunding, contour bunding, ridging, conservation furrows, key line and contour cultivation can concentrate rainwater in a small portion of the cultivated area to be used for irrigating crops. Arid horticulture crops such as pomegranate, dates and other crops can be successfully grown in water scarce regions (Sharma and Smakhtin, 2006).

Managed Aquifer Recharging

In Asia, few studies have been conducted on artificial recharge of aquifers. In India, the Central Ground Water Board (CGWB) conducted a feasibility study on artificial recharge in drought prone areas of Gujarat, Maharashtra, Tamil Nadu and Kerala. It found that the cost for construction and operation of artificial recharge structures was reasonable, but the cost for artificial recharge of wells in alluvial aquifers and tidal areas was very expensive. Moreover, the cost of artificially recharged water used for irrigation was comparatively higher than other sources. The cost of recharged water was about $15–50/ha/crop. The cost of artificially recharged water for domestic use (about $0.05–$0.15/person/year) was considered reasonable, especially in water scarce areas.

Institutional Adaptations and Considerations

Promoting Local Management in Groundwater

Unlike surface water, groundwater development is often carried out on an individual or small group basis and does not demand a larger institutional framework for water provision (Bhandari and Shivakoti, 2005). Therefore, local groundwater management can be an effective way of managing groundwater resources. Decentralised collective management is often mentioned as an alternative or supplementary option. However, promoting local groundwater management needs guidance and support from central governments. Groundwater users often employ self-regulation to control and manage groundwater resources locally. Therefore, promoting and supporting local groundwater management can reduce the burden on central governments and ensure the sustainability of groundwater resources management.

Assigning Groundwater Use Rights

Well defined groundwater use rights entitle individual users or user groups to an abstraction allocation at a certain point in time or during a specified time period in certain aquifer conditions. Groundwater use rights needs to be carefully designed, changed and adapted to different conditions. For groundwater use rights to function as a management instrument, the following aspects need to be in place: (i) initial allocation; (ii) a registration mechanism and maintained registry system; (iii) a functioning monitoring system; (iv) enforcement of limits set by individual or communal use rights; and (v) a credible sanctioning system (Kemper, 2007). To establish groundwater use rights, groundwater should be regarded first as a public good among groundwater users.

Introducing a Pricing Scheme

While some countries in Asia have already introduced groundwater tariffs or fees, in most cases they are not successful. Since abstraction of groundwater usually takes places on private land and with private equipment, a unique pricing mechanism is needed. In addition to a price of the groundwater resource itself, pricing the other inputs needed in order to pump groundwater such as the pump, borehole, or energy can also be included in a pricing scheme (Kemper, 2007).

Capacity Building, Education, Training and Public Awareness

Stakeholders' involvement, empowerment and capacity building at all levels, especially in universities and centres of excellence, are vital to enable developing countries to adapt to climate change. Providing education and training to local communities about rainwater and runoff water harvesting for domestic use, agriculture use and for groundwater recharge will enhance the structural adaptation options to cope with current and anticipated future problems. External support is needed for institutional capacity building, including establishing and strengthening centres of excellence and building up hydro-meteorological networks. Training for stakeholders in all sectors would help to develop specialised tools for planning and implementing adaptation activities and thus promote action by local and national governments.

Conclusions and Recommendations

The impact of climate change on groundwater resources will increase the pressure on resource and adaptation opportunities to provide a new agenda for groundwater management. The following recommendations are made to reduce the vulnerability and to cope with the negative impacts caused by climate change on groundwater resources:

- Measures to cope with current groundwater stress and potential impacts of climate change include conserving and increasing groundwater storage and diversifying water sources to minimise the risk of water shortages.

- Rainwater harvesting structures for groundwater recharge and for domestic and agricultural use is a feasible structural adaptation option, but new policies to promote rainwater harvesting need to be developed.
- Institutional adaptation should be promoted, including enhancement of groundwater governance and strengthened local groundwater management. Groundwater management policies can be made more effective by raising local awareness.
- Innovative funding, like the Adaptation Fund, should be used to strengthen institutions, build capacity, educate the public and conduct research on the effects of climate change on groundwater resources.
- Extensive research at local scales is needed to reduce the knowledge gap regarding the potential impact of climate change on groundwater resources. This information will help to formulate policies to counteract the impacts of climate change. This section should be a brief explanation of the significance and implications of the work reported.

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PART 6

Environmental Management

Food or Environment: An Alternative Solution to Tradeoff of Water Allocation in Oasis Regions of China

Minjun Shi and Weichun Tao

Abstract Land degradation and desertification due to excessive water use has become a severe problem in arid and semi-arid areas. In order to combat these conditions, it is necessary to reduce water allocation to agricultural activities. To maintain farm production, it is important to extend water-saving techniques while reducing water use. This paper presents an insight into the impacts of water use reduction on food production based on a case study in oasis regions of China. The results indicate that water use reduction will cause a negative impact on food production so that farmers cannot produce enough grain to supply themselves. Extension of water-saving techniques and increasing off-farm job opportunities may alleviate the negative effect. If subsidies for grain crops would lead to adoption of water-saving techniques, it would be feasible to maintain the level of food self-supplying. However the quantity of commercial wheat is quite low. Increasing of off-farm opportunities may improve household income to a certain extent. It is believed that the alternative solution to the conflict of water allocation between food security and ecological security will mainly depend on subsidy measures for promoting extension of water-saving technologies in the raising of grain crops.

Key words: Food security, ecological security, oasis regions, off-farm opportunity, subsidy, water allocation, water-saving technology

Introduction

Persistent increasing water demand with population growth and economic development has caused overuse of water resources in arid and semi-arid areas. Land degradation and desertification induced by overuse of water resources have become a serious environmental problem (Hong Yang, 2002). Where people earn their liv-

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ing mainly by farm activities, land degradation and desertification have brought a severe threat to agricultural and rural development in arid areas. In the northwestern part of China, Oasis regions are the main agricultural areas. Agriculture accounts for the largest part of water use in Oasis regions. In addition, Oasis regions are grain storage facilities that provide most commercial grain. The Hexi Corridor Region provides 33% of grain, 70% of commercial grain, 41% of oilseeds and 99.6% of cotton in Gansu Province (Chao Bao and Chuang-lin Fang, 2006). As a result, water resources were exported virtually through crop exportation from the Oasis to other regions. For example, the net grain export of Shiyang River Basin was 688,600 ton in 2003 (Wuwei Statistics Bureau, 2004). According to water use efficiency of this region, 14.97×10^8 m^3 of its water resource had been consumed to produce exported grain, which occupies 69.5% of total water use and 78.8% of total agricultural water use. Food production and food export to other regions consumes a mass of water resources and spurs their shortage. Consequently, excessive mining of ground water to offset water shortages caused environmental degradation, including a decline in groundwater table, rise of mineralization degree, serious soil salinization and desertification. To restore the ecosystem, it is crucial to restrain over-mining of ground water (Xuetao Sun, 2004). However, it is obvious that reduction of water allocation to agriculture will cause negative effects on food production and farmers' income. Because Oasis regions are the most important source in arid areas, the decrease in grain prodcution induced by adjustment of water allocation will threaten food security of those areas. Therefore, the question before us is to seek for a solution to tradeoff of water allocation between food production and environmental restoration. What is the necessary extent of improving efficiency of water use to alleviate the negative effect of reduction of water allocation on food production? Would it help considerably to increase off-farm employment opportunities to offset the decrease in farmers' income caused by reduction of water supply? This paper focuses upon the discussion of solutions to tradeoff of water allocation between food security and ecological security in Oasis regions of China, based on a case study in Minqin Oasis of Gansu Province.

Study Site

The Shiyang River Basin consists mainly of Wuwei Oasis in the upper reaches and Minqin Oasis in lower reaches. The Minqin Oasis region has an area of 15,870 km^2 (from 101°49′ to 104°12′E and from 38°03′ to 39°28′N), surrounded by the Badan-Jilin Desert in the west and north and Tenggeri Desert in the east. The region has an arid continental climate with a mean annual precipitation of 110 mm, half of which concentrates in July and August. Average annual evaporation is 2664 mm, 24 times of annual precipitation (Sun Danfeng et al., 2006). The surface water for irrigation comes from the Shiyang River. However, due to over-consumption of water resources of Wuwei oasis in the upper reaches, the annual surface runoff has decreased from 4.6 $\times 10^8$ m^3 in 1950s to 0.98 $\times 10^8$ m^3 (Minqin Water Bureau, 2004).

Minqin oasis is an important production region of commercial grain in Gansu Province. In past decades, farm production expanded significantly. The total grain yield increased from 7.2 $\times 10^4$ ton in 1970s to 16.8 $\times 10^4$ ton in 2004. In 2004, the grain yield per household had reached 2915 kg, 1.66 times the average level in Gansu Province. 49% of total grain yield is provided as commercial grain (Wuwei Statistics Bureau, 1999, Minqin Statistics Bureau, 2004). The main grain crop is wheat, which accounts for 70.6% of total cropping area. The cash crops include cotton, melon for seeds, sunflower, fennel, capsicum, sweet melon. Sheep, pig and chickens are main livestock animals which are fed for household consumption and sale. Cattle and donkeys are fed for draught animals. The main feeds are corn and bran. Household income is mainly from agriculture. Since the 1990s, agriculture income accounts for 90% of total net income on average (Minqin Statistics Bureau, 2004). In 2004, 45.7% of family laborers have part-time or full-time off-farm jobs.

The main part of Minqin Oasis is Hongyashan irrigation region along the Shiyang River. The Hongyashan irrigation region is divided into three sub zones: Huqu zone, Quanshan zone and Baqu zone. Baqu zone and Quanshan zone are main grain production regions. The sowing area of grain crops per household is 0.41 hm^2 in Baqu and 0.97 hm^2 in Quanshan. The yield of grain per household is 3538 kg and 6762 kg respectively. About 90% of household income is from farm activities. Income from providing commercial grain accounts for 4% of household income in Baqu and 24% in Quanshan. In Huqu, due to declines in ground water tables and soil salinization, the sowing area of grain crops has decreased so that this zone cannot provide commercial grain nowadays.

Water use for agriculture accounts for 94%, among which grain crop consumed 36% of agricultural water use. Currently, the total water demand in Minqin is 6.4 $\times 10^8$ m^3. The surface water resource is no more than 1.5 $\times 10^8$ m^3. The gap between supply and demand is 5 $\times 10^8$ m^3. To fill up the gap, farmers use a mass of ground water. In the 1970s the number of wells increased to more than 7000. The average amount of annual over-mining of ground water has reached 2.96 $\times 10^8$ m^3. As a result, the ground water table has decreased from 0–1 m in 1970s to 18–30 m nowadays. The deepest place reached 35 m (Jinzhu Ma et al., 2006). Consequently, 40,000 hm^2 of arable land has been abandoned in the north of Minqin. A lot of trees died away at the edge of the Oasis.

According to Shiyang river rehabilitation planning, it is required that annual mining amount of ground water must be reduced to less than 0.89 $\times 10^8$ m^3. This means that 4.28 $\times 10^8$ m^3 of mining amount of ground water should be cut down. Considering an increase in surface water from upper reaches and the other river, the total available volume of water resource is 3.39 $\times 10^8$ m^3. That means that 2.76 $\times 10^8$ m^3 of total water supply should be cut down (Gansu Water Bureau, 2006). As over 90% of the water is used for agriculture, it is obvious water allocation to agriculture should be cut down. In other words, water allocation per household must be cut down more than 4,000 m^3 on average. In some regions such as Quanshan, 5,558 m^3 of water allocation per household is required to be reduced. As reduction of water supply will have a negative effect on farm production and household income, it is crucial to improve efficiency of water use by extending water-saving techniques and to diversify income source by increasing off-farm job opportunities.

Method

Model

A bio-economic model can provide an analytical framework to link household economic activities with bio-production activities (Minjun Shi, 2004; 2005; 2006). This paper uses linear programming to build a bio-economic model. The model will simulate household behavior by maximizing net income under constraints when water supply, off-farm job opportunity and techniques changed. Constraints in the model include: land, water, labor resources and food supply and demand, imperfect market and budget.

The model function is as follows:

Objective function:

$$\begin{aligned}\text{Max}\,M = &\sum_{c=1}^{C}\left\{P_c\left(\sum_{g=1}^{G}A_{cg}y_{cg}(x)-b_c-s_c\right)-\sum_{g=1}^{G}\sum_{i=1}^{n}A_{cg}e_{icg}x_{icg}\right\}\\ &+\sum_{v=1}^{V}\left\{P_v(L_v y_v(x)-b_v-s_v)-\sum_{i=1}^{n}L_v e_{iv}x_{iv}\right\}\\ &-\sum_{j=1}^{J}p_j f_j+\sum_{o=1}^{O}w_o z_o-\sum_{k=1}^{K}w_k h_k \qquad (1)\end{aligned}$$

Subject to:

$$A=\sum_{c=1}^{C}\sum_{g=1}^{G}A_{cg} \qquad (2)$$

$$Z_h = z_j + z_o \qquad (3)$$

$$\sum_{v=1}^{V}365\alpha_v L_v \le S \qquad (4)$$

$$365\gamma P \le \sum_{c=1}^{C}\beta_c b_c+\sum_{j=1}^{J}\beta_j f_j \qquad (5)$$

$$\sum_{c=1}^{C}\sum_{g=1}^{G}\sum_{i=1}^{n}A_{cg}e_{icg}x_{icg}+\sum_{v=1}^{V}\sum_{i=1}^{n}L_v e_{iv}x_{iv}+\sum_{j=1}^{J}p_j f_j+\sum_{k=1}^{K}w_k h_k \le M_0 \qquad (6)$$

Table 1 Variable definition.

Variables	Explanation	Variables	Explanation
M	Net income	M_0	Cash income
Pc	sale or purchase price of crop production	pv	sale or purchase price of livestock production
A	land area	Acg	arable land area
ycg	yield function of crop production	yv	yield function of livestock production
Bc	household consumption of crop production	bv	household consumption of livestock production
Sc	crop production supplied for own	sv	livestock production supplied for own
$eicg$	crop production cost of inputs	eiv	livestock production cost of inputs
$xicg$	crop production inputs	xiv	livestock production inputs
Lv	livestock store	pj	price of food purchased
Fj	quantity of food purchased	wo	wage of off-farm job
wk	wage of hiring labor	Zh	total household labor
Zj	household agricultural labor	Zo	household off-farm labor
Hk	hiring labor	α	Daily fodder requirement of livestock v
B	Nutrition content of food	γ	Daily subsistent nutrition requirement of human
R_0	Price of purchasing young animal		

$$\sum_{c=1}^{C}\sum_{g=1}^{G}\sum_{i=1}^{n}A_{cg}e_{icg}x_{icg}+\sum_{v=1}^{V}\sum_{i=1}^{n}L_v e_{iv}x_{iv}+\sum_{j=1}^{J}p_j f_j$$
$$+\sum_{k=1}^{K}w_k h_k+\sum_{v=1}^{V}p_v l_v \leq M_0+R_0 \tag{7}$$

The definition of variables in the above equations is given in Table 1.

Data and Base Run

Two surveys were implemented in 2005 and 2006. The first survey in 2005 covered six villages and 60 households. The second survey in 2006 was carried out in three villages and covered 45 households. The three villages are Songhe village in Baqu, Dongda village in Quanshan, Jianggui village in Huqu. A village model is built based on the data of Dongda village.

The population of Dongda village was 1851. Family labor is 1277 persons. 4.7% of family labor engaged with constant off-farm jobs. Nobody is engaged in part-time off-farm jobs. Average sowing area per household is 0.53 hm^2. 39% of cultivated land is leased land. The main crops are wheat, capsicum, melon for seeds, corn, cotton, sunflower. Average yield of grain crops per capita is 1,527 kg. The commercial grain provided per capita is 1,031 kg, accounting for 67.5% of grain yield. 55% of commercial grain is wheat. Net income per capita is 3647 yuan. 91% of net income is from agriculture.

Table 2 compares the base run results with actual data in 2005. The base run results are significantly close to the actual situation. The simulation results suggest that households should grow more wheat-corn instead of wheat and corn so that they can spare land to grow melon for seeds and cotton to earn cash income. One of the reasons for the gaps is the lack of investment constraint in the model. Actually,

Table 2 Comparison between base run results and actual situation.

	Items	Unit	Base run results	Actual situation in 2005
Crop production	Wheat	hm^2	0	273
	Capsicum	hm^2	196	203
	Melon for seeds	hm^2	386	157
	Corn	hm^2	0	110
	Cotton	hm^2	196	105
	Sunflower	hm^2	0	101
	Clover	hm^2	0	4
	Inter-crop of wheat and corn	hm^2	190	25
Livestock	Sheep	Head	4259	4449
	Pig	Head	363	239
	Chook	Head	1125	6389
Land supply	Family land	hm^2	593	593
	Leasing land	hm^2	374	384
Grain yield	Wheat yield	kg	968200	1559289
	Corn yield	kg	1107735	1267311
Commercial grain	Commercial wheat	kg	241762	777888
	Commercial corn	kg	925710	1131120
Net income	On-farm income	yuan	5912477	4997339
	Off-farm income	yuan	300000	418000
	Total family income	yuan	6212477	5415339

households are facing a shortage of investment when they want to grow more cash crops. Another reason may be the risk averting behavior of households. Planting more cash crops may bring higher income, though they have to face high risk due to sharp prices influence. As a result, farmers prefer to grow wheat for staple food and to sell wheat to earn cash income in actual situation.

Scenario Design

In order to simulate the impact of extension of water-saving technology and increasing of off-farm income source on land use decisions and household income with reduction of water use, several scenarios are designed as listed in Table 3. As a primary measure of ecological rehabilitation, water use is reduced at every scenario. The first scenario (R) is designed to reduce water allocation without other measures to get insight on impact of water use reduction. The second scenario (RTO) simulates the effect of extension of water-saving techniques with an increase in off-farm job opportunity on land use decision and household income while water allocation is reduced. The water-saving techniques include: (1) border Irrigation, matching with grain crops and cotton; (2) dropping Irrigation, matching with cotton, capsicum and melon for seeds.

Table 3 Scenario definitions.

Scenario	Water use	Technique	Off-farm job opportunity
R	Reduced	none water-saving techniques	5%
RTO	Reduced	Extended water-saving techniques	5–100%
RTOSG	Reduced	Subsidy for grain crops with water-saving technique	5–100%
RTOSA	Reduced	Subsidy for all crops with water-saving technique	5–100%

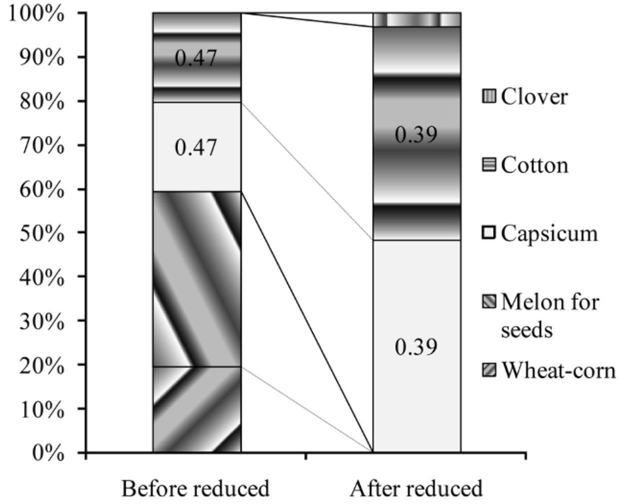

Fig. 1 Change in cropping system due to reduced water supply.

Based on the above two scenarios, the third scenario (RTOSG) simulates the effects of a subsidy for grain crops where water-saving techniques have been adopted, in order to discuss whether a subsidy may raise food security level. In contrast, the forth scenario (RTOSA) simulates the effect of the same subsidy for all crops where water-saving techniques have been adopted.

Simulation Results

Impacts of Reducing Water Use

If 5,558 m^3 of water use per household is reduced, households will not grow wheat-corn and melon for seeds. Area of cotton and capsicum will also decrease (Figure 1). Total sowing area will be reduced to 35% of that which existed prior to water use reduction (Figure 2). As a result, household net income and grain yield will decrease to 28 and 0% of previous levels, respectively (Figure 2).

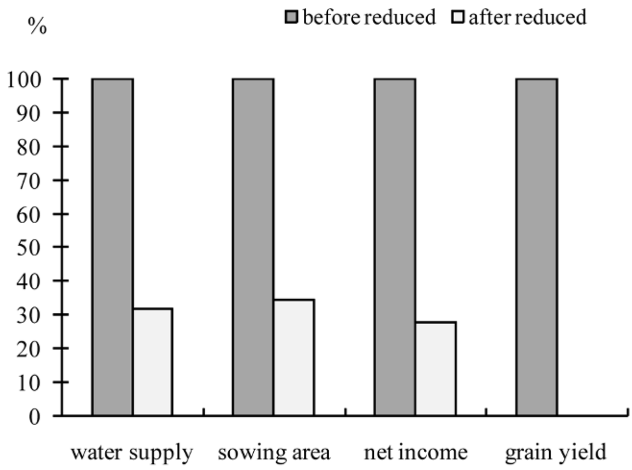

Fig. 2 Change in income and grain yield due to reduced water supply.

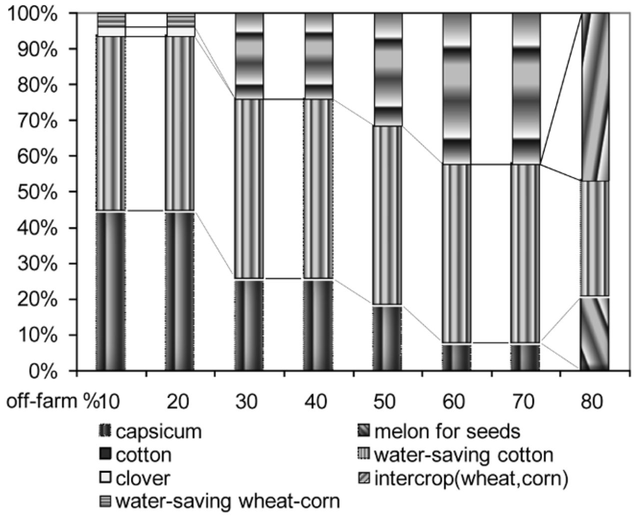

Fig. 3 Change in cropping system extending water-saving techniques with off-farm opportunities increased.

Effects of Water-Saving Techniques Extension and Off-Farm Job Opportunity Increase

The result shows that farmers will adopt water-saving technique to grow cotton and wheat-corn. With the off-farm opportunity increasing, capsicum will be substituted gradually by wheat-corn where a water-saving technique has been adopted (Figure 3). Total sowing area tends to decrease. Family net income will increase linearly

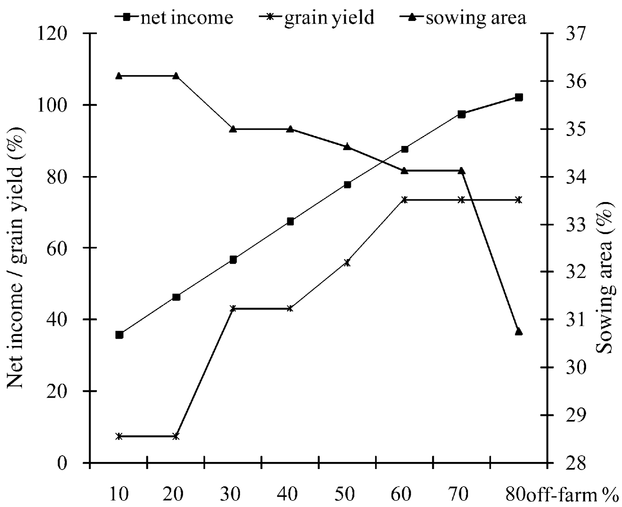

Fig. 4 Change in sowing area, income and grain yield extending water-saving techniques with off-farm opportunities increased.

with increases in off-farm opportunity. Grain yield also increases (Figure 4). When off-farm opportunity reaches 80%, the net income may revert to the level before water use was reduced, and grain yield reaches 73% of that before water use reduction. Nevertheless, it is difficult to achieve 80% of off-farm job opportunity.

The Level and Cost of Food Security Could Be Maintained

With increases in subsidy and off-farm job opportunity, wheat yield will rise gradually under both RTOSG and RTOSA scenarios (Table 4). To compare the costs to maintain grain yield, three levels of food security are designed according to wheat yield which can be achieved under RTOSG scenario (Table 4):

1. Elementary security level: wheat yield per household is more than 1700 kg, just sufficient for farm household consumption, namely wheat purchase and sale are zero.
2. Second security level: wheat yield per household is more than 1,990 kg, with 270 kg of wheat for sale.
3. Third security level: wheat yield per household is more than 2,110 kg, with 390 kg of wheat for sale.

Table 4 Wheat yield under varies of subsidies.

Scenario	Subsidy (yuan/hm^2) Off-farm	0	750	1500	1800	2250	6000
RTOSG	5%	169	1583	1702	1991	1991	1991
RTOSG	30%	997	1583	1702	1991	1991	1991
RTOSG	50%	1293	1583	1702	1991	1991	1991
RTOSG	70%	1702	1991	1991	1991	2115	2115
RTOSA	5%	169	576	576	576	612	669
RTOSA	30%	997	1152	1210	1210	1253	1285
RTOSA	50%	1293	1688	1700	1700	1699	1699
RTOSA	70%	1702	1702	1700	1700	1699	1699

Table 5 Total subsidy sum (yuan/household).

Scenario	Subsidy (yuan/hm^2) Off-farm	750	1500	1800	2250	6000
RTOSG	5%	233	501	703	878	2342
RTOSG	30%	233	501	703	878	2342
RTOSG	50%	233	501	703	878	2342
RTOSG	70%	250	586	703	933	2488
RTOSA	5%	708	1417	1700	2183	5973
RTOSA	30%	663	1381	1657	2140	5807
RTOSA	50%	613	1402	1682	2121	5696
RTOSA	70%	546	1402	1682	2121	5696

Direct Cost of Subsidy for Improving Food Security

When the subsidy is 1,500 yuan/hm^2 under RTOSG scenario with 5% of off-farm opportunity, wheat yield per household rose to 1,702 kg (Table 4), reaching the elementary level of food security. Compared with no subsidy, the increment of wheat yield per household is 1,443 kg. Total subsidy payment per household is about 500 yuan (Table 5). Hereby, the direct cost to maintain the elementary level of food security is 0.35 yuan/kg, which makes up 19% of the farm purchase price of wheat.

When the subsidy is 1,800 yuan/hm^2 under RTOSG scenario with 5% of off-farm opportunity, wheat yield per household rose to 1,991 kg, and reached the second level of food security. The increment of wheat yield per household is 1,732 kg. Total subsidy payment per household is about 703 yuan. In this case, the direct cost to realize the second level of food security is 0.41 yuan/kg, which makes up 23% of the farm purchase price of wheat.

A third level of food security could not be achieved unless off-farm opportunity is increased to 70%. And it requires an amount of no less than 2,250 yuan/hm^2 subsidy for RTOSG scenario. Wheat yield per household rose to 2115 kg, 413 kg more than that without subsidy at 70% of off-farm opportunity. Total subsidy payment per household is about 933 yuan. Thus, the direct cost to reach the third level of food security is 2.2 yuan/kg, which is equivalent to 122% of the farm purchase price of wheat.

Table 6 Family net income under varies subsidies and off-farm job opportunity (yuan/household).

Scenario	Subsidy (Yuan/hm^2) Off-farm	0	750	1500	1800	2250	6000
RTOSG	5%	4456	4592	4842	4947	5123	6587
RTOSG	30%	8446	8596	8847	8952	9127	10591
RTOSG	50%	11553	11745	11995	12100	12276	13739
RTOSG	70%	14482	14732	15024	15142	15326	16881
RTOSA	5%	4456	5119	5828	6111	6545	10249
RTOSA	30%	8446	9060	9739	10015	10440	14055
RTOSA	50%	11553	12100	12730	13010	13433	16987
RTOSA	70%	14482	15028	15638	15918	16341	19895

Opportunity Cost with Concomitant Structural Change to Maintain Food Security

If a subsidy is paid for grain crops where water-saving technologies have been adopted in order to attain food security, the cropping system will change and sowing area of grain crops will increase. Since profits of grain crops are lower than cash crops, such a structural change will lead to a gap of income increment between RTOSG scenario and subsidy payment. This loss may be considered as one of opportunity costs to maintain food security. Structural change also may lead to a decrease in household income in contrast with the case of subsidy for all crops adopting water-saving technologies. The gap of net income increment between RTOSG and RTOSA scenario may be considered as another opportunity cost.

Table 6 shows that if the elementary level of food security in case of 5% of off-farm opportunity is maintained, net income per household may reach 4,842 yuan. If no subsidy, the net income is 4,456 yuan. The increment of net income per household is 386 yuan, while subsidy payment per household is 501 yuan. That means a sum of 115 yuan is the cost for pursuing the elementary level of food security. In the same way, for maintaining the second level of food security, the subsidy payment per household is 703 yuan, while the increment of net income is 491 yuan. The gap is 212 yuan. For the third level of food security, the gap is 89 yuan.

Comparing the income under RTOSG scenario with RTOSA scenario, if the same subsidy payment is provided to maintain the elementary level of food security under the RTOSA scenario, the net income per household is 5,828 yuan, 986 yuan more than the case under RTOSG scenario. The difference of subsidy payment per household between RTOSA scenario and RTOSG scenario is 916 yuan. Thus, the gap in income increment excluding subsidy payment between these two scenarios is 70 yuan. In case of the second level of food security, the gap of income increment between these two scenarios is 167 yuan.

The Effects of Increasing Off-farm Opportunity

Table 5 indicates that when the elementary and second level of food security are attained, net income per household is not more than 5,000 yuan, far less than that before water use was reduced, 14,826 yuan. Thus, it would be very expensive to ensure food security. Improving access to off-farm job opportunity may increase household income. If off-farm job opportunity reached 50%, net income per household would increase from 4,842 yuan to 11,995 yuan just to ensure the elementary level of food security, and net income per household would increase from 4,947 yuan to 12,100 yuan to maintain the second level of food security. If off-farm opportunity reached 70%, net income per household would reach 14,482 yuan. Even without subsidy payment, the elementary level of food security can be ensured. However, to maintain the second level of food security, the subsidy payment for grain crops per household may decrease from 703 yuan in case of 5% of off-farm opportunity to 586 yuan.

Conclusions and Implications

The above discussion may be concluded as follows:

- When water allocation to agriculture is reduced, farmers cannot produce enough grain for their self-supplying. If a subsidy payment for grain crops adopted water-saving techniques, households may produce more grain for their self-supplying. Furthermore, farmers may provide a bit of commercial grain despite the amount of commercial grain being low.
- It will take a significant expenditure to maintain food security. The subsidy payment for grain crops to ensure the elementary level of food security is 0.35 yuan/kg, which makes up of 19% of the farm purchase price of wheat. The subsidy payment for grain crops to maintain the second level is 0.41 yuan/kg, which makes up 25% of the farm gate price of wheat. Besides the direct cost, the indirect opportunity costs with concomitant structural change to maintain food security also should be taken into account.
- In case of 5% of off-farm opportunity, farmers need to purchase 1443 kg of wheat per household for self-supplying to make up food shortage due to reduced water allocation. It will take 2597 yuan to purchase 1443 kg. While providing subsidy for grain crops adopting water-saving techniques, a payment of 501 yuan per household may meet self-supplying of grain. Therefore, it is feasible to provide subsidy for grain crops adopting water-saving techniques to maintain the elementary level of food security rather than providing subsidy to purchase food. The subsidy payment for grain crops adopting water-saving techniques may be considered as the compensation to households while water allocation was reduced for environmental improvement. As water allocation was reduced 5558 m^3 per household, the subsidy payment to maintain elementary level of food secu-

rity costs 0.09 yuan/m^3 of reduced water. As the whole region should reduce 2.76×10^8 m^3 of water allocation, the subsidy for the whole region demands a sum of 2,484 $\times$ 10^4 yuan totally.
- For maintaining the second level of food security, it needs to increase payment of 202 yuan per household rather than the elementary level. The increase in commercial wheat is 272 kg per household. It means that the subsidy cost to provide 1 kg of commercial wheat will increase 0.74 yuan. The increased subsidy cost accounts for 41% of the sale price of wheat. It is not economical to maintain the second level.
- Water allocation reduction will result in a lot of surplus farm labor. It is important to improve access to off-farm employment for surplus labor due to water allocation reduction. If off-farm opportunity reached 30%, household net income may rise at 60% of that before water allocation was reduced, even though there is still a 30% surplus of laborers. However, it is not easy to increase off-farm employment from the present level of 5% to the level of 30%. Consequently, it is believed that the alternative solution to conflict of water allocation between food security and ecological security will mainly depend on a subsidy measure for promoting extension of water-saving technologies in grain crops.

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Impacts of Water Environment and Conservation for Sustainable Development in Northern Philippines

C.M. Pascual, W.D. Balizon, J.M. Caraang, L.A. Castro, M.O. Ganda and S.N. dela Cruz

Abstract This paper presents two case studies to quantify impacts on water environment and conservation for sustainable development, such as: (1) feasibility of using a low-cost gravity-type drip irrigation system (LCDIS) for lettuce (*Lactuca sativa*) and tomato (*Licopersicum esculentum*) during two dry seasons from 2004–2006; and (2) re-use of greywater (such as kitchen and laundry wastewater from households) for swamp cabbage (*Ipomea aquatica*) under controlled environments. Field plot experiments using LCDIS revealed savings of 50% of water applied for lettuce and tomato with a yield increase up to 3 t ha^{-1} during the dry season as compared to the traditional irrigation methods used by farmers. Economics of scale suggest that LCDIS is feasible for large areas planted to high value food crops under sustainable water resources. For the greywater studies, after six weeks and thereafter, the plants reacted to the different dilutions where most plants wilted and were severely injured as compared to plants cultured under lower dilution and tap water (as control). One hundred percent (100%) survival was observed under amended greywater (lower dilution) and clean tap water. The foregoing results showed that there is a need to refine greywater if reused for garden agriculture and industry in the near future.

Key words: Greywater, sustainable development, water conservation, water environment

Introduction

Food production, safety and security coupled with water scarcity and water pollution are some of the crucial issues in the world. One of the ways to reduce the impact of water scarcity and pollution is to expand water and wastewater reuse. Ac-

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cess to water supply and improved sanitation is one of the key factors in improving health and economic food productivity. In order to increase access to water supply the following three elements are especially important; (1) development of new water sources; (2) prevention of water resource degradation; and (3) improvement in efficiency of water consumption for food production and industries. Agricultural irrigation is crucial for improving the quality and quantity of food production. Worldwide, agriculture is the largest user of water; the sector has accounted for 67% of total freshwater withdrawal in the world. Therefore more efficient use of agricultural water through wastewater reuse is essential for sustainable water management. Sustainable development of our landscapes will require an economic system that supports environmental goals. There is growing demand for accountability of both taxes spent and the imposition of regulations by all government programs. Justifying spending on environmental programs or regulating land use will require demonstration of the benefits and performance of various policies and practices. This is never a simple task but is particularly challenging in the environmental world where natural weather and landscape variability can mask the best of intentions. As demand for conservation and environmental programs continues to grow, a question emerges from policy makers, agencies, interest groups, and the public: How do we measure success? How do we best communicate to the public our success? Environmentally sound technologies protect the environment, pollute less, use resources in a more sustainable manner, recycle more wastes and products, and handle residual wastes in a more acceptable manner than the technologies which they replace. Environmentally sound technologies in the context of pollution are technologies that generate low or no waste, and they may also cover end of the pipe technologies for treatment of pollution after it is generated. Environmentally sound technologies are not just individual technologies, but total systems which include know-how, procedures, goods and services, and equipment as well as organizational and managerial procedures. Some of these technologies include the drip irrigation system (Cuenca, 1989; Pascual and Dumaoal, 1999; and van Lier, 1999). For water conservation and reuse of greywater for household or garden irrigation which are often overlooked and has showed some potential uses but needs baseline information for environmental concerns (Guerrero and Guerrero, 2004). And since the cost of irrigation depends on water supply and energy resources, there is a need for an appropriate irrigation scheme for cash crops like lettuce (*Lactuca sativa* L.) and tomato (*Licopersicum esculentum).*

Thus, Case Study 1 generally aimed to evaluate the performance of a low-cost gravity-type drip irrigation system under field conditions. Specifically, the study aimed to: (a) determine the irrigation efficiency using gravity-type drip irrigation and furrow methods of irrigation; (b) assess the growth and yield of lettuce and tomato as affected by different irrigation methods; and (c) compare the economic feasibility of a gravity-type drip irrigation system with the farmer's practice on lettuce and tomato. Case Study 2 aimed to ascertain the effects of greywater such as kitchen waste water (KWW) and laundry waste water (LWW) from a household sitting on swamp cabbage. Specific objectives were to: (a) estimate the major chemical properties of KWW and LWW from a household; (b) evaluate the effects of the level of concentration of detergent in KWW and LWW on the number of shoots, net growth and root length of swamp cabbage (*Ipomea aquatica*); and (c) estimate the actual evapotranspiration of swamp cabbage as affected by the level of concentration of KWW and LWW.

Materials and Methods

Case Study 1

Case Study 1 was conducted at the vegetable production area of the Mariano Marcos State University Batac, Ilocos Norte, Philippines. The experiment covered a total area of 200 m^2 each, planted to lettuce and tomato, separately. The low-cost gravity-type drip irrigation system (US$ 0.48/m^2) was operated at constant water head of 3 m with 20 m length of dripperlines to simulate the steady flow rate of the emitters, which irrigated half of the area. The other half of the area was irrigated using the furrow method. Each study area of 200 m^2 was divided into two plots to represent two treatments, the drip irrigation system and furrow irrigation. The irrigation performance indicators for drip include: the coefficient of manufacturing variation (Cv) was used as a measure of the anticipated variations in discharge for emitters (Van Lier et al., 1999); uniformity coefficient (EU) (Van Lier et al., 1999) and application efficiency (AE). Methods used in the studies were presented by Ganda (2005) and Balenzon (2006). The height of the plants was taken from 10 sample plants in each treatment with the use of a meter stick set at the base of each plant. The diameter of the head was based on the polar and equatorial diameter of the samples from each treatment using a vernier caliper. The yield per hectare was computed based on the yield obtained from the harvest area. For alternative project cost analysis, three discounted measures commonly applied to agricultural projects were used namely, benefit-cost ratio (BCR), net present value (NPV) and internal rate of return (IRR) as described by Cuaresma (2001). The emitter discharges of the drip irrigation system were analyzed using randomized complete block design (RCBD) with four replications. The crop yield was analyzed also using RCBD with three replications. The treatment means were compared using the least significant difference test at 5% level of significance. T-test for uncorrelated means was used to analyze irrigation parameters and agronomic parameters of lettuce and tomato and separate experiments.

Case Study 2

Case Study 2 was conducted at the Agricultural Engineering Model Farm, College of Agriculture and Forestry, Mariano Marcos State University, Batac, Ilocos Norte,

Table 1 Hydraulic parameters of two set-ups of gravity-type drip irrigation system.

Set-up	$Q_{emitter}$ (lph) ns	Cv (lph) ns	EU (%) ns
1	0.195	0.088	66.38
2	0.190	0.145	59.85
Mean	0.1925	0.117	63.12

ns – not significant

Philippines. Four different levels of concentration of greywater such as kitchen waste water (KWW) and laundry waster water (LWW) were the treatments used in two separate controlled experiments. Three replications were laid out using a completely randomized design (CRD). The KWW and LWW set-ups were placed in a 1 l (1,000 ml) plastic bottle where the swamp cabbage was contained with soil anchorage. The following data were gathered: pH level using pH indicator paper; nitrate–nitrogen (NO_3–N) was determined using cadmium reduction method; evapotranspiration (ET) using a calibrated water level indicator was installed where the specimen was contained. Agronomic parameters gathered include vine length, number of shoots, root length, total *N* using the Kjeldahl method. Details of measurements are presented by Castro (2006) and Caraang (2006).

Results and Discussion

Case Study 1

The low-cost gravity-type drip irrigation system that was used by dela Cruz (2004) which was donated by Plastro Philippines Inc., was used in the evaluation. The system was operated at 3 m high water head with 20 m length of dripline to evaluate the performance of the system and compare with furrow (farmer's practice) method of irrigation. Two plots were made and planted to lettuce to evaluate the performance of both irrigation methods (Ganda, 2005). The other two plots were also planted to tomato (Balenzon, 2006). The specific hydraulic parameters of the gravity-type drip irrigation system such as emitter discharge ($Q_{emitter}$), coefficient manufacturing variation (Cv) and emission uniformity (EU) were determined (Table 1). Emitter discharge is very important to consider in the design, operation and maintenance of drip irrigation system. Emitters were designed to discharge a small uniform flow of water at a constant rate. There were no significant differences on the emitter discharge between the two set-up of gravity-type drip irrigation system.

The coefficient of manufacturing variation was also determined and used to measure the anticipated variations in the discharge of emitters. The Cv value for Set-up 1 and Set-up 2 were 0.088 lph and 0.145 lph, respectively. Such Cv values were within the permissible level of emitter design. The emission uniformity (EU) was

Table 2 Plant height, head size (polar and equatorial) and yield of lettuce and tomato as affected by different methods of irrigation.

Treatment	Plant height (cm)	Head size (cm)		Yield
		Polar	Equatorial	(t ha^{-1})
		Lettuce		
	ns	ns	ns	ns
Drip irrigation	13.20	11.93	14.79	16.09
Flush flooding	11.64	11.55	14.14	15.49
		Tomato		
	ns	ns	ns	ns
Drip irrigation	80.17	4.41	3.98	36.57
Flush flooding	78.97	4.35	3.92	33.95

ns – not significant

determined and used to describe the water distribution uniformity of the drip irrigation system. Field measurements revealed that the EU of Set-up 1 and Set-up 2 were 66.38 and 59.85%, respectively. Low EUs could be attributed to the clogging of emitters during flow measurements. However, studies of dela Cruz (2004) showed high EU of 89 to 90%. The plant parameters such as plant height, head size (polar and equatorial) and yield were considered to evaluate the performance difference between two irrigation methods. Table 2 shows that the average plant heights, head size and yield of lettuce and tomato were not significantly affected by the two methods of irrigation.

However, the plants irrigated by the drip irrigation were numerically taller than those irrigated by flush flooding method. Furthermore, Table 2 shows that the yield of lettuce and tomato produced in plots irrigated by drip irrigation are higher than by furrow method of about 1.5 to 3 tons but did not differ significantly. The application efficiency of an irrigation system is an important indicator to know how efficiently the water was applied to the field in order to minimize water waste. Table 3 shows that the application efficiency obtained on the drip irrigation system did not differ significantly from the flush flooding method. The drip irrigation system gave numerically higher application efficiency because water was directly applied to the plants from time to time with a total saving on water by 50% as compared to the farmer's practice. Water might have been applied directly to the rootzone; hence, losses due to evaporation and runoff were minimized.

A discounted measure using BCR, NPV and IRR showed that both irrigation systems are economically feasible (Table 4).

However, drip irrigation having the higher BCR is more attractive to invest in than the flush flooding method. The projected NPV indicates the net present value of money as well as the stream of cash flows on the entire life of investment. However, drip irrigation is more profitable than the flush flooding practice; thus, it is advisable to invest in a drip irrigation system. Both IRR estimates are greater than the opportunity rate of investment of 13% which reflects that both investment options are attractive and feasible. The foregoing economic analysis showed that drip irri-

Table 3 Application efficiency on lettuce and tomato as affected by the gravity-type drip irrigation system and furrow method of irrigation.

Treatment	Depth of water (cm)		Application
	Applied	Applied	efficiency (%)
	Lettuce		
			ns
Drip irrigation system	2.658	2.087	78.51
Furrow irrigation	4.301	3.334	77.58
	Tomato		
			**
Drip irrigation system	4.77	3.78	79.20
Furrow irrigation	4.69	3.25	69.29

**Significant at 1% level; ns – not significant

Table 4 Economic analysis per hectare of lettuce and tomato for agricultural production using drip irrigation system and furrow methods of irrigation.

	Discounted economic measure		
Treatment	BCR	NPV (US$)	IRR (%)
	Lettuce		
Drip Irrigation System	1.99	50,158	49.07
Furrow irrigation	1.76	41,809	43.67
	Tomato		
Drip Irrigation System	1.64	33,096	38.11
Furrow irrigation	1.39	22245	36.43

gation is more attractive and feasible to invest in than the furrow irrigation method. The economics of scale suggest that a drip irrigation system should be invested in a large production area planted with high value crops.

Case Study 2

Table 5 shows that the pH, NO_3-N, ET, vine length, root length, net growth and total *N* of KWW showed significant differences among treatments of varying levels of concentration. As of this time the pH level is within the recommended values for irrigation (Van Lier, 1999).

For NO_3-N, concentrations are below the maximum contamination level of 10 ppm set by the WHO. It is worth noting that most plants obtain nitrogen as NH_4^+ and NO_3^- ions from the soil solution. Hence, irrigation with nitrogen rich effluents is beneficial to soils and plants. The foregoing results showed that the different level of concentration of KWW severely injured the swamp cabbage onward after 4th WAP. In Treatment I, the survival rate was 100% with tap water as the medium. Based

Table 5 Chemical properties of greywater KWW and LWW and agronomic characteristics of swamp cabbage (*Ipomoea aquatica*) as affected by the level of concentration of treatments.

Treatment	pH	NO_3-N (ppm)	ET (mm d^{-1}	Vine length (mm) at 4th WAP	Root length (mm) at 4th WAP	Net growth (mm)	Total N (%)
KWW							
	*	**	**	**	**	**	*
T_1-0 (0%)	7.78 a	1.23 a	3.46 a	534.89 a	147.61 a	72.39 a	1.82 b
T_2-Low (25%)	7.75 a	0.21 c	2.60 b	374.94 d	24.00 c	–28.67 c	2.55 a
T_3-Medium (50%)	7.58 b	0.29 b	3.33 a	386.33 c	28.89 c	–2.67 c	2.28 a
T_4-High (100%)	7.48 c	0.33 b	2.76 b	426.00 b	50.22 c	–13.50 d	2.22 a
CV (%)	1.31	10.05	8.70	1.81	8.47	7.68	9.01
LWW							
	ns	ns	ns	ns	*	*	ns
T_1-0 (0%)	7.9	0.14	2.04	16.43	59.60 b	0.23 a	1.84
T_1-Low (25%)	7.8	0.18	1.46	16.07	44.20 c	0.27 a	1.85
T_3-Medium (50%)	7.9	0.17	2.44	22.33	66.67 a	–3.73 c	1.82
T_4-High (100%)	7.8	0.22	2.03	14.28	59.57 b	–0.19 b	1.89
CV (%)	0.70	11.57	13.22	16.61	11.95	14.47	1.71

Notes: *significant at 5% level; **significant at 1% level; ns – not significant; CV – coefficient of variation. Comparison between the treatment mean of a control and each of the 3 levels of concentration treatments, using the LSD.

on the results of the study, a high concentration of kitchen waste water severely injured swamp cabbage toward the 6th week after planting. Survival was observed for all sample plants of swamp cabbage when cultured with tap water. There is a need to treat KWW if used in irrigating aquatic plants like swamp cabbage. At this time, KWW is not suitable for irrigation. Such a finding corroborates the study of Guererro and Guerrero (2004).

For the LWW, no significant differences were observed on pH, NO_3–N, ET, vine length, total *N*, except on root length and net growth among four treatments (Table 5). It was observed however, that LWW is not detrimental to the growth and development of swamp cabbage up to 35 days after planting. Different levels of LWW severely injured swamp cabbage about 42 days after planting. There is a need to treat LWW before it is used for irrigation. It is not advisable to use LWW to irrigate plants especially those that are fragile and sensitive to pollutants.

Conclusions

Economic indicators such as BCR, NPC and IRR revealed that both irrigation methods are economically feasible. However, the low-cost gravity-type drip irrigation system is more attractive to invest in than the furrow irrigation method. The economics of scale suggest that a drip irrigation system should be chosen for larger production area of more than 1 ha planted to high value crops. However, there is a need to consider some technical, economic and social attributes that distinguish low-cost drip irrigation systems from commercial, and other state-of-the-art micro-irrigation systems. Likewise, fertigation using a drip irrigation system should be explored. Since the fertilizer is one of the most basic needs of the plants, there is a need to know how the drip irrigation system distributes the fertilizer and how this practice can affect the growth and yield of plants. Moreover, the performance of the drip irrigation system should be evaluated on other high value crops in the locality. Based on the results of Case Study 2 on greywater, a high concentration of KWW and LWW severely injured swamp cabbage about the 6th week after planting. Survival was observed for all sample plants of swamp cabbage when cultured with tap water. There is a need to amend KWW and KWW if used in irrigating aquatic plants like swamp cabbage. As of this time, it is not advisable to irrigate plants especially those that are fragile and sensitive to pollutants.

Effluent reuse for agriculture should be practiced with good management to reduce negative human health impacts that could be caused by uncontrolled use, so the effluent intended for reuse should be treated adequately and monitored to ensure that it is suitable for the intended use. Effluent reuse for agriculture needs to be planned with attention to target crops and existing water delivery methods. Excess nitrogen may cause overgrowth, delayed maturity, and poor quality of crops.

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Material Flow Analysis of Nitrogen and Phosphorus for Regional Nutrient Management: Case Study in Haiphong, Vietnam

Toshiya Aramaki and Nguyen Thi Thu Thuy

Abstract The aim of this study is to quantify nitrogen and phosphorus flows in urban areas of Haiphong city by using Material Flow Analysis in order to identify weaknesses related to nutrient management in this region. The system boundary is defined by the five urban districts in Haiphong city, and eight components are included in the system model developed for nutrient flows in the urban area. Each flow in the model is quantified through literature and interview surveys. The visualization of N and P flows showed that, ordinary household activities are the processes that produce the highest amount of N and P loading to the environment. The main potential to mitigate environmental impact by these nutrients is the appropriate management of human excreta and wastewater from households.

Key words: Haiphong, material flow analysis, nitrogen, nutrient management, phosphorus

Introduction

Material Flow Analysis (MFA) is defined as a systematic assessment of the flows and stocks of materials within a system defined in space and time. It connects the sources, the pathways, and the intermediate and final sinks of a material (Brunner and Rechberger, 2004). MFA is considered as an attractive tool for environmental planning through the analysis of various pollutants. Nutrients, such as nitrogen and phosphorus are essential substances for our life, but they also contribute to deterio-

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ration of the local environment, such as eutrophication. The application of MFA for nutrients has been done by several researchers, such as Belevi et al. (2002), Cau et al. (2003), Montangero et al. (2004) and Sinsupan (2004). In this chapter, MFA is applied to get an overview of the existing nutrient flows in Haiphong, Vietnam, to identify weaknesses of nutrient management.

Methods

Haiphong is located on the delta of Red River in the northern part of Vietnam. It is the third largest city in Vietnam, just after Hanoi and Ho Chi Minh City, and is a major port and industrial center with a growing tourism center. It has a subtropical climate, dominated by the monsoons. The average temperature in winter is 19°C, in summer is 26°C, and the annual average precipitation is 1,754 mm.

The city contains a dense network of rivers, canals and ponds and suffers flood events frequently due to heavy monsoon rainfall and insufficient drainage capacity. There is a sewer network in the three central districts, but no wastewater treatment has been done. According to our survey of 100 households, approximately 80% of households use a septic tank, and 10% of households use other sanitary latrines. Due to the untreated greywater, seepage of septic tanks and the inappropriate handling of septage, rivers, ponds and canals in the city are heavily polluted. Regarding solid waste management, it is estimated that 605 tons/day of municipal solid waste are generated in the five districts of Haiphong City, and 78% of them are collected (VIWASE, 2004).

There are 14 administrative units in Haiphong including 5 urban districts, 1 town and 8 suburban districts. The population of the city is 1,770,800 and its density is 1,166 people/km^2 (Haiphong Statistical Office, 2005). The annual population growth during the past years has been around 1% per year in the urban areas. The total area of Haiphong city is about 1,519 km^2 of which the agriculture area occupies 55.5%, forestry land occupies 10.2%, and water surface occupies 15.3%.

In this study, five urban districts were selected as a target area. The population is about 0.62 million and the area is 165.4 km^2. The agricultural area occupies only 15.8% of the total area in the five urban districts. Eight important components are selected to develop the model of nutrient flows. Figure 1 shows the model of nutrient flows in Haiphong city, developed in this study. The indicators to be analyzed are nitrogen (N) and phosphorous (P).

Estimation of Material Flow

To quantify each flow of the models shown in Figure 1, a literature survey and interviews with the relevant authorities and 100 households were carried out. Table 1

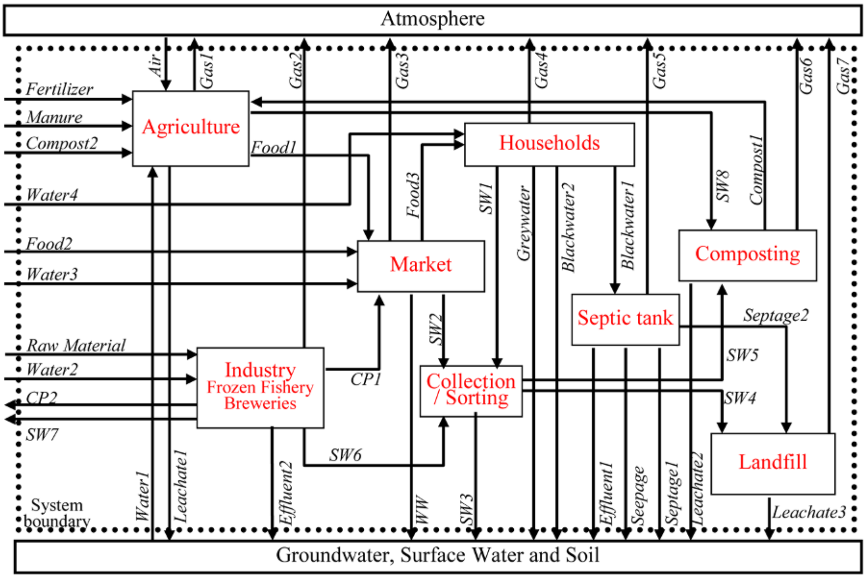

Fig. 1 The model of nutrient flows in Haiphong City (*CP*: Consumer products, *SW*: Solid waste, *WW*: Wastewater).

shows the methodology to determine each flow, and data or data source for determination.

Major agriculture activities are rice, fruit, and vegetable cultivations in this area. Because they have only data collected in the whole city area, data on agricultural activities are allocated to five urban districts according to the actual percentage of agricultural land use. Chemical fertilizer and manure are imported from outside the system boundary. To simplify the estimation, it is assumed that only buffalo and pig manure are used in the process. Irrigation water also contains nutrients, some of which are taken by plants whereas some were losses through drainage water and percolate into the soil. Crop residuals, mainly leaves, are normally composted onsite by informal composting and used as soil amendment in the area. All of the crops produced are transferred to the markets for city consumption.

The key industrial sectors in the city are machinery manufacture, footwear, garments, construction material production, food processes, breweries and rubber. Among them, frozen fishery and breweries are selected as important industries in terms of nutrient flows.

Four main markets in the city are considered in the “Market” component. The “Households” component includes all households, schools, restaurants, department stores, hospitals, hotels, offices and universities. The “Composting” component represents informal composting of agricultural waste and windrow composting of organic waste. There is one composting plant that serves five urban districts in the city,

Table 1 Determination method and data source for material flows.

Flow	Determination method	Data or data source
Fertilizer	N, P contents × S [fertilizer (ton/ ha cultivated area) × area (ha) × cycle (cycle/y)]	N, P contents, fertilizer: Haiphong Department of Agricultural and Rural Development (2004) area: Haiphong Statistical Office (2005) cycle: according to the interview (2–3 cycles per year)
Manure	N, P contents × S [manure (ton/ cultivated area) × area (ha) × cycle (cycle/y)]	N, P contents, manure: same as N, P contents and fertilizer in "Fertilizer" area: same as area in "Fertilizer" cycle: same as cycle in "Fertilizer"
Compost 1	transfer coefficient of N,P in composting × (SW8 + SW5) (ton/y)	transfer coefficient of N,P in composting: 69% for N, 99% for P
Compost 2	N,P contents × S [compost (ton/ha cultivated area) × area (ha) × cycle (cycle/y)] – Compost 1 (ton/y)	N,P contents, compost: same as N, P contents and fertilizer in "Fertilizer" area: same as area in "Fertilizer" cycle: same as cycle in "Fertilizer"
Food 1	S [N,P contents × production (ton/y)]	N,P contents: same in "Food 3" Production: Haiphong Department of Agricultural and Rural Development (2004)
Food 2	Mass balance of "Market"	
Food 3	(For crop commodities) N/P ratio × P contents × S [food consumption (ton/y)] (For livestock commodities) N/P ratio × N contents × S [food consumption (ton/y)]	N/P ratio: 10.0 except for Soybean in crop commodities, 5.0 (Frge et al, 2000) for livestock commodities P contents: 0.4 mg/g (vegetable),0.2 mg/g (fruits), 0.1 mg/g (sugar), 3.3 mg/g (cereals), 0.185% (rice) N contents: 3.2 (fish), 0.5 (milk), 19.87 (meat) and 11.95 (egg) from several literatures
Raw material	S [N,P contents × raw material (ton/product) × production (product/y)]	N,P contents : 3.2% for N, 0.64% for P in fishery factory, 33mg/g for N and 3.3 mg/g for P in Beer factory raw material: 1.1 ton/1 ton fishery product, 1 kg/ 1L beer product production: Haiphong Statistical Department, 2005
Consumer Products 1	S [N,P contents × production (ton product/y) × %consumption within area]	N,P contents: same in "Raw material" (for fishery product), 0.65g/l for N and 0.41g/l for P (for Beer product) production: same in "Raw material" %consumption: 10% of beer and fishery product
Consumer Products 2	S [N,P contents × production (ton product/y) × %export	N,P contents: same in "Consumer products 1" production: same in "Raw material" %export: 90% of beer and fishery product

Table 1 Continued.

Flow	Determination method	Data or data source
Water 1	N,P contents × S [water consumption (m^3/ha/cycle) × area (ha) × cycle (cycle/y)]	N, P contents: 0.25mg/l for N (average quality in water source), P is negligible water consumption: same as fertilizer in "Fertilizer" area: same as area in "Fertilizer" cycle: same as cycle in "Fertilizer"
Water 2	N,P contents × S [water consumption (m^3/product) × production (product/y)]	N,P contents: 0.15mg/l for N, P is negligible water consumption: 8m^3 / 1 ton fishery product, 10L water / 1L beer product production: same as production in Raw material
Water 3	N,P contents × Total water consumption for market/ day * 365 days/y	N,P contents: 0.15mg/l for N, P is negligible Total water consumption for market: 5,211 m^3/day
Water 4	N,P contents × Total domestic water consumption/ day * 365 days/y	N,P contents: 0.15mg/l for N, P is negligible Total domestic water consumption: 85,600 m^3/day
Grey water	N,P concentrations × {TC of domestic WW * Water 4 (m^3/y) – [flush water (l/p/d) * population (person) * 365 days/y * percentage of HH access to sanitation]/1000}}	N,P concentrations: 49.5 mg/L for N, 2.85 mg/L for P TC of domestic WW: 85% water consumption in households flush water: 30L/c/d population: 620,400 percentage of HH access to sanitation: 90%
WW	Transfer coefficient of WW × Water3 (m^3/y)	Transfer coefficient of WW: 90%
Effluent 1	N, P concentrations × [flush water (l/p/d) * population (person) * 365 days/y * percentage of HH access to septic tank] /1000] × % discharge to drainage	N, P concentrations: 2.97mg/L for P, 57mg/L for N flush water and population: same as grey water percentage of HH access to septic tank: 80% % discharge to drainage: 90%
Effluent 2	N, P concentration × wastewater (m^3/product) × production (product/y) and N,P emissions (kg/product) × production (product/y)	N, P concentration: 45mg/L for N and 18mg/L for P in beer factory N, P emission: 8.4 kg/ton for N and 2.73kg/ton for P wastewater: 9L/1L beer product production: same as production in Raw material
Seepage	mass balance in "Septic tank"	
Leachate 1	Transfer coefficient of seeping water in soil × Water 1 (m^3/y)	Transfer coefficient of seeping water in soil: 45% by Kruitkul (1997)
Leachate 2	Transfer coefficient of leachate in compost × (SW5 + SW8)	Transfer coefficient of leachate in compost: 1% for N and P
Leachate 3	Transfer coefficient of leachate in landfill × (SW4 + Septage 2)	Transfer coefficient of leachate in landfill: same in "Leachate 2"
SW1	N,P contents × Total domestic SW collected by municipality per day × 365 days/y	N,P contents: 3.18 g/kg for N (Lemna International, Inc., 2002), 0.205% for P (L.N. Cau, 2002) Total domestic SW collected by municipality: 218 ton/day(57% for food waste) (VIWASE, 2004)
SW2	N,P contents × Total market SW collected by municipality per day × 365 days/y	N,P contents: same in "SW1" Total market SW collected: 193 tons/day

Table 1 Continued.

Flow	Determination method	Data or data source
SW3	N,P contents × (SW1+SW2+SW6) × % of illegally dumped SW	N,P contents: same in "SW1" % of illegally dumped SW: 22%
SW4	N,P contents × (SW1+SW2+SW6) × % of SW transported to landfill	N,P contents: same in "SW1" % of SW transported to landfill: 78%
SW5	% Organic SW to composting × SW4	The process has stopped, so considered as 0.
SW6	N,P contents × SW per product (ton/product) × production (ton/y)	Only for fishery industry N,P contents: same in "Raw material" SW per product : 0.1ton / ton fishery product production: same as production in Raw material
SW7	N,P contents × SW per product (ton/product) × production (ton/y)	Only for beer industry N,P contents: same in "Raw material" SW per product : 0.34 kg/L beer product production: same as production in "Raw material"
SW8	N,P contents × S Agriculture SW use for composting per cycle (ton/cycle) * cycle/y	N,P contents: 4mg/g for N, 0.4 mg/g for P Agriculture SW use for composting: 50% of rice straw, produced 5.5–8 ton/ha (interview)
Air	Planted area of soybean × N fixation per area	Planted area of soybean : same as area in "Fertilizer" N fixation per area: 56,250 g N/hectare
Gas 1	Rice straw burnt (tons) × NOx and N_2O emissions per straw burnt + respiration	Rice straw burnt: 50% of rice straw, produced 5.5–8 ton/ha (interview) NOx and N2O emissions per straw burnt: Andreae M. O. and P. Merlet Respiration: 20% of N loading
Gas 2	Mass balance in "Industry"	
Gas 3,4 and 5	ignored	
Gas 6	Transfer coefficient of gas in compost × (SW5 + SW8)	Transfer coefficient of gas in compost: 30% for N, 0% for P
Gas 7	Transfer coefficient of gas in landfill × (SW4 + Septage 2)	Transfer coefficient of gas in landfill: same in "Gas6"
Blackwater1	N substance per person per day in human waste * population * days/y * % household access to sanitation	N,P emissions per person: 12.5 for N and 1.5 for P population: same in "Grey water" % household access to sanitation: 90%
Blackwater2	N,P emissions per person per day in human waste * population * days/y * % household do not access to sanitation	N,P emissions per person: same in "Blackwater 1" population : same in "Grey water" % household do not access to sanitation: 10%
Septage 1	N,P contents × septage generation (kg/c/d) × population (persons) × 365 days/y * % HH access to sanitation × % illegally septage discharged	N,P contents: 0.97% for N, 0.17% for P septage generation : 1 kg/capita/day
Septage 2	N,P contents × septage generation (kg/c/d) × population (persons) × 365 days/y × % HH access to sanitation * % septage transported to landfill	N,P contents: same in "Septage 1"

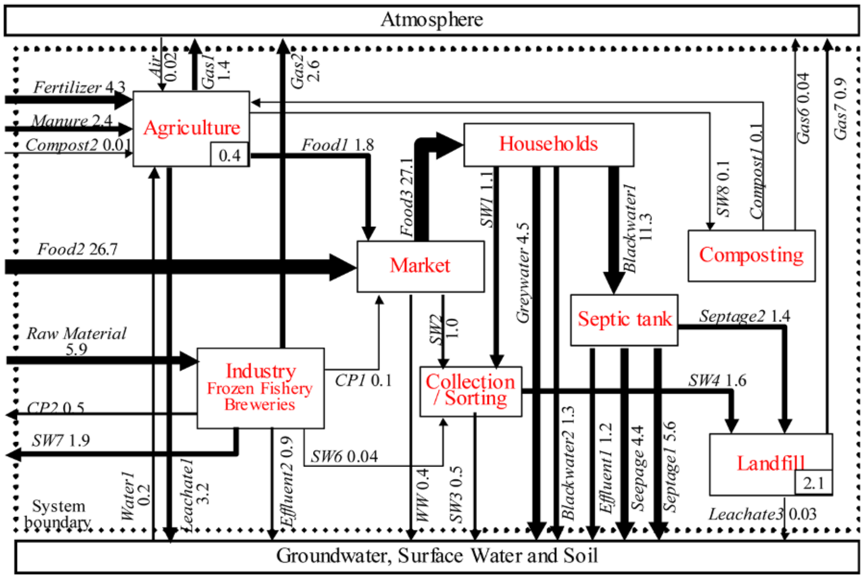

Fig. 2 N flows in the system of "Haiphong Urban Districts" in g/person/day.

but it is not operating now due to the problems in implementation and management of the system.

Results and Discussion

Through balancing input and output in each component, the estimated nitrogen and phosphorus flows per person of Haiphong city are presented in Figures 2 and 3.

Figure 2 indicates that food imporst account for 2/3 of total nitrogen input to the system. Raw materials to the industries and the import of chemical fertilizer account for more than 10% of total nitrogen input. Regarding the nitrogen output from the system, direct disposal of septage to the environment makes the highest contribution, which accounts for 20% of total output. Discharges of seepage from septic tanks and grey water also have significant portions, around 15% of total output.

Figure 3 shows that food importation is also the most important flow for phosphorus input to the system. It accounts for 55% of total phosphorus input. Chemical fertilizer and manure are also important flows, which account for 23% and 15%, respectively. Regarding the phosphorus output from the system, discharge from agricultural activity is the most significant flow, and it accounts for 40% of total phosphorus output. Direct disposal of septage to the environment also significantly contributes to the phosphorus output.

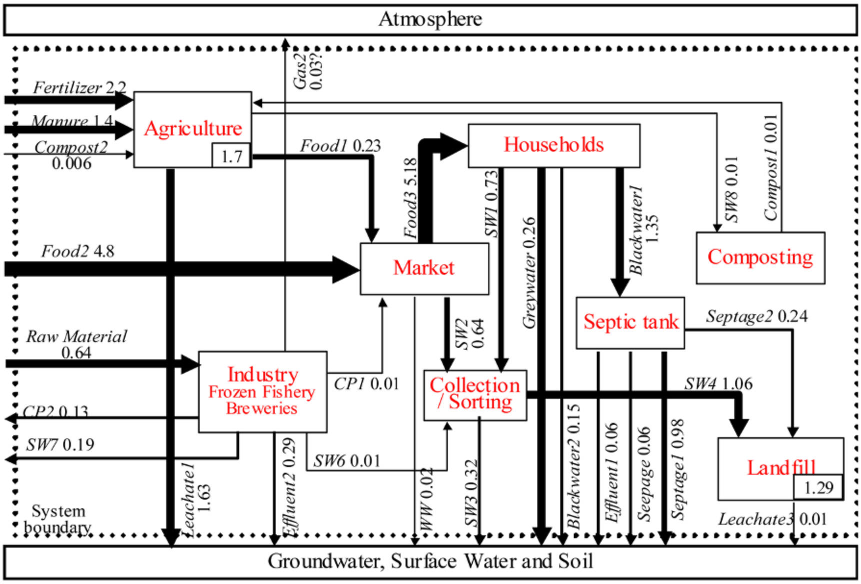

Fig. 3 P flows in the system of "Haiphong Urban Districts" in g/person/day.

Food importation is hard to control in terms of nutrient management, thus the appropriate management of seepage from septic tanks is the most important issue, identified through this analysis. Reduction of nitrogen in seepage and grey water discharge is also important, especially for nitrogen. The appropriate usage of fertilizer seems to be more important for controlling phosphorus emissions.

However there are several points that are difficult to explain in these results. As the result of mass balance in the "Industry" component, there is a significant value for "Gas2" in Figure 3, which is usually considered as negligible. Both for nitrogen and phosphorus, around 50% of input is discharged in the "Households" component. It means that the remaining 50% of input are stored in our body, but it seems to be higher than we have imagined. These points imply that further investigations and discussions are necessary to improve these results.

Conclusions

This study was conducted to quantify nutrient flows using MFA, to identify weaknesses related to nutrient management in Haiphong, Vietnam. The system model of nutrient flows is developed first, then each flow in the model was quantified through literature and interview surveys. The visualization of N and P flows through the system shows that "Households" is the important component that produces a significant amount of N and P loading to the environment. The main potential to improve nutrients emission is to optimize excreta and wastewater management from households. Fertilizer practice is also important especially for phosphorus control. Finally, we would like to express our appreciation for financial support by the CREST program in Japan Science and Technology Agency to conduct this study.

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Application of Sulfur Denitrification Process to Remove Nitrate-nitrogen Discharged from Agricultural Field

Kiyo Hasegawa-Kurisu, Katsura Shimizu-Ishii, Ikuro Kasuga and Keisuke Hanaki

Abstract A sulfur denitrification process was applied to actual agricultural fields and the characteristics of the treatment were evaluated from the viewpoints of water quality and microbial community. Nitrate was almost completely removed by the containers packed with sulfur (S0)-$CaCO_3$ blocks at both sites. An increase in sulfate levels indicated that nitrate was removed by sulfur denitrification. Nitrate removal efficiency was influenced by the water temperature, and optimal performance resulted when longer hydraulic retention times were used. Little information about the functional microbial community working in the field was obtained from PCR-DGGE and sequence analyses. However, when this information was combined with results of the cultivation method, the bands contributing to sulfur denitrification or sulfur oxidation were recognized by the temporal changes of pixel intensity in one particular band. These methods clearly demonstrated that indigenous sulfur denitrifiers were working at each site and that there was competition between sulfur oxidizers and sulfur denitrifiers, particularly in the process with continuous air influx.

Key words: Autotrophic denitrification, groundwater, PCR-DGGE, sulfur denitrifier

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Introduction

Contamination of groundwater with nitrate-nitrogen is a serious problem, particularly in agricultural areas where nitrogen loading is generally high. Recently, sulfur denitrification has attracted increasing interest for removal of the discharged nitrate. This process is based on autotrophic denitrification by sulfur-oxidizing bacteria (Baalsrud and Baalsrud, 1954; Kuenen, 1989; Kuenen et al., 1992; Lee and Sublette, 1990; Robertson and Kuenen, 1992), and therefore is applicable in agricultural areas where organic matters are generally limited. During this process, nitrate is reduced as an electron acceptor, whereas reduced sulfur is oxidized to sulfate as an electron donor.

We have already demonstrated the efficiency of sulfur addition into soil for nitrate removal through batch and column experiments. Sufficient removal of nitrate using a column packed with a mixture of soil and sulfur powder indicated the applicability of sulfur addition to an actual soil environment (Hasegawa et al., 2000, 2001). To construct an optimal system, the demonstration of reactors functioning in the field is essential. Moreover, in order to gain more information about the sulfur denitrification process at actual sites, the identification of bacterial groups that contribute to and compete with sulfur denitrification is necessary.

In this study, the applicability of sulfur denitrification was investigated from the viewpoint of nitrate removal efficiency, and the molecular biological technique, polymerase chain reaction – denaturing gradient gel electrophoresis (PCR-DGGE), was used in combination with a cultivation method for analyzing the functional aspects of the microbial community in the field.

Materials and Methods

Field Survey

Two sites where sulfur denitrification was performed for nitrate removal were surveyed. Site-1 is a valley-bottom field (Ibaraki, Japan), where groundwater contaminated with nitrate appears as spring water. Two 40 L containers packed with sulfur (S^0)-$CaCO_3$ blocks (SC11, Nittitsu, Japan) were connected in series and the spring water was fed into the containers at approximately 200 mL/min. Air influx to the containers and exposure to sunlight were prevented by using lids and a black cloth, respectively. Surveys were conducted in June, October and December of 2001. Site-2 was used for the treatment of wastewater discharged from a plastic greenhouse in which nitrate was used as a fertilizer for growing roses (Saitama, Japan). The wastewater was fed into a 12 m-long channel (width: 33.5 cm, height: 25 cm) at 150–350 mL/min. Most (0–10 m) of the channel was packed with sulfur-$CaCO_3$ blocks (SC11, Nittitsu, Japan) and the remaining part (10–12 m) was packed with zeolite. Transparent vinyl cloth and lids full of pores were used so as not to reduce air influx or sunlight. Surveys were conducted in November and December of 2001, and in February of 2002. The diameter of the sulfur-$CaCO_3$ blocks was approximately 1 cm, and the weight ratio of elemental sulfur to $CaCO_3$ was 1:1.2 in each block.

Bacterial Community Analysis

Bacterial community working in the reactors were analyzed using PCR-DGGE and cultivation methods.

DNA Extraction

DNA was extracted for PCR-DGGE. Sulfur-$CaCO_3$ blocks were put into zipper bags that were kept on ice in an insulated box, and temporarily stored at −20°C in the laboratory. The blocks were broken with a hammer over the bags and 0.5 g of the fragments was used for DNA extraction using the Fast DNA Spin Kit for soil (Qbiogene, USA) within the same day. We followed the optimum extraction procedure described by the manufacturer. For pure cultures or water samples, 20 mL of the sample was filtered onto a polycarbonate filter (pore size: 0.20 μm, Millipore, USA), and DNA was extracted in the same way as above.

PCR-DGGE Method

Extracted DNA was amplified by PCR. The procedure used for PCR-DGGE was modified from that described by Muyzer et al. (1993). In order to amplify V3 region of bacterial 16SrDNA, 341f-GC (*Escherichia coli* positions: 341–357, sequence: 5′-gc-clamp-CCTACGGGAGGCAGCAG-3′, target: Bacteria) and 517r (*E. coli* positions: 517–534, sequence: 5′-ATTACCGCGGCTGCTGG-3′, target: Bacteria, Arcahea and Eucarya) were used as forward and reverse primers, respectively. Since the PCR product was used for DGGE analysis, GC-clamp (40-bp GC-rich sequence, 5′-CGCCCGCCGCGCGCGGCG-GGCGGGGCGGGGGCACGGGGGG-3′) was attached to the 5′ end of the forward primer. PCR was performed in a 100-μL volume containing 0.5 μL of AmpliTaq Gold (5 U/μL, Applied Biosystems, USA), 10 μL of PCR buffer (10×, Applied Biosystems, USA), 10 μL of dNTPs (Applied Biosystems, USA), 0.2 mM of each primer, and 1 μL of template. PCR was initiated at 94°C for 9 min, and 30 cycles (94°C for 30 sec, 53°C for 30 sec, and 72°C for 30 sec) were carried out, followed by final extension at 72°C for 5 min. The GeneAmp 9600 thermal cycler (Applied Biosystems, USA) was used.

The PCR product (20 μL) was mixed with 4 μL of loading dye (6×) and loaded onto a polyacrylamide gel (8%), which was made with a gradient of denaturants urea and formamide. The 100% denaturant is defined as 7 M urea and 40% [vol/vol] formamide. The electrophoresis was run using the Dcode System (Biorad, USA) at 130V at 60°C for 5 h. After electrophoresis, the gel was stained with Vistra Green (Amersham Pharmacia, USA) for 15 minutes and scanned by Fluor-Imager 595 (Molecular Dynamics, USA). The pixel intensity of each DGGE band was analyzed using Fragment NT Analysis software (Molecular Dynamics, USA) setting the noise factor and scale factor at 10.0 and 0.25, respectively.

Sequencing of DGGE Bands

The target band separated by DGGE was excised with a cutter blade. DNA was extracted from the band by three cycles of freezing at –20°C and thawing at room temperature. The extracted DNA was used as the PCR template and PCR-DGGE was carried out again. In order to purify the DGGE band, this protocol was repeated until nonspecific bands were no longer present. PCR was performed using the purified DGGE band as a template. Bidirectional sequencing of the product was carried out using the Vistra Sequencing Kit (Amersham Pharmacia, USA) with an automated sequencer (SQ-5500, Hitachi, Japan). The homology was searched by BLAST in the DNA Data Bank of Japan (DDBJ, http://www.ddbj.nig.ac.jp).

Cultivation Method

Sulfur-$CaCO_3$ blocks taken from the field were cultivated in specified media and changes in the PCR-DGGE band patterns were investigated to see the function of each band. Conditions designated A, B, and C were set up for enrichment of heterotrophic denitrifiers, sulfur denitrifiers, and sulfur oxidizers, respectively. Sulfur-$CaCO_3$ blocks (70 g) from each site were placed into 1 L of medium and kept at 28°C during cultivation. Heterotrophic medium contained 1.0 g of peptone and 5.0 g of KNO3 in 1 L distilled water, which was purged with N2 gas and sealed to maintain anoxic conditions (A). Basal medium for *Thiobacillus denitrificans* was used as the mineral medium; it contained (g/L distilled water): 1.2 Na2HPO4, 1.8 KH2PO4, 0.1 MgSO47H2O, 0.1 (NH4)2SO4, 0.03 FeCl3, 0.02 MnSO4, 10.0 Na2S2O3, 0.5 $NaHCO_3$, and 5.0 KNO3. The medium was purged with N2 gas, sealed to maintain anoxic conditions, and used for promoting sulfur denitrifiers (B). The same medium without $NaHCO_3$ and KNO3 was shaken under aerobic conditions to stimulate sulfur-oxidizing bacteria (C). In the cases of A and B, nitrate was added and the medium was purged with N2 gas again when nitrate was depleted from the media.

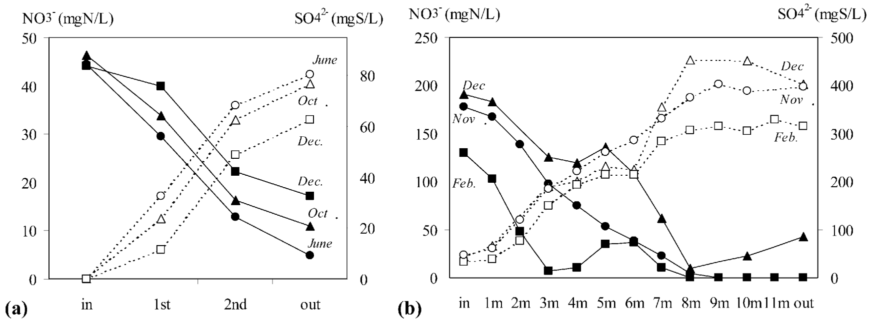

Fig. 1 Nitrate removal by sulfur denitrification in Ibaraki and Saitama. The spatial changes in the concentrations of nitrate (solid line, closed symbol) and sulfate (dotted line, open symbol) were measured. Surveys were conducted in Site-1 (a) in June (○, ●), October (△, ▲) and December (□, ■) of 2001, and in Site-2 (b) in November (○, ●) and December (△, ▲) of 2001, and February (□, ■) of 2002. "In", "out", and "m" represent inlet, outlet, and meters along the channel, respectively.

Results and Discussion

Water Quality

Figure 1a shows the results of water quality evaluation for Site-1. The concentration of nitrate in the influent water was maintained at approximately 45 mgN/L. The nitrate concentration decreased with an increase in sulfate concentration along the water flow. Removal efficiencies of nitrate were 89.2, 76.5, and 61.0%, while the temperatures in the 1st tank were 17.6, 16.1, and 12.5°C in June, October, and December, respectively.

The change in water quality along the channel in Site-2 is shown in Figure 1b. The concentration of nitrate in the wastewater was higher (approximately 200 mgN/L) than that in Site-1. This nitrate was almost removed by the channel packed with sulfur-$CaCO_3$ blocks. Nitrate removal efficiencies were 100, 78, and 100% in November, December, and February, respectively. More than 95% of the nitrate was removed in the 0–8 m section of the channel in all three surveys. The water level became lower at the rear part of the channel and surface blocks were exposed to air in the 8–12 m section. In December, 2.1 mgN/L of ammonium was detected at the 5 m point, which would be nitrified and contribute to the increase in nitrate at the latter part of the channel. The temperature of the inlet water at Site-2 was maintained at approximately 18°C, because the wastewater was warmed inside the plastic greenhouse. However, it declined to about 10–12°C along the channel. The apparent hydrological retention time (HRT) of the containers was approximately 7 hours in Site-1, whereas it was almost 10 times longer in Site-2. This longer HRT in Site-2 would result in high removal efficiencies in the channel, even in winter.

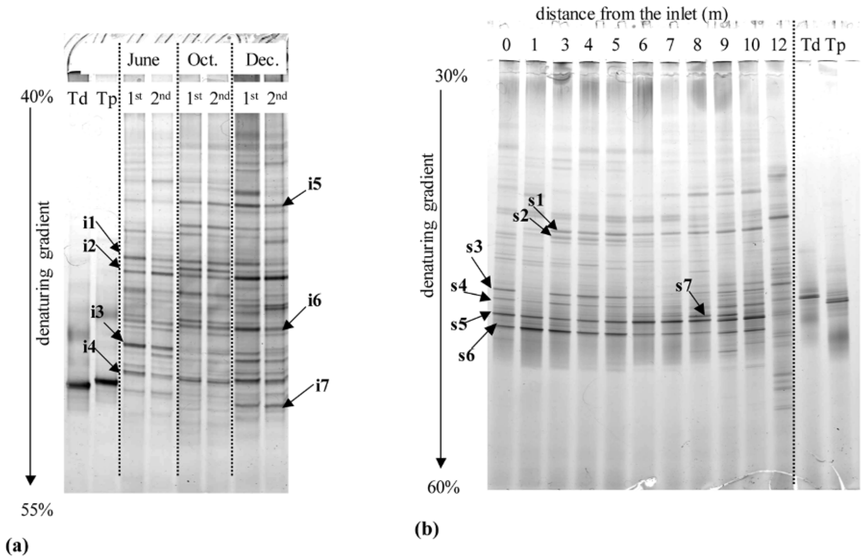

Fig. 2 Seasonal changes in the microbial community at two sites. Samples taken from Site-1 in June, October, and December (a) and from the channel in Site-2 in November (b) were analyzed by PCR-DGGE. Td and Tp represent pure cultures of *T. denitrificans* (ATCC 23644) and *P. pantotrophus* (ATCC 35512), respectively.

Microbial Community Analysis by PCR-DGGE and Sequencing

Figure 2a shows the seasonal changes of the bacterial community in Site-1. The detected constitutive bands (i1–i6) were similar, while the dominant bands were different in the three surveys. Band i3 was particularly thick in June, while bands i2, i5, i6, and i7 were thick in December. Band i4 was consistently found in all of the surveys. The differences between the two containers were small.

Figure 2b shows the spatial changes in the bacterial community in Site-2. The detected constitutive bands were similar, except for the sample from 12 m, where zeolite was packed instead of sulfur-$CaCO_3$ blocks. Bands s1 and s5 became more pronounced, while bands s2 and s6 became weaker along the channel. Band s7 appeared particularly at 8 m and 9 m. The dominant bands were different between samples from the two sites.

In the case of Site-1, sequence analysis identified typical bacteria found in the soil environment. However, no further information could be gained from the results of sequencing. The bands from samples from Site-2 provided more detailed information. The sequences of bands s1 and s2 had high homology with the green sulfur bacterium *Chlorobium*, which is known to be a sulfur-oxidizing bacterium under obligatory anaerobic and phototrophic conditions. Bands s4 and s5 were similar to *T. denitrificans*, a well-known sulfur denitrifying bacterium (Kuenen, 1989; Kuenen et al., 1992). Band s7 appeared in samples taken from a relatively oxidative part of

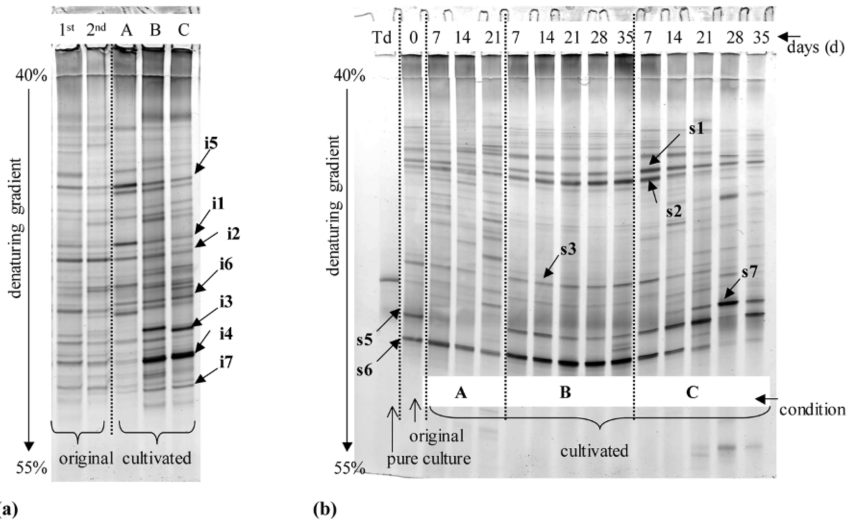

Fig. 3 Cultivation of Ibaraki and Saitama samples under three conditions. Samples taken from Site-1 in June, October, and December (a) and from the channel in Site-2 in November (b) were analyzed by PCR-DGGE. Td and Tp represent pure cultures of *T. denitrificans* (ATCC 23644) and *P. pantotrophus* (ATCC 35512), respectively.

the channel, and its sequence had high homology with *Thiomonas* sp., which is a sulfur-oxidizing bacterium transferred from the *Thiobacillus* group because of its mixotrophic characteristics (Moreira and Amils, 1997).

Changes in DGGE Bands by Cultivation

To investigate the functional aspects of the specific bacterium represented by each band, sulfur-$CaCO_3$ blocks were cultivated with three types of culture media and temporal changes in the bands obtained by PCR-DGGE were observed. Figure 3a shows the results of cultivation of the sample taken from Site-1 in December. The bands that increased in intensity under each type of growth condition were different. The change in the band thickness was clearly observed by pixel intensity. Bands i1 and i5 thickened under anoxic heterotrophic conditions (A) and may contribute to heterotrophic denitrification in this system. On the other hand, bands i3 and i4 thickened under conditions B (anoxic with sulfur) and C (aerobic with sulfur), and seemed to play a prominent role in sulfur oxidation and sulfur denitrification activities in this system.

Samples taken from Site-2 in February were also cultivated for 35 days under three types of conditions. Sulfate formation was observed under condition A at the beginning of the cultivation. However, the concentration of sulfate declined under condition A after seven days, whereas it continuously increased under conditions B and C. As shown in Figure 3b, bands s2 and s6 were less intense under conditions A and C, whereas they increased in intensity in the case of condition B. This indicates that these two bands contributed to sulfur denitrification in this channel.

Sequence analysis showed that band s2 was closely related to an anaerobic photosynthetic bacterium. However, this incubation was done in the dark under anoxic conditions. To check this contradiction, the bottle that was cultivated for 35 days under condition B was covered with aluminum foil and cultivated again under anoxic conditions with sulfur in the same incubator. The pixel intensity of band s2 increased five times for a further 21 days. Therefore, this bacterium seemed to have the characteristics of a chemotrophic sulfur denitrifier, rather than a green sulfur bacterium.

The intensities of bands s1, s5, and s7 only increased under condition C. Band s5 was observed at each sampling point of the channel, excluding the 12 m-point. Band s5 became stronger at the latter part of the channel, a section that was more oxidative than at the beginning of the channel. Band s7 appeared after 14 days only under condition C. In the actual field survey, this band also appeared at the latter part of the channel. Therefore, bands s5 and s7 were considered to be sulfur oxidizers competing with sulfur denitrifiers (bands s2 and s6). The organism represented by band s7 appeared to prefer more oxidative conditions compared to that of band s5.

Discussion

The concentration of nitrate in the influent was much higher than the WHO standard at both sites. This nitrate was sufficiently removed by the sulfur denitrification system, consisting of containers packed with sulfur-$CaCO_3$ blocks. The increase in sulfate indicated the occurrence of sulfur denitrification. As shown by the Site-1 samples, bacterial activity was influenced by water temperature, and nitrate removal efficiency decreased with declining water temperature. Yamamoto-Ikemoto et al. (2000) demonstrated sulfur denitrification in an upflow biological filter reactor using thiosulfate as an electron donor. They showed that the removal performance declined when the temperature dropped below 15°C. However, the results of Site-2 indicated that high removal efficiency is possible with longer HRT even at low-temperatures. Kö enig and Liu (1997) also showed the increase of nitrate removal efficiency during sulfur denitrification when the HRT increased in a packed bed reactor system.

The changes in the bands upon cultivation provided additional evidence for functional aspects of constitutive bands. The dominant bands (i3 and i4) were sulfur denitrifiers and no competition with other sulfur oxidizers was observed in Site-1, where the air influx and sunlight were prevented. On the other hand, competition of the sulfur denitrifiers (s2 and s6) with other sulfur oxidizers (s1, s5, and s7) was observed in Site-2. Bands (s1 and s2) that had high homology with a photosynthetic bacterium were also observed in this site. The operation of air influx and sunlight may have caused the differences between these two sites.

The strain represented by band s7 preferred more aerobic conditions based on the results of the survey and cultivation. Sulfur denitrifiers also have the ability to oxidize sulfur. However, the oxygen concentration that can be tolerated by colorless sulfur bacteria varies among species. Several species prefer more aerobic conditions than sulfur denitrifiers, such as *Thiobacillus denitrificans* and *Thiomicrospira denitrificans* (Kuenen, 1989). Therefore, the control of air influx into the system can suppress the sulfur oxidizing bacteria and establish the dominance of sulfur denitrifiers.

Conclusions

Following points are concluded:

- Sufficient nitrate removal can be gained by sulfur denitrification in the field.
- The process efficiency is influenced by temperature and HRT.
- The dominant sulfur denitirifiers were different at each site. This indicates that indigenous sulfur denitrifiers can work in the field.
- The operating conditions, such as air influx and sunlight, can affect the community of sulfur oxidizers and denitrifiers.

Both the results of water quality and PCR-DGGE analyses will allow the characterization of the sulfur-related bacteria working at actual treatment sites. With regard to the sulfur denitrification process, further molecular biological approach focusing on functional aspects is needed.

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Bioremediation of Soil and Groundwater Contaminated by Volatile Organic Compounds

Futoshi Kurisu and Osami Yagi

Abstract Recently, soil and groundwater contamination has been treated very actively in Japan due to the implementation of new laws and rising concern for the environment. Bioremediation, biological treatment of the contaminated sites, of volatile organic compounds (VOCs) is very promising technology especially for sites with relatively low strength contamination. Both chlorinated ethylenes and benzene can be degraded biologically both under aerobic and anaerobic conditions. Present status and research progress for VOCs are discussed.

Key words: Bioremediation, soil and groundwater contamination, volatile organic compounds

Soil/Groundwater Contamination in Japan

Like the other industrialized countries, Japan has a long history in soil and groundwater contamination. One of the first biggest issues in environmental problems in Japan is the heavy metal contamination of soil and water in the downstream of Ashio copper mine in the late 19th century. Since that time, many places had been contaminated, and until quite recently, they had been left untreated unless there had been a direct chance of polluting drinking water source or agricultural products. Recently, a soil contamination countermeasures law was implemented in 2003, and companies must inspect the contamination and treat the contaminated soil/groundwater when they change the usage of the land to non-industrial purpose. This has also a spillover

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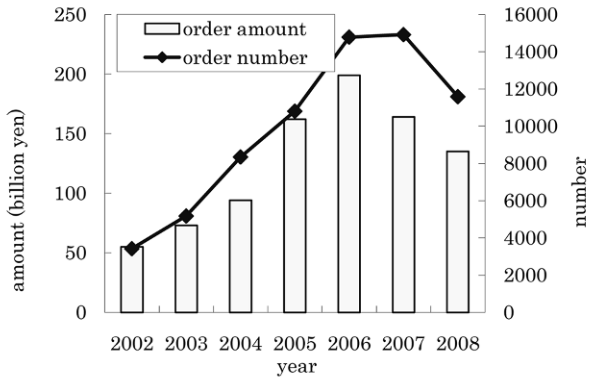

Fig. 1 Order amount and number for soil/groundwater treatment business in Japan.

Table 1 Groundwater quality survey in Japan in 2008.

Substances	# of wells examined	above standard	ratio (%)
Nitrate and nitrite	3,830	167	4.36
Arsenic	3,239	77	2.38
Fluoride	3,537	23	0.65
Lead	3,193	10	0.31
Tetrachloroethylene	3,660	9	0.25
Boron	3,149	9	0.29
Trichloroethylene	3,658	3	0.08
Total mercury	2,944	2	0.07
cis-1,2-Dichloroethylene	3,353	1	0.03

effect on companies to initiate the treatment of contaminated sites to prepare for the future changes of land use. Figure 1 shows the recent growth of the soil/groundwater treatment business in Japan (Geo-Environmental Protection Center, 2009).

Table 1 summarizes the data on a groundwater survey in 2008 by Ministry of Environment Japan (published in 2009). It shows the components and the number of sites exceeding the environmental standard. Nitrate and nitrite contamination is mainly caused by excess dosage of the fertilizer and by livestock wastes. Arsenic and fluorine are mainly from natural sources. Except them, volatile organic compounds (VOCs) such as chlorinated ethylenes and benzene, and heavy metals such as lead and mercury, are the two major groups of groundwater contamination. This survey has been done to reveal the degree of contamination all over Japan by sampling randomly. If we limit the data to the industrial sites where there have been histories of using hazardous chemicals, 70 out of 122 (36%) of the sites were found contaminated with more than one substance exceeding the environmental standard (Ministry of Environment, 2006).

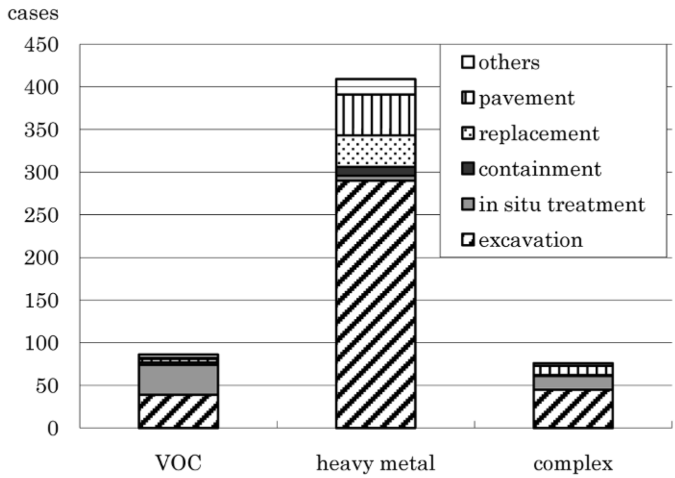

Fig. 2 Treatment methods used for the VOCs, heavy metals and complex (site with both contamination) in Japan, in 2008.

Treatment Methods

There are many options for the technologies to treat contamination. They include construction methods without treatment to minimize the effect of the contamination as well as cleanup technologies. Both methods are done either *in situ*, without soil excavation or groundwater pumping, or *ex situ*. The treatment technologies which were employed for the contaminated sites in Japan in 2008 is shown in Figure 2 (Ministry of Environment, 2009). Compared to the heavy metal contamination, VOC contaminations are more commonly treated *in situ*.

Cleanup technologies are based on either physical, chemical and biological methods or a combination of them. One of the physical methods is adsorption by activated carbon treatment, chemical treatments include chemical reduction of chlorinated compounds by zero-valent iron, and biological treatments employ the biodegradation or bioaccumulation of the contaminants mostly by microorganisms or plants. Figure 3 shows the details of the treatment methods for VOC indicated as "*in situ* treatment" in Figure 2 (Ministry of Environment, 2009).

Recently, bioremediation technologies have been becoming more popular. The number of the sites treated by bioremediation is increasing recently. It is because bioremediation has advantages over other physicochemical methods in terms of the cost and the environmental impact. It is suitable for contamination with relatively low concentration, as microorganisms cannot degrade the compounds at high concentration. In addition, it takes a longer time to complete the cleanup than other methods, as it involves moderate biological reactions. Thus, bioremediation is suitable for the treatment of widely spread and low concentrated contamination, which may usually be found after the treatment of the core contamination by physicochem-

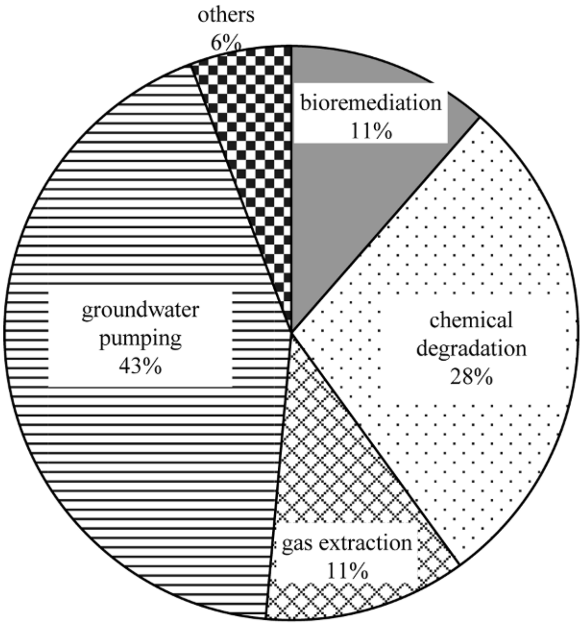

Fig. 3 Details in the *in situ* treatment for VOCs in Figure 2.

ical methods. Although bioremediation technologies are promising and already used at many contaminated sites, there are many aspects left unknown and intensive research work is still needed to support the technologies.

Bioremediation of Chlorinated Ethylenes

Aerobic degradation of chlorinated ethylenes (CEs) can be achieved by the cometabolism of bacteria such as toluene degrading bacteria, phenol degrading bacteria and methane oxidizing bacteria. The aerobic treatment can be employed for all the CEs except tetrachloroethylene (PCE). PCE cannot be degraded under aerobic condition. As the bacteria cannot use CEs as their carbon source for growth, treatment of CEs must be coupled with the supplement of their substrates, or be done with the bacteria grown separately from the substrates prior to the treatment. We have isolated the trichloroethylene (TCE) degrading methanotroph (methane oxidizing bacteria), *Methylocystis* sp. strain M (Uchiyama et al., 1992). It has strong ability to degrade TCE to carbon dioxide with trace amounts of residual by-products.

PCE and TCE can easily be degraded to *cis*-1,2-dichloroethylene (*cis*-DCE) under anaerobic condition. It is called "anaerobic dechlorination". Several diverse kinds of bacteria and methanogens have been reported to perform the reaction.

However, dechlorination of cis-DCE to vinyl chloride (VC) and VC to ethylene can only be done by genus *Dehalococcoides*. *Dehalococcoides* uses hydrogen as direct electron donor to dechlorinate the CEs as electron acceptors. Hydrogen, which is necessary for the reaction, can be supplied as a fermentation product from organic matters under anaerobic conditions. Although *Dehalococcoides* is widely found in many places in the world and its growth (and thus the dechlorination) can be stimulated by adding organic compounds in soil, the factors affecting its growth in soil is still unclear. We have been studying the effect of hydrogen to clarify the mechanisms affecting the dechlorination.

Bioremediation of Benzene

Benzene is normally found in contaminated sites with its derivative chemicals such as toluene, ethylbenzene and xylene, and they are called BTEX compounds. BTEX can be easily degraded under aerobic conditions and many reports have been done on their degradation. In practice, only aeration of the contaminated soil or groundwater is normally enough to clean up the contamination. However, anaerobic degradation of these compounds, especially benzene, is still a big challenge. There are only a few studies reporting on anaerobic degradation and the microorganisms which play an important role on the degradation. We have established an enriched culture which can degrade benzene under complete anaerobic conditions. We have analyzed the microbial consortia and found that some novel bacteria in delta-proteobacteria may be involved in the benzene degradation under methanogenic condition using a combination of stable isotope and molecular microbiology (Sakai et al., 2006, 2009). The combination of anaerobic CEs degradation and benzene degradation would become promising technology if we can achieve it by understanding the mechanisms of both anaerobic degradation.

Summary

Bioremediation of volatile organic carbons is promising technology especially for sites with relatively low strength contamination. Both chlorinated ethylenes and benzene can be known to be degraded biologically, but more knowledge on the biological degradation in the environment as well as in the laboratory will improve the methodology of the remediation greatly in the near future.

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Cadmium Extraction from Contaminated Soil Using an Iron Chloride Solution in Asian Countries

Ozaki Hirokazu, Ida Shingo, Pu Jian, Zhang Yanfeng, Jiang Chunxiao, Sun Hongwen and Fukushi Kensuke

Abstract Iron chloride ($FeCl_3$) is known to be an efficient agent for removing Cd from contaminated soil. However, there is little information on the combined effects of the $FeCl_3$ concentration and the contact time on the efficiency of Cd extraction. Soil that was artificially polluted with Cd was used for batch extraction tests. The amount of Cd extracted was proportional to the $FeCl_3$ concentration up to 100 $mmol_c$/L, at which point the amount of Cd removed leveled off after a 5 hr shaking. A longer shaking time was not effective at increasing the amount of Cd removed, but rather the $FeCl_3$ concentration was the major factor in determining the leaching of Cd. These findings may be useful in balancing Cd mobilization and the uptake speed of Cd-accumulator plants to enhance phytoremediation.

Key words: Cadmium, heavy metal pollution, iron chloride, soil remediation

Introduction

Meeting the increasing worldwide demand for food, particularly in developing countries (Population Division, UN, 2006; FAO, 2006), presents a challenge, given the limited amount of arable land on the Earth. Global warming is threatening crop production and promoting unstable food trade (IPCC, 2007). Additionally, biofuel

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production is beginning to compete with food production for the available arable land, further increasing food costs. As Japan has produced only about 40% of its own food, on a caloric basis, over the past 10 years, the progressive destabilization of the global food supply will have a major influence on Japan, presenting concerns regarding food security (MAFF, 2007).

Food safety is also of great concern. For example, the proliferation of genetically modified plants (McAfee, 2008) and the outbreak of bovine spongiform encephalopathy (Shaw, 2004) have highlighted potential safety risks within a globalized food market. Furthermore, the contamination of food by hazardous substances derived from environmental pollution has been widely investigated (Shute and Macfie, 2006). Food safety is receiving renewed interest, as evidenced by the positive list system and novel standards established by the Codex Alimentarius Commission (Nishio and Sato, 2007). Higher Cd concentrations have been detected in rice, a principal diet of Asian countries, in Taiwan, Indonesia, Malaysia and especially in Japan where many nonferrous metal mines are located (Asami, 1997).

An extensive amount of farmland in China, which provides the majority of food imported by Japan, is known to be polluted with heavy metals. The Ministry of Environmental Protection of the People's Republic of China documented that 123,000 km^2 of farmland (more than 10% of the total farmland in China) were polluted with sewage water and waste materials in 2006, and 12 million tons (2–3%) of the agricultural products of China were contaminated with hazardous metals. Many of the farms in Hunan, Guangdong, and other provinces in southern China are severely polluted with heavy metals from mine wastewater (Liu et al., 2005a; Zhou et al., 2007; Duzgoren-Aydin, 2007).

Rapid urbanization is another cause of environmental pollution in China (Chen and Pu, 2006; Kuang et al., 2007). Beijing and Tianjin are the largest urbanized regions in China, and their suburban agricultural areas are vital food sources for these urbanized areas. Unfortunately, suburban agriculture is affected by city-derived pollution. The serious water shortages and poor effluent treatment that have occurred around Beijing and Tianjin have prompted the use of wastewater as irrigation water for approximately the last 30–50 years, resulting in severe heavy metal pollution in the suburban farmlands. Consequently, health hazard warnings have been proposed due to contaminated agricultural products (Liu et al., 2005b; Shi et al., 2005; Wang and Zhang, 2005; Zhang and Guo, 1991).

Iron chloride ($FeCl_3$) has been reported to be an environmentally friendly, low-cost, and effective agent for removing Cd from contaminated soil (Makino et al., 2006). However, little information exists regarding the effects of the $FeCl_3$ concentration and the soil-solution contact time on the efficiency of Cd extraction. Meanwhile, heavy metal removal by accumulator plants (phytoremediation) is considered to be a promising strategy for soil decontamination in China (Cheng, 2003). To support enhanced phytoremediation of farmland soil, the present study provides operational knowledge of the efficient mobilization and removal of Cd using $FeCl_3$.

Materials and Methods

Artificially Polluted Soil

Commercially supplied, non-contaminated, black soil (Andisol) was dried at 40°C for 72 hr and passed through a non-metallic 2-mm mesh. A total of 100 g of the dried non-contaminated soil were mixed with 10 ml of a 1000-ppm Cd solution (AAS standard solution) to prepare artificially and highly polluted soil containing 100 ppm Cd. Subsequently, 900 g of the non-contaminated soil were mixed with the highly polluted soil to produce test soil contaminated with 10 ppm Cd (Artificially polluted soil).

Extraction Test and Determination of Leaching

To prepare the extraction agent, 0.901 g of $FeCl_3 \cdot 6H_2O$ (special-grade chemical) were dissolved in Milli-Q water to a final volume of 100 ml, yielding a solution of 100 $mmol_c$/L $FeCl_3$. The 100 $mmol_c$/L $FeCl_3$ was serially diluted to 15 $mmol_c$/L and 3 $mmol_c$/L $FeCl_3$.

Five grams of artificially polluted soil were placed in a sealable 50-ml centrifuge tube, and 12.5 ml of $FeCl_3$ solution (3, 15, and 100 $mmol_c$/L) were added. Milli-Q water was used for the control (0 $mmol_c$/L $FeCl_3$). A side-over-side shaker was used at 200 rpm with a 5-cm shaking width at 25°C, for 1, 2, 3, 4, 5, 24, and 72 hr. After shaking, the samples were centrifuged at 3000 rpm for 10 min and passed through a 0.45-μm filter. The filtered solution was separated into two samples. The Cd concentration was determined by ICP-MS (Agilent HP4500) in one sample, and the pH value was measured in the other sample. Each experiment was performed in triplicate.

Results and Discussion

Relationship between Cd Extraction and $FeCl_3$ Concentration

The amount of Cd extracted increased significantly with increasing $FeCl_3$ concentration, regardless of the shaking period ($p < 0.05$, t-test; Figure 1 and Table 1). The maximum amount of extracted Cd, 3.64 ± 0.07 mg/kg (mg Cd per 1 kg dry soil) or 36.4% of the total Cd content, was obtained with 100 $mmol_c$/L $FeCl_3$ after 72 hr of shaking. The maximum amounts of Cd extracted by the Milli-Q water control and 3 $mmol_c$/L and 15 $mmol_c$/L $FeCl_3$ were 0.04 ± 0.00, 0.09 ± 0.01, and 0.59 ± 0.01 mg/kg, respectively. A Cd extracted rate of about 0.03 mg Cd per 1 $mmol_c$/L of $FeCl_3$ was observed regardless of $FeCl_3$ concentration till 5 hr of shak-

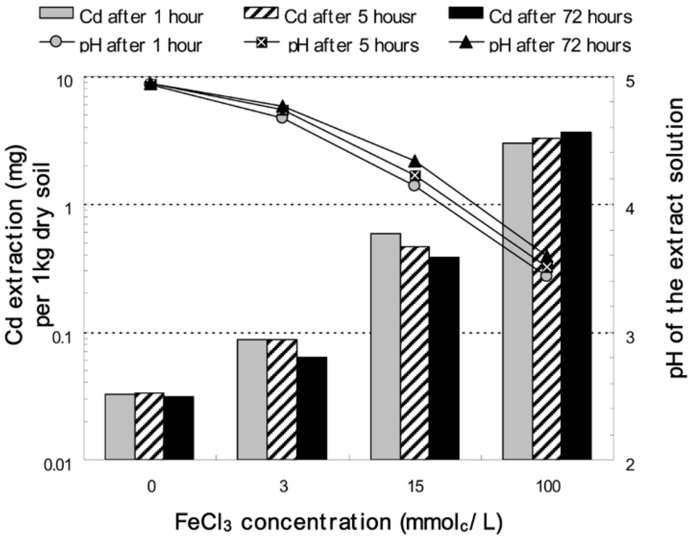

Fig. 1 Relationship among $FeCl_3$ concentration, Cd extraction, and pH for artificially polluted soil.

Table 1 Amount of Cd extraction (mg) per 1 kg dry soil and pH of the solution after 1, 2, 3, 4, 5, 24 and 72 hours shaking with different $FeCl_3$ concentration.

Shaking period (hr)		1			2			3			4			5			24			72		
	Fe ($mmol_c$/ L)	Avr		SD	Avr		SD	Avr		SD	Avr		SD	Avr		SD	Avr		SD	Avr		SD
Cd extraction (mg Cd/ kg dry soil)	0	0.03	±	0.00	0.03	±	0.00	0.04	±	0.00	0.04	±	0.00	0.03	±	0.00	0.04	±	0.00	0.03	±	0.00
	3	0.09	±	0.01	0.08	±	0.00	0.08	±	0.00	0.09	±	0.01	0.09	±	0.00	0.06	±	0.00	0.06	±	0.00
	15	0.59	±	0.01	0.53	±	0.00	0.51	±	0.02	0.47	±	0.01	0.46	±	0.02	0.47	±	0.01	0.38	±	0.02
	100	2.99	±	0.06	3.10	±	0.06	3.02	±	0.16	3.25	±	0.10	3.28	±	0.03	3.36	±	0.06	3.64	±	0.07
pH	0	4.94	±	0.01	4.93	±	0.00	5.16	±	0.06	4.92	±	0.03	4.95	±	0.00	4.92	±	0.03	4.95	±	0.00
	3	4.67	±	0.01	4.67	±	0.00	4.66	±	0.01	4.73	±	0.03	4.74	±	0.01	4.73	±	0.01	4.77	±	0.00
	15	4.14	±	0.00	4.20	±	0.01	4.21	±	0.02	4.22	±	0.00	4.22	±	0.00	4.22	±	0.01	4.34	±	0.01
	100	3.44	±	0.02	3.48	±	0.01	3.49	±	0.00	3.49	±	0.02	3.51	±	0.00	3.54	±	0.01	3.59	±	0.01

ing (0.033 ± 0.006 mg/$mmol_c$/L for 1 hr of shaking and 0.031 ± 0.002 mg/$mmol_c$/L for 5 hr on the average of the amount of extracted with different $FeCl_3$ concentration), indicating a proportional relationship between the amount of Cd extracted and the $FeCl_3$ concentration.

The pH of the extracted solution decreased significantly with increasing $FeCl_3$ concentration ($p < 0.05$, t-test; Figure 1 and Table 1). The drop in pH results from the hydrolysis of $FeCl_3$, as shown in the formula below, and plays an important role in Cd desorption from the soil into solution (Makino et al., 2006).

$$FeCl_3 \rightarrow Fe^{3+} + 3Cl^-$$

$$Fe^{3+} + 3H_2O \leftrightarrow Fe(OH)_3 + 3H^+$$

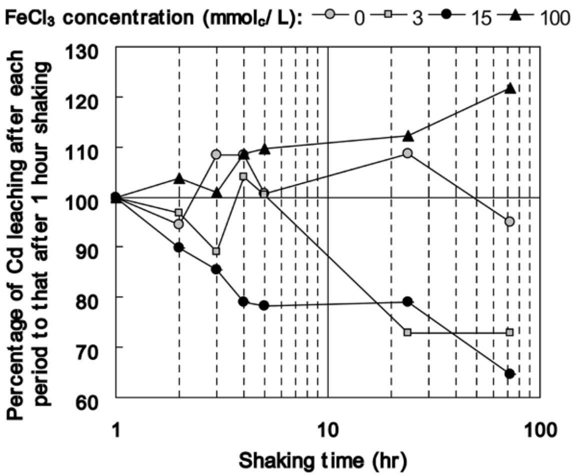

Fig. 2 The percentage of Cd leached after each shaking period compared with the value after 1 hour.

Cadmium Extraction Behavior According to Shaking Period

The temporal trend of Cd extraction varied with the $FeCl_3$ concentration (Figure 2). The amount of Cd extracted with 100 $mmol_c$/L $FeCl_3$ increased with the shaking period, reaching a maximum of 36.4% of the total content after 72 hr. However, the hourly rate decreased with shaking time, as shown in Figure 2.

The extractions using 3 $mmol_c$/L and 15 $mmol_c$/L $FeCl_3$ showed a trend toward decreased Cd removal with longer shaking time (Figure 2). A marked decreasing trend was seen for up to 5 hr of shaking with 15 $mmol_c$/L $FeCl_3$, and little change occurred thereafter. In addition, only 0.87% and 5.9% of the total Cd content of the soil were extracted after 1 hr of shaking with 3 and 15 $mmol_c$/L $FeCl_3$, respectively (Table 1). These amounts represent about 1/15 and 1/5, respectively, of the Cd extracted with 100 $mmol_c$/L $FeCl_3$. Therefore, the 3 $mmol_c$/L and 15 $mmol_c$/L $FeCl_3$ may be too dilute to effectively remove Cd.

The pH of the extract solution increased from 4.67 (1 hr) to 4.77 (72 hr) with 3 $mmol_c$/L $FeCl_3$, from 4.14 (1 hr) to 4.34 (72 hr) with 15 $mmol_c$/L $FeCl_3$, and from 3.44 (1 hr) to 3.59 (72 hr) with 100 $mmol_c$/L $FeCl_3$ (Table 1). Similar to the extracted Cd, the pH value was obviously increased with time up to 5 hr, and thereafter little change occurred with any $FeCl_3$ concentration. We speculate that the soil buffering effect is a major cause of the recovery of the pH. The Cd extraction and the pH change of the Andisol used in our study appeared to reach equilibrium after 5 hr of shaking.

In general, Cd is labile at soil pH values of less than 6 (Trauna, 1999). However, our results suggest that with 3 $mmol_c$/L and 15 $mmol_c$/L $FeCl_3$, Cd may be readsorbed after its initial desorption. The Cd extraction rate remained at about 0.03 mg Cd per 1 $mmol_c$/L $FeCl_3$, with only small decreases (–0.008 and –0.014) for 3

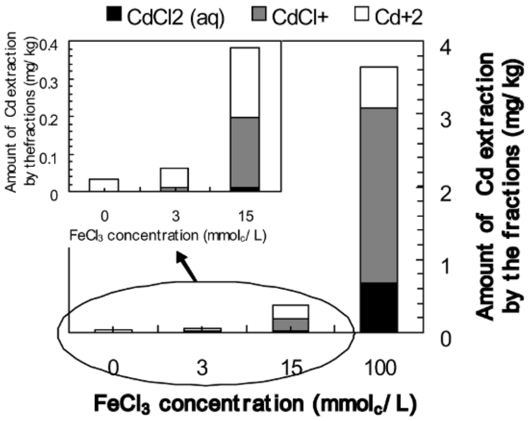

Fig. 3 Amount of Cd extracted according to the chemical forms, after 72 hr shaking.

$mmol_c$/L and 15 $mmol_c$/L $FeCl_3$ and a slight increase (+0.006) for 100 $mmol_c$/L $FeCl_3$, from 1 hr to 72 hr of shaking, and the slope for the correlation between the amount of Cd extracted and the $FeCl_3$ concentration did not indicate a significant difference among the shaking periods ($p > 0.05$, t-test). Therefore, we conclude that a longer shaking period is not effective for increasing the efficiency of Cd extraction.

Chemical Form Distribution of Soluble Cd

Chloride complex formation is another major factor in Cd mobilization (Sakurai and Huang, 1996; Makino et al., 2006). Most of the chloride will remain soluble in the extract solution owing to its negative charge. Therefore, the chloride concentration in the extract solution was expected to be similar to the initial concentration, although we did not determine the actual concentration in the extract. The Cd speciation was roughly calculated using Visual-MINTEQ software (Gustafsson, 2004). As a result, it was expected that 19.6, 51.1 and 84.7% of the chloride fraction ($CdCl^+$ and $CdCl_2$aq) would be complexed in the extracted Cd after 72 hr of shaking with 3, 15, and 100 $mmol_c$/L $FeCl_3$, respectively. The product of the amount of Cd extracted and the fractionation ratio indicated that the increase in Cl-accounts for the majority of the leached Cd (Figure 3).

Conclusions

The amount of Cd extracted depended largely on the $FeCl_3$ concentration and was efficiently extracted from artificially polluted soil by 100 $mmol_c$/L $FeCl_3$. A longlasting solubilization of Cd can be expected with the addition of a suitable concentration of $FeCl_3$, with stable Cd leaching over time. Thus, we propose that $FeCl_3$ may be a potential accelerator for the transport of Cd from soil into hyper accumulator plants through the soil solution, i.e. "enhanced phytoremediation" with low risk and low cost in Asian countries.

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A Strategy in Assessing Plant Residue Material Quality to Enhance Sustainability of Lowland Agricultural Systems

Gina Villegas-Pangga

Abstract Organic materials are vital resources in the replenishment of nutrients in soil and in affecting the sustainability of rice production. It is worthwhile studying their uses and potentials in a lowland agricultural environment, specifically in rice-based farming systems.

A Straw Quality Index (SQI) was developed from a series of perfusion experiments to determine the decomposition rate of straw from different rice varieties (*Oryza sativa* L.). The correlation matrix of the initial composition of straw samples and the cumulative C release established the relationships between plant quality parameters and decomposition rates: SQI = –56.85 + (11.68 × % Nitrogen) + (1.25 × % Digestible Organic Matter) + (2.59 × % Lignin). These findings indicate that SQI is a tool in assessing the quality of straw materials in predicting their usefulness in lowland agricultural systems.

A field experiment was conducted to evaluate the influence of "quality" of organic materials on rice yield and soil properties. The leaves of tree species (*Gliricidia sepium* and *Macaranga tanarius*) and rice straws were incorporated on a low-fertility clayey soil (*Aquandic Epiaqualf*) in the Philippines. Application of organic materials improved rice grain yield and soil organic matter level. The study recognized the value of plant residue quality as an important aspect of low-input sustainable rice production systems. Maintaining adequate levels of soil organic matter is an important factor in the long-term productivity of such systems.

Key words: Decomposition rate, organic material, plant quality, plant residues, soil organic matter

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Introduction

Rice is cultivated in 4.1 M ha ricelands and remains the agricultural commodity with foremost political and economic significance in the Philippines. Despite increasingly rising domestic production, the Philippines is still the world's largest rice importer as local production fails to keep pace with rapidly growing population It has a population growth rate of 2.04%. and Filipinos consume about 33,000 tons of rice daily (PDI, 2008).

Over the past decade, the average annual yields ranged from a low of 2.7 t/ha (1998) and 3.19 t/ha (2001) to a high of 5.0 t/ha (2007). Seventy-five (75%) of every 100 farmers produce less than 4 t/ha owing to their inability to benefit from high-yielding technologies arising from high costs of production (farming inputs) relative to profitability and uncertainties in production (decreasing soil fertility, insect pests, diseases, typhoons and drought). With the increasing cost of fertilizers, doubling domestically compared to the previous year, the government has started giving fertilizer subsidies to poor farmers. Although these initiatives are temporary solutions to the existing problems, some alternative measures that will provide long-term benefits to the resource poor farmers need to be instigated. Attention should be given to alternative low-input production technologies that will enhance the sustainability of lowland agricultural production systems.

With grain: straw ratio of 1:1.5, 13.5 MT ('000 Metric ton) palay will correspondingly produce 20 MT rice straw (Pangga, 2006). Most of these crop "residues" or "wastes" are not collected for composting neither for nutrient recycling, but they are commonly burnt or left in the field for natural decomposition to occur. The term "residue" with its connotation of "something left over that nobody wants" gives a false impression of the value of the straws, stubbles, and other vegetative parts of crops that remain after harvest. Organic residues, like rice straws remaining after harvest, accounts for a large portion of the organic matter added to soils. Application of organic materials in a lowland rice environment is a well known agricultural practice for maintaining soil nutrient levels and ameliorating soil physical properties to sustain crop production. They have beneficial effects on soil structure, influence soil microclimate and serve as a substrate for the decomposing microorganisms.The amount of nutrients contributed by crop residue depends on the crop and the stage at which it is incorporated. Contradictory results have been reported when studying the chemical characteristics of crop residues that control the decomposition process (Quemada and Cabrera, 1995). However, Honeycutt et al. (1993) suggested that part of this apparent disagreement might be due to different lengths of the studies, to the absolute content and relative proportion of the chemical constituents in the plant materials, and to the methodology and interpretations.

Materials and Methods

Laboratory Experiment

Straw of 20 different rice varieties requested from International Rice Research Institute (IRRI) were used in experiment 1. The straw was cut into small pieces (1–2 cm) and oven dried at 60°C for approximately 24 h. A 3.5 g sample of each straw was placed into the sample compartment of the perfusion apparatus. Nutrient concentration in the initial and final residues was determined by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES) after digestion in a sealed chamber (Anderson and Henderson, 1986). Total nitrogen and carbon were analysed by Automatic Nitrogen and Carbon Analyser/Mass Spectrometer (ANCA-MS) System. (Part of this experiment has already been presented in Pangga et al., 2000.)

A series of laboratory experiments were conducted using a 0.005M $CaCl_2$ recycling system (UNE *in vitro* perfusion apparatus, Lefroy et al., 1995). The set-up and management for these *in vitro* perfusion experiments was the same as those described in Pangga et al., 2000. These experiments were carried out in the controlled temperature laboratory (25°C) at the Division of Agronomy and Soil Science, University of New England, Armidale, New South Wales, Australia. Decomposition rate was measured through the amount of CO_2 released from the residues that was trapped in 0.05 M KOH.

Field Experiment

Three rice varieties, IR-54, IR-36 and IR-72, were selected from a wide range of rice varieties used in experiment 1. Multi-purpose plant materials or legume prunings such as *Leuceana leucephala, Gliricidia sepium, Calliandra calothyrsus, Cicer arietinum, Trema orientalis* and *Macaranga tanarius* were collected from the field to test their qualities. The “quality” and “availability” of an organic material are the main criteria used in the selection process. Among the materials collected, *Gliricidia sepium* and *Macaranga tanarius* were selected because of their higher nutrient composition and availability of supply all year round.

The experimental site is on low-fertility clayey soil, *Aquandic Epiaqualf*, a widely distributed soil used for lowland rice production in the Province of Laguna, Philippines. Field experiment was prepared with 28 plots measuring 6 m × 6 m with a total area of 0.175 ha. Rice variety PSB Rc18 was used as the test crop. The treatments used are the following: straws of 3 rice varieties (IR 36, 54 and 72), *G. sepium*, *M. tanarius*, and farmers’ recommended rate (mineral fertilizer at 90–30–30 and 120–30–30 for Wet and Dry Season, respectively). A control treatment, where no residue was added into the plot, was also included with other treatments. Treatments were arranged in a Randomized Complete Block Design (RCBD) and replicated four times.

Initial plant nutrient concentrations and organic constituents (acid-detergent fibre, cellulose, detergent lignin and digestibility); and soil samples that were collected from each of the plots after each cropping seasons were analysed in the Analytical Service Laboratory in U.P. Los Baños. The SQI formulated in experiment 1 was used to assess and integrate the different qualities of the other plant materials. Data were analysed by the analysis of variance using the NEVA program (Burr, 1982). Separation of treatment means were achieved using Duncan's Multiple Range Test (DMRT).

Results and Discussion

Laboratory Experiment

The initial nutrient composition of the straw varied considerably between the 20 varieties (Table 1). The pattern of decomposition differed between rice varieties with the peak release varying from 2 to 4 days, before decreasing rapidly to a relatively constant rate. More than 50% of the total cumulative C was released in the first 9 days. Variety Soc Nau had the highest initial C evolution rates, reaching its peak at day 2. After 42 days, 38.4% of C has been released from this variety which was more than 2 times of the amount released by variety Intan and PSBRc18. Second to Soc Nau, variety Suakoko 8 released 30.3% of its C. A relatively high amount of C (24.7%) was released from variety IR65564 which had the lowest concentration of ADF, lignin and cellulose but had the highest concentration of soluble phenolics and DOM.

The correlation matrix of the initial composition of straw samples and the cumulative C release are presented in Table 2. The maximum coefficient values were recorded between cumulative C release and total N ($r = 0.85$), and C release and DOM ($r = 0.82$). Digestible organic matter (DOM) is the primary factor governing the nutritive value of herbage grasses and considered important in determining the proportion of feed that a ruminant can utilise (Raymond, 1969). No relationship was observed between C release and initial lignin or phenolic concentration. Negative correlations between the C release and C:N ratio ($r = -0.77$); C release and ADF ($r = -0.53$); and C release and cellulose ($r = -0.59$) were also observed. The positive correlation of total N with DOM was comparable to that of total P, with r value of 0.67 and 0.70, respectively. When relationships of DOM were further examined with ADF and cellulose, higher negative correlation was obtained. Correlation values were –0.84 and –0.86, respectively. A lower correlation value was obtained between detergent lignin and DOM (–0.51), and between the C:N ratio and DOM (–0.58). No correlation was found between DOM and soluble phenolics most likely because the condensed tannins would not likely have been extracted and these are more likely to influence breakdown.

Table 1 Nutrient concentration (%), organic constituents and SQI of straw from different rice varieties used in experiment 1.

Variety	N	C:N ratio	DOM* (%)	Cellulose (%)	Lignin (%)	Phenol-ics (yttb -ppt)	Straw Quality Index
IR-8	0.69 defg	51.4 cd**	48.9 bcd	47.1	3.2	3.9	20.6
IR-36	0.87 bc	37.7 fg	51.5 b	47.2	3.0	4.3	25.5
IR-54	0.52 hi	62.7 a	47.2 de	49.8	2.9	4.1	15.7
IR-72	0.69 defg	47.6 cde	49.6 bcd	46.1	2.8	4.7	20.4
PSBRc18	0.65 efgh	51.1 cd	45.9 efg	47.0	3.0	4.6	15.9
IR65564-44-5-1	0.76 cdef	46.2 de	56.7 a	39.9	2.4	5.7	29.2
IR65600-77-4-2-2	0.69 defg	49.7 cd	49.3 bcd	51.6	3.6	5.2	22.2
IR66159-164-5-3-5	0.80 bcde	41.4 ef	49.6 bcd	50.9	4.5	4.8	26.0
IR66738-118-1-2	0.82 bcd	40.5 ef	46.0 ef	54.4	3.8	5.7	20.1
IR67962-84-2-2	0.94 b	37.0 fg	48.5 cde	52.5	4.3	1.4	25.9
Intan	0.48 i	63.4 a	43.3 gh	59.8	4.0	4.1	13.2
Khao Seetha	0.93 b	34.7 fg	50.8 bc	49.2	3.5	1.6	26.7
Kurkaruppan	0.65 efgh	47.7 cde	47.0 de	53.4	4.3	2.0	20.6
Soc Nau	1.13 a	30.5 g	55.0 a	45.9	4.1	1.9	35.8
Suakoko 8	0.94 b	35.9 fg	49.1 bcd	50.5	5.0	3.3	28.4
K. Rondo Marong	0.64 fgh	50.2 cd	44.0 fgh	55.4	4.8	2.0	18.0
Ketan Bandang	0.58 ghi	54.4 bc	44.2 fgh	56.7	4.6	1.4	17.1
Ketan Lombok	0.67 efg	47.0 cde	43.1 h	56.5	5.1	1.9	18.1
Ribon	0.58 ghi	59.0 ab	46.0 ef	52.0	4.5	5.4	19.2
Rodjolele	0.51 hi	63.3 a	46.1 ef	53.5	4.0	3.8	17.1

*Digestible Organic Matter
**Numbers within a column followed by the same letter are not significantly different according to DMRT at $P \leq 0.05$.

Table 2 Correlation matrix (r) between composition of straw from different rice varieties (%) and their cumulative C release (%).

	C release	C:N ratio	N	P	DOM*	ADF**	Lignin	Cellulose	Phenolics
C release	1.00	–0.77	0.85	0.76	0.82	–0.53	–0.07	–0.59	–0.16
C:N ratio			–0.96	–0.54	–0.58	0.32	–0.08	0.37	0.28
N				0.69	0.67	–0.38	0.04	–0.44	–0.25
P					0.71	–0.55	–0.14	–0.59	–0.04
DOM[1]						–0.84	–0.51	–0.86	0.18
ADF[2]							0.78	0.99	–0.38
Lignin								0.71	–0.52
Cellulose									–0.34

*Digestible Organic Matter
**Acid Detergent Fibre

The relationship between decomposition rate and nutrient composition of straw from 20 rice varieties has been examined and several equations were formulated to obtain their correlations. Multiple regression analysis including stepwise regression was carried out using SYSTAT (Wilkinson, 1990). Results of the multiple regressions between mean cumulative C release and the chemical composition of straw residues are given in the following equations:

Adjusted Square Multiple R

Variance proportions: Constant and Nitrogen (%)
SQI = 0.21 + (29.92 × nitrogen) $r^2 = 0.677$ (2)

Variance proportions: Constant and Phosphorus (%)
SQI = 5.03 + (134.25 × phosphorus) $r^2 = 0.478$ (3)

Variance proportions: Constant and C:N ratio
SQI = 44.79 – (0.48 × C:N ratio) $r^2 = 0.584$ (4)

Variance proportions: Constant and DOM
SQI = –41.97 + (1.33 × DOM) $r^2 = 0.597$ (5)

Variance proportions: Constant, C:N ratio and DOM
SQI = –4.65 – (0.30 × C:N ratio) + (0.85 × DOM) $r^2 = 0.748$ (6)

Variance proportions: Constant, DOM and lignin
SQI = –78.03 + (1.76 × DOM) + (3.90 × lignin) $r^2 = 0.783$ (7)

Variance proportions: Constant, C:N ratio, lignin and phenolics
SQI = 49.85 – (0.48 × C:N ratio) – (1.05 × lignin) – – (0.31 × phenolics) $r^2 = 0.548$ (8)

Variance proportions: Constant, C:N ratio, DOM, and lignin
SQI = –46.24 – (0.17 × C:N ratio) + (1.37 × DOM) + + (2.78 × *lignin*) $r^2 = 0.812$ (9)

Variance proportions: Constant, N, DOM, and lignin
SQI = –56.85 + (11.68 × nitrogen) + (1.25 × DOM) + + (2.59 × lignin) $r^2 = 0.814$ (10)

Among the equations, Equations (9) and (10) gave the highest correlation, with almost the same adjusted r^2 values (0.812 and 0.814, respectively). However, the *F* value of C:N ratio in Equation (9) was not significant. Equation (10) was then selected and used in the present and succeeding experiments, and hereafter referred to as Straw Quality Index (SQI).The estimates of the straw quality parameters obtained showed a direct correlation ($r^2 = 0.84$) between SQI and cumulative C release.

Table 3 Straw Quality Index, total *N* and organic constituents (%) in the plant materials used in the field experiment at Lot E, IRRI-UPLB Central Experiment Station, College, Laguna.

Variety	Total N	DOM	ADF	Lignin	Cellulose	Hemicellulose	SQI
IR-36	0.6	51.5	50.3	5.7	44.6	17.8	25.5
IR-54	0.3	47.2	52.6	5.2	47.4	14.7	15.7
IR-72	0.8	49.6	54.9	4.7	50.2	14.1	20.4
G. sepium	3.3	55.0	22.2	8.6	13.6	11.5	72.8
M. tanarius	2.75	41.3	30.1	10.6	19.6	7.1	54.2

Field Experiment

Rice varieties IR36, IR72 and IR54 have high, moderate and low SQI, respectively. The nutrient concentration and organic constituents in straw, *G. sepium* and *M. Tanarius* are presented in Table 3. There was a wide range in the initial total N concentration between rice straws and the two plant species. The DOM in plant residues ranged between 41.3% for *M. tanarius* and 55.0% for *G. sepium*. Measurement of the composition of the plant samples showed varying concentrations of organic compounds. Acid detergent fiber (ADF) in the plant samples contained a relatively low amount of detergent lignin that ranged from 4.7 to 10.6%. Since cellulose is assumed to be the difference between ADF and detergent lignin, this constituent of plant materials would contribute higher concentration in straw materials (44.6–50.2%) than *G. sepium* and *M. tanarius*, with 13.6 and 19.6%, respectively. Hemicellulose ranged between 7.1% for *M. tanarius* and 17.8% for IR 36. Using the equation of SQI, highest value (72.8) was exhibited by *G. sepium* and closely followed by *M. tanarius* (54.2). Straw Quality Index of the straw treatment ranged from 15.7 to 25.5.

The influence of different treatments on rice grain yield is presented in Table 4. There was no significant difference between plant residue treatments. After six rice crops, results suggest that plant residue materials are good alternatives to mineral fertilizers in supplying nutrients to lowland rice and that application of "quality organic materials" improved the chemical and physical properties of soil. The response of rice crop to different types of plant residue materials suggests that management of residue decomposition, by choice of species and method of incorporation, can have significant effects on the short, medium and perhaps even long-term availability of nutrients. Therefore, management of residue materials can affect the input of carbon and other nutrients into the system and the rate at which soil organic matter (SOM) turns over. This in turn will affect the amount of soil organic matter pools and, therefore, the overall supply of nutrients and the availability of nutrients in general – chemical, physical and biological fertility of the soil (Pangga et al., 2000). The management systems used in this experiment increased the level of SOM but have not resulted in a significant difference in the amount of organic matter between the plant residue treatments. The shift in management systems from conventional system to organic approach can be best learned with time; and the im-

Table 4 The Influence of plant residue materials on rice grain dry yield (t/ha).

Treatment	DS 2003	WS 2003	DS 2005	DS 2006	WS 2006	DS 2007
IR 36	3.65 ab[1,2]	3.11 bc	3.89 ab	3.31 b	3.78 ab	3.75 abc
IR 54	3.80 a	2.53 d	3.45 b	3.27 b	3.41 bc	3.34 d
IR 72	3.70 ab	3.30 b	3.87 ab	3.52 ab	3.54 abc	3.50 cd
G. sepium	4.01 a	3.17 bc	4.44 a	3.68 ab	4.04 a	3.97 ab
M. tanarius	3.97 a	3.04 c	3.77 b	4.07 a	3.94 ab	3.57 cd
Mineral fertilizer (recommended rate)	3.60 ab	3.59 a	3.81 b	4.09 a	4.11 a	4.27 a
No-residue control	3.31 c	1.89 e	2.79 c	2.52 c	3.08 c	2.76 e

[1]Numbers within a column followed by the same letter are not significantly different according to DMRT at $P \leq$ at 0.05
[2]Damaged by rats and birds
WS – wet season
DS – dry season

pact of organic fertilization on the amount of organic matter can be measured with time. Although the plant residue materials have potential major roles in increasing crop yields and enable more organic matter to be returned to soil, better management strategies are required to enhance the sustainability of lowland rice environment.

The breakdown of plant residues to soil organic matter is controlled by a large number of factors. One factor that affects plant residue material decomposition and its associated nutrient release is the quality of residue. The application of high quality residue, with high SQI, high nutrient concentration and in forms which are easily broken down by soil biota, are likely to result in rapid release of plant-available nutrients. Conversely, the application of lower quality residues, with low nutrient concentration and low SQI, will release less nutrients and may reduce the availability of certain nutrients to plants, at least in the short term. In this study, *G. sepium* and *M. tanarius* fall into the former group, whilst rice straws are in the latter group. Information has given on the chemical and organic composition of the plant residue materials.

Conclusions

The Straw Quality Index formulated and used in these experiments integrated the dominant constituents of straw (N, DOM and lignin). The results confirmed that SQI is an important tool in assessing the quality of plant organic materials in predicting their usefulness in lowland agricultural systems. The strategy of effective management of plant residue materials has been recognized as an important aspect of low-input sustainable crop production systems. The application of organic materials played a crucial role in improving soil fertility and crop yields, especially in times when mineral fertilizers are very costly and unavailable to most farmers.

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Redesigning Institutions and Governance Systems for Urban Water Demand Management: Case of Developing City Delhi, India

Anand Prakash Tiwari

Abstract Water crisis is a manifestation of crisis in governance and institutional failure in the developing world. The traditional perspective of public good character of water has led to problems relating to resource and demand management in developing countries. In India the city governance model and state dominated institutions reflect the wasteful use of water, poor treatment of water sources and an unsustainable demand usage pattern leading to chaos in the sector. The social benefits of managing such demand through institutional change are immense.

The present study attempted to identify empirically the demand management factors that drive choice of institutions based on perception of experts, stakeholders and consumers in the developing city of Delhi. The research uses multi-criteria analysis using efficiency, equity and sustainability indicators for the choice of delivery institutions. The determinants of optimal social choice were built using multi-nomial logit modeling.

The results indicate that the water losses defined in terms of non-revenue water and recycling for resource use are dominant sustainability indicators for choice of institutional change. The shift in reform strategy to demand management interventions by bringing efficiency in distribution and use can eliminate the chronic supply shortages in developing cities. Systemic institutional change by redesigning of the governance systems incorporating gradual private sector participation will be vital for sustainability of the sector.

Key words: Governance, institution, multi-nomial logit, resource, sustainability

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Introduction

Water crisis is a manifestation of crisis in governance and institutional failure in the developing world. Provision of an efficient and reliable water supply is the common infrastructure problem in developing countries (HABITAT, 2006). In most developing countries water as a common pool resource has been in the domain of public entities of the national and local governments. The public sector model has led to excessive wasteful use of water, poor treatment of water sources and an unsustainable demand usage pattern resulting in water crises in urban centers of India.

In most Asian cities Urban Local Bodies (ULBs) are struggling to provide adequate water supply services. Water supply in urban centers of India are besieged with problems of high unaccounted for water, efficiency is low, cost recovery is poor leading to unreliable supply of water to the growing population. (Zerah, 2000; Raghupathi and Foster, 2002; Nickson, 2003; Saleth and Dinar, 2004). This public sector model of water supply has led to low coverage, high volumes of unaccounted for water and low tariffs, which do not reflect costs. The lack of water availability disproportionately affects the urban poor.

In India the city governance model and state dominated institutions reflect the wasteful use of water, poor treatment of water sources and an unsustainable demand usage pattern leading to chaos in the sector. Making existing institutions more efficient and pro-poor is an urgent priority for achieving millennium development goals. The means to address this challenge is presented as a mix of market mechanisms, state planning and community action. The social benefits of managing the demand of water through institutional change are immense.

Context and Issues

Water management, the lifeline of society, is characterized by the interaction of social, natural and sustainability dimensions and requires long term planning. The problems with the water sector pose particular challenges to decision making processes in the political and economic realm due to short-term focus of democratic decision making, usually of a five year period. State actors, private business, civil society organizations and other institutions vary in their capacity to deal with the long-term dimension. The demand side analysis constitutes a vital input to the economic decision making process which must underpin any long-term sustainable policy for reform of the water supply.

Pricing and institutional realignment have been identified as the key demand management policy tools in the economic literature for maximizing the efficiency and sustainability of the sector. Marginal cost pricing (MCP) has been the conventional focus for obtaining efficiency through the Increasing Block Tariffs (IBTs). This insight has been at the core of economics advocating IBTs and cost reflective prices. The experimentation of this pricing-led demand management reform strategy in developing countries has found little support due to increasing costs and poor quality of delivery of services especially in developing countries. The starting point of the debate is the obvious tension or paradox between the economic theory, which supports MCP as the right solution, and practical experience suggesting institutional settings as the crucial constraint for improving utility performance.

Several studies have addressed the issue of inefficiency in public water supply systems and the potential for sector wide reforms. A common thread running through almost all the studies cites reforming and improving the institutional systems for gains in equity, efficiency and reliability (Saleth and Dinar, 2004). Researchers recommend private sector participation to be the solution for failure of publicly managed water utility around the world (Clarke, 2000; Whittington, 2002).

Recent research has discussed the challenges of institutions as the foci for addressing long-term problems in the urban water sector. Methodologically, numerous approaches emerged that aim at integrative modes of scientific research. A central assumption in modern policy discourse is the incorporation of the institutional principle in public policy i.e. decisions should be based on involvement of users and stakeholders. Public preferences before initiating policy reforms should be studied in-depth (World Bank, 2006). The institutional dimensions need to operate within two key processes involving vision orientation and reformist thinking based on expert opinion and democratic sustainability framework based on stakeholder opinion in decision-making. Opinions of experts, stakeholders and customers are therefore important elements in policy design.

With this is the backdrop, the prime objective of the research is to explore perception and preference of realigning the water delivery institutions with PSP based on a demand side analysis in the developing city of Delhi, the hub of infrastructure reform in India. This was important so as to demonstrate how experts, stakeholders, customers' choice and preference structure influence the design of water institutions.

Materials and Methods

Demand side analysis is a utility concept referring to measurement of targeting users attitudes by pricing, level of satisfaction as well as interventions that improve the efficiency of distribution and use. This study attempts to identify preferences for choice of institutions with varying degrees of Private Sector Participation in various institutional formats by assessing the causal factors and impact of demand management reforms strategy in the developing capital city of Delhi, the hub of infrastructure reform in India.

In analyzing expert, stakeholder and consumer perception for assessing impacts on sector performance, it is important to consider the variables/components affecting the performance. In the present study, these have been analytically decomposed in terms of efficiency, equity and sustainability criteria. In designing indicators the family of criteria has been chosen in such a way that all major concerns about sustainability of water and institution have been taken care of. In doing analysis, the following type of indicators have been considered:

- Efficiency indicators: quantity, quality, and reliability of services.
- Financial aspects: adequacy of cost recovery for operation.
- Equity aspects: affordability, equitable access and participation in decision.
- Sustainability and environmental aspects.

In order to assess various options across a common platform, we developed the framework of criteria, which we then applied to the various institutional Models/mechanisms experimented with in various sectors viz Corporatisation, Management contract, Concession contract and Divestiture options. The measurement of perception of sector performance through a set of indicators of efficiency, equity and sustainability is the key area of perception measurement based on expert and stakeholder survey on a likert scale. Decision makers, experts and stakeholders were the key informants for the opinion generated through focus group discussions and detailed surveys. The methodology used combines qualitative and quantitative approaches of analysis both from primary and secondary sources. The primary sources here include customer surveys, expert opinions and stakeholder opinions besides semi-structured interviews with resident welfare associations. This was achieved in a two-way process:

- Strategic review of water demand usage and patterns.
- Stakeholder consultation of selected options in criteria option matrix.

A multi-pronged survey instrument was applied in this research study. Firstly, there was a discussion with key informants, experts and stakeholders about the strengths and weaknesses of existing water supply institutional reforms in international and national scenarios and their management; secondly, a random institutional survey of water experts and stakeholders.

Demand Side Analysis of Water Utility in Developing City of Delhi

The capital city's water utility, the Delhi Jal Board (DJB) is the primary provider of piped water supply and sewerage services. It serves a total population of nearly 14 million through 1.47 million water connections. Delhi Jal Board (DJB) has not been able to keep pace with rapid urbanisation of Delhi. There is a shortage of 270 million gallons per day (MGD) of water against the projected requirement of 1050 MGD. The demand–supply gap persists in the range of 25–35%. The distribution of water is also not equitable. 10% of Delhi's population had no piped water supply at all and 30% had grossly inadequate access. The level of consumption is very low. The average water consumption in Delhi is generally cited at being 240 LPCD, but, according to consumer reports cited in studies, the average consumption per household is low. About 30% of the city's million people have access to less than 25 liters a day.

Reliance on groundwater amongst both planned and unplanned dwellers is high. Despite the existence of a piped water system at least 36% of the planned population meets 90% of its water need from personal tube wells. The large-scale extraction of groundwater is a result of a widening gap between the demand and supply of water. Wastewater is not properly conveyed and treated. Around 90% of the wastewater produced is collected in the sewer system but of this amount, only 60% is conveyed to treatment works.

Around 40% (600 million liters/day) of the collected wastewater is discharged as raw wastewater into drains and Nallah's, flowing ultimately into the Yamuna River. This results in severe pollution and nuisance. Currently the effluent quality in river Yamuna is poor. The BOD reported was 50 mg/litre, 17 times the prescribed maximum standard of 3 mg/litre. The DO in the river at certain stretches is zero against a minimum of 5 mg/litre. Coli form, an important indicator to measure water cleanliness reported at downstream okhla barrage is 70033333 in 2006 against the norm of 500/100 ml 0.14 million less. Water at most treatment works does not consistently meet the current 20 mg/litre BOD and 30 mg/litre SS effluent standards, with limited coliform reduction.

The typical urban water system (Figure 1) of Delhi city, divided into various subsystems from extraction/exploration of resource, surface and sub-surface, treatment of water, transmission, disposal, recycling, are defined in the resource accounting framework in the diagram.

Non-Revenue Water (NRW) in Delhi City

There is a trend of high non-revenue water (NRW) depicting wastage of the precious resource. According to DJB the percentage of UFW was as high as 50% in 2001 and has been going up in recent years from about 53% in 2002–2003 to 65% in 2006–2007 (Table 1). The latest reports indicate distribution losses comprising leakage from lines and water that is stolen to the tune of 40% against the acceptable limit of 15% prescribed by the Union Development Ministry. The real losses comprising transmission and distribution losses are 37%. Total water billed is estimated to be 300 MGD while the total production of filtered water for supply is 650 MGD and the rate of recovery on revenue demanded is about 57%. The latest CAG report indicates that about 56% of total water supplied in Delhi in the last five years did not fetch any revenue resulting in a loss of Rs 19905.4 million. Delayed repair of leaks in transmission and distribution lines in 2006–2007 led to an estimated loss of 84 million gallons of water. The trends in NRW are listed in Table 1.

All this has resulted in a vicious cycle of non-performance. DJB was supposed to produce an additional 400 MGD of water but was able to actually achieve a production increase of only 130 MGD because of these plaguing ills, so much that it is unable to invest in augmenting supplies due to failure of institutional and gover-

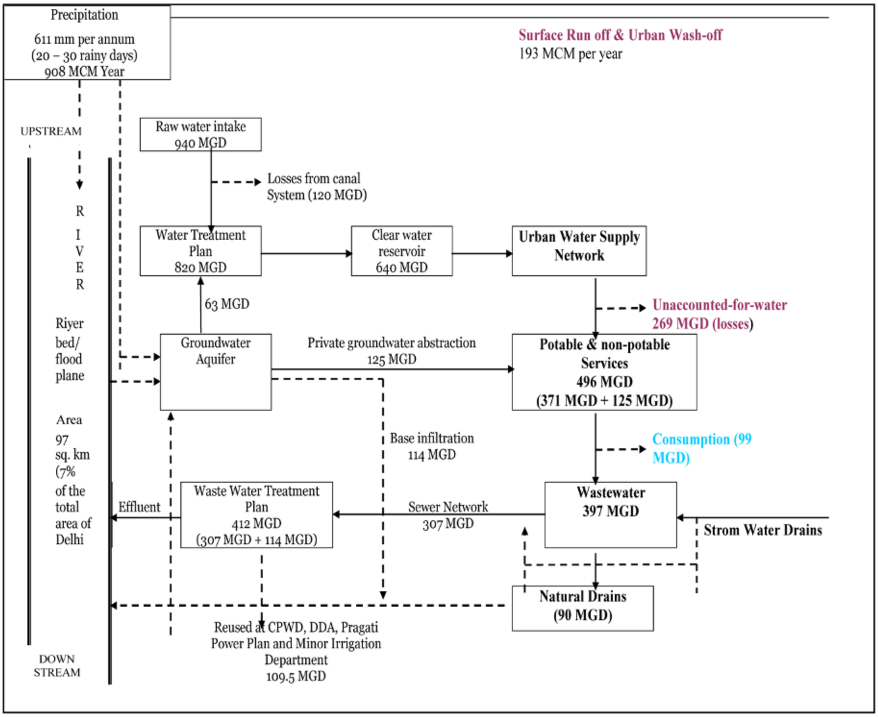

Fig. 1 Flow of water and wastewater in Delhi through a simplified flow diagram.

nance systems prevalent in the water utility. Scientific studies show that the present level of system losses could be reduced to 25% in the medium term (2012) and by 15% (2021) in the long term at an estimated 50 million US dollars required for upgrading and replacement. Leaky pipes, unmet red connections and faulty meters are problems that can be attributed to the institutional failure of the water utility and can be corrected by realigning the institutional systems with a focus on performance improvement based on demand management strategy through private sector participation.

Results and Discussion

The research attempts to identify empirically the demand management factors that drive choice of institutions based on perception of experts, stakeholders and consumers in the developing city of Delhi. The research uses multi-criteria analysis, specifically, efficiency, equity and sustainability indicators for the choice of delivery institutions. The key research issue was identification of how ceteris paribus changes in the elements of the independent variables effect are dependent variables

Table 1 Unaccounted fo Water (UFW) in the city of Delhi. Source: DJB (2001).

<table>
<tr><td rowspan="8">System Input Volume</td><td rowspan="4">Authorized Consumption (60%)</td><td rowspan="2">Billed authorized consumption (50%)</td><td>Billed meter consumption</td><td>14%</td><td rowspan="2">Revenue water consumption (50%)</td></tr>
<tr><td>Billed unmetered consumption</td><td>36%</td></tr>
<tr><td rowspan="2">Unbilled authorized consumption (10%)</td><td>Unbilled meter consumption</td><td>1%</td><td rowspan="6">Non-Revenue water (50%)</td></tr>
<tr><td>Unbilled unmetered consumption</td><td>9%</td></tr>
<tr><td rowspan="4">Water losses (40%)</td><td rowspan="2">Apparent losses (3%)</td><td>Unauthorised consumption</td><td>2.5%</td></tr>
<tr><td>Metering in accuracy</td><td>0.25%</td></tr>
<tr><td rowspan="2">Real Transmission and Distribution Losses (37%)</td><td>Leakage on transmission main</td><td>14%</td></tr>
<tr><td>Leakage on distribution of mains and service connections to the point of metering</td><td>23%</td></tr>
</table>

i.e. the response probability. Theory and intuition suggest that preferences for improved water institutions would differ across stakeholder groups with different educational levels, knowledge bases, socio-demographic characteristics, existing water situations, and opinions about institutional change and governance policy. Choices in the study for stakeholders, experts and consumers have been analyzed employing a multi-nomial logit approach.

An analysis of the expert/stakeholder opinion in ordinal scale was performed to establish important criteria in each of the options through regression of the variables. This was done with an MNL Model so as to see the important attributes in each of the options, as the responses of experts and stakeholders are an outcome generated from observations of reality and from their expectations of a desirable situation.

A sequential maximum likelihood methodology for analyzing the qualitative data generated was used. The significance of an individual coefficient has been assessed with reference to their statistic. A statistic greater than 1.96 indicates that the attribute coefficient is statistically significantly different from 0 at 5%. The overall fit of the model, measured by Mcfaden, R-square (0.21) is low by conventional standards used to describe regression and realistic discrete choice models. The log likelihood statistic, which also explains explanatory power, is significant.

Variables used:

NRW = Possibility of Reduction in Non Revenue Water
FRR = Expectation of Financial Rate of Return
POLACC = Political and Social Acceptability
SRU = Sustainability of Resource Use Possibility
AFF = Affordability
AOB = Accuracy of Billing
LLR = Life Line Rates
MOR = Management of Risks in Transition

ICB = Institutional Capacity Building
LOS = Level of Satisfaction
TR = Technological Reliability
EOI = Ease of Implementation
CPM = Community Participation in Management
USO = Universal Service Obligations

The yield parameters of significance indicate that coverage in terms of quantity, quality, reduction in water losses, cost of services, lifeline rates, affordability, level of satisfaction, ease of implementation, management of risks, political acceptability and sustainability of resource use are the important attributes in either of the options which needs to be considered for designing of institutions in policy planning. Financial rate of return and affordability, which were also important in the divestiture option, can be considered as proxy to price/user charges.

All the variables in the Government and Corporatization option emerge as insignificant in the selection of institutions based on performance analysis under the MNL model, as all of them have t-values less than required. They show a low level of significance, an expected negative sign. However with increasing PSP from Management contract to Divestiture, the non-revenue water (NRW), Quality, FRR, Affordability in Concession mode and Quality, Quantity, NRW, FRR, AFF, Ease of implementation in case of Divestiture are all significant with expected signs.

The result of this analysis is shown in Table 2. The group specific differences suggest that consumers and social activists give considerable importance to the equity and resource aspects, and the experts and officials give more weight to physical and financial performance. However, considering the consistency of the significance of many key institutional criteria, this is restricted more to micro details rather than macro policy.

The results indicate that the water losses defined in terms of non-revenue water, unaccounted-for water and recycling are dominant sustainability indicators for choice of institutional change. The shift in reform strategy through demand management interventions, discouraging wasteful use by bringing efficiency in distribution and use, can eliminate the chronic supply shortages in developing cities.

Conclusions and Policy Implications

Our findings, in a nutshell, support the commonly held view of an unacceptable level of inefficiency due to losses in the system as the primary cause of chronic shortages. Inadequate provision of water supply due to resource and technical constraints may be a partial diagnosis of these shortages, but the major reason for the present crisis is the misdirected emphasis on investing in physical infrastructure without ascertaining sustainability in terms of resources and institutions. Gradual introduction of private sector participation in the water sector can bring in efficiency improvements, which can help in making water more accessible and more affordable. The results clearly indicate that people by and large favor demand management led reforms with

Table 2 Results of analysis.

	Stakeholder views on important attributes
Log likelihood function	–196.9037
Restricted log likelihood	–249.4629
Pseudo R-squared	0.21069

Corporatisation ($Y = 1$)				
	Coeff.	Std.Err.	T-ratio	P-value
NRW	–0.493934	0.52012	–0.949655	0.342288
FRR	0.647484	0.452555	1.43.073	0.152507
POLACC	0.295025	0.27925	1.05649	0.290744
SRU	–0.862509	0.615996	–1.40019	0.161458
Management Contract ($Y = 2$)				
QUANTITY	0.945469	0.675358	1.39995	0.161527
QUALITY	–0.671042	0.553099	–1.21324	0.225038
NRW	1.20052	0.6296681	1.90656**	0.0565781
FRR	1.06133	0.655566	1.61896	0.105456
LLR	–0.623031	0.62242	–1.00098	0.316835
AFF	–0.75867	0.807503	–0.939526	0.347461
AOB	0.636392	0.641645	0.933612	0.350504
ICB	0.851054	0.742093	1.14683	0.251452
SRU	–0.664657	0683549	–0.972362	0.330871
Concession ($Y = 3$)				
QUANTITY	1.2168	0.730643	1.66538	0.0958373
QUALITY	–1.08256	0.611351	–1.77077**	0.0765995
NRW	0.863003	0638485	1.35164	0.17649
FRR	1.36601	0.649431	2.10339*	0.0354317
AFF	–1.70269	0.835067	–2.03899*	0.0414513
ICB	0.612573	0.674953	0.907579	0.364101
SRU	–0.752075	0.681093	–1.10422	0.269499
Divesture ($Y = 4$)				
QUANTITY	2.02519	0.781119	2.59268*	0.00952321
QUALITY	–1.1051	0.589891	–1.8734**	0.06101138
NRW	1.23363	0.675376	1.82658**	0.0677623
FRR	1.38802	0.644428	2.15388*	0.0312495
AFF	–1.93769	0.858452	–2.25718*	0.0239965
LOS	–1.22238	0.98141	–1.24553	0.212937
TR	1.17481	0.970947	1.20996	0.226293
EOI	–1.33653	0.780983	–171134**	0.0870179

*Acceptability above 99% confidence level; **Acceptability above 95% confidence level

a growing tendency of private sector participation in the reform process. The solution lies in restructuring of water utilities coupled with Corporatisation into various strategic business units with management contracts for the private sector to improve efficiency.

The government/state can introduce the management contract model only after a thorough analysis, after introduction of corporatization, wherein the loss-making spatial zones can be delineated and subsequently the losses can be linked to performance improvements by the private sector. This essentially means public service delivery improvement through reduction of water losses in the current water supply network through management contracts. This can help in creating a climate for incentivizing the reform model via PSP acceptable to all stakeholders, especially consumers in the short and medium term.

The results are influenced both by endogenous (efficiency, equity effectiveness and sustainability criteria) and also by exogenous factors characterizing the general socioeconomic and political economy and equity politics. The cost of transacting institutional reforms in a given political economic context can be minimized through a gradual but sequential reform strategy.

The empirical results indicate that Institutional choice is not only about specifying decisions based on different criteria/attributes in policy but also determining the rules that govern the way that these choices are adopted in policy design as the policy variables of risk and effectiveness are robust in the statistical results. The new direction of reforms should therefore adopt institutional choices by choosing organizational forms incorporating PSP in delivery of urban water supply in local context and choosing policy tools which reform the governance framework led by an effective demand-led strategy. Systemic institutional change by redesigning of the governance systems incorporating gradual private sector participation will be vital.

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The Impact of Regulatory Change on Trading Partners: Race to the Bottom or Convergence to the Top?*

Makiko Matsuo

Abstract Japan-China agricultural trade is on the increase. However, as is represented by the Japan-China "frozen spinach case" in 2002, food safety is causing a major trade conflict. In May 2006, Japan greatly strengthened its regulation on chemical residues in food by enforcing *Positive List System for Agricultural Chemical Residues in Food*. What impact will this regulatory change have on its trading partners and non-state actors? The objective of this paper is to explore the impact of Japan's introduction of stringent food safety regulation on China's regulations based on the arguments of International Relations. The paper offers a hypothesis for future scenarios and an analysis of key mechanisms through which "Race to the top" takes place. It argues that Japan's positive list system requires China to improve its food process management system, which could be considerably costly. Nonetheless, the paper also suggests China has many reasons to improve its system. It concludes that in the short term, it is likely that food safety regulation for export is enhanced. Whether this measure is enforced throughout China in the long run depends on who is willing to accept the cost of the institutional, social and regulatory change in the whole food safety system.

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* Note: this paper was originally prepared in 2006 for the Symposium on "Food and Water Sustainability in China 2007". Thus the arguments and evidence provided in this chapter is based on the research conducted at that point. Since then, important incidents and changes worth mentioning has taken place. There was food safety scandal, caused by the poisoned frozen dumpling exported from China to Japan (the so-called frozen "gyoza" dumpling incident), which again caused serious political tension between Japan and China. It has led to the agreement of "food safety promotion initiative" between the two countries. It seems the situation is changing in China. China has set in place a new food safety law in 2009 that tightens the regulation on food safety. How and through what mechanism these changes occurred and what impact these changes will have would be another research topic to be explored in the future.

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Key words: Food safety regulation, Japan-China agricultural trade, race to the bottom, trading up, policy convergence

Introduction

China experienced a general trend of agricultural overproduction in the latter half of the 1990s. Since then, agricultural trade between China and Japan has been steadily increasing. Now Japan represents the largest export market for China. In 2002, China entered into the WTO. With this accession, however, China has the obligation to reshape its regulations in accordance with the WTO rules. With respect to food standard, the Codex standards developed by the Codex Alimentarius Committee (CAC), a joint FAO/WHO food standard setting body, are the reference points of the WTO. Yet, it is said that these standards are not fully fulfilled in China. China's trade disputes over food safety are becoming a major issue not only between Japan but also with the EU. For example, in 2001, the EU repeatedly found residues of chloramphenicol, an antibiotic drug which was banned for use in food producing animals, in samples from shrimps imported from China. In 2002, Japan banned the import of Chinese frozen spinach on the ground that pesticide residue has exceeded the Japanese standards. With this prohibition, the agricultural trade between China and Japan has fallen by 10% in 2002 as compared to that of the previous year (Fujishima et al., 2004). Following the negotiations between Japan and China, the Chinese government made an effort to improve its export product quality control system. Meanwhile, Japanese trading firms with facilities in China sought to establish a food quality control system. Banning was finally lifted in 2005. The trade between China and Japan resumed that year and is on the increase.

In May 2006, Japan enforced a regulation of chemical residues in foodstuff, *Positive List System for Agricultural Chemical Residues in Food* (hereafter, positive list system), mainly in response to the consumer demand for food safety. With this ruling in place, Japan's regulation on pesticide residue is significantly strengthened. Again, this has immediately affected China's export. In June 2006, the export value of agricultural products to Japan dropped by US 131 million dollars, 18% from the same period in 2005 (Financial Times Information, 2006).[1] This may be a temporal decrease since in August in 2006 the statistics of Japanese custom showed a 5.9% increase in the amount from the same period in 2005 (Japan Ministry of Finance, 2006a). Still, with the new law in effect, the number of violations has increased considerably.

Regulatory change has a significant impact on its trading partner's regulations and non-state actors, such as producers and exporters. This chapter attempts to explore the impact of Japan's stringent food safety regulation on Chinese regulations and the non-state actors, especially the firms, using the framework of "Race to the top (RTT)". It attempts to identify the important factors for future food safety in

[1] This number is widely reported among the newspapers but statistics from Japan's Ministry of Finance show 8.3% decrease (Japan Ministry of Finance, 2006a).

China and Japan. It also aims to contribute to the general discussion of RTT within International Relations (IR) by providing an empirical case study. Following IR discussions, the RTT framework is employed for investigating the impact of Japanese positive list system on China's regulations. Sources used in this paper are mainly based on Japanese and English literature, and information from the websites. Several interviews were conducted.

Debate of Trading Up and Down

As a result of long trade negotiations of GATT and the WTO, reduction of tariffs has almost been achieved amongst the developed countries, except for some politically sensitive topics, such as agriculture. In order to facilitate free trade, harmonization of regulations is encouraged by the WTO. Yet, the divergence of national regulations remains. Such divergence is becoming the center of trade disputes because of its trade restrictive effect. These so-called "Non Tariff Barriers (NTB)" include regulation on food safety, health, labor and environment. What is the effect of trade liberalization on states' domestic regulations? Does it have the effect of making the states' regulation more strict or more relaxed? To answer this question, the hypothesis of "Race to the bottom (RTB)" and "Race to the top (RTT)" has been much debated (Vogel, 1995; Porter, 1999; Wheeler, 2001; Drezner, 2001; Vogel and Kagan, 2002).

According to the proponents of RTB, trade liberalization inevitably leads to a lower standard. The RTB hypothesis is based on the so-called "Delaware effect," which assumes that firms move to locations where regulation is lax so as to maximize their profits (Vogel and Kagan, 2002). In order to retain firms in their countries, the authorities compete to relax their rules. Consequently, the countries' standards converge at a lower level.

On the other hand, RTT proponents, such as Vogel, argue that free trade does not necessarily push states to lower standards but rather, it leads states to stricter standards (1995). RTT hypothesis is based on the famous "California effect," which assumes that green states that have rigid environmental regulations could drive the other states to move towards the strict rules (Vogel and Kagan, 2002). Once firms adopt strict regulations, they push for further regulation because it could be a source of their competitiveness.

Vogel and Kagan. have further developed the study of RTT (2002). By reviewing the literature on RTT and by examining the case studies, they argue that there is little evidence that support RTB. In most of the cases the convergence is incomplete, yet there is a general trend toward upward convergence. For this "upward convergence" to take place, they emphasize the importance of the states' willingness and interest. They showed three types of mechanisms through which convergence occurs: market mechanism, institutional mechanism, internationalization of norms and international advocacy. These mechanisms can work together but sometimes work individually. The section below briefly summarizes their points.

Three Mechanisms through which RTT Occurs

The first mechanism through which RTT takes place is the *Market Mechanism*. Based on the "California effect", they pointed out there are several conditions under which RTT materialize through this mechanism. The first condition has to do with the type of regulation; whether the regulation is aimed at the product or the process. It is assumed that product standards are more likely to lead to RTT than process standards. The second condition is the market size of the trading partners. The larger the market of the stricter country is, the more likely it is that the lower strengthens its standards. Moreover, if a country's major export countries have stricter regulatory standards, it has the incentive to adopt strict standards. The third condition is the cost of regulatory change. If the cost of the regulatory change is low relative to the benefits of trade, it is in the lower country's interest to move towards the stricter regulation. In addition to these conditions, they stress the importance of informal mechanism by multinational corporations (MNCs). Although their study does not place MNCs in market mechanism, this chapter places this informal mechanism within the market mechanism.

The second mechanism is the *Institutional Mechanism*. RTT is more likely to take place if there is a relevant international organization or international agreement.

The third mechanism is the *Norms and International Advocacy*. If the relevant norm is shared internationally, it is more likely for RTT to occur. If there are international NGOs that support and play the role of a watch dog, this could also contribute to the enhancement of regulations.

Food Safety Regulation

Chinese Food Safety Regulatory System: MOA and AQSIQ

Food for Domestic Use

China's food safety system has two primary regulatory authorities: The Ministry of Agriculture (MOA) and The General Administration of Quality Supervision, Inspection and Quarantine (AQSIQ).

MOA is mainly responsible for the supervision of domestic food safety. However, the enforcement and implementation of food safety regulation is left in the hands of local authorities. It is, therefore, said that there is a disparity in implementation and enforcement across the country. In the 1980s, the collective farm system was abandoned, and now small-sized farms are managed individually. Brokers or organizations, such as agricultural co-operative associations like those of Japan that help farmers by distributing necessary materials and providing marketing channels, have not been developed. As a result, there is no mechanism to disseminate knowledge of handling and using pesticides (Wei, 2003). It is still a practice to do "buying and selling" face to face, and the wholesale market is still underdeveloped (Suganuma, 2006). Under these circumstances, systems like traceablity are difficult to be introduced. To ensure food quality, monitoring and inspection systems are critical, but these are also developing in a non-uniform manner. Some provinces like Shangdon have established inspection sites but others have yet to set up such facilities.

Nevertheless, food safety related issues have gained much public awareness these days with the growth of wealthy consumers in urban areas. The Chinese government is making efforts to enhance the quality of food. These include a campaign of controlling pesticide residue and establishment of a grading food system by MOA, and the establishment of organic food certification system by the State Environmental Protection Administration (SEPA) and other commissions. However, it is said that the benefit of these improvements is mainly enjoyed by rich urban consumers.

Food for Export

On the other hand, food for export is said to have a higher quality compared to food for the domestic market. Export food products are directly supervised by AQSIQ to meet the stricter importing countries' regulation. It has 35 direct State Administration for Entry-Exit Inspection and Quarantine (CIQs) in the provinces and localities (JIFDS, 2004). In August 2002, laws regarding the control of farm products for export were introduced. With this, firms that want to export agricultural products are obliged to register in advance, have their land inspected and notify the use of pesticide (IAA Center for Food Quality, Labeling and Consumer Services, 2005).

The State Food and Drug Administration (SFDA) was established to oversee the whole food safety regulatory system and to coordinate domestic and international aspects of food safety. However, it is said that the disparity in the quality of food between domestic and export remains.

Japan's Regulation on Pesticide Residues in Foodstuffs: Positive List System for Agricultural Chemical Residues in Food

The Ministry of Health Welfare and Labor (MHLW) oversees Japan's food safety regulation of pesticide residue under the food hygiene law. Until the enforcement of the new positive list system, Japan's regulation on pesticide residue had been controlled on a negative list basis. This means that unlisted pesticides were not prohibited by law, even if it had adverse effects on health. There were 283 substances on this negative list. The new law increased the number of substances up to 799, which include pesticides, food additives and veterinary drugs, and established provisional MRLs (Maximum Residues Limits) for each substance. The uniform limit of 0.01 ppm was set for the substances that had no MRLs. There were 65 substances that were exempt from the list as they did not pose harmful effects on human health.

In criticizing the new law, China argued that Japan unfairly used regulation to protect its agricultural producers. It is true that Japan has serious concern for protecting producers. From the fact that Japan's calorie-based rate of self-sufficiency is only 40%, Japan may well have reason to be seriously concerned in protecting producers for food security. However, it was the Japanese Consumers' Co-operative Union, supported by consumers, that was one of the main driving forces in the creation of this new law. Japanese agricultural producers were rather fearful of the new law since they themselves were unsure if they could fulfill these strict requirements. Their major concern was the so-called "drifting issue". They argued that because many kinds of agricultural products were raised on small-scale farms, pesticides could drift to the neighboring fields, which might lead to an excessive pesticide residue in food. In response, MAFF prepared a manual to prevent drift of pesticide. It can be said that consumer's safety concern was a strong push in shaping the new law. In Japan, food safety is high on the political agenda. Besides, Japan is not the only country that has a positive list system. In fact, the United States and EU have already adopted such a system prior to Japan. Regarding the uniform limit of 0.01 ppm for products with no MRLs, Germany has the same limit. There is a general tendency to adopt stringent food safety regulation among the developed countries.

The Impact of Regulatory Change

Four Scenarios

The following four scenarios can be hypothesized.[2] First, the impact of Japan's regulatory change only affects China's food regulation on export. While the food safety system for export product is enhanced in response to Japan's strict regulation (as it did in the past, e.g. "the frozen spinach case"), food safety regulation for domestic food remains uninfluenced. Thus, the dual system of the Chinese food regulatory system remains unchanged. Second, the strict regulation of Japan affects the whole Chinese food safety system. It not only strengthens food regulation for export products but also affects domestic safety regulation, which, in the long term, could lead to elimination of the dual system and create a unified food system. Third, the regulation in each country has no impact on each other; both countries give up the effort to coordinate and strive to find other export/import countries. Fourth, on the contrary, China somehow affects Japanese regulation to move towards a laxer one.

In these four scenarios, this paper only limits its exploration on first and second scenarios. The third case seems unlikely when taking into consideration the constant growth in trade despite past food safety related trade disputes. The fourth case is

[2] The hypotheses are based on an assumption that China's agricultural export continues to expand. However, some argues that China may turn into an agricultural importing country in the near future. In such case, another hypothesis may have to be considered.

also unlikely because food safety is high on the political agenda in Japan. It may potentially be possible that China brings each case into the WTO dispute settlement body should it seriously feel that Japan's food safety standard is a discriminatory "Green Barrier." Nevertheless, it seems unlikely that China would appeal to such a measure so far. Hence, the following section examines the first and the second scenarios. It examines each condition presented by the RTT debate.

Application of the Framework

The Willingness and Interest of the Country

The willingness and interest of the country is important in bringing about the RTT. Agricultural products are one of the important export goods of China. Thus, China now sees food safety as a source of competitiveness. It also regards expanding export of agriculture as an important source of the farmers' income (P.R.C. Ministry of Commerce, 2005). Therefore, China has a good incentive to strengthen its food safety regulation.

The Mechanisms through which RTT Takes Place

As shown in the second section of this paper, Vogel and Kagan (2002) argue that there are three ways through which the RTT takes place; *Market Mechanism*, *Institutional Mechanism* and *Internationalization of Norms and International Advocacy*. Of these three mechanisms, this paper does not address the third mechanism. Although there is a growing role played by NGOs, they are not so strong as to have influence on state's decision at this stage.

(a) Market Mechanism

The type of regulation: product or process

Food safety, by nature, is only established if the whole food process, "from farm to folk", is ensured. Hence, food safety requires alteration of the whole food management system. Positive list system represents a complex case, in that its regulations do not target a certain single food but any foods. Inspection of the pesticide residue is carried out at the end of the food process but the process of the product (how pesticide was sprayed, how many times it was sprayed, how products were kept in the storage, etc.) greatly influences the resulting residue. Therefore, it is hard to separate product quality from process management. In cases where the (green) process regulation has less to do with the quality of the end product, it is assumed that RTT is hard. However, in a case like the positive list system where the separation of product and process is difficult, RTT seems more likely. Since the process directly or indirectly affects the quality of the product itself, it can be said that China may have the incentive to change the whole system.

The market size of the trading partner

Japan is China's largest export market, accounting for one third of the total amount of agricultural export. In 2005, China's total agricultural export was US 8 billion dollars, with 16 million farmers involved and nearly 40% or about 6,300 of China's export-oriented agricultural firms have Japan as their leading export market (Embassy P.R.C. in Japan, 2006). China's second major agricultural trading partner, EU, also has a strict regulation with a significant emphasis on food safety. Other export oriented countries such as the US, Canada, Australia and New Zealand, all have a strict regulation in place, so it seems unlikely that these countries are negatively affected by the new Japanese law. This means that China is forced to enhance food safety regulation if it wishes to strengthen its competitiveness amongst them.

The cost of regulatory change

The market size suggests that China may have good reason to move upward. The question is whether the benefit exceeds the cost of regulatory and institutional change. As is discussed in the previous section, China's food safety regulatory system is a dual system, consisting of two different mechanisms for food for domestic purpose and export. Despite the regulatory cost, it seems likely that the system of the latter will be enhanced. However, whether this change spreads across the whole Chinese system is unknown.

In an effort to cope with the new law, the Chinese Ministry of Commerce and relevant agencies held training courses for export enterprises from the end of 2005 to provide information on Japan's positive list system. Over 4,000 people, from about one-third of the companies that export agricultural products to Japan, attended (Asia Pulse, 2006). So as to reduce the number of violations, China has to adjust its methods and system of testing and sampling. However, introduction of testing technology and sophisticated equipment are costly. It is said that the new law could raise the cost of farm products by 20% (Pesticide & Chemical News, 2006). These costs make it impossible for small export-oriented firms to keep their business. As a consequence, this may promote mergers of small and medium sized firms by the larger ones (Ohshima, 2003). Furthermore, the cost of changing the whole social and institutional system is high. Training small-sized farmers and individual peasants is also costly as there is no system like agricultural cooperation associations. To ensure food safety "from farm to folk", a control system that can trace back to upstream treatment of a certain product is required. This November, China has announced establishment of such a system (The Japan Agricultural News, 2006). A huge amount of investment must be made to make this system effective across the country.

Informal mechanism: MNCs and export-oriented firms

It is said that the "frozen spinach case" changed the preference of Japanese trading companies. Before the incident, the quality they required of producers in China was the "appearance" of the product. In other words, it requested the product without worm-eaten spots. They did not care much about the process of the product. However, after the event, Japanese firms shifted their requirements to the "safety" of the product. They developed, partly together with Chinese firms, their system of direct management of farmland, pesticide use, transfer, processing, storage and testing. Several companies established an inspection and testing center in China. Chinese firms are also developing their original systems. Once these domestic and international firms adapted to stricter regulation, these firms may pressure for upward regulatory change in China to secure their competitiveness.

(b) Institutional Mechanism

The Codex Alimentarius Commission has standards for pesticide residues in food. The Codex standard is a voluntary standard but it is recognized as a "bench mark" for a food standard. This is because it is clearly stated in the Sanitary and Phytosanitary Agreement that Codex is the reference point of WTO with regard to food issues. The standard concerning pesticide residues is elaborated in the Codex Committee on Pesticide Residues (CCPR). In 2006, China ran for the host of CCPR and actually won this position. The fact that China has entered the WTO, and the fact that it has expressed interest in becoming the host country of CCPR, gives China an obligation to abide by international food standards. Although this may not have an immediate impact, the position in the international arena may compel China to tighten its food safety regulations over a longer term.

Conclusions

This chapter explores the impact of Japan's strict food safety regulations on China. It offers potential future scenarios and analyzes the key mechanisms and conditions under which China may strengthen its food regulatory system in response to Japan's regulatory change.

From the type of regulation, it can be said that Japan's positive list system is a difficult case because it requires China to improve the food process from upstream to downstream. Nevertheless, in so far as the quality of the product is dependent on the process management, China will have the incentive to strengthen its system. Moreover, to expand the agricultural market, China cannot ignore food safety if it wishes to strengthen its competitiveness. Not only the largest importer, Japan, but also the second largest importer, EU, has a strict regulation on food safety. The informal mechanism of Japanese trading companies and export-oriented firms in

China might work as a push towards stricter regulation by individually establishing a direct process management system and investing to enhance techniques on the use, control and inspection of pesticides. If these individual actions spread across China, it can work as one of the major forces of changing the entire food safety system. The accession of WTO and the role of the host country at CAC will also press China to comply with more rigid food safety regulations in the long term. However, China has a lot of tasks to enhance food safety standards, and the regulatory, social and institutional change could be considerably costly. Although China has made efforts to improve its food safety regulation in the recent years by setting legislations and launching campaigns, the effect of these improvements differs from one place to another. But because enhancement of food safety standards improves public health standards, China may have an incentive to change the whole system.

All things considered, it is likely that food safety regulation for export managed by AQSIQ is strengthened, in the short term. Whether the change leads to the elimination of the dual systems or not depends on who is willing to pay the burden of the cost for institutional, social and regulatory change. Hence, further study is necessary to identify the actors (e.g. Government, local authority, producers, small peasants, large-scale farmers, firms etc.), their power and their incentives for regulatory change.

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