Minoru Yoneda · Mazlin Mokhtar
Editors

Environmental Risk Analysis for Asian-Oriented, Risk-Based Watershed Management

Japan and Malaysia

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General Description of the Concept of Environmental Risk Analysis for Asian-Oriented Risk-Based Watershed Management

The initiation of active research exchanges between the research group centered on the Kyoto University environmental engineering researchers and the researchers in environmental risk in Malaysia dates back to the activities of the Environmental Risk Management Sub-group of the Core University Programs in Asia "Environmental Science" (2000–2009) of the Japan Society for the Promotion of Science (JSPS). Through this project, many researchers in Japan and Malaysia involved in environmental risk management met, exchanged detailed information, and began joint research. These activities were continued as part of the activities of the Health Risk Management Sub-group within the JSPS Global COE Program "Global Center for Education and Research on Human Security Engineering for Asia Megacities" (2008–2012). Furthermore, the activities were carried over to the Environmental Risk Analysis Sub-group in the JSPS Asian Core Program "Research and Education Center for the Risk Based Asian Oriented Integrated Watershed Management" (2011–2015), which was adopted in a form to further develop the outcome of these activities. During this time, dozens of researchers from Japan and Malaysia made dozens of visits between the two countries, writing a large number of coauthored papers and working to foster the next generation of researchers.

The Asian Core Program described above focused particularly on watershed management and chemical risk assessment and identified issues in river basins placing an emphasis on Asian climate characteristics, lifestyles, and culture. In addition to establishing methods of evaluation and a knowledge base for hydrological, water quality and substance risks and governance, it aimed to realize a sanitary watershed environment that can withstand abnormal weather resulting from global warming. In the twentieth century, Japan achieved rapid economic growth in a small country with a large population, at the same time facing severe pollution problems and resolving many of them. To solve the water environment problems that arose, Japan established and is developing a watershed management system based on risk assessments. As well as sharing this Japanese knowledge with Malaysian researchers, we hope to find solutions to key challenges that can be expected to occur in the future by sharing information and conducting joint research concerning different climates and cultures that cannot be experienced in Japan. Based on this thinking, the researchers of the Environmental Risk Analysis Sub-group in the Asian Core Program above wrote this book to summarize the knowledge and technologies of environmental risk management that should be disseminated in Asia. Particularly when considering the movement of toxic chemicals in the environment, the researchers who have conducted repeated research exchanges in Japan and Malaysia explain essential knowledge and technologies for reducing the health risks in watersheds, which can be thought of as a single environmental unit. The content of this book does not specifically apply to Japan and Malaysia. It can be used effectively for environmental risk management in Asia and many countries around the world. I hope this book will be widely used in Japan, Malaysia, and many countries in Asia and will help in establishing education programs for fostering the next generation of researchers and engineers in this field.

Kyoto, Japan Minoru Yoneda
22 December 2017

Future Perspective About Asian-Oriented Risk-Based Watershed Management

Everyone wants a better quality of life, even in VUCA settings of today, i.e., under circumstances of increasing volatility, uncertainty, complexity, and ambiguity. These are situations encountered by many due to increasing pressures caused by increasing population and hence demands. Knowledge and experiences of multi-, inter-, and transdisciplinary experts and professionals are much needed and valuable in helping communities, government, industry, and academia to find sustainable development solutions to various issues and problems of today. Bringing expertise and wisdom of natural sciences and social sciences to help us make better decisions and better policies is the order of the current times. Journeys toward sustainable development via various integrated and holistic approaches are much promoted and practiced by many stakeholders at various localities, and scales.

Asian-based and integrated watershed management being discussed in this special book is certainly one good example of such an instrument to bring communities and other relevant stakeholders toward more sustainable lifestyles and livelihoods. These special move and actions were mooted via a special research program in various selected river basins of Peninsular Malaysia, namely the Langat River Basin, Selangor River Basin, and Johor River Basin. This special integrated watershed management was here focused on risk-based management concept. The risk-based approach is indeed quite a novel approach within the Malaysian context and need be scrutinized as part efforts to mainstream knowledge from natural and physical sciences, and social science and humanities and the arts into processes of decision and policy makings of today and tomorrow. Researchers and stakeholders from both the Malaysian and Japanese sides who were involved in this JSPS program of years 2011 to 2014 of Group 4 tasked with Environmental Risk Management had indeed worked very hard in thinking and mobilizing this relatively new concept of risk based for Intefrated Watershed Management (IWM). We really hope and pray that the sharing of results, findings, knowledge, and experiences via the special chapters captured in this book will catalyze and inspire our peers and future generations to think and act better, in our continuing endeavors toward a more prosperous, harmonious, and sustainable Malaysia, Japan, and Asia, and beyond.

Asian-Oriented, Risk-Based Integrated Watershed Management in Malaysia. Watersheds are defined as a unique landscape approach toward sustainability comprising physical, ecological, and social attributes. The interactions among these attributes are termed social-ecological systems that provide ecosystem services valued by society. The watershed risk assessment carried out here was based on the scientific data that had been generated and gathered, hopefully for better environmental decisions and policy making and implementation. The risk aspects being considered in watershed management were not only issues of developing countries but also in developed countries, because water demands are increasing rapidly with the fast-growing world population. This is also being exacerbated by increasing number of people that are facing inadequate access to safe water, where a majority of the global population is still not getting safe treated water supply. Therefore, in risk assessment and management of the watershed, the incorporation of both the natural and physical science and social science and humanity and the arts had been given due emphasis in the design of measures to promote science, in the design of current and future regulatory frameworks and economic planning, as well as in social and environmental policy making and implementation to transform the behavior of individuals. In Malaysia, surface water is the prime source of drinking water and rivers provide more than 97% of the raw water for drinking purposes including for agriculture and industrial purposes. However, the raw water is at risk both from the point and nonpoint sources of pollution. Since the climate is changing and Malaysia is situated in the tropical region, the changing rainfall patterns had contributed to the more frequent devastating floods. These floods including landslides were polluting the watersheds through runoffs from the rural, urban, and industrial areas. Sewerage and industrial discharges to waterbodies were potential threats to water quality, and pollution of rivers had forced several water treatment plants to be closed more frequently nowadays because of threats to humans and the ecosystem. Since Malaysia has an aspiration to declare the country as a developed nation by 2020, the overexploitation of natural resources and misuse and abuse of the surrounding environment including for water are becoming quite more common. Malaysia has already prepared various roadmaps for the integrated water resources management approach via integrated watershed management, integrated river basin management, and integrated lake basin management, along with several other integrated and holistic approaches and policies. The implementation of these policies and strategies is still inadequate, however. Hence, the appropriate leadership is still much needed to link aspects of risk communication, risk perception, and public's willingness to pay for the watershed management in order to attain the aspired ecological sustainability and total human well-being. The integrated watershed management approach is indeed appropriate to reduce the water pollution as well as to reduce flood impacts, and other disasters, including under changing climate. In this regard, capacity building and training of human capacity and capability through international collaboration such as this JSPS program as well as networking among the national and international academicians, researchers, policymakers, volunteers, and professionals will ensure better the achievements of the Global Agenda 2030, TN2050 of Malaysia, and more.

Thank you.

Bangi, Selangor Darul Ehsan, Malaysia Mazlin Mokhtar
18 December 2017

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Part I
Introduction

Chapter 1
Watershed Pollutants: Risk Assessment and Management of Chemicals and Hazardous Substances

Mazlin Mokhtar, Goh Choo Ta, Lubna Alam, and Mohd Talib Latif

Abstract Watersheds provide ecological services that benefit flora and fauna, and people are also benefited from the ecological services, particularly for living and development purposes. Hence, watersheds must be managed in holistic and integrated manners to ensure their sustainability. Nonetheless, rapid development has polluted watersheds, and some of the watershed pollutants are chemicals and hazardous substances. This chapter explains the concept of chemical risk and introduces a framework for chemical risk assessment and management that takes into account the importance of human and environmental health. The chapter also discusses chemicals that cause air pollution (such as ground-level ozone and asbestos) and water pollution (such as different types of heavy metals). In the conclusion, this chapter highlights that we cannot avoid dealing with chemicals in our daily life but we can reduce the risks associated with them.

Keywords Watershed pollutants · Chemical risk · Chemical assessment · Chemical management · Pollution

1.1 Introduction

Watershed is part of the ecosystem that provides ecological services, such as offering habitat for flora and fauna, as well as providing water resources for living organisms within the boundaries of watershed. Abundant water resources in the watershed have attracted diverse human activities, including farming and agriculture, housing and

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human settlement, manufacturing and services industries. People are benefiting from the ecological services provided by the watershed, and in order to ensure sustainability of the ecological services provided, watershed must be managed in holistic and integrated manners. Hence such interaction between human and the ecology is crucial especially to achieve sustainable watershed management. Nonetheless, overwhelming and uncontrolled human activities have created emerging challenges for watershed management, particularly via the release of excessive, untreated and uncontrolled chemicals and hazardous substances, namely, the watershed pollutants.

With the development of our lifestyle, the production and utilization of chemicals have increased remarkably where chemicals have become fundamental part of our lives in the areas of health protection, of food production and of national economies including input and output of industrial processes. Evidently the uses of chemicals provide substantial benefits, but at the same time, their use and misuse at any stage in their life cycle can cause undesirable effects on human health and the environment even though with careful steps to control and monitor their production, transportation, use and the disposal of wastes. Hence the risk of chemicals and hazardous substances must be assessed and managed properly to avoid undesired circumstances.

1.1.1 What Is Risk?

Virtually all aspects of life involve exposure to risks (National Research Council 2008). According to Whyte and Burton (1980), the word “risk” has two diverse meanings. In one context it can mean “a hazard” or “a danger”, that is, an exposure to mischance or peril. In this perspective the degree of risk is related both to its probability and to the magnitude of its consequences. On the other hand, risk is interpreted more narrowly to mean the probability or chance of suffering an adverse consequence, or of encountering some loss.

According to International Programme on Chemical Safety (IPCS 2004), risk is the probability of an adverse effect in an organism, system or (sub) population caused under specified circumstances by exposure to an agent. Or in other words, risk can be expressed via a formula, i.e. risk = hazard × exposure, where hazard mean the inherent/intrinsic property of an agent having the potential to cause adverse effects when an organism, system or (sub) population is exposed to that agent.

As far as chemicals and hazardous substances are concerned, formula above has been adopted in the context of chemical risk, i.e. chemical risk = chemical hazard × chemical exposure. The first parameter of chemical risk – chemical hazard – means the intrinsic hazard properties of chemicals, such as flammability, toxicity and carcinogenicity. Different countries and competent authorities have their respective systems to define or classify chemical hazard, and usually these systems are similar but not the same. For example, a chemical that is classified as toxic in one country might not be classified as toxic when the chemical crosses the country’s borders and it all depends on the cut-off values, such as LD_{50} for oral toxicity, particularly different cut-off values adopted by exporting and importing countries (note: LD_{50} means amount of a chemical, given all at once, which causes 50% death in the test population, e.g. mice, rats). To address challenges caused by different systems, the

United Nations (UN) has developed an internationally accepted voluntary system known as “Globally Harmonised System of Classification and Labelling of Chemicals (GHS)” that classifies chemical hazard into three main intrinsic hazards, namely, physical hazard, health hazard and environmental hazard (United Nations 2011). It is anticipated that the GHS will be adopted worldwide.

Second parameter of chemical risk, i.e. chemical exposure, is the amount (quantitative) of chemicals that are exposed to target population. In general, there are two types of target population, namely, human and the environment. Chemicals can be exposed to human in multiple routes, including ingestion (via contaminated food and vegetables), inhalation (via toxic gases and vapours) and dermal contact (via toxic liquids and solids). The effect on human health is depending on the dose that they have been exposed, and normally high dose of exposure will cause acute health effects. Nonetheless, low chemical exposure is also dangerous to certain vulnerable groups such as pregnant women and children. As far as environment and ecology is concerned, emission of hazardous gases into the atmosphere and discharge of heavy metals in to river and drainage will cause damage to the natural states of the environment, as well as threatening vulnerable species such as birds and animals.

1.1.2 Chemical Risk Assessment and Management

Risk assessment can be conducted in a systemic manner, and there are four generic steps for risk assessment, namely, (i) hazard identification, (ii) hazard assessment, (iii) exposure assessment and (iv) risk characterization (enHealth 2004). The concept of risk assessment has been adopted by various organizations in different context, for example, the World Health Organization (WHO) has developed human health risk assessment toolkit for chemical hazards (WHO 2010), whereas the US Environmental Protection Agency has developed guidelines for ecological risk assessment (US EPA 1998). If risk is known or identified in the risk assessment process, then risk management, which is basically a decision-making process to accept a known or assessed risk and/or the implementation of actions to reduce the consequences or probabilities of such an occurrence, should be implemented. The risk management tools should be scientifically sound and cost-effective and integrate actions that reduce or prevent risks, while taking into account social, cultural, ethical, political and legal considerations.

As far as chemical risk assessment and management is concerned, the ultimate goal for chemical risk assessment and management is to ensure protection of human health and the environmental health by eliminating or reducing chemical risks. Figure 1.1 illustrates the framework for chemical risk assessment and management. It is important to emphasize that this framework highlights potential areas that are affected by chemical pollutants (in chemical risk assessment), potential tools for chemical risk management and risk communication, as well as multi-scale and multi-stakeholder approaches, and tools and facilities that support the framework. Generic steps for risk assessment method (that are discussed above) are not part of the

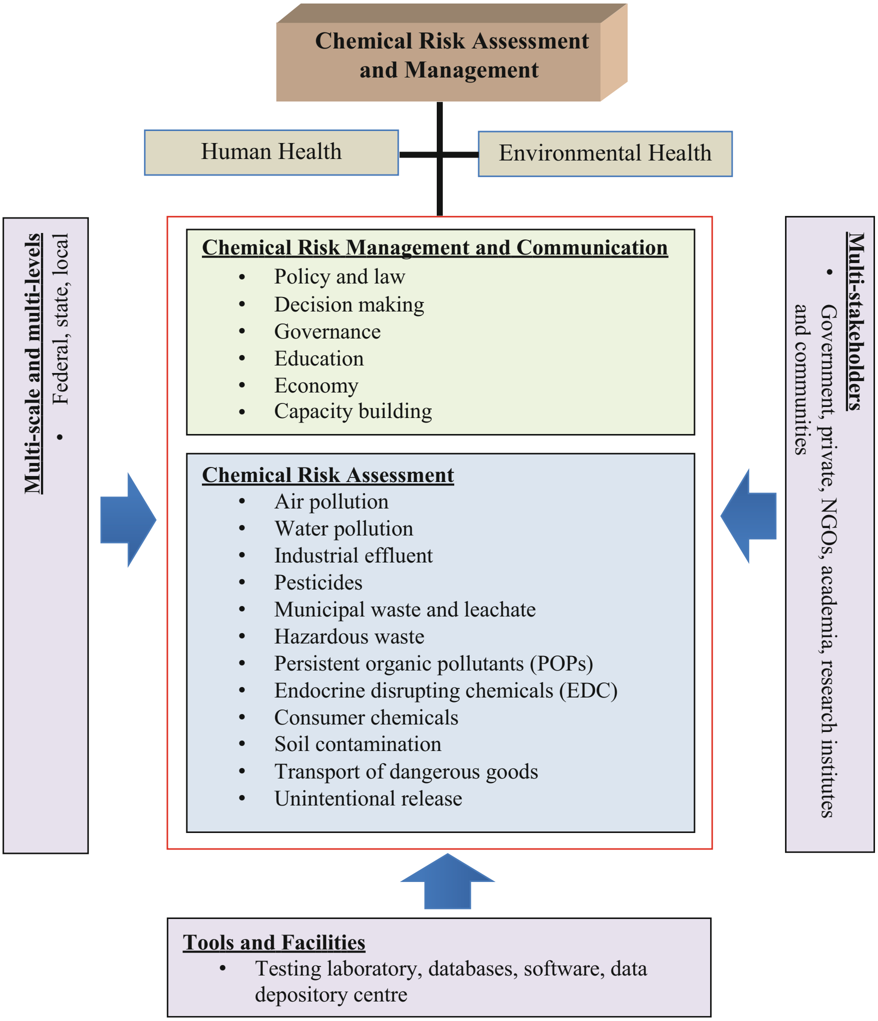

Fig. 1.1 Framework for chemical risk assessment and management

framework. Two specific areas have been selected for further elaboration, namely, the air pollution and water pollution.

1.2 Air Pollution

Air pollution is a mixture of solid particles and gases in the air. There are several main sources of air pollutants including car emission, industrial activities, mining, power plant and incinerators. Other than anthropogenic sources, from time to time air pollutants also can be generated by several natural factors such as forest fire, dust storm and volcanic eruption. There are several main pollutants, which have been considered as criteria air pollutants due to the significant effect to human being and environment, such as suspended particulate matter, sulphur dioxide, nitrogen dioxide, carbon monoxide and ozone. Other than these criteria air pollutants, there are many other air pollutants in the environment that also contribute to human health and environmental issues. The issues of air pollutants do not just happen in the ambient air (earth atmosphere), it also happens in indoor environment, where most people spent the time in the last decade.

1.2.1 General Effect of Air Pollution

Air pollution affects many aspects of our environmental visual qualities, vegetation, animal, soil, water quality, natural and artificial structures and human health. Air pollution affects visual resources by changing the colour, creating hazy condition and reducing visibility in the atmosphere. This phenomenon usually occurs in the urban environment (Botkin and Keller 2010). The air pollutants affect the vegetation by damaging the leaf tissue, needles and fruit resulting in the reduction of growth rate and reduction of reproductive processes. There are many studies indicating that the gas such as surface ozone in the atmosphere has ability to damage the leaf tissues and at the same time reduce the plant growth by eliminating the uptake of nitrogen from soils (Yamaguchi et al. 2011; Bhatia et al. 2012). Air pollution can also degrade soil and water resources when pollutants from the air are deposited (Botkin and Keller 2010). Soil and water may become toxic from deposition of various pollutants. Soil may also be leached of nutrients by pollutants that form acids. The effects of air pollutants on human-made structures include discolouration, erosion and decomposition of building materials.

Air pollutants can affect human health in several ways. The effects on an individual depend on the dose and concentration of the pollutants. Some of primary effects of air pollutants include toxic poisoning, cancer, birth defects, eye irritation and irritation of respiratory system. Irritation to the respiratory system will lead to susceptibility of viral infection and increase susceptibility to heart disease. Many air pollutants have synergistic effect in which the combined effects are greater than the sum of the separate effect.

1.2.2 Major Air Pollutants and Human Health

The main air pollutants in ambient air are recognized as “criteria air pollutants” or known as six common air pollutants by the US EPA. They are particle pollution (often referred to as particulate matter), ground-level ozone, carbon monoxide, sulphur oxides, nitrogen oxides and lead. These pollutants can harm your health and the environment and cause property damage. According to the US EPA (2013), among six criteria air pollutants are particle pollution and ground-level ozone which are the most widespread health threats. In Malaysia particulate matter is usually contributed by haze episode due to biomass burning in Sumatra and Kalimantan, Indonesia, particularly during southwest monsoon between June and September each year. Due to its location in the tropical region, the concentration of O_3 is higher almost every day due to high UV intensity (Azmi et al. 2010).

Particulate matter (PM) is the term for a mixture of solid particles and liquid droplets found in the air. Some particles, such as dust, dirt, soot or smoke, are large or dark enough to be seen with the naked eye. Others are so small; they can only be detected using a microscope (US EPA 2013). Some particles, known as *primary particles*, are emitted directly from a source, such as construction sites, unpaved roads, fields, smokestacks or fires. Others form in complicated reactions in the atmosphere of chemicals such as sulphur dioxides and nitrogen oxides that are emitted from power plants, industries and automobiles. These particles, known as *secondary particles*, make up most of the fine particle pollution. Fine particles which have the ability to go through until the alveoli usually are the most dangerous to human being. According to Dominick et al. (2012), in Malaysia motor vehicles and industrial activities are among the main contributors of particulate matter in ambient air.

Chemical compositions also have significant function to the toxicity on human body. The major components of PM are transition metals, ions (sulphate, nitrate), organic compound, quinoid stable radicals of carbonaceous material, minerals, reactive gases and materials of biologic origin. Results from toxicological research have shown that PM have several mechanisms of adverse cellular effects, such as cytotoxicity through oxidative stress mechanisms, oxygen-free radical-generating activity, DNA oxidative damage, mutagenicity and stimulation of pro-inflammatory factors. Surface properties (surface chemistry) appear to play an important role in ultrafine particle toxicity. Small sizes (ultrafine particles) largely escape alveolar macrophage surveillance and gain access to the pulmonary interstitium after deposition in the lung (Oberdörster 2001). Some studies showed that the extractable organic compounds (a variety of chemicals with mutagenic and cytotoxic properties) contribute to various mechanisms of cytotoxicity; in addition, the water-soluble fraction (mainly transition metals with redox potential) plays an important role in the initiation of oxidative DNA damage and membrane lipid peroxidation (Valavinidis et al. 2008).

Ozone is a highly reactive gas that is consumed by reactive processes on reaching the first interface in the lung, the lung lining fluid compartment (Mudway and Kelly 2000). Ozone reacts rapidly with a number of biomolecules, particularly those containing thiol or amine groups or unsaturated carbon-carbon bonds in the lung. These reactions and their products are poorly characterized, but it is thought that the ultimate effects of ozone exposure are mediated by free radicals and other oxidant species that then react with underlying epithelial cells, with immune cells and with neural receptors in the airway wall (US EPA 2013). In Malaysia, ozone usually shows higher concentration in suburban and downwind area due to contribution of ozone precursor from the city centre. The complexity of ozone concentration due the reaction of NOx and volatile organic compounds (VOC) let the complexity to reduce the amount of ozone in the ambient air (Latif et al. 2012).

Other major air pollutants such as carbon monoxide, sulphur dioxide, nitrogen dioxide and lead even though still dangerous to human being, nevertheless, the concentration of these pollutants in ambient air is considered low and reducing due to the high efficient combustion technology and development of instrument to reduce the amount of pollutants in the ambient air (Azmi et al. 2010).

1.2.3 Air Pollutants and Indoor Environment

Due to time spent in indoor environment, the toxicity of indoor air pollutants to human being has been discussed by many researchers lately. The type of building materials, ventilation system, location and different type of activities determined the type of pollutants in indoor environment. Outdoor sources maybe the main contributor to indoor concentrations of a number of non-biological pollutants commonly found air. This is especially the case for contamination in building situated in urban areas and close industrial zones or streets with heavy traffic (Jones 1999).

Combustion in indoor environment has been considered as major sources of indoor air pollutants. In many part of the world, combustion is still used for cooking and heating (Hosgood et al. 2012; Oluwole et al. 2012). Combustion in indoor environment contributes to the high amount of toxic gases such as carbon monoxide, suspended particulate matter and its composition especially related to elemental and organic carbon. Smoking also can be considered as another combustion contribution to indoor air quality. The best approach, therefore, is to examine the toxicity of the entire mixture, as has been done with the most well-studied biomass smoke, that from tobacco burning. According to Naeher et al. (2007), there have been more than 4000 compounds identified in tobacco smoke, many dozens of which possess toxic properties, and there are few well-understood links between individual constituents and many of the health effects are known to be caused by exposure to this mixture.

Building materials contribute to different type of air pollutants in indoor environment. Asbestos use for fire retardant and insulation, for example, has been long considered as one of toxic materials in indoor environment (Jones 1999). In Malaysia asbestos can be found in building materials in the building before the regulation on asbestos amount in building material was implemented in the 1980s. Study by Latif et al. (2011) during the renovation action in a building found that the concentration of asbestos (between 0.0022 and 0.0038 fibre/cc) was higher than the concentration of asbestos in background environment. Building materials also produce other pollutants such as radon, a radioactive gas that can be found in some types of phosphogypsum and can be toxic in indoor air with low ventilation rates (Pacheco-Torgal and Jalali 2011). New furniture has been found to produce certain amount of organic pollutants such as formaldehyde in indoor air. Volatile organic carbon can be produced in ambient air from paints and varnishes. Some of these building materials are prone to trigger which can be a risk to the occupants (Pacheco-Torgal 2012).

Heavy metals have been found to be accumulated in indoor dust within the indoor environment especially renovation action activities. Study by Latif et al. (2011) showed that the concentration of heavy metals in indoor dust during renovation was very high due to improper procedures taken during the renovation action in building. Heavy metals also can be generated from building materials such as paints and other building materials and equipment within the building. The location of building also determined the amount of heavy metals coming from outdoor sources particularly from road dust and wind-blown soil.

1.3 Water Pollution

Water, which is a very important resource for people and the environment, covers over 70% of the Earth's surface and considered to be a crucial component for healthy living. Water pollution refers to any change or modification in the physical, chemical and biological properties of water that might have a disadvantageous effect on living things. It occurs when pollutants (particles, chemicals or substances that make water contaminated) are discharged directly or indirectly into water bodies without enough treatment to get rid of harmful compounds. Based on the origin, sources of surface water pollution are divided into two categories: point and nonpoint source. Point source water pollution refers to contaminants that enter a waterway from a single, identifiable source, such as a pipe or ditch. Nonpoint source pollution refers to diffuse contamination that does not originate from a single discrete source. Nonpoint source of pollution is often the cumulative effect of small amounts of contaminants gathered from a large area. Chemical contaminants are generally grouped into organic, inorganic and radioactive. The water can be polluted due to natural and anthropogenic reasons where the most common causes are the anthropogenic ones including agriculture run-off, storm water run-off, leaking sewer lines, mining activities, foundries, accidental leaks and spills, intended/illegal discharges of waste, burning of fossil fuels, transportation, construction activities, plastic materials/wastes in contact with water, disposal of personal care products and household chemicals, improper disposal of car batteries, leaking landfills, animal wastes and so on.

1.3.1 Risk of Chemical Pollution in Water

Although there are many definitions of the word risk, the US EPA (2012) considers risk to be the chance of harmful effects to human health or to ecological systems resulting from exposure to an environmental stressor where a stressor can be any physical, chemical or biological entity that can induce an adverse response. Stressors might have unfavourable impact on specific natural resources or intact ecosystems, including plants and animals, as well as the environment with which they interact. An outline of chemical risk on human life is summarized in Table 1.1.

Table 1.1 Effects of water pollutants on human health

No.	Pollutant	Effects
1.	Zinc (Zn)	More than 165 mg for 26 days causes vomiting, renal damage, cramps, etc.
2.	Copper (Cu)	More than 470 mg is toxic for human body and may cause hypertension, sporadic fever, uraemia, coma and pathological changes in brain tissue
3.	Barium (Ba)	More than 100 mg may cause excessive salivation, colic, vomiting, diarrhoea, tremors, paralysis of muscles or nervous system, damage to the heart and blood vessels
4.	Iron (Fe)	More than 10 mg per kg of body weight causes rapid respiration and pulse rates, congestion of blood vessels, hypertension and drowsiness
5.	Cadmium (Cd)	Very toxic, 50 mg may cause vomiting, diarrhoea, abdominal pains, loss of consciousness, decrease of red blood cells, impairment of bone marrow, lumber pains, disturbance in calcium metabolism, softening of bones, fractures, skeletal deformations, damage of kidney, hypertension, tumour formation, heart disease, impaired reproductive function, genetic mutation, etc.
6.	Mercury (Hg)	Very toxic. More than 100 mg may cause headache, abdominal pain, diarrhoea, destruction of haemoglobin, tremors, very bad effects on cerebral functions and central nervous system, paralysis, inactivates functional proteins, damage of renal tissues, hyper coagulability of blood, Minamata disease and even death
7.	Lead (Pb)	More than 400 mg of lead can cause brain damage, vomiting, loss of appetite, convulsions, uncoordinated body movements, helplessly amazed state and coma. It is retained in the liver, kidney, brain, muscle, soft tissues and bones, leads to high rate of miscarriages, affects skin and respiratory system and damages the kidney, liver and brain cells
8.	Arsenic (As)	Greater than 25 mg of arsenic causes vomiting, diarrhoea, nausea, irritation of nose and throat, abdominal pain, skin eruptions inflammations and even death. May cause cancer of the skin, lungs and liver, chromosomal aberration and damage, gangrene, loss of hearing, injury to nerve tissue and liver and kidney damage. Minor symptoms of arsenic poisoning, weight loss, hair loss, nausea, depression, fatigue and white lines across toenails and fingernails
9.	Vanadium (V)	It is very toxic and may cause paralysis
10.	Silver (Ag)	Causes pathological change in the kidney and liver and may even damage kidney. May cause argyria (discolouration of skin). Affects mucous membranes and eyes
11.	Radioactive materials/ metals/substances	Generally cause "gene" mutation, ionization of body fluids, chromosomal mutations and cancers. Destroy body cell tissue, adversely affect reproductive system. When mother is exposed to radiation during pregnancy, it causes severe mental retardation and leukaemia in infants. Radioactive metals like heavy metals are nephrotoxic and damage kidneys

(continued)

Table 1.1 (continued)

No.	Pollutant	Effects
12.	Fluoride	Excess fluoride intake in body results in progressive crippling scourge (sponging)/fluorosis of bones and teeth. May cause metabolic alternations in soft tissues and their functional mechanism
13.	Selenium (Se)	More than 4 mg causes fever, nervousness, vomiting, falling of blood pressure, causes damage to liver, kidney and spleen and loss of nails and hair and causes blindness to animals
14.	Chromium (Cr)	Any chromium compound is toxic but haxavalent chromium greater than 70 mg is very toxic. It causes cancer, anuria, nephritis, gastrointestinal ulceration and perforation in partition of nose. It penetrates cell membrane and badly affects central nervous system. Causes respiratory trouble, lung tumours when inhaled. May cause complications during pregnancy
15.	Manganese (Mn)	Concentration greater than 100 ppm is toxic and causes growth retardation, fever, sexual impotence, muscles fatigue and eye blindness

Source: Rajni and Keshav (2010)

1.4 Risk Assessment and Management in Malaysia

Risk assessment is now a hot spot in environmental study, and a great deal of research has been conducted over the recent years. In the case of Malaysia, many researchers focused on the water quality monitoring, but unfortunately risk-based studies are very limited, and to our best knowledge, no studies have been found about the chemical risk assessment of water. However, aquatic organisms can be used as indicator of the status of ambient water, and, therefore, few studies carried out in Malaysia can be linked with risk-based research. The study of Santhi et al. (2012) showed that bisphenol A is a ubiquitous contaminant in surface, tap and bottled mineral water where exposure to BPA from drinking water is very low and is less than 0.01% of the tolerable daily intake (TDI). Aquaculture food products from aquaculture farms in Malaysia indicated no health hazards as none of the values exceeded the Joint FAO/WHO Expert Committee on Food Additive (JECFA) guideline values (Mok et al. 2012). Concentrations of trace elements were determined in the muscle and liver of 12 species of marine fish collected from coastal areas in Malaysia where Hg levels are higher than the guideline value by the US EPA which indicated that consumption of these fish might be hazardous to Malaysian people (Agusa et al. 2005). A study was conducted from 2002 to 2003 to determine the levels of selected organochlorine and organophosphate pesticides in the Selangor River in Malaysia where the pesticide levels exceeded the European Economic Community Directive of water quality standards (Leong et al. 2007). Mirsadeghi et al. (2011) investigated the concentration of carcinogenic polycyclic aromatic hydrocarbons present in the sediment and water of Peninsular Malaysia as well as in the cockle *Anadara granosa*. The average cancer risks were found to be classifiable as unsafe according to the US EPA standard. Concentration of butyltin compounds including tributyltin (TBT), dibutyltin (DBT) and monobutyltin (MBT) and total tin (SSn) were determined in green mussel (*Perna viridis*), fish and sediment from coastal waters of Malaysia where the parent compound TBT was found to be the highest than those of its degradation compounds, DBT and MBT, which indicated input of TBT to the Malaysian marine environment (Sudaryanto et al. 2004). Alam and Mohamed (2011) studied about the radioactive pollution in a coal-burning power plant area of Malaysia and concluded that the seafood consumption is at considerable risk.

Most of the chemical risks of concern are related to urbanization and industrialization which indicates the risk of economic development, and therefore a link exists between risks and countries or those regions within countries that are vastly industrialized. Many studies have proved that rapid industrialization and unrestrained urbanization around many cities and coastal areas have led to alarming increase in the pollution levels of the aquatic environment of Malaysia. As a result the Straits of Malacca as well as river system is subjected to a great variety of pollutants. This pollution is directly linked with human health, and that is why, there is a need for understanding and forecasting risks that can provide fundamental information desirable for sustainable development resolution.

1.5 Conclusion

Chemical risk assessment and management is one of the vital components in ensuring protection of human health and the environment. As we cannot avoid using chemicals in our daily life (such as food additive, petrol, cosmetics, etc.), hence we should use and handle chemicals in a proper and appropriate manner, by understanding the hazards and accepted exposure limits of a particular chemical. However, one of the most challenging tasks for Malaysia is to develop an integrated chemicals database where information related to chemicals can be shared between government and private sectors, as well as to make available to public. Perhaps competent authorities in Malaysia will take the initiatives to share their respective chemical databases into single integrated chemical database in the future.

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Part II
Situation of Environmental Risk in a Watershed

Chapter 2
Potential Health Risk of Heavy Metals in Malaysia

Nobumitsu Sakai and Minoru Yoneda

Abstract This chapter summarized the pollution of heavy metals in the atmospheric and water environment in Peninsular Malaysia, and potential health risks caused by the chronic exposure of the heavy metals were assessed. Heavy metals such as arsenic and lead were detected in suspended particulate matters, and the pollution sources were identified mainly from motor vehicles and biomass burning. The heavy metals were widely detected in surface and groundwater and accumulated in coastal areas especially near urban regions due to anthropogenic sources. Furthermore, contaminations of naturally deposited heavy metals especially from former tin mining ponds and gold mining areas were concerned. The heavy metals were detected in various freshwater and marine species, and the contamination levels of mercury and arsenic in local population were indicated at concerned levels. The assessment of potential non-cancer risks caused by the consumption of local fish showed that some population could be threatened by the chronic exposure of arsenic and mercury.

Keywords Heavy metal pollution · Peninsular Malaysia · Pollution source · Food contamination · Health risk assessment

2.1 Introduction

The urbanization is rapidly progressed in Malaysia, particularly in the capital region (i.e., Klang Valley). The main industry in the Klang Valley used to be tin mining since the nineteenth century, but most of the areas have been transformed into urban and industrial cities, and there are very limited active tin mining zones. There are

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many environmental issues in Malaysia mostly due to anthropogenic influence. Biomass burning in local and Indonesia causes haze during dry seasons. A huge amount of gas emissions from motor vehicles and industry also contribute to the air pollution. The water environment is deteriorated especially in urban areas, and high nutrient levels and turbid surface water are observed due to inadequate treatments of domestic sewage, direct discharges of industrial effluents, and improper land clearing activities for housing. Therefore, there is a high potential for heavy metals contaminations through these pollution sources. Furthermore, heavy metals which are naturally deposited could be released to streams once the ground is disturbed by earthworks. The heavy metal pollutions as well as adverse health effects to local people are concerned, and many studies have reported the serious pollution levels in the environment, food, and human specimens.

In this chapter, heavy metal pollutions in the atmospheric and water environment in Peninsular Malaysia are reviewed, and pollution sources are indicated. The contamination of heavy metals in freshwater and marine species is summarized and associated with the water pollution. The exposure of heavy metals in local people is indicated, and potential health risks due to the inhalation of heavy metals as well as the chronic exposure of heavy metals by the consumption of local fish are assessed.

2.2 Heavy Metals in the Environment

2.2.1 Air Pollution and Heavy Metals

According to the Department of Environment Malaysia (2015), a number of unhealthy air quality days were recorded at various locations in the west and east coast of Peninsular Malaysia in 2014. Particulate matters (PM_{10}) were predominant pollutants that had caused unhealthy conditions during the dry seasons. The unhealthy days during these periods were dominantly due to forest and peatland fires occurred locally and transferred from Indonesia. Furthermore, the concentrations of PM_{10}, ozone, sulfur dioxide, nitrogen dioxide, and carbon monoxide in urban and industrial areas were significantly higher than suburban and rural areas because of the emissions from motor vehicles and industries. According to Khan et al. (2015a), an average concentration of $PM_{2.5}$ in the west coast of Peninsular Malaysia (25.13 μg/m^3) was observed. It is nearly two times higher than the east coast of Peninsular Malaysia (14.3 μg/m^3) (Mohd Tahir et al. 2013) and a 24 h guideline (25 μg/m^3) set by the World Health Organization. The mean concentrations of total suspended particulates (TSP), PM_{10}, $PM_{2.5}$, and PM_1 collected in the southern part of the Klang Valley (Bangi) were 14.37, 14.11, 12.53, and 10.53 μg/m^3, respectively, and the particle size in more than 99% was less than 500 nm (Khan et al. 2015b). These results indicate that the west coast is seriously affected by $PM_{2.5}$ due to the haze and gas emissions, and the small particle size could enhance the toxicity.

According to Wahid et al. (2014), heavy metals in PM_{10} were dominated by iron (172 ng/m^3) and zinc (84.5 ng/m^3) followed by lead (23.1 ng/m^3), copper (6.08 ng/m^3), manganese (4.43 ng/m^3), cadmium (0.39 ng/m^3), and nickel (0.05 ng/m^3). Similarly, predominant heavy metals in $PM_{2.5}$ were iron (3052 ng/m^3) followed by zinc (389 ng/m^3), chromium (107 ng/m^3), copper (28.3 ng/m^3), lead (21.8 ng/m^3), and arsenic (5.76 ng/m^3) (Khan et al. 2015a). The high concentration of iron could be attributed to the earth's crust (Wahid et al. 2014), while most of other heavy metals could be originated from anthropogenic sources. The arsenic concentration was close to an air quality guideline standard (6 ng/m^3) set by the European Commission.

The pollution sources of $PM_{2.5}$ were identified by positive matrix factorization (PMF) (Khan et al. 2015a). The largest pollution source (31%) was derived from motor vehicle emissions and biomass burning. It was associated with lead, zinc, nickel, arsenic, vanadium, and cadmium which represent a motor vehicle emission source (Wu et al. 2007). The average concentration of $PM_{2.5}$ (61.2 μg/m^3) collected in Singapore during hazy days in 2014 was significantly higher than non-hazy days (22 μg/m^3), and heavy metals in the hazy days ((e.g., iron (1290 ng/m^3), zinc (164 ng/m^3), nickel (164 ng/m^3), chromium (63.3 ng/m^3), copper (50.1 ng/m^3), arsenic (38.6 ng/m^3), manganese (15.8 ng/m^3), lead (10.9 ng/m^3), cobalt (6.68 ng/m^3), and cadmium (1.75 ng/m^3)) were also higher than those in the non-hazy days (Huang et al. 2016). Therefore, it is obvious that the motor vehicle emissions and the biomass burning contribute to the heavy metals pollution in the atmosphere.

Another anthropogenic source of $PM_{2.5}$ was associated with coal-fired power plants (19%) (Khan et al. 2015a). There are four coal-fired power plants in Peninsular Malaysia, and the power generation sector will have more coal plants up to 64% by 2019 (Mokhtar et al. 2014). In the flue gas collected in one of the four coal-fired power plants, mercury was detected at 0.01 mg/N-m^3, and lead, cadmium, and zinc were also detected at a minimal level (Mokhtar et al. 2014).

2.2.2 Water Pollution and Heavy Metals: Anthropogenic Source

According to the annual monitoring of 473 rivers in Malaysia (Department of Environment 2015), 244 (52%) rivers were clean, 186 (39%) rivers were slightly polluted, and 43 (9%) rivers were polluted. In case of the Klang Valley, 37 rivers in the Selangor, Klang, and Langat River basins were categorized as slightly polluted and 3 rivers in Klang River basin were categorized as polluted (Department of Environment 2015). Kondo et al. (2015) surveyed microorganism (*E.coli*) pollution in the Selangor River basin and found that impermissible levels of *E.coli* were detected in tributaries flowing populated areas in Rawang. It is suggested that the coverage of sewer pipes is inadequate or poorly maintained, and untreated wastewater could be directly discharged into the streams.

In the Klang Valley, arsenic (8.54 μg/L), cadmium (0.11 μg/L), cobalt (0.64 μg/L), chromium (1.13 μg/L), nickel (7.29 μg/L), and lead (1.07 μg/L) were detected in surface water near the estuary of the Langat River basin (Lim et al. 2012), and cadmium (0.48 μg/L), arsenic (24.7 μg/L), lead (8.0 μg/L), chromium (8.77 μg/L), and zinc (52.9 μg/L) were detected near the estuary of Klang River basin (Sany et al. 2013). Our surface water analysis in the entire Selangor River basin also detected several heavy metals such as cobalt (1.10 μg/L), chromium (2.49 μg/L), cadmium (0.23 μg/L), nickel (0.67 μg/L), lead (12.0 μg/L), and zinc (32.9 μg/L), and populated areas in Rawang and Kundang were more polluted by these heavy metals compared to rural areas. The arsenic concentration in the Klang River basin exceeded a recommended raw water quality standard set by the Ministry of Health Malaysia (10 μg/L). Similarly, sediments were contaminated by arsenic (16.2 mg/kg), cadmium (0.06 mg/kg), cobalt (2.10 mg/kg), chromium (15.9 mg/kg), nickel (4.47 mg/kg), and lead (30.4 mg/kg) near the estuary of the Langat River basin (Lim et al. 2012) and arsenic (60.4 mg/kg), cadmium (52.9 mg/kg), mercury (52.9 mg/kg), and lead (52.9 mg/kg) near the estuary of the Klang River basin (Sany et al. 2013). These values especially in the Klang River basin were far higher than the background concentrations in the west coast of Peninsular Malaysia (Sany et al. 2013). It is obvious that the heavy metals were mainly discharged from anthropogenic sources and distributed toward estuary. They could be accumulated in marine species which local people consume as seafood.

Landfill is a predominant way of waste disposals in Malaysia, and leachate from unsanitary landfills is concerned about the heavy metal pollution. Most of waste disposal sites are poorly maintained without any leachate treatment. In 2011, 111 were closed and 150 are active landfills, and only 16 landfills out of the active landfills had leachate treatment (Yusoff et al. 2013). Most landfills were open dumping or open-tipping sites and leachate could spread and contaminate groundwater. For instance, groundwater quality in the vicinity of Ampar Tenang open-tipping site near the Labu River was affected by leachate migration from the overlaying garbage. Some heavy metals such as iron (0.97–2.82 mg/L), copper (0.212–0.993 mg/L), lead (0.075–1.057 mg/L), and cadmium (0.002–0.067 mg/L) were detected in the groundwater (Rahim et al. 2010). Groundwater in Taman Beringin ex-landfill site was contaminated by lead (ND-0.094 mg/L), nickel (0.010–0.024 mg/L), and iron (0.028–1.44 mg/L) which exceeded the drinking water quality standards set by the Ministry of Health Malaysia (Atta et al. 2015). Leachate from active uncontrolled and controlled landfills as well as a closed controlled landfill was released into rivers, and the heavy metal load was estimated at manganese (0.09–5.78 kg/day), chromium (0.06–0.21 kg/day), lead (0.01–0.06 kg/day), and cadmium (0.003–0.04 kg/day) (Yusof et al. 2009). Furthermore, many illegal dumpling sites piled up with domestic and industrial wastes could also contribute to the heavy metals contamination.

2.2.3 Water Pollution and Heavy Metals: Natural Source

Malaysia was the largest tin production country since richest tin deposits had been discovered in Kinta Valley in the nineteenth century. Many former tin mining ponds are still found in the Selangor and Perak States. The abandoned tin mining fields have been gradually rehabilitated to use for oil palm plantation, housing estates, flood control (e.g., the SMART tunnel), or recreational purposes as the economic transition progressed. The tin mining areas are usually enriched by other heavy metals. Soils near former tin mining ponds in Bestari Jaya contained tin (404 mg/kg), copper (125 mg/kg), zinc (115 mg/kg), lead (105 mg/kg), manganese (85 mg/kg), and arsenic (79 mg/kg) (Ashraf et al. 2011a). Sediments at former tin mining ponds in Bestari Jaya contained tin (100–112 mg/kg), zinc (62.4–72.0 mg/kg), chromium (40.2–49.2 mg/kg), lead (26.1–32.4 mg/kg), copper (7.7–22 mg/kg), and arsenic (0.11–0.23 mg/kg) (Ashraf et al. 2012). Furthermore, fish samples collected in the same area were contaminated by tin (56.3–153 mg/kg), zinc (16.2–104 mg/kg), copper (<1.51–36.3 mg/kg), lead (0.07–1.78 mg/kg), and arsenic (0.0025–0.83 mg/kg) (Ashraf et al. 2011b). Therefore, there is a high potential for the contamination of heavy metals from the former tin mining ponds. Many former tin mining ponds are used for aquaculture, and the fish could be contaminated by heavy metals.

There are gold mining areas in Kuala Lipis located at the central gold belt of Peninsular Malaysia. A small underground mine was operated from 1892 to 1897 (Henney et al. 1995), and 15–21 small-scale alluvial and lode gold mines were operated in the States of Johor, Kelantan, Pahang, and Terengganu (USGS 1994). Some of the alluvial samples showed a slight enrichment in mercury content and the presence of high mercury values in rims on some of the alluvial grains indicated the influence of the alluvial mining where mercury was used for gold extraction (Henney et al. 1995). The emission of mercury from artisanal small gold mining is significant because the operation needs as high as 20:1 or 50:1 of mercury for the amalgamation of gold (Telmer 2008). Furthermore, a significant enrichment of arsenic (0.07 mg/L) in river water around gold mines in Kuala Lipis was observed (Abu Bakar et al. 2015). The arsenic pollution could be attributed to leaching from sediments and soils containing arsenopyrite. The arsenopyrite exists in gold mining sites, and the arsenic could be released due to its oxidization. According to the Department of Environment (2015), the concentrations of arsenic, iron, and manganese in groundwater collected nationwide exceeded the national drinking water quality standards (arsenic, 0.01 mg/L; iron, 0.3 mg/L; manganese, 0.1 mg/L) in many monitoring wells. In our heavy metals analysis in groundwater collected in the Langat River basin, arsenic was also detected (2.3–48.9 μg/L). Therefore, there is a potential of the heavy metals pollution by natural sources, and it could be worsened by mining activities.

2.3 Heavy Metals Contamination in Freshwater and Marine Species

The concentrations of six heavy metals (cadmium, copper, lead, zinc, arsenic, and mercury) in freshwater and marine species collected in Peninsular Malaysia are summarized in Table 2.1. Compared by Malaysian Food Regulation (1985), some specimens exceeded the permissible levels such as cadmium (0.51–1.22 μg/g dry weight) and lead (2.0–8.76 μg/g dry weight) in green-lipped mussels (Yap et al. 2002), arsenic (0.73–1.88 μg/g wet weight) in mangrove snails (Cheng and Yap 2015), and mercury in squids (0.099–2.72 μg/g dry weight) (Ahmad et al. 2015). Yap et al. (2004) analyzed heavy metals in both sediments and soft tissues of green-lipped mussels (*Perna viridis*) in contaminated and uncontaminated sites in Peninsular Malaysia. The sediment in Kampung Pasir Putih (a contaminated site) has the highest concentrations in cadmium (1.46 μg/g), copper (103.4 μg/g), lead (69.8 μg/g), and zinc (149.3 μg/g), and the soft tissues of the green-lipped mussel also has the highest concentrations in copper (20.1 μg/g), lead (8.76 μg/g), and zinc (128.9 μg/g) compared to uncontaminated sites. The same team also found significant correlations between cadmium, copper, and lead concentrations in soft tissues of the green-lipped mussel and sediments collected at 10 sites in the west coast of Peninsular Malaysia (Yap et al. 2002). Therefore, it is suggested that the heavy metals could be accumulated in coastal sediments particularly around urban areas, and marine species could be contaminated by heavy metals. On the other hand, mercury concentrations in crustacean were significantly higher in the east coast of Peninsular Malaysia (0.364 μg/g dry weight) compared to the west coast (0.245 μg/g dry weight) (Ahmad et al. 2015). Total mercury level in mackerel was 0.778 μg/g wet weight in the east coast, while it was 0.229 μg/g wet weight in the west coast (Hajeb et al. 2010). Agusa et al. (2005) reported that concentrations of mercury, copper, zinc, selenium, silver, cadmium, and cesium in bigeye scads in the east coast were significantly higher than the west coast. These trends indicate a negative correlation with population because the population in the east coast is lower than the west coast. Therefore, the pollution sources could be different between the west and east coast of Peninsular Malaysia, and the mercury contamination in the east coast needs further investigations.

Tilapia samples collected from a former tin mining pond showed the highest concentrations in cadmium (0.05 μg/g wet weight), copper (0.27 μg/g wet weight), zinc (4 μg/g wet weight), arsenic (1.07 μg/g wet weight), and mercury (0.0081 μg/g wet weight) compared to those collected from concrete tanks sand earthen ponds (Low et al. 2015). The aquaculture in the former tin mining ponds is common in Malaysia, and it dominates about 25% of the total aquaculture industry (Department of Fisheries Malaysia 2013). Tilapia is the most popular species cultured in the former tin mining ponds, and catfish and carp are also cultured. Therefore, the heavy metal contamination in the former tin mining ponds is concerned, and further studies are necessary to elucidate the contamination level.

Table 2.1 Concentrations of six heavy metals (cadmium, copper, lead, zinc, arsenic, and mercury, μg/g) in freshwater and marine species collected in Peninsular Malaysia

Species	Specimen	Body weight	Heavy metals concentration (μg/g)						References
			Cadmium	Copper	Lead	Zinc	Arsenic	Mercury	
Green-lipped mussel (*Perna viridis*)	Soft tissue	Dry	0.51–1.22	6.31–20.1	2.0–8.76	69.4–129	–	–	Yap et al. (2002)
Marine fish (12 species)	Muscle	Dry	0.001–0.203	0.862–3.48	0.025–0.072	15.4–60.1	–	<0.05–0.67	Agusa et al. (2005)
Marine fish (12 species)	Muscle	Wet	–	–	–	–	–	0.001–0.149	Hajeb et al. (2009)
Short-bodied mackerel	Muscle	Wet	–	–	–	–	–	0.229–0.778	Hajeb et al. (2010)
Longtail tuna	Muscle	Wet	–	–	–	–	–	0.225–0.914	Hajeb et al. (2010)
Catfish (*Arius maculatus*)	Muscle	Wet	0.14	1.21	1.5	41.8	–	–	Alam et al. (2012)
Prawn (*Penaeus merguiensis*)	Muscle	Wet	0.1	12.06	1	42.4	–	–	Alam et al. (2012)
Cockle (*Anadara granosa*)	Muscle	Wet	0.82	3.39	0.97	51.6	–	–	Alam et al. (2012)
Tilapia (*Oreochromis niloticus*)	Muscle	Dry	0.04	1.69	0.38	23.36	–	–	Taweel et al. (2013)
Tilapia (*Oreochromis mossambicus*)	Liver and gill	Wet	0.6–2.6	0.5–17	–	16–52	–	0.002–0.067	Naji et al. (2014)
Marine snail (*Thais clavigera*)	Soft tissue	Dry	2.67–5.74	70.9–216	0.21–2.14	50.8–869	–	0.13–0.44	Mohd Miskon et al. (2014)
Mangrove snail (*Nerita lineata*)	Soft tissue	Wet	0.14–1.30	1.32–5.37	0.21–10.5	21.3–27.2	0.73–1.88	0.00083–0.013	Cheng and Yap (2015)
Tilapia (*Oreochromis spp.*)	Muscle	Wet	0.05	0.27	0.011	4	1.07	0.0081	Low et al. (2015)

(continued)

Table 2.1 (continued)

Species	Specimen	Body weight	Heavy metals concentration (μg/g)						References
			Cadmium	Copper	Lead	Zinc	Arsenic	Mercury	
Tilapia (*Oreochromis spp.*)	Muscle	Wet	0.019	0.21	0.01	3.8	0.91	0.0067	Low et al. (2015)
Tilapia (*Oreochromis spp.*)	Muscle	Wet	0.02	0.16	0.02	3.5	0.41	0.0049	Low et al. (2015)
Cuttlefish (2 species)	Muscle	Dry	–	–	–	–	–	0.233–0.486	Ahmad et al. (2015)
Squid (5 species)	Muscle	Dry	–	–	–	–	–	0.099–2.72	Ahmad et al. (2015)
Prawn (6 species)	Muscle	Dry	–	–	–	–	–	0.129–0.465	Ahmad et al. (2015)
Shrimp (6 species)	Muscle	Dry	–	–	–	–	–	0.057–0.817	Ahmad et al. (2015)
			1	30	2	100	1	0.5 (predatory)/ 1 (others)	Malaysian Food Regulation (1985)

2.4 Indication of Heavy Metal Exposure and Potential Health Risk

Mercury was detected in hair samples collected from communities in Kedah (13.69 µg/g dry wet), Terengganu (10.85 µg/g dry wet), Johor (9.94 µg/g dry wet), and Selangor (6.78 µg/g dry wet weight). Furthermore, a significant positive correlation between the hair mercury concentration and their fish consumption was observed in all communities (Hajeb et al. 2008). Sarmani et al. (1994) also reported the same trend that fishermen in Terengganu showed a higher mean value of mercury concentration in hair samples (12.08 µg/g) compared to those in Penang (3.61 µg/g), and the fish consumption in Terengganu was twice. Tengku Hanidza et al. (2008) found that a very high level of mercury was detected in hair samples from two persons living in Alor Setar (224 µg/g dry weight) and Kota Bahru (803 µg/g dry weight) which exceeded no observable adverse effect level (50 µg/g dry wet weight) set by the World Health Organization. These facts could be linked with the mercury contamination in various marine species (Table 2.1), and some population could be exposed by a considerable amount of mercury.

In comparative studies, concentrations of manganese (15 µg/g), iron (58 µg/g), copper (817 µg/g), zinc (751 µg/g), selenium (47 µg/g), and antimony (44 µg/g) in hair samples collected from sanitation workers were higher than a control group, and arsenic (27 µg/g), mercury (35 µg/g), and lead (38 µg/g) were only detected in the sanitation workers (Khudzari et al. 2013). Contamination levels of arsenic in hair samples collected from a selected population in Penang (1.16 µg/g) were relatively higher in the world (Aldroobi et al. 2013). Lead levels in blood samples collected from women living in the Klang Valley had a slight difference among their races and places of work (Hisham et al. 1998). Therefore, it is concerned that some population could be exposed by heavy metals at a hazardous level.

There are epidemiological facts that the air pollution causes respiratory diseases. According to (Emmanuel 2000), there was a 30% increase in outpatient attendance for haze-related conditions, and an increase of PM_{10} levels from 50 to 150 $\mu g/m^3$ was significantly associated with increases of 12% of upper respiratory tract illness, 19% asthma, and 26% rhinitis. This might not be directly attributed to the heavy metals detected in $PM_{2.5}$. The sum of hazard quotients (i.e., non-cancer risks) by a lifetime exposure of heavy metals in $PM_{2.5}$ was 0.357, which indicates that the contamination level was negligible (Khan et al. 2015a). Nevertheless, there could be synergistic effects due to the specific fate and transport of $PM_{2.5}$ in biological systems. $PM_{2.5}$ is efficiently deposited in all regions of the respiratory tract and even moved into the blood and lymph circulations (Oberdörster et al. 2005). The heavy metals associated with $PM_{2.5}$ could be transported along the specific exposure pathway and trigger some adverse effects.

The potential non-cancer risks by a chronic exposure of heavy metals through the local fish consumption were assessed by target hazard quotient (THQ) and hazard index (HI). The THQ provides an indication of the non-cancer risk level calculated by the following equation (Cheng and Yap 2015; Taweel et al. 2013):

$$\mathrm{THQ} = (\mathrm{EF} \times \mathrm{ED} \times \mathrm{CR} \times \mathrm{Mc}) \div (\mathrm{RfD} \times \mathrm{BW} \times \mathrm{AT}) \times 10^{-3}$$

where EF is the exposure frequency (day/year); ED is the exposure duration (year); CR is the consumption rate; Mc is the metal concentration (μg/g); RfD is the oral reference dose (mg/kg/day); BW is the average body weight (kg); AT is the averaging time (day); and 10^{-3} is the unit conversion factor. The HI is the sum of the THQ in the target pollutant. In this simulation, the annual fish consumption (i.e., EF × CR) referred to the food supply quantity (kg/capita/year) in 2011 recorded in FAOSTAT which shows the amount of six categories (i.e., marine fish, pelagic fish, demersal fish, freshwater fish, cephalopods and crustaceans, and mollusks) (Food and Agriculture Organization 2011). The ED was set at 60 years as a lifetime exposure. The Mc referred to the maximum contamination values of each heavy metal shown in Table 2.1 for simulating a worst level of the heavy metals exposure. The RfD referred to the World Health Organization (1993) for lead and Integrated Risk Information System (USEPA 2015) for others. The BW referred to 64 kg for adults in Malaysia (Taweel et al. 2013). The AT stands for a total duration time (i.e., 365 (days/year) × ED). Table 2.2 shows the THQs of each fish category and the HIs of the six heavy metals. The HIs in cadmium, copper, lead, and zinc did not exceed one, which indicates that there would be negligible non-cancer risks even in the worst scenario. However, the HIs in arsenic and mercury exceeded one. It is attributed to the high contamination levels in mangrove snails, tilapia, longtail tuna, squid, etc. This result is supportive to the high contamination levels of arsenic and mercury in the hair samples of local population (Aldroobi et al. 2013; Hajeb et al. 2008). Therefore, the potential health risks by arsenic and mercury associated with the local fish consumption are concerned, but further studies are necessary to elucidate the linkage.

2.5 Conclusions

The heavy metal pollutions in Malaysia are caused by various anthropogenic and natural sources. The high concentrations of $\mathrm{PM}_{2.5}$ are observed in urban areas because of motor vehicles and haze occurred by biomass burning. Heavy metals exist in $\mathrm{PM}_{2.5}$ at negligible levels, but they could trigger or enhance the toxicity because $\mathrm{PM}_{2.5}$ can pass our biological defense and reach alveoli and other sensitive organs. Heavy metals are accumulated in coastal sediments especially around urban regions probably because of anthropogenic inputs such as untreated wastewater and leachate from unsanitary landfills. Also, naturally deposited heavy metals could worsen the pollution as observed in former tin mining ponds and gold mining areas. Nevertheless, the contributions from these pollution sources have not been clearly shown, and they could be different between the west and east coast. Some

Table 2.2 Target hazard quotient (THQ) and hazard index (HI) for the assessment of non-cancer risks by the chronic exposure (60 years) of heavy metals through the local fish consumption at the highest contamination levels (Cmax, μg/g) (average body weight in Malaysia, 64 kg)

	Consumption rate[a]	Cadmium		Copper		Lead		Zinc		Arsenic		Mercury	
Species	(kg/capita/year)	Cmax[b]	THQ	Cmax	THQ	Cmax	THQ	Cmax	THQ	Cmax	THQ	Cmax	THQ
Molluscs	3.2	5.74	0.79	216	0.74	10.5	0.41	869	0.40	1.88	0.86	0.44	0.20
Marine fish	12.2	0.203	0.11	3.48	0.05	0.072	0.01	60.1	0.10	–	0.00	0.67	1.17
Palagic fish	19.4	–	0.00	–	0.00	–	0.00	–	0.00	–	0.00	0.914	2.53
Dersamal fish	9.4	0.14	0.06	1.21	0.01	1.5	0.17	41.8	0.06	–	0.00	–	0.00
Freshwater fish	6.7	0.05	0.01	1.69	0.01	0.38	0.03	23.36	0.02	1.07	1.02	0.0081	0.01
Cephalopods	4.7	–	0.00	–	0.00	–	0.00	–	0.00	–	0.00	2.72	1.82
Crustaceans	2.5	0.1	0.01	12.06	0.03	1	0.03	42.4	0.02	–	0.00	0.817	0.29
RfD (mg/kg/day)			0.001[c]		0.04[c]		0.0035[d]		0.3[c]		0.0003[c]		0.0003[c]
HI			0.97		0.84		0.66		0.59		1.88		6.02

[a] Consumption rates of each fish category referred to FAOSTAT (FAO 2011)

[b] Cmax of each heavy metal referred to the highest values shown in Table 2.1

[c] Reference dose (RfD) referred to USEPA (2015)

[d] Reference dose (RfD) referred to WHO (1993)

local fish are moderately contaminated by heavy metals, and they could be a main source of the heavy metals exposure in local population. The assessment of potential health risks suggests that there could be non-cancer risks caused by the chronic oral exposure of arsenic and mercury through the local fish consumption. Furthermore, high contamination levels of arsenic and mercury have been found in local population. There are few studies which analyzed the heavy metals in other food, and it would be more advanced if further quantitative analyses in local food have been conducted. In addition, Malaysian government plans to expand the groundwater usage for covering the frequent water shortage during dry seasons, while arsenic pollution in groundwater has been observed nationwide. Therefore, future changes of the food and water consumption patterns also need to be considered to predict the potential health risks.

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Chapter 3
Atmospheric Emission of Mercury in Malaysia

Masaki Takaoka, Habuer, Naoko Yoshimoto, Takashi Fujimori, Kazuyuki Oshita, Nobumitsu Sakai, and Sharifah Aishah Syed Abd Kdir

Abstract Mercury is emitted to the atmosphere from both anthropogenic and natural sources. Mercury subsequently enters the oceans, lakes, and rivers, directly as atmospheric deposition or from diffuse or concentrated sources in surrounding watersheds. Some inorganic mercury in water is converted into organic mercury, which is very toxic and subject to biological accumulation. To prevent mercury contamination, we have to control atmospheric emissions of mercury internationally. First, for the appropriate management of mercury, it is necessary to clarify the emission sources and amounts. In this study, we developed a mercury emission inventory for Malaysia by conducting a literature review, consulting with the Malaysian Ministry of the Environment, and measuring actual mercury levels in emissions from various sources. The inventory was compared to the United Nations Environment Programme (UNEP) global mercury emission inventory and the atmospheric emissions of mercury in Japan.

Keywords Mercury · Emission · Inventory · Source · Reduction

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3.1 Introduction

Because of its high volatility, mercury is emitted into the atmosphere from both anthropogenic and geogenic sources. Recently, the United Nations Environment Programme (UNEP) summarized the global mercury cycle in its global mercury assessment 2013, as shown in Fig. 3.1 (UNEP 2013). Mercury can remain in the atmosphere for up to a year, where it can be transported globally. The residence time of mercury in the atmosphere depends on the species. Subsequently, it enters the oceans, lakes, and rivers directly from the atmosphere or from deposition in surrounding watersheds, even when there is no local source of mercury. A significant amount of mercury in the environment is reemitted due to its volatility, forming a global mercury cycle. Some of the inorganic mercury in water is converted into organic mercury, which is very toxic and can undergo biological accumulation. Long-term exposure to either organic or inorganic mercury can permanently damage the brain and kidneys, and exposure during embryonic development can damage the fetus. Therefore, the emission of mercury is of great concern.

Heavy mercury pollution can lead to conditions such as Minamata disease, a neurological syndrome caused by severe organic mercury poisoning that occurs in the vicinity of easily identified emission sources. Low levels of mercury pollution occur in locations around the world, even in areas where obvious emission sources are not present. The consumption of contaminated fish and shellfish is currently the main source of methylmercury exposure, especially in populations that rely heavily on the consumption of predatory fish. In 2004, the Joint FAO/WHO Expert

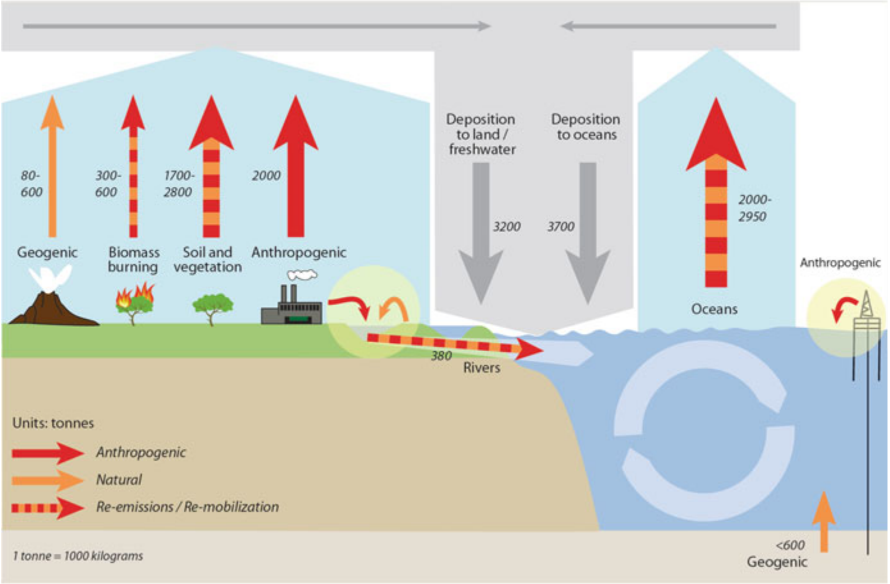

Fig. 3.1 Global mercury cycle (UNEP 2013)

Committee on Food Additives (JECFA) established a tolerable weekly intake of 1.6 μg/kg bodyweight for methylmercury to protect the developing fetus from neurotoxic effects; the previous standard for tolerable weekly intake, 3.3 μg/kg of body weight, was set for the general population (WHO 2004).

In Malaysia, high concentrations of mercury have been reported in several areas.

Agusa et al. (2005) measured mercury concentrations in the muscles and liver of 12 species of marine fish in Malaysia. The concentrations recorded depended on the species and location. The average concentration in the muscles and liver ranged from <0.05 to 0.67 mg/kg-dry and <0.05 to 2.4 mg/kg-dry, respectively. Some specimens of marine fish had mercury levels higher than the guideline set by the US Environmental Protection Agency (EPA), indicating that consumption of these fish species at the present rate may be hazardous to the Malaysian people.

Praveena et al. (2013) reported mercury concentrations due to industrial activities in West Port, Malacca Straits, Perai, and Johor. The total mercury concentration in sediments from West Port and Sungai Pulai, Johor, ranged from 0.11 to 0.41 mg/kg, and high mercury concentrations (0.03–0.08 mg/L) were detected in the rivers of Sungai Pok Kechil, Sungai Pok Besar, and Teluk Buih in Johor, as well as in seawater around Merambong Island (Praveena et al. 2013). High concentrations of mercury in the diet have been found on the west coast of the peninsula and have been associated with seafood intake from specific geographical locations; for example, mercury levels in food samples from the Straits of Malacca were 1.1–3.2 mg/kg (the permitted level in Malaysia is 0.5 mg/kg) (Praveena et al. 2013). Mercury is also present in tropical fruits due to agrochemical and fertilizer use in Malaysia (Praveena et al. 2013; Hajeb et al. 2012). Recently, a more comprehensive study of mercury levels in fish was conducted by Ahmad et al. (2015). The mercury concentrations in the edible portion of 46 species of marine fish ($n = 297$) collected from the selected ports and markets throughout peninsular Malaysia were measured. Although it was rare for the Malaysian permitted level and JECFA guideline value of 0.5 mg/kg methylmercury in fish to be exceeded, mercury concentrations were found to be significantly higher in demersal fish compared to pelagic fish and were also higher in carnivorous fish. Fish collected from Port Klang, Kuala Besar, and Pandan had significantly higher mercury concentrations compared to fish from other sampling locations. The mercury levels were positively related to fish size in all samples. Because of its impacts on human health, the identification and reduction of mercury in the environment and its bioaccumulation have become urgent issues.

To protect human health and the environment from the adverse effects of mercury, the Minamata Convention on Mercury (MCM) was established in January 2013 and was adopted by the Conference of Plenipotentiaries on October 10, 2013, in Minamata, Japan. The main outcomes of the MCM included a ban on opening new mercury mines (mining is allowed for 15 more years in currently active mines), a phase-in of mercury control measures to tackle atmospheric emissions, and international regulation of the informal sector of artisanal and small-scale gold mining (ASGM) (WMCM 2015). Malaysia signed the MCM agreement on September 24, 2014, and Japan ratified the MCM agreement on February 2, 2016.

Malaysia has a certain level of mining and industrial activity that emits and releases mercury to the environment. For the reduction and appropriate management of mercury, it is necessary to clarify the emissions and release sources as well as the amounts released. Although the Malaysia government produced a rough inventory in 2006 (MNRE and DOE 2006), the published results contain many uncertainties due to inaccurate mercury emission inventory data. It is therefore important to clarify the actual mercury emissions to support policy decisions. We attempted to update the mercury emission inventory based on statistics, actual measurements, and reliable quantitative information obtained during interviews with the Department of Environment (DOE), Malaysia. We then estimated the emissions and release of mercury into various media at the substance level in Malaysia.

3.2 Methodology of the Mercury Emission Inventory

3.2.1 Identification of the Uses and Sources of Mercury in Malaysia

By considering studies conducted for UNEP and in Malaysia (UNEP Chemicals 2011; Hajeb et al. 2012; MNRE and DOE 2006; Habuer et al. 2016), mercury uses and source categories were identified. For the purposes of this study, these were divided into four categories: combustion, manufacturing, intentional uses, and others. Combustion emissions are mainly derived from six sources: coal, oil (petroleum), natural gas, oil refineries, solid waste, and medical waste. Manufacturing emissions are mainly derived from eight sources: nonferrous metals, cement, gold mining (no amalgamation), artisanal small-scale gold mining (ASGM), ferrous metals, pulp and paper, limestone, and biomass power stations. Emissions from intentional uses of mercury are mainly derived from eight sources: thermometers, dental fillings, batteries, electric switches and relays, light sources, manometers, gauges, and miscellaneous uses. Other emissions include the landfilling of municipal solid waste (MSW) and crematoria.

3.2.2 Emissions to the Atmosphere in Malaysia

The amount of potential emissions and release can be calculated as follows:

$$\text{Amount of potential emissions and release} = \text{Activity rate} \times \text{Input factor} \tag{3.1}$$

The activity rate refers to the amount of a product containing mercury that is consumed or a mercury-containing material that is fed into a process (Civancik and Yetis 2015). The input factor is the mercury concentration in the material or in a unit weight of the product. Activity rate data were obtained from various published reports, statistical yearbooks, statistical databases, and field surveys in Malaysia. At the time of the study, activity data for nonferrous metals (lead) and for secondary and ferrous metals were available for 2010 and 2011, respectively. It was assumed that there were no significant changes in the data between 2012 and the previous 2 years. The input factors for coal combustion, solid waste incineration, and the landfilling of solid waste were based on actual measurements. The input factor for an oil refinery in Malaysia was based on a personal communication. The input factor for the manufacturing of nonferrous metal (lead) was based on a Japanese emissions inventory (Kida et al. 2008), and for ferrous metal, the input factor was based on a report by the Malaysian DOE (MNRE and DOE 2006). All other input factors were based on the UNEP Toolkit (UNEP Chemicals 2011).

The amount of mercury emitted to the atmosphere can be calculated as follows:

$$\begin{aligned}&\text{Amount of emissions to the atmosphere}\\&\quad = \text{Potential emissions and release} \times \text{Distribution factor}\end{aligned} \tag{3.2}$$

Distribution factors identify the ways in which the estimated mercury input from a particular activity/source is distributed to different environmental media (Civancik and Yetis 2015). The distribution factors in the UNEP Toolkit (UNEP Chemicals 2011) are widely used for this estimation. However, in that toolkit, the amount of emissions to air from sources such as coal combustion, incineration of solid waste, and oil refining was calculated by multiplying the activity rate by the overall emissions factor of each sector. Here, the overall emission factors for coal combustion and the incineration of solid waste were obtained by actual measurements, and the overall emission factor for oil refining was obtained from a personal communication with an expert in Malaysia.

3.3 Mercury Emission Inventory in Malaysia

Table 3.1 provides the potential emissions and emissions to air of mercury in Malaysia in 2012, broken down by category. The total potential emissions were estimated to be 7.60–59.09 tons (Habuer et al. 2016).

3.3.1 Potential Emissions and Release

The largest potential source of mercury was found to be ASGM. In ASGM, elemental mercury is mixed with gold-containing materials, forming a mercury-gold amalgam that is then heated, vaporizing the mercury to obtain the gold. This process emits and releases mercury and lead, leading to significant mercury exposure, health risks, and environmental pollution. Zainal Abidin MD Nor, deputy director of the Minerals and Geosciences Department, Malaysia, gave an overview

Table 3.1 Potential emissions and releases and emissions to air of mercury in Malaysia in 2012 (Habuer et al. 2016)

Category	Source		Activity rate	Potential emission and release		Emission to air		
			$(10^3$ ton/year)	IF[a] (g-Hg/ton)	Amount (ton/year)	DF[b] (%)	OEF[e] (g-Hg/ton)	Amount (ton/year)
Combustion	Coal		24,633	0.06–0.65	1.43–16.01	–	0.04–0.11	0.99–2.71
	Oil	Light distillates	9287	0.001–0.01	0.06–0.56	100	–	0.06–0.56
		Middle distillates	10,494	0.001–0.01				
		Fuel oil	3635	0.01–0.1				
		Others	6383	0.001–0.01				
	Natural gas		$31567^* \ 10^6$ Nm^3/year	0.00003–0.0004 mg/Nm^3	0.00–0.01	100	–	0.00–0.01
	Oil refinery		26,181	0.094–0.104	2.46–2.72	–	0.0047–0.0052	0.12–0.14
	Incineration of solid waste		48	0.032–0.204	0.002–0.01	–	0.007–0.18	0.00–0.009
	Incineration of medical waste		47.41	8–40	0.379–1.90	50	–	0.190–0.948
Manufacture	Nonferrous metal (lead), secondary		71	0.716	0.051	10	–	0.005
	Gold mining (no amalgamation)		0.00463	2×10^3–50×10^3	0.009–0.231	4	–	0.000–0.009
	Artisanal small-scale gold mining (ASGM)		0.00005–0.007	1×10^3–3×10^6	0.00–21	60	–	0.00–12.6
	Cement		21,726	0.02–0.2	0.435–4.345	60–80	–	0.261–3.476
	Ferrous metal		5612	0.02–0.1	0.112–0.561	95	–	0.107–0.533
	Pulp and paper		1943	0.007–0.07	0.014–0.136	90–100	–	0.012–0.136
	Lime		1000	0.02–0.2	0.02–0.2	60–80	–	0.012–0.16
	Biomass power station		1000	0.01–0.07	0.01–0.07	100	–	0.01–0.07

Intentional use[b]	Thermometers	40,000–120,000 items	1–2.5 g/item	0.04–0.3	10	–	0.004–0.03
	Electrical switches and relays	–		0.48–1.44	10	–	0.048–0.144
	Light sources	–		0.20–0.80	5	–	0.01–0.04
	Dental fillings[c]	–		1.20–4.90	2	–	0.02–0.10
	Batteries with mercury	–		0.10–0.30	–	–	–
	Manometers and gauges	–		0.02–0.15	10	–	0.002–0.015
	Miscellaneous uses	–		0.20–1.00	10	–	0.02–0.1
Others	Landfilling of solid waste	10,583	0.032–0.204	0.339–2.159	1	–	0.003–0.022
	Crematoria	34,481-body	1.0–4.0 g/body	0.034–0.138	100	–	0.034–0.138
Total				**7.60–59.09**			**1.91–21.97**

[a] Input factor; [b] Distribution factor

[c] No or very limited separate intentional collection of used products. All or most general waste is collected and handled in a publicly controlled manner during the use and disposal phases

[d] In countries where most dental clinics are equipped with high-efficiency amalgam filters (95% retention rate)

[e] Overall emission factor

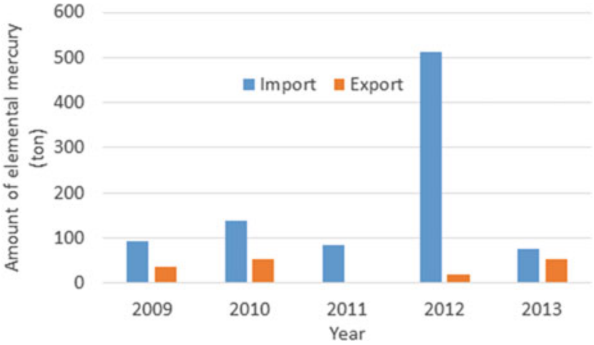

Fig. 3.2 Imported and exported elemental mercury in Malaysia (UN Comtrade 2014)

of the ASGM situation in Malaysia in the UNEP Conclusion Workshop, Artisanal Small-Scale Gold Mining Strategic Planning Project held in Cambodia in 2011 (UNEP 2011). He reported that in Malaysia, ASGM does not produce much gold (approximately 7 tons per year), and it operates mostly in the central parts of Malaysia. In 2010, about 250,000 small-scale miners were estimated to work at these sites. Because the range of input factors was so wide, the emissions were estimated to range from 0.007 to 21 tons. The amount of imported and exported elemental mercury from 2009 to 2013 in Malaysia is shown in Fig. 3.2 (United Nations 2014). Every year, the amount of imported elemental mercury exceeded the amount exported. This elemental mercury is either consumed or stored inside Malaysia. However, according to a report from the Ministry of Natural Resources and Environment (MNRE) and DOE in 2006, the total amount of intentional use was less than 9 tons (Table 3.1), which suggests that a certain amount of metal mercury may still be used for ASGM.

The second largest potential source is coal combustion. Because the range of input factors based on actual measurements is relatively great, the emission was estimated to be from 1.43 to 16.0 tons. Compared to the emissions from an oil refinery, incineration of solid waste, incineration of medical waste, and nonferrous industry, the combustion of coal does not release high concentrations of mercury, but large volumes of coal are burned. Some other sources, e.g., oil refineries, medical waste, the cement industry, electrical switches and relays, dental fillings, and the landfilling of solid waste, also had high potential for mercury emission (maximum value, >1.0 ton).

3.3.2 *Emissions to the Air*

Atmospheric emissions of mercury were estimated to be 1.91–21.97 tons in 2012. The geometric mean was 11.9 tons. The largest emission source was ASGM (0.004–12.6 tons). The second and third largest emission sources were the cement

Table 3.2 The global mercury emission inventory (UNEP 2013)

Sector	Emission (range), tons	%
Coal burning (all uses)	474 (304–678)	24
Oil and natural gas burning	9.9 (4.5–16.3)	1
Primary production of ferrous metals	45.5 (20.5–241)	2
Primary production of nonferrous metals (Al, Cu, Pb, Zn)	193 (82–660)	10
Large-scale gold production	97.3 (0.7–247)	5
Mine production of mercury	11.7 (6.9–17.8)	<1
Cement production	173 (65.5–646)	9
Oil refining	16 (7.3–26.4)	1
Contaminated sites	82.5 (70–95)	4
Artisanal and small-scale gold mining (ASGM)	727 (410–1040)	37
Chlor-alkali industry	28.4 (10.2–54.7)	1
Consumer product waste	95.6 (23.7–330)	5
Cremation (dental amalgam)	3.6 (0.9–11.9)	<1
Grand total	1960 (1010–4070)	100

industry (0.26–3.48 tons) and coal combustion (0.22–2.71 tons), respectively. These three sources accounted for 84% of the total in emissions on average.

The total volume of atmospheric emissions in Malaysia in 2012 was greater than that in 2005 and was estimated to be 0.9–6.4 tons by the Malaysian DOE (MNRE and DOE 2006). The difference was caused by the small estimate for ASGM emissions in 2005. The emissions from coal combustion and the cement industry in 2012 increased relative to values for 2005.

ASGM, coal combustion, and the cement industry are major sources of mercury around the world. Table 3.2 shows global mercury emissions from various sectors (UNEP 2013). In the table, emissions are expressed in a range using tons per year and as a percentage of total anthropogenic sources. The global emission inventory for 2010 estimated that 1960 tons of mercury were emitted to the atmosphere as a direct result of human activity. However, the following emission sectors are not included: biofuel production and combustion, vinyl chloride monomer production, production of secondary metals and ferroalloys, oil and gas extraction, transport and processing (other than refinery emissions), industrial/some hazardous waste incineration and disposal, sewage sludge incineration, and preparation of dental amalgam fillings and disposal of removed fillings containing mercury. In the global emission inventory, ASGM, coal combustion, and the cement industry account for 37, 24, and 9% of the total, respectively. The Malaysian inventory is similar to the global inventory.

Table 3.3 shows an atmospheric mercury emission inventory for Japan (MOE 2016). The inventory was recently updated using actual measurement data and activity rates for 2014. The total emissions in 2014 were estimated to be 17 tons, which was the same level as in 2010. The total emissions were not very different from the Malaysian level (12 tons). Cement production was a major source of mercury in both countries; however, other sources were different. First, ASGM

Table 3.3 Atmospheric emissions of mercury from anthropogenic sources in Japan (MOE 2016)

Sectors		Emissions in 2010 (ton/year)	Emissions in 2014 (ton/year)
Coal-fired power plants		0.83–1.0	1.3
Coal-fired industrial boilers		0.21	0.24
Nonferrous metal production		0.94	1.4
Waste incineration	Municipal solid waste	1.3–1.9	1.5
	Industrial waste	0.73–4.1	2.5
	Sewage sludge	0.17–0.85	1.4
Cement production		5.3	5.5
Iron and steel production	Primary steel production	4.1	2.0
	Secondary steel production	0.62	0.54
Oil refining		0.1	0.1
Oil and natural gas production		<0.001	0.00005
Combustion of oil and gas		0.031	0.015
Manufacturing processes using mercury or mercury compounds		Not observed	Not observed
Manufacturing mercury add products		0.0104	0.005
Others		1.5	0.48
Grand total		16–21	17

does not occur in Japan. Second, the emissions from waste incineration in Japan were relatively large (5.4 tons) because the incineration of solid waste is common in Japan, accounting for almost 80% of municipal solid waste disposal (Takaoka et al. 2011). The incineration of solid waste is currently limited in Malaysia (Abd Kadir et al. 2013), although incineration has become a waste management option in urbanized areas. In the future, emissions from waste incinerators will be measured and evaluated. The third largest source in Japan was iron and steel production. In 2010, the emissions from this sector were almost equal to those from waste incineration and cement production. However, emissions decreased by 2.54 tons in 2014. The MCM requires that a party with relevant sources take measures to control releases, and a national plan may be produced, setting out the measures to be taken to control releases and establishing targets, goals, and outcomes. A relevant source means a source falling within one of the source categories listed in Annex D (WMCM 2015). In Japan, new regulations for the source categories listed in Annex D will be established in the near future. Although iron and steel production is not listed in Annex D, the industry will voluntarily reduce its emissions of mercury.

Because mercury is an element, we cannot decompose it. Even if the mercury in flue gas is removed, it will remain in the solid phase. Therefore, mercury waste management is important (Takaoka 2015). In particular, the long-term storage or disposal of mercury and mercury-containing waste is an issue that must be addressed in the future.

3.4 Conclusion

We developed a mercury emission inventory for Malaysia. The total potential emissions and release for 2012 were estimated to be 7.60–59.09 tons. The main overall contributors were ASGM and coal combustion. Atmospheric emissions of mercury were estimated to be 1.91–21.97 tons in 2012. The geometric mean was 11.9 tons. The main overall contributors were ASGM, cement production, and coal combustion. The inventory indicated that Malaysian and global emission sources were similar, but there were differences between the Malaysian and Japanese inventories. Because the Malaysian inventory was not established using sufficient measurement data, it contains much uncertainty.

In the future, it is necessary to create reliable inventories, not only for the atmosphere but also for other media in Malaysia, by collecting more measurement data. In particular, it is important to measure the concentration of mercury released from cement factories and coal combustion, which is anticipated to be high, and to gather more information on ASGM.

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Chapter 4
Indoor Environmental Pollution Associated with Floods and Dampness

Kenichi Azuma and Ikuko Bamba

Abstract In the areas close to watersheds, ambient humidity is likely to be high. Elevated humidity and increased indoor mold growth may occur in homes in such areas. Because of climate change, more frequent and extreme precipitation events may be expected in future, along with increased flooding. Localized torrential downpours can cause serious flooding along rivers and other waterways. This chapter describes the health effects of flooding and the impacts of dampness and mold on residents' health.

Keywords Dampness · Flooding · Health effect · Humidity · Mold

In the areas close to watersheds, ambient humidity is likely to be high. Elevated humidity and increased indoor mold growth may occur in homes in such areas. Because of climate change, more frequent and extreme precipitation events may be expected in the future, along with increased flooding. Localized torrential downpours can cause serious flooding along rivers and other waterways. This chapter describes the health effects of flooding and the impacts of dampness and mold on residents' health.

4.1 Health Effects of Flooding: Public Health Perspective

Flooding in the aftermath of torrential downpours or typhoons endangers residents' health and compromises the quality of housing. This section provides a comprehensive review of the effects of water-damaged homes after flooding. In particular, we review the health status of residents and the environmental risk factors to housing

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after floods. We also propose recommendations for risk management to mitigate the health effects associated with flooding.

4.1.1 Flood Risk

Approximately 800 million people live in flood-prone areas, and approximately 70 million people live in areas that are typically exposed to floods each year (UNISDR 2011). Flooding is expected to occur more frequently and with greater intensity in the future owing to rising sea levels. In addition, more frequent and extreme precipitation events may be expected in the future because of climate change (WHO 2003, 2009), which may cause increased flooding. Population growth and urban expansion may also increase exposure to floods (Muis et al. 2015; UNISDR 2011).

Given the lack of complete datasets on past flood events and the uncertainty of projected future flood frequencies and magnitudes, future flood hazards cannot be easily estimated. Climate change has the potential to substantially change human exposure to flood hazards, but different projections of regional change in climate, particularly by precipitation, have led to considerable uncertainty about the magnitude of this impact. Arnel and Gosling (2016) reported that approximately 31–449 million flood-prone people would be exposed to a doubled flood frequency by 2050 across 21 climate models. The total global flood risk was also projected to increase by −9% to 376%, compared to the situation in the absence of climate change. Peduzzi et al. projected that the average number of people exposed to floods per year globally would increase by 256% from 1970 to 2030 from population growth alone (IPCC 2012). In relative terms, Africa has the largest rate of increase in physical exposure to floods. In absolute terms, Asia has more than 90% of the world's flood-exposed population (IPCC 2012). During the last 30 years, approximately 40% of all flood events in the world occurred in Asia, as compared with 25% in the Americas, 17% in Africa, 14% in Europe, and 4% in Oceania (Jha et al. 2011). Muis et al. 2015 projected that the urban extent would increase by 215%–357% (5th and 95th percentiles) from 2000 to 2030. Such increases in human exposure would elevate flood risk by 76% and 120% on an average for river and coastal floods. While sea-level rise would further increase the exposure-induced trend by 19%–37%, the response of river floods to climate change is highly uncertain. Thus, urban expansion may be the main driver of future risk.

Although a number of factors underlie increased impacts from floods, flood risk has increased so far, and the risk will certainly increase in the future. Thus, flooding is among the most serious public health threats in many countries.

4.1.2 Effects of Flooding on Human Health

The health effects of flooding can be divided into those associated with the short-term event and those arising afterward (Alderman et al. 2012; Azuma et al. 2014; Vardoulakis et al. 2015; WHO Europe 2013) (Table 4.1). Immediate effects are

Table 4.1 Potential health effects of flooding

	Health effect
Short-term health outcomes of floods	Mortality due to drowning, acute trauma, and electrocution
	Injuries (injuries from walking or driving through floodwater, contact with debris in floodwater, falling into hidden manholes, injuries from submerged objects, injuries while trying to move possessions during floods)
	Exposure to chemical hazards (carbon monoxide poisoning, chemical pollution of floodwater and soil)
	Infections and risk for epidemics (gastrointestinal diseases; fecal-oral transmission by ingesting contaminated food or water; respiratory, skin, and eye infections; vector-borne disease; rodent-borne disease)
	Stress, short-term mental health issues
Longer-term impacts of floods	Exposure to chemical hazards (carbon monoxide poisoning, chemical pollution of soil)
	Exposure to damp buildings
	Psychological distress (mental health problems due to duration of flood recovery and fear of recurrence, indirect effects of stress in dealing with insurance claims and refurbishing properties, post-traumatic stress disorder)
	Noncommunicable diseases (cardiovascular disease, chronic lung diseases, diabetes, and interruption of treatments such as dialysis, domiciliary oxygen therapy, artificial respiration, and tubal feeding)

caused by the floodwater and the debris it carries and include drowning and injuries. However, floods continue to impact public health during the cleanup process; these impacts may persist for months or years. Longer-term health effects include those resulting from damage to buildings, infrastructure, and food and water supplies, along with the mental health impacts of displacement and disruption of people's lives.

Flood-related deaths arise from drowning, physical trauma, heart attacks, electrocution, carbon monoxide (CO) poisoning, or fire (Jonkman and Kelman 2005). Fatalities vary according to environmental, socioeconomic, and cultural factors of each affected area. In low-income countries, those at a higher risk of flood-related death tend to be those from ethnic minorities who are poor, live on floodplains in unstable dwellings, females, and the very young and elderly (Jonkman et al. 2009).

Physical injuries can occur during all phases of flooding. Injuries following flooding can be caused by direct contact with floodwaters during evacuation, the cleanup process, or the collapse of a building (Jakubicka et al. 2010). Injuries incurred before and during a flood are often associated with people attempting to remove themselves, their families, pets, or valued possessions from approaching floodwater. Water can displace vehicles, trees, and materials such as chemical drums; it can also harbor unseen hazards such as debris, which can cause injuries (WHO Europe 2013).

The disruption and damage cause by floods can release hazardous chemicals that can endanger residents. CO poisoning is a serious health risk associated with flooding; it occurs in the aftermath of floods when generators or fuel-powered equipment are used indoors for drying or pumping out floodwater (WHO Europe 2013). The indoor use of portable generators and cooking and heating appliances designed for outdoor use during periods of gas and power outages has been a particular problem. In the recovery phase, equipment for pumping, dehumidifying, and drying out property poses additional risks. In the long term, mortality and morbidity associated with the renewed use of boilers during flooding has been recognized (Waite et al. 2014).

Floodwaters can move chemicals from their normal storage locations, releasing toxic chemicals. Thus, health impacts from exposure to toxins are greatest for residents living near flood-impacted industrial or agricultural areas. Significant risk factors for respiratory and nasal symptoms included proximity to industrial and waste incineration plants (Azuma et al. 2014). Floodwaters and soils can become contaminated with pesticides, agricultural chemicals, polycyclic aromatic hydrocarbons, particulate matters, nitrosamines, and heavy metals such as arsenic, cadmium, chromium, iron, lead, manganese, strontium, and zinc (Euripidou and Murray 2004; Hoppe et al. 2012; Presley et al. 2006). Although exposure to these pollutants has been associated with cancer and cardiovascular, gastrointestinal, kidney, liver, and neurological diseases, the causal pathway between floods, pollutants, and related health outcomes in affected residents has not yet been scientifically verified (Alderman et al. 2012).

Floods are associated with an increased risk of waterborne and vector-borne diseases. Although infectious disease transmission often presents a higher risk to human health, outbreaks rarely occur immediately following floods. The risk increases when the infrastructure is heavily impacted, residents are displaced, and water supply systems are damaged, leading to contamination of drinking water. Diseases resulting from water contamination include cholera, diarrheal disease, hepatitis A and E, leptospirosis, parasitic diseases, rotavirus, shigellosis, and typhoid fever. Specific waterborne diseases related to floods include wound infections, dermatitis, conjunctivitis, and ear, nose, and throat infections (Alderman et al. 2012; WHO Europe 2013).

Residents who stay in damp buildings after floods, often for long periods, have been reported to have health problems. Respiratory symptoms have been reported in residents living in water-damaged homes 6 months after hurricanes (Cummings et al. 2008). Moisture damage to buildings is associated with the growth of mold and bacteria and an increased indoor concentration of endotoxins and glucan (Barbeau et al. 2010; Hoppe et al. 2012). Fungal species observed in flooded dwellings include *Cladosporium*, *Aspergillus*, *Penicillium*, *Alternaria*, and *Stachybotrys* (Solomon et al. 2006; Dumon et al. 2009). The adverse health effects most often associated with dampness and mold in buildings are mainly respiratory (cough, wheeze, rhinitis) and irritation of the eyes and skin. Although many studies have reported an association between moisture damage in buildings and health problems such as allergies, asthma, chronic respiratory infections, and skin and respiratory tract irritation, no causal relations have been demonstrated (WHO Europe 2009, 2013).

Noncommunicable diseases, including cardiovascular disease, diabetes, and interruption of treatments such as dialysis, domiciliary oxygen therapy, artificial respiration, and tubal feeding are also potential long-term health impacts (Sakai 2003; Takemura et al. 2007). Individuals aged 75 years or older and who receive such long-term care were more likely to have their treatment interrupted by floods. This interruption causes a fourfold risk of worse health outcomes than those of patients with continued care (Tomio et al. 2010).

Psychological distress is one of the most significant issues following flooding. Mental health disorders most commonly found in people affected by natural disasters including floods are post-traumatic stress disorder (PTSD), followed by depression and anxiety (Chen and Liu 2015; Fernandez et al. 2015). A meta-analysis of 14 studies indicated that the combined incidence of PTSD among flood victims was 15.7%. The incidence of PTSD was lower 6 or more months after a flood (11.5%) than within the first 6 months (16.0%) of a flood (Chen and Liu 2015). The risks of stress symptoms and depression were significant for 6 months after flooding. The risk of anxiety was also significant even long after flooding (Azuma et al. 2014). Significantly high risks were observed for stress symptoms, depression, and anxiety in homes with high flood levels (Azuma et al. 2014). Reacher et al. (2004) also reported a fourfold higher risk of psychological distress in residents living in flooded areas compared with those living in non-flooded areas and a highly significant increase in risk according to flood depth.

4.1.3 Mitigating Health Effects Associated with Flooding

Reports on flood-related impacts on public health and environmental quality of housing vary widely. Floods impact communities unequally and in different ways, with direct and indirect effects in both the short and long term. A week after flooding, respiratory, dermal, ocular, and nasal symptoms increased significantly more in water-damaged homes than in non-damaged homes. The risk of psychological distress remained significant for 6 months after flooding. A higher risk of psychological distress was found to correspond to increased indoor dampness or high flood levels (Azuma et al. 2014). Prompt intervention, including cleanup and rebuilding of water-damaged homes after flooding, should be performed to mitigate health impacts to residents. Long-term psychological support should be provided after flooding. Several other risk factors for the development of psychological disorders following flooding have been identified, such as previous flood experience and disaster preparedness, family structure, socioeconomic status, and social support (Alderman et al. 2012). Thus, these factors also need to be considered when planning support for psychological disorders.

Azuma et al. (2011) conducted a survey of the actions taken in past flood events and the action programs for flooding in 38 Japanese local public health centers that experienced flood events in their jurisdictions. Twenty-eight local public health centers responded. For past actions in flooding, approximately half the public health centers provided medical consultation and psychological support to the residents, healthcare support to vulnerable people, sterilization of flooded areas, and waste disposal support. Providing psychological support to residents, healthcare support to vulnerable people, and monitoring the hygienic status of housing increased with high flood levels. Of the public health centers, 30%–50% had not developed an action program, and 80% of the centers had no mechanisms for monitoring sanitary conditions in housing. Comprehensive action programs for flooding should be developed in all local public health centers in areas that risk flooding in the future because public health centers play an important role in regional health crisis management.

4.2 Influence of Dampness and Mold on Residents' Health and Comfort

This section presents a comprehensive review of the effects of dampness and molds on houses and residents' health. Dampness and molds may cause damage to buildings and decay of wood, paper, and food. Health disorders may occasionally be caused by molds, including infectious diseases such as aspergillosis and mycotoxicosis. A previous report indicated that fungal exposure and dampness contributed to respiratory symptoms such as asthma. In addition, the results of a survey of fungi in houses in Malaysia and Japan is described in this section.

In a room, moisture is generated by various human activities, including cooking, heating, and washing. Relative humidity is the ratio (expressed as a percentage) of moisture in air relative to the amount that would be present if the air was saturated, and this characteristic is affected by temperature. This temperature is called the dew point, and excess steam becomes liquid water at lower temperatures, attaching to wall and glass surfaces during dew condensation. Relative humidity is the ratio of steam in humid air but changes into equal quantity with steam because the quantity of saturated steam is changed by temperature.

Steam is generated during human activities, including cooking, washing, and bathing. If the amount of steam in a room is high, relative humidity increases but is finally determined by moisture absorption through the ventilation and wall surfaces. In addition, when the outside temperature is low and the air is dry, the dry air penetrates the room through the ventilation. In a heated room, the relative humidity decreases and may reduce air moisture.

The relative humidity of a room affects the comfort and health of people using it. Various health factors are associated with humidity. In low humidity environments, the risk of viral infection increases, while under high humidity environments, the risk of fungi and mites increases (Sterling et al. 1985). The most comfortable range of relative humidity is between 40% and 60%.

Outbreaks of molds and dew condensation and water stain and leakage in a building are collectively referred to as dampness. Dampness is defined as "any

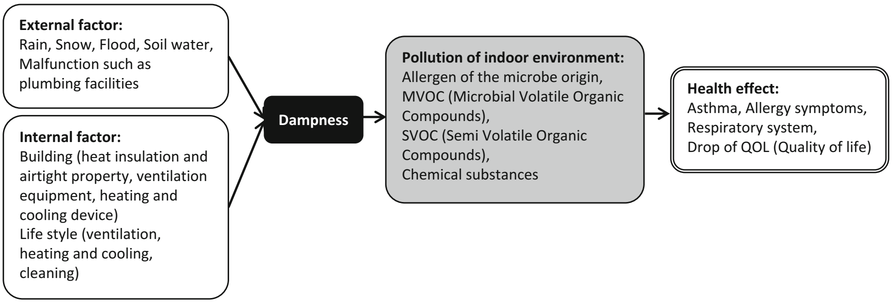


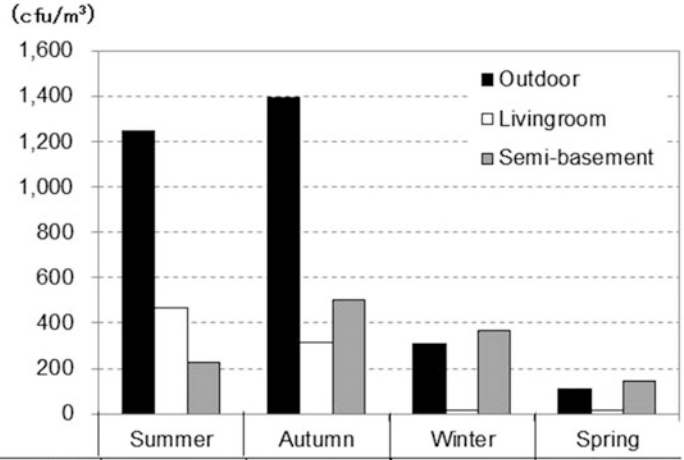
Fig. 4.1 Dampness and its effects on health

visible, measurable or perceived outcome of excess moisture that causes problems in buildings, such as mold, leaks or material degradation, mold odor or directly measured excess moisture (in terms of relative humidity or moisture content) or microbial growth." Humid states (dampness) such as that in living rooms are more likely to cause the onset of allergic symptom and respiratory illness according to World Health Organization (WHO) guidelines (WHO Europe 2009). Although small, as for the direct effect of moisture on health, mold tick reproduction and outbreak of microbial volatile organic compounds are promoted by the moisture in a building. Allergens derived from microbes are thought to have a negative effect on human health (Fig. 4.1).

Here, molds are described in detail. Molds are ubiquitous in their natural environments and are utilized in various beneficial ways. For example, penicillin is used in medicine and *Aspergillus oryzae*, for sake, miso, and soy sauce production. However, molds may cause damage to buildings or decay of wood, paper, and food. Molds are formally called fungi, which are considered microbes. Fungi can be classified into filamentous fungus and yeast.

If a house environment consists of a nourishment source and favorable temperature-humidity condition, fungi multiply. Nourishment sources found in abundance in residence environments include building materials and house dusts. Fungi are divided into psychrophile, low-temperature bacteria, mesophile, and high-temperature bacteria according to the growth temperature range. Mesophilic bacteria assume room temperature (20–25°C) as the most suitable growth temperature. The growth temperature level of these molds ranges from 5°C to 45°C. In addition, the minimum relative humidity for fungal growth is said to be 70%. Our living environment may be considered an ideal condition for fungal growth.

Human illnesses caused by molds can be classified into three groups. The first is a fungal infection penetrating the body through the skin or taken in orally, in which a spore settles and multiplies on the skin or in the lungs (mycosis) (Anderson et al. 1996). Second is the generation of various allergic fungi (Engvall et al. 2001; Platt et al. 1989). Allergic diseases caused by molds include bronchial asthma, hypersensitivity pneumonitis, and nasal allergy. Third is mycotoxicosis, a food



		Summer	Autumn	Winter	Spring
Outdoor	(°C)	27.7 ± 2.9	16.8 ± 3.4	2.5 ± 3.1	5.8 ± 5.1
	(RH%)	80 ± 14	75 ± 16	51 ± 13	74 ± 22

Fig. 4.2 Seasonal changes in outdoor air temperature-humidity and fungal concentration in Japan

poisoning symptom caused by poisonous molds (mycotoxins) (Flannigan et al. 1991).

In this paragraph, fungal densities in Japan and Malaysia are presented. Airborne fungi were measured by using a rotary centrifugal air sampler (Sabouraud-Dextrose agar strips) for yeasts and molds. At a height of 120 cm, 40–80 L of air was sampled (40 L/min). Fig. 4.2 shows the fungal concentration results and outdoor thermal environment in a detached house in Japan (Bamba et al. 2014). Japan experiences remarkable changes in annual temperature and relative humidity. The outdoor fungal concentration significantly differs by season, and outdoor airborne fungal concentrations are higher in summer and autumn than in winter and spring. The heat and humidity from autumn to summer that go with the wet season are important factors. The fungal concentration in the living room is high from summer to autumn. This is because opening windows is frequent, whereby fungi from the outdoor air easily flow inside the room. Fungi are thought to grow favorably in rooms with high temperatures and humidity. The effect of season change is smaller in a semibasement without windows than in the living room. Because the annual temperature change is affected by soil moisture under the effect of even the slightest terrestrial heat, the basement has higher fungal density than a living room, except in the summer. Fig. 4.3 shows the fungal concentrations in living rooms and bedrooms in Malaysia. The average temperature was 30.6°C, and the relative humidity was 58% at the time of the measurement in a room that represented the house environment during the summer in Japan. Fungal concentration remarkably differed by house but remained at the same level in rooms on various floors. The high fungal concentration in a house was the same level as that in Japanese outdoors. This is possibly because of the frequent opening of windows without using air conditioning during the daytime.

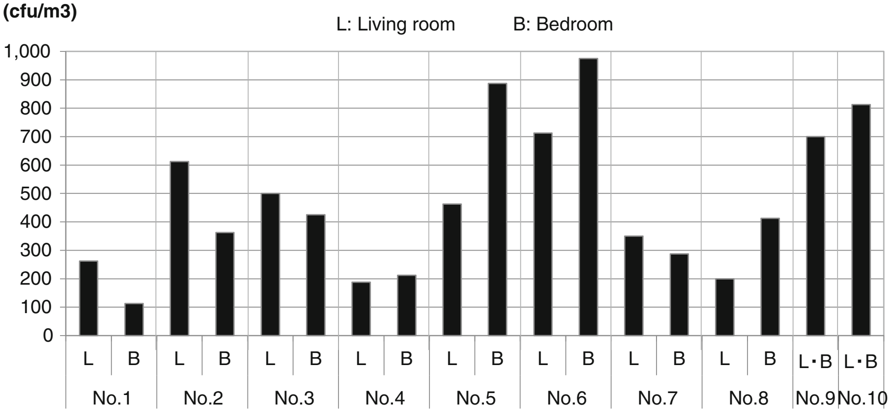


Fig. 4.3 Fungal concentration of living rooms and bedrooms in Malaysia

Indoor fungal density is affected by the fungal density in fresh air, the quantity of fresh air introduced, and the indoor temperature-humidity environment. In addition, house dust is a nourishment source of fungi. For the measurement of fungal growth in a house environment, control of humidity by ventilation, dehumidification, and reduction of the nourishment source by cleaning are important. However, the kind of fungus should be considered because the existence of fungi that cause pathogenic conditions and toxins is undesirable. Generally, *Cladosporium* is predominant, and *Penicillium*, *Aspergillus*, and *Alternaria* are detected in indoor air.

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Part III
Screening Methods of Environmental Risk in a Watershed

Chapter 5
Whole Effluent Toxicity: Tool for Risk Assessment and Management of Hazardous Chemicals in Watershed Area

Hiroshi Yamamoto

Abstract The number of chemical compounds used by human activities has continuously been growing, but the risk assessment/management of hazardous chemicals is usually based on individual compound, and the risk of unknown/unregulated compounds and mixture effects are ignored. Thus, whole effluent toxicity using aquatic organisms has been used for effluents of factories and municipal wastewater treatment plants in some countries such as the USA, Canada, Germany, and South Korea. In this section, the bioassay protocol proposed in Japan is introduced, and some results obtained from the application to the selected effluents and watershed areas are presented.

Keywords Algae · Ambient water · Daphnia · Ecotoxicity · Fish embryo

5.1 Introduction

The number of chemicals manufactured, used, and disposed for our daily life is steadily increasing, and the one registered to the Chemical Abstracts Service (CAS) of the American Chemical Society (ACS) is passed 120 million in November 2016 (Chemical Abstracts Service 2016). In Japan, the number of chemicals used and in the market is approximately 30,000 under the Chemical Substance Control Law (CSCL) for the general industrial chemicals (National Institute of Technology and Evaluation (NITE) 2016) in addition to those chemicals used for food products, pharmaceuticals, cosmetics, and agrochemicals including pesticides and fertilizers. Despite that such a huge number of chemicals could be in natural environment, the number of items in discharge limits and environmental quality criteria are very limited (e.g., 28 items for human health protection and 15 items for conservation of living environment in the list of water quality standards (Ministry of the Environment, Government of Japan 2011)). From the effluent of wastewater treatment

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plants and surface water, various emerging hazardous micropollutants have recently been detected including neonicotinoid pesticides, surfactants, endocrine-disrupting chemicals, pharmaceuticals, personal care products, organofluorides, brominated flame retardants, and rare metals, which attract attentions from public. While very small concentrations in the order of ng/L in the natural environment can now be easily detected due to the recent progress of analytical instrument such as mass spectrometry, the cost for the monitoring of such a huge number of items started to burden the local and national governments.

Currently, most of the risk assessment of chemicals is based on the individual chemicals both for existing chemicals and new chemicals in OECD countries with only a few exceptions such as some metal compounds, dioxins, and surfactant mixtures (OECD 2016). These risk assessments were based on the level of exposure of the individual chemical (measured concentration in the environment or predicted using model simulations) and that of dose-response relationship (toxicity test results using aquatic organisms and mammals). This type of approach can neither properly reflect the natural environment with existing various hazardous chemicals together nor cover the risk of those emerging or unknown chemicals with few monitoring/toxicity data.

To address the risk assessment and management of mixtures and new/unknown chemicals, bioassay is directly applied to effluent and ambient water to complement the individual chemical analysis (Fig. 5.1) in some countries (Power and Boumphrey 2004). Among these, the USEPA's whole effluent toxicity (WET) system was first implemented in 1995 (USEPA 2004) and has been effective to control the hazardous effects of chemicals in effluent and receiving water bodies on aquatic organisms.

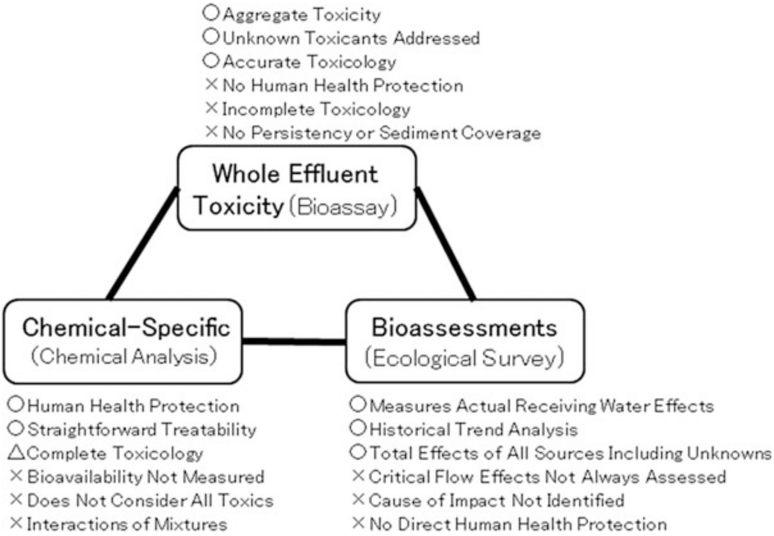

Fig. 5.1 Components of integrated approach to water quality-based toxics control (USEPA 1991)

This system utilizes direct short-term chronic (or acute) bioassay using marine/ estuarine test organisms for water samples collected from outfall of the factories and/or receiving water bodies to evaluate the adverse effects. If the detected toxic effect is higher than a certain limit value, dischargers must reduce the toxicity to achieve the goal, but the major toxicants are not always required to be identified once the toxicity is successfully reduced.

In Europe, several acute toxicity tests (e.g., fish, daphnia, and umu test) are required under the Wastewater Ordinance (enacted in 1976) to set the tax charge in Germany (Federal Ministry for the Environment, Germany 2004). Similarly, tax charge is determined by acute toxicity in France. Similar effluent management is conducted in Sweden, while a similar system called "Direct Toxicity Assessment" was not accepted as a regulation in England.

As for in Asia, Korea started their discussion in 2006, and the WET testing was implemented in 2011 with shortened *Daphnia* acute toxicity test (Korea Ministry of Environment 2006), while Taiwan implemented this system in 2015. Japan also started the discussion in 2009, and the draft testing procedure was publicized in 2013 by the National Institute for Environmental Studies (NIES) and Ministry of the Environment (MOE) (Ministry of the Environment and National Institute for Environmental Studies, Japan 2013). Voluntary monitoring for the final effluent is considered to be implemented in the future.

In this section, the possible use of WET testing for the risk assessment and management of hazardous chemicals in watershed area is discussed based on our previous case studies on several watershed areas in Japan. Advantages and disadvantages of the WET system for the protection of the water environments are compared to the conventional approach using chemical analyses.

5.2 WET Test Methods

As presented above, WET testing procedures in the USA (Table 5.1) are published by USEPA. The latest edition was publicized in 2002 for acute tests (5th edition) (USEPA 2002a), freshwater chronic (4th edition) (USEPA 2002b), and marine/ estuarine chronic (3rd edition) (USEPA 2002c). The test duration for the acute tests ranged from 24 to 96 h, while chronic tests take longer to cover multiple life stages of the test organism with endpoints related to growth and reproduction, which are more relevant to the ecosystem (Fig. 5.2). Most of the states with permitting system with National Pollutant Discharge Elimination Systems require chronic WET limits rather than acute ones. The WET limits are established based on the dilution factor at the mixing zones.

In Germany, five acute testing methods are used to determine the tax charge in Wastewater Ordinance, started in 1994 and last amended in 2005. The testing methods are listed in Table 5.2. More recently, fish embryo testing is used instead of young or adult fish acute toxicity tests due to the animal welfare perspectives.

Table 5.1 WET test methods publicized by USEPA (2002a, b, c)

	EPA No.	Organism(s)	Endpoint(s)
Freshwater, acute	2000.0	Fathead minnow, *Pimephales promelas*, and Bannerfin shiner, *Cyprinella leedsi*	Mortality
	2002.0	Daphnia, *Ceriodaphnia dubia*	Mortality
	2019.0	Rainbow trout, *Oncorhynchus mykiss*, and Brook trout, *Salvelinus fontinalis*	Mortality
	2021.0	*Daphnia pulex* and *Daphnia magna*	Mortality
Marine/estuarine, acute	2004.0	Sheepshead minnow, *Cyprinodon variegatus*	Mortality
	2006.0	Silverside, *Menidia beryllina*, *Menidia menidia*, and *Menidia peninsulae*	Mortality
	2007.0	Mysid, *Americamysis bahia*	Mortality
Freshwater, chronic	1000.0	Fathead minnow, *Pimephales promelas*	Larval survival and growth
	1001.0	Fathead minnow, *Pimephales promelas*	Larval survival and teratogenicity
	1002.0	Daphnia, *Ceriodaphnia dubia*	Survival and reproduction
	1003.0	Green alga, *Pseudokirchneriella subcapitata*	Growth
Marine/estuarine, chronic	1004.0	Sheepshead minnow, *Cyprinodon variegatus*	Larval survival and growth
	1005.0	Sheepshead minnow, *Cyprinodon variegatus*	Embryo-larval survival and teratogenicity
	1006.0	Inland silverside, *Menidia beryllina*	Larval survival and growth
	1007.0	Mysid, *Americamysis bahia*	Growth and fecundity
	1008.0	Sea urchin, *Arbacia punctulata*	Fertilization

Fig. 5.2 Various ecotoxicity test methods and their concepts (Yamamoto et al. 2015)

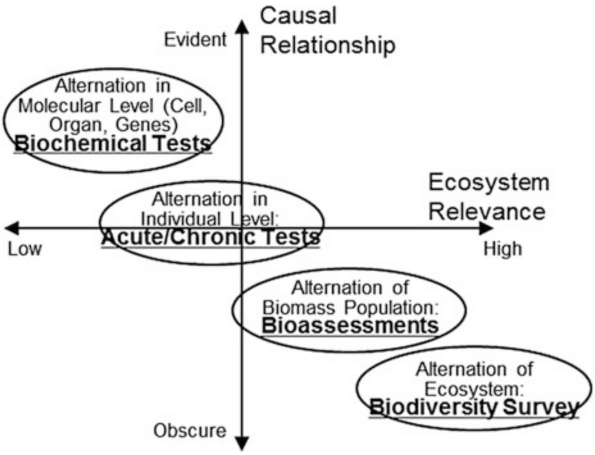

Table 5.2 Testing methods used in the German Wastewater Ordinance (USEPA 1991)

Organism	Duration	Endpoint
Fish, *Leuciscus idus*	48 h	Mortality
Daphnia, *Daphnia magna*	24 h	Immobilization
Luminescent bacteria, *Vibrio fischeri*	0.5 h	Luminescence
Alga, *Scenedesmus subspicatus*	72 h	Growth (biomass)
Mutagenicity, *Salmonella typhimurium* (umu test)	2 h	–

In Korea, only 24 h daphnia test is used temporarily, but the duration is planned to be elongated into 48 h in conformity to OECD test guideline No. 202 with possible implementation of chronic tests.

In Japan, the draft test methods were publicized from NIES and MOE in 2013 (Ministry of the Environment and National Institute for Environmental Studies, Japan 2013), and slight modification was made in 2014 (Ministry of the Environment and National Institute for Environmental Studies, Japan 2014). Due to the strict compliance by the factories all over Japan, no significant acute effects are evident. Only freshwater chronic testing methods (Table 5.3) are proposed in the test methods similar to the ones in USEPA. Zebrafish is the primary option for the fish due to the shorter duration required for hatching than medaka. The proposed test methods for daphnia and green alga are similar to those in USEPA (2002b).

5.3 Case Studies for Ambient Waters

Whole effluent toxicity testing is used not only for effluents from factories and municipal wastewater treatment plants but also for ambient waters all over the world. The Society of Environmental Toxicology and Chemistry held a workshop on this topic in 1999, and a special edition with several papers was published as No. 1 of Volume 19 of the society's journal, *Environmental Toxicology and Chemistry*, in 2000. For example, Vlaming et al. (2000) conducted WET testing for river water in Sacramento, California, in the USA and found that the major toxicants for *Ceriodaphnia dubia* were organophosphorus insecticides such as diazinon and chlorpyrifos. Similarly, Bailey et al. (2000) investigated the effects of effluents of wastewater treatment plants in South Wales in Australia on *C. dubia* and *P. subcapitata* to find that diazinon and chlorpyrifos are the major toxicants. Sarakinos et al. (2000) investigated the effluent of industrial factories discharged into the St. Lawrence River watershed of Canada and found a strong relationship between the toxicity and various priority substances such as heavy metals and PAHs using luminescent bacteria, green alga (*P. subcapitata*), and daphnia (*C. dubia*). In this issue, Maltby et al. (2000) indicated a strong relationship between the benthic macroinvertebrate community and WET testing results for *D. magna* and amphipod, *Gammarus pulex*.

Table 5.3 Draft testing methods publicized by NIES and MOE in Japan (Ministry of the Environment and National Institute for Environmental Studies, Japan 2014)

Organism	Initial condition	Repetition (concentration)	Endpoint	Duration	Temperature/light	Vessels
Zebrafish, *Danio rerio* (and Medaka, *Oryzias latipes*)	4 h post fertilization embryo	4	Hatch and larval survival	8 days (14 days)	25 ± 1 °C (16 h light/8 h dark)	50 mL glass beaker
Daphnia, *Ceriodaphnia dubia*	Less than 24 h animal	10 (1 animal ea.)	Survival and reproduction	7–8 days	25 ± 1 °C (16 h light/8 h dark)	30 mL glass beaker
Green alga, *Pseudokirchneriella subcapitata*	Exponential growth stage (5 × 10^3 cells/mL)	3	Growth	72 h	25 ± 1 °C (continuous lighting)	250 mL Erlenmeyer flask

More recently, USEPA's Norberg-King et al. published a book on toxicity reduction evaluation (TRE) and toxicity identification evaluation (TIE) from SETAC Press (Norberg-King et al. 2005). In this book, a few case studies were presented for ambient water. Anderson et al. (2006) conducted WET testing for river water and sediment using *C. dubia* and *Hyalella azteca*, respectively, for the samples collected in Santa Maria River of California, to find organophosphorus and pyrethroid insecticides that were major toxicants. Kayhanian et al. (2008) conducted toxicity testing for roadway runoff in the suburb of Los Angeles, California, using *C. dubia*, sea urchin, fathead minnow, and Microtox. They indicated the mixture effects of heavy metals such as copper and zinc in the runoff.

In Europe, Vigano et al. (1996) used *C. dubia* reproduction test for the evaluation of the river water collected in the River Po watershed area of North Italy. Peeters et al. (2001) reported the correlation between toxicity to *D. magna*, midge, *Chironomus riparius*, and luminescent bacteria and contaminant concentrations to discuss the possible impacts on macroinvertebrate community in the Rhine-Meuse delta area.

In Asia, Baun et al. (1998) conducted an algal toxicity test and *D. magna* toxicity tests for surface water collected in agricultural area of Phuket Island, Thailand, in combination of concentration process, while WET testing has been widely conducted in Korea for effluent of wastewater treatment plants and their receiving water bodies (Ra et al. 2007) with the implementation of the WET system in 2011. In highly developing area of Pearl River Delta area of South China, WET test methods such as zebrafish embryo test, D. magna acute test, and algal growth inhibition test are used for toxicity identification evaluation (Fang et al. 2012).

Ambient water studies have also been extensively conducted in Japan. Sasaki et al. (2000) conducted *D. magna* acute toxicity tests and algal growth inhibition tests using *P. subcapitata*, Microtox, and Ames test for river waters collected in the Tone River watershed and the Tama River watershed in Tokyo metropolitan area in the late 1990s. They also conducted chemical analysis of selected surfactants and pesticides and found moderate correlation of organophosphorus insecticide concentration with daphnia toxicity and herbicides with algal toxicity. Hatakeyama et al. (1991) also found acute toxicity of freshwater shrimp in rivers of Ibaraki Prefecture and compared results with the monitoring data of selected organophosphorus insecticides and found significant correlations. Okamura et al. (1996) also monitored the *D. manga* acute toxicity for the rivers of Kojima Bay watershed area, while Hosokawa et al. (1995) investigated the *D. magna* immobilization of the concentrated river water samples from all over the Yodo River watershed area and found significant toxicity near the outfall of the wastewater treatment plants, but the concentrated process might skew the results. Later, Kikuchi et al. (2008) monitored *D. magna* toxicity for the Naka River of Tone River watershed for 10 years between 1994 and 2004 to find the improvement of the toxicity level mainly due to the decrease in the use of organophosphorus insecticides.

More recently, the author's research group has conducted short-term chronic toxicity tests for urban streams (Yasuda et al. 2011) and class A (or "first class" in

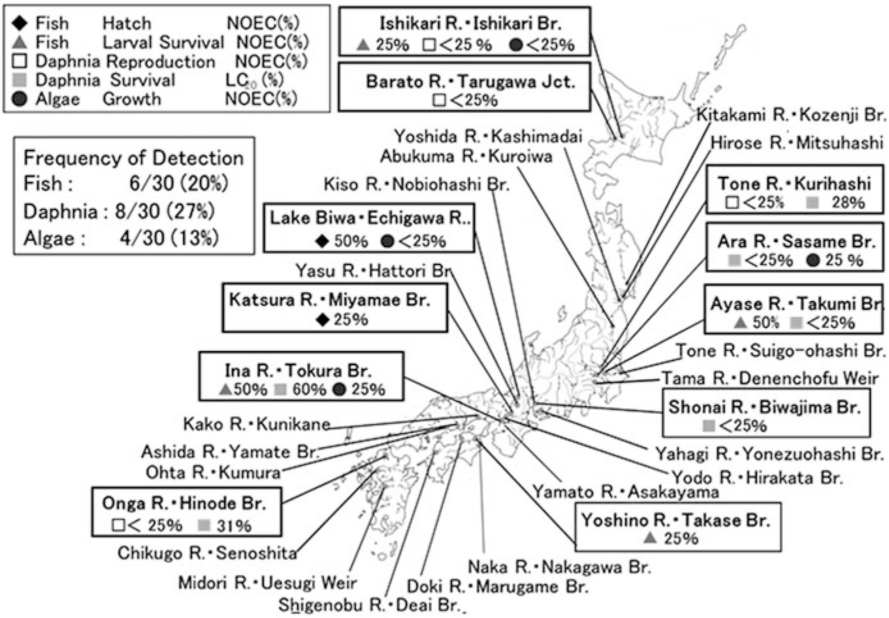

Fig. 5.3 Results of short-term chronic toxicity tests for 30 class A rivers all over Japan

Japanese) rivers all over Japan (Morita et al. 2012). As can be seen from Fig. 5.3, river water samples collected in 11 out of 30 sites of class A rivers all over Japan were found to be toxic to at least one species of fish, daphnia, and algae (Morita et al. 2012), while more than a half of the samples were found to be toxic for urban streams (Yasuda et al. 2011). In these river water samples, we also chemically analyzed selected pharmaceuticals and surfactants, and some antimicrobials and surfactants were found to be potential major toxicants for algae and fish/daphnia, respectively (Tamura et al. 2017). The combination of WET testing, chemical analysis of the selected hazardous chemicals, and bioassay of these chemicals might be the effective approach for the toxicity identification and efficient risk assessment/management of complex mixture of hazardous chemicals in the watershed area as with the effect-directed analysis (Brack et al. 2003).

5.4 Future Perspectives

Since we manufacture, use, and dispose thousands of hazardous chemicals, mixture effects such as additive, antagonistic, and synergistic effects are likely to be observed. As can be seen from Fig. 5.4, not only anthropogenic compounds but also natural compounds could be hazardous (Daughton C, Personal Communication), and both of these compounds are discharged from various sources in

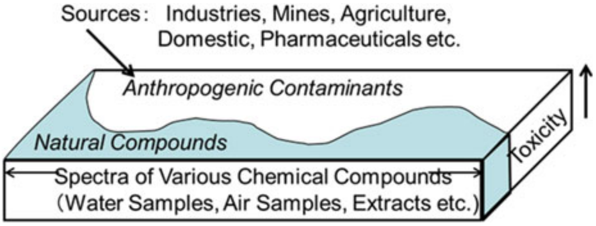

Fig. 5.4 Schematic diagram about the spectrum of chemical substances in the environment (Daughton C, Personal Communication)

watershed area. Thus, there are some limitations in risk assessment/management of individual hazardous chemicals simply by chemical analysis to pursue the identification of major toxicants, and the WET-type approach might be very helpful for the complex mixture such as effluent and ambient waters. The toxicity reduction with characterization of the group of major toxicants (without the exact identification of major toxic chemicals) might be useful due to the increasing number of chemicals and the unknown mixture effects.

On the other hand, the reliability of bioassay has long been argued compared to chemical analysis. In some developed countries such as Japan, various high-technology analytical instruments such as LC/MS/MS and ICP-MS are available in reasonable price, and the quality assurance (QA)/quality control (QC) has developed to enhance their reliability, while bioassay is considered as simplified alternative with relatively low quality. In the chemical management and the establishment of criteria such as environmental standards, discharge limit, and even acceptable daily intake (ADI), results of bioassay including animal testing are used as evident key data. If the good laboratory practice is properly comprised, the quality of the data is reliable as with chemical analysis.

To assess and manage the hazardous effects of chemicals, the extent of the effects on human health and wildlife is of course the key point. Not only the chemical-specific "measure" but also the biological "measure" is plausible for citizens. The effects on living organisms should be evaluated by bioassay, the assay using living organisms. Furthermore, the next step is the implementation of bioassessment or ecological survey in addition to chemical-specific and bioassay as used in environmental effect monitoring (EEM), implemented first in Canada (Environment Canada 2013). This approach might help in understanding the historical trend, actual receiving water effects, and total effects of all sources including unknowns (Fig. 5.1).

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Chapter 6
Environmental Toxicity and Evaluation

Lee Yook Heng, Lia Ooi, Izumi C. Mori, and Dedi Futra

Abstract The basic concept of environmental toxicity and its importance in the evaluation of ecosystem health will be introduced. Toxicity evaluation theory and practice will be briefly discussed. Traditional techniques such as bioassays for environmental toxicity evaluation will be introduced where the advantages and disadvantages will be presented. But the main focus of environmental toxicity evaluation will be on the use of more recent techniques for rapid environmental toxicity assessments such as toxicity biosensor and its basic concept, current applications, and future prospects.

Keywords Environmental toxicity · Toxicity measurement · Environmental security · Bioassay · Toxicity biosensor

This section will introduce the basic concept of environmental toxicity and its importance in the evaluation of ecosystem health. Toxicity evaluation theory and practice will be briefly discussed. Traditional techniques such as bioassays for environmental toxicity evaluation will be introduced where the advantages and disadvantages will be presented. But the main focus of environmental toxicity evaluation will be on the use of more recent techniques for rapid environmental toxicity assessments such as toxicity biosensor and their basic concept, current applications, and future prospects.

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6.1 Understanding the Basic Concept of Toxicity

Toxicity refers to the capacity of a chemical (toxin) to affect an organism adversely. Environmental pollutants are usually appertained to the term xenobiotics, which are chemical compounds found in but not naturally produced within an organism or a biological system. Environmental xenobiotics mostly are wastes from anthropogenic activities (e.g., agriculture, mining, industrialization, urbanization, chemical spills, etc.), which can be grouped as pharmaceutical drugs, environmental pollutants, food additives, pesticides, carcinogens, antioxidants, hydrocarbons, and many more. The study of the toxicity effects of a chemical is known as toxicology. Classical toxicology, which was studied since centuries ago, is the study of the adverse effects of chemical, biological, and physical agents in biological systems which possess adverse effects on living organisms. The father of toxicology, Theophrastus Phillipus Auroleus Bombastus von Hohenheim (1493–1541), who was also known as Paracelsus, wrote "*sola dosis facit venenum*" (the dose makes the poison), which brought to the formation of the dose-response relationship.

Environmental toxicology (Entox) is an expeditiously expanding multidisciplinary field of science, concerned particularly in determination of the sources, fate, transformations, effects, and risks of toxicants on the environment, wildlife, and human health. Fig. 6.1 illustrates the major components of

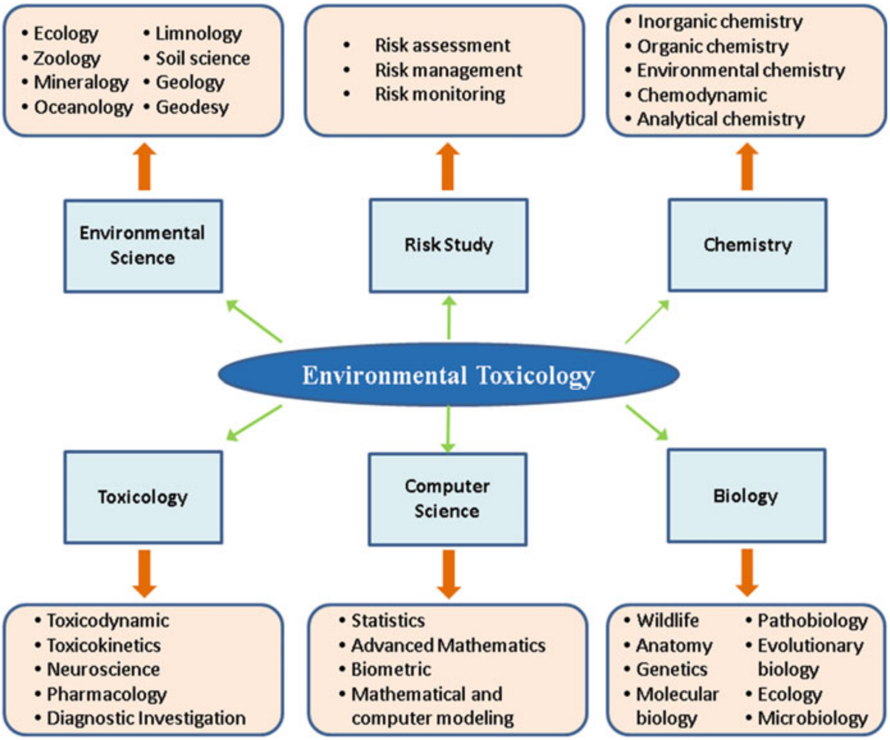

Fig. 6.1 Environmental toxicology and its components

environmental toxicology. Note that Entox is a multidiscipline; thus, its components consist of but not limited to those stated in the figure. The study of the toxic effects of environmental toxicants began in the 1960s, when Rachel Carson, the mother of environmental toxicology, who wrote the book *Silent Spring*, described the harmful environmental impacts of dichlorodiphenyltrichloroethane (DDT), which was widely used as insecticide. The book raised an unprecedented extend of public awareness among the US people regarding environmental toxicity and its impacts on the wildlife and human health. It eventually led to a nationwide ban on DDT usage and the formation of the US Environmental Protection Agency (US EPA) (Carson 2002; Paull 2013). In 1969, a French toxicologist René Truhaut (1909–1994) introduced the term "ecotoxicology" to describe the study of environmental toxicity which distinguishes it from classical toxicology (Truhaut 1977). Ecotoxicological studies provide invaluable information on potential hazards found in the environment via identification of important impacts of pollutants to living organisms.

Over time, urbanization and science development have brought industrialization and chemical invention to flourish. Hundreds of thousands of man-made chemicals have been created in the laboratory, and many more have been released into the environment every day. Researchers and the authorities are alarmed by the degradation of the environmental quality and observation of health impacts on organisms and human health in contaminated areas. Laws and legislations have been established, promulgated, and enforced for environmental protection. Numerous legislations have been made starting in the 1970s to reduce environmental toxicity. In other words, Entox is legislation driven. The National Environmental Policy Act of 1970 was the first piece of environmental legislation which brought to the foundation of US EPA. Clean Air Act of 1970, Federal Environmental Pesticide Control Act of 1972, Federal Water Pollution and Control Act of 1972, Safe Drinking Water Act of 1974, Toxic Substances Control Act of 1976, Resource Conservation and Recovery Act of 1976, Comprehensive Environmental Response, Compensation and Liabilities Act of 1980 (a.k.a. Superfund), and Clean Water Act of 1987 are several examples of acts created for environmental protection.

The degree of toxicity of a toxicant can vary depending on in which stage of the life cycle the exposed organism is and where it is found within the food web. Environmental toxicants enter a food chain via bioaccumulation and gradually increase in concentration when they move from one trophic level of the food web to another through biomagnification. These phenomena enable small amount of chemicals in the environment to be found in high dosage in the organisms sitting on top of a biomass pyramid. Environmental toxicant can enter the body of organism or human through several portals of entry, namely, inhalation, skin (or eye) contact, digestion, and injection. Three phases are involved when an environmental toxicant penetrates its way into an organism (Djuric 2015):

1. The exposure phase

   Comprises of all processes arising between the toxicants and the influence of environmental factors including degradation, biodegradation, chemical transformations, etc.

2. The toxicokinetic phase

   Comprises the absorption of toxicants into the organism followed by transportation, distribution, and accumulation of toxicants in the tissues and organs and the biotransformation of the toxicants
3. The toxicodynamic phase

   Comprises the interaction of (the bioavailable fractions of) toxicants with specific receptors in the organism, which eventually brought to the formation of a toxic effect.

Toxicity can be divided into three major categories based on the duration of time taken for the adverse effects to emerge, which are (i) acute toxicity, in which the harmful effects can be observed through a single or short-term exposure, where death is a major concern; (ii) subchronic toxicity, which results from repeated exposure for weeks or months and requires more than 1 year but less than the lifetime of the exposed organism for the effects to be observed; and (iii) chronic toxicity, which causes malignant effects to the exposed organism over an extended period of time. Bhopal disaster which happened in 1984 is a suitable example to study toxicity effects. The leakage of at least 27 tons of methylisocyanate (MIC) gas from a pesticide plant (Union Carbide India Limited) in Bhopal, India, exposed more than 500,000 people to the odorless, colorless, and deadly gas. It killed at least 3800 people immediately (acute effect) and 15,000–20,000 in the next three decades due to disaster-related deaths majorly caused by chronic inflammatory damage to the eyes and lungs (Knight and Riesenberger 2014; Monosson 2008).

The toxicity of a toxicant can also be classified as systematic toxicity (which affects the entire body or multiple organs of an organism) and target organ toxicity (which affects only specific tissues or organ in the organism) based on its target site in the organism. Target organ toxicity can be further categorized to dermal toxicity, ocular toxicity, hepatotoxicity, immunotoxicity, nephrotoxicity, neurotoxicity, reproductive toxicity, and so forth. Hydrogen cyanide is an example of systemic toxicant; it binds to cytochrome oxidase in the organism causing cellular hypoxia and rapid death (Monosson 2013). On the contrary, vinyl chloride monomer (VCM), a colorless gas which is majorly used in the production of polymer polyvinyl chloride (PVC), is an example of hepatotoxicant. Its hepatotoxicity has been long established since the 1930s. Studies in test animals and VCM worker found that even just a single short-term exposure to high dosage of VCM caused liver damage (Waite et al. 1930). Due to its high volatility, VCM has rarely been detected in surface waters. It was detected to have concentration of only 56 μg/liter even in highly polluted rivers in Osaka. However, in closed environment, VCM can be found in high concentrations in leachate (60,000 μg/liter), contaminated sand aquifer (56,000 μg/liter), groundwater (120,000 μg/liter), and well water (up to 200,000 μg/liter) in the vicinity of a PVC plant after 10 years of leakages (WHO 2004). This possesses environmental health risk to wildlife and human.

Dose, exposure, and response are the basic three factors that determine the adverse effects of a toxicant. “The dose makes the poison,” and the *dose* of a toxicant is the amount of it that comes into contact with and is deposited within the body of a living organism. Threshold dose is the term used to describe the dose

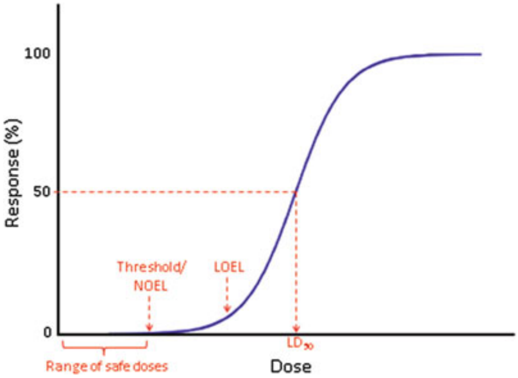

Fig. 6.2 Dose-response curve

level at which toxicity is first encountered. Any condition which provides opportunity for an external environmental agent to enter the body of an organism is referred to as *exposure*. Environmental exposure can be expressed as the amount of a xenobiotic in a unit of the media (e.g., mg/L for liquids, mg/g for solids, and mg/m^3 for air). *Response* is the biological effect of the chemical agent on the exposed organism.

A dose-response curve can be used to effectively display the dose-response relationship of an environmental toxicant to the response of the exposed organism. A dose-response relationship can be *graded* (for responses that are measured on a continuous scale in a single biological unit, e.g., heart rate) or *quantal* (for all-or-none responses in a population, e.g., mortality). Quantal dose-response curve is usually constructed in environmental toxicity study, where mortality rate of the exposed organisms is referred to as the response toward environmental toxicant exposure. The median lethal dose/concentration (LD_{50} or LC_{50}), the no-observed-adverse-effect level/concentration [NO(A)EL or NOAEC], and lowest-observed-adverse-effect level/concentration [LO(A)EL or LOAEC] of an environmental toxicant can be determined from a quantal dose-response curve (Fig. 6.2). Information from a dose-response curve is crucial to assist in assessing the risk of environmental toxicity.

From ecotoxicological aspects, *risk* refers to the chance of adverse effects to human health or to ecological systems resulting from exposure to an environmental stressor (USEPA 2015a). An environmental risk assessment (ERA) is a systematic process to predict and characterize the potential adverse effects to human health and the environment due to the exposure to a chemical substance. In 1983, the National Research Council (NRC) published NRC Red Book extensively describing about the four significant stages in risk assessment (RA): (i) hazard identification, (ii) dose-response assessment/hazard characterization, (iii) exposure assessment/consequence assessment, and (iv) risk characterization/risk estimation (NRC 1996). A comprehensive ERA should consist all of those listed key stages applying the conceptual model of the source-pathway-receptor. In this conceptual model, the pathway between the source of contamination (the hazard source) and the particular ecosystem (the receptor) is investigated (RSC 2013). The pathway is the linkage between the receptor and the hazard; exposure risk exists when a pathway exists and vice versa. The presence and the concentration of a toxicant in an environmental medium, the probability of an ecological receptor to be exposed to the toxicant, and the inherent toxicity of the toxicant resulting from the exposure are three factors deciding the risk (USEPA 2015a).

ERA can be categorized into human health risk assessment (HHRA) and ecological risk assessment (EcoRA). In both RAs, information on the toxic properties of environmental stressors and dose-response relationships are crucial for the exposure risk to be accurately assessed. Although advanced analytical instruments are excellent in detecting even a very small amount of chemicals in environmental samples, only living organisms can demonstrate the toxicity effects of a toxicant (Cairns and Mount 1990). Toxicity information is usually obtained from animal studies, epidemiological investigation and clinical studies of exposed human populations, or accident case reports of exposed humans. A toxicity test encompasses a test organism (ranging from cellular material of microorganisms to higher-order organisms), a biological endpoint (ranging from physiological changes to death), an exposure period, and a dose or series of doses (EHS 2002). US EPA has developed extensive guidelines and reports on dose-response modeling and assessment. Two of the most popular guidelines on environmental toxicity studies are the whole effluent toxicity (WET) methods and aquatic toxicity identification evaluations (TIE).

WET investigates the toxicity of pollutants in a facility's effluent (wastewater) on aquatic organisms by measuring its effects from the aspect of survival, growth, and reproduction of the test organisms. It is practiced as part of the implementation of Clean Water Act which prohibits the discharge of toxic pollutants in toxic amounts into the environment. Several freshwater, estuarine, and marine organisms have been selected as test organisms for WET test, such as fathead minnow (*Pimephales promelas*), bannerfin shiner (*Cyprinella leedsi*), rainbow trout (*Oncorhynchus mykiss*), brook trout (*Salvelinus fontinalis*), water flea (*Ceriodaphnia dubia*, *Daphnia pulex*, *Daphnia magna*), sheepshead minnow (*Cyprinodon variegatus*), silversides (*Menidia beryllina*, *Menidia menidia*, *Menidia peninsulae*), and mysid shrimp (*Americamysis bahia*) (USEPA 2015b). An acute toxicity WET test predominantly includes exposure of test organisms to each of different effluent concentrations in a test duration ranging from 24 to 96 h (USEPA 2015c).

Similar to WET, TIE approach was developed for effluent evaluations, but its methods and techniques can be directly applied to different kinds of aqueous samples, for instance, sediment pore waters, ambient waters, waste leachates, and sediment elutriates (USEPA 1991). It consists of three phases which involved the characterization of the physical/chemical nature of the toxic constituents, the identification of toxicants, and the confirmation of the suspected toxicants. TIE assists in the characterization, identification, and confirmation of toxicant in aqueous samples. Water fleas (*Ceriodaphnia dubia*, *Daphnia magna*, *Daphnia pulex*), fathead minnow (*Pimephales promelas*), scud (*Hyalella azteca*), and bluegill (*Lepomis macrochirus*) are some of the species of test organisms suggested to be used in TIE to identify acute and chronic effluent toxicity (USEPA 1991, 1993).

The emergence of sophisticated technologies in molecular and cellular biology has evolved the focus of toxicological studies from whole animal and population testing to cellular and molecular testing of the test organisms. In 2007, the Committee on Toxicity Testing and Assessment of Environmental Agents published a book titled *Toxicity Testing in the twenty-first century: A Vision and a Strategy*, which comprehensively illustrated the committee's vision for toxicity testing which will be conducted based on rapid *in vitro* assays. A toxicity testing which is pathway-based and consistent with the stages of RA stated in the 1983 Red Book has been developed (NRC 2007). Progressive toxicity testing tools such as high-throughput screenings, bioinformatics, functional genomics, computational systems biology, structure-activity relationships, molecular and genetic epidemiology, physiologically based pharmacokinetic models, stem cell biology, and so forth can be applied in assisting the modern risk assessment especially in environmental toxicity evaluation and in the effort to achieving *environmental security*, which is an environment protected from harm or adverse effects from natural or anthropogenic processes so that resources are sustained for future generations (DEFRA 2011; Krewski et al. 2011).

Improper handling of industrial wastes can result in irremediable and remorseful effects on wildlife and human health. The *Four Big Pollution Diseases of Japan* which occurred in 1912–1960s were all due to environmental toxicity as a result of inappropriate disposure of industrial wastes. These man-made diseases are Itai-itai disease, Minamata disease, Niigata Minamata disease, and Yokkaichi asthma. Itai-itai disease which first occurred in 1912 literally translates to "it hurts-it hurts disease." It was the first documented mass cadmium poisoning in the world (Rasnake 2009). Significant amounts of cadmium were released from the mining sites in the mountains into Jinzu River in Toyama Prefecture, Japan. Fish death and growth retardation in rice irrigated with the polluted water were observed. Local communities who were exposed to the polluted water and food experienced symptoms like debilitating pain, fragile bone, skeletal deformities, kidney failure, and eventually death. Mitsui Mining and Smelting Co., the mining company, was found guilty and was urged to pay health expense compensation to the victims and to clean up the polluted areas through soil restoration. The cadmium cleanup project began in 1979 which lasted for 33 years and finally marked its completion on 2012 after replacing 863 hectares of land in the Jinzu River basin (Kyoda 2012). Only 4 of its 196 victims were reported to be alive in 2012.

Minamata disease was another man-made disease reported in Minamata, Kumamoto Prefecture of Japan in 1956. It was identified as methylmercury poisoning when Chisso Corporation, a chemical factory, dumped the by-product of the chemical reactions into the waters of Minamata. Massive dead fish began to wash ashore in 1950, and cats in the area began to have convulsion and go mad (known as "the dancing cat disease" by the locals). The same symptoms appeared in human starting 1953 in people who ate the fish and seafood from the local waters. The victims suffered blindness, convulsions, incredible pain, and madness due to the neurotoxic effect of mercury poisoning (Hachiya 2006). In 1965, patients of Minamata disease were also reported in the Agano River basin in Niigata Prefecture (Niigata Minamata disease) (MOE Japan 2002). It was until 1968 that Chisso plant was declared to be responsible for the outbreak of Minamata disease. Environmental toxicity by heavy metals affected numerous areas in Japan, which was then brought to the enaction of the Prevention of Soil Contamination in Agricultural Land Law of 1970 and Japanese Water Pollution Control Act of 1970.

6.2 Bioassay Methods of Ecotoxicity Assessment

Technological advance after the industrial evolution has made enormous changes to human lifestyle. Our daily life is getting abundant and we receive a benefit of the technologies. Lying behind the benefit, however, environmental problem arising from the technology has become a global concern.

Environmental pollution by a trace amount of hazardous chemical can be a problem that causes ecological casualties (Truhaut 1977). More than one hundred million of chemicals have already been registered to the Chemical Abstract Service database, the information division of the American Chemical Society. Millions of novel chemicals are being registered to the database annually (Binetti et al. 2008). Some of these chemicals that are potentially hazardous to the ecosystem are inferable to be discharged to the environment. Ecotoxicology (or Entox) aims at elucidating the fate of hazardous chemicals in environment and the toxic action of chemicals to the components of the ecosystem. Furthermore, it accumulates fundamental data of potential toxicants for the establishment of environmental regulations, which are eventually utilized for conservation and management of the biological resources of watersheds.

Assessment of toxicity of chemicals to a certain organism is an essential component of ecotoxicology. Bioassay (short for biological assay or biological assessment) is a practical means for assessing toxic effect of environmental samples and chemical products on a test organism. The purpose of bioassay is to determine toxicity parameters of water samples, chemical products, etc. Fishes, invertebrates, unicellular algae, and bacteria are often utilized as the test organisms in bioassays. Since evaluation of toxicity to a single organism is insufficient for comprehensive elucidation of ecotoxicity, the implementation of the batteries (a suite of bioassays) is recommended (Keddy et al. 1995). In practice, a combination of acute toxicity tests consisting of three organisms, alga, cladoceran (water flea) (e.g., genera *Daphnia* and *Ceriodaphnia*), and fish, is preferably used for a *battery test*. Each organism shares an ecological niche in the food chain, which is a structural aspect of the ecosystem. Since bioassays are carried out in a laboratory, the assay results are not necessarily appropriate to estimate the toxic effect at an actual pollution site. To understand the impact of a chemical on ecosystem, functional aspects of ecosystem in addition to structural aspects and specific property of the actual scene/site must be taken into account. Realistically, a method to comprehensively evaluate environmental toxicity having sights from both functional and structural aspects has not been established. Currently, ecotoxicity assessment relies on analyses of elementary

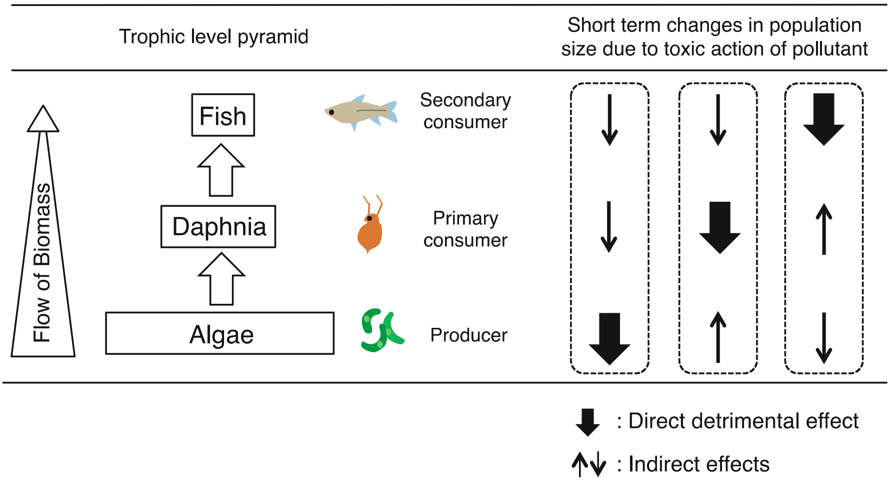

Fig. 6.3 Direct and indirect detrimental effects of pollutants on organisms through food chain. The short-term impact of pollutants on a population of a trophic level indirectly affects populations of other trophic levels through insufficiency of biomass flow or the decrease of feeding activity

process of toxic effects on each organism as a matter of fact. Biomonitoring that observes biota and ascertains whether the aquatic life is endangered is operated to complement bioassay. (USEPA 1978).

Since a species is linked to another species in the environment such as predator-prey relationship or competition for resources, therefore, an impact on a certain species may influence other species directly or indirectly in the ecosystem. The predator-prey relationship, in other words "food chain", is often taken into account for ecotoxicity evaluation (Fig. 6.3). Organisms in three different trophic levels, for example, producer (algae), primary consumer (cladoceran), and secondary consumer (fish), are preferably chosen as keystone species in freshwater aquatic ecosystem. Biomass is transferred to upper trophic level through feeding behavior. A detrimental impact on the population of an organism, which is immediately below trophic level, may cause a decreased biomass flow to the upper level. However, it should also be noticed that an ecological niche could be competed by several species. Hence, a chemical impact on a species might increase the population of other species through the reduced competitive pressure. On the other hand, a pollutant may exhibit detrimental effects on multiple species in the same level, which may cause a reduction of the population of the trophic level. Acute toxicity tests are practical but not flawless, as chronic and subchronic toxicity should also be taken into account.

Aquatic toxicity is examined under a static, semi-static, or flow-through condition. Static test is a test performed without replacing the test solution in the test vessel throughout the exposure period. Semi-static test is a test performed by replacing the test solution in the test vessel at a certain interval. Flow-through test is a test performed by constantly exchanging the test solution in the test vessel throughout the exposure period. If the concentration of the test substance is unstable, a semi-static or flow-through test is recommended. Test chemicals added to the test solution can be lost by volatilization, photolysis, precipitation, or metabolism. The standard test method of the Japanese Ministry of the Environment recommends that the concentration of the test substance be preferably maintained at $\geq$80% of the initial concentration (METI 2013). Determining actual concentration of the toxicant in the test solution is a better indicator than nominal concentration.

Lethality is the most widely used indicator (endpoint) in toxicity tests. Lethality test possesses several very useful properties for a toxicity testing. Apparently, death is an important adverse effect on organisms. It is equally applicable to all test organisms, and any toxicant is applicable to the test. It can be measured rather easily without the use of specialized equipment. Terrestrial organisms are dosed by oral administration or hypodermal injection for toxicity tests. On the other hand, aquatic organisms are placed in a solution containing a toxicant for an aquatic toxicity testing. Therefore, the endpoint of aquatic toxicity test is LC_{50} instead of LD_{50}. An endpoint can be other parameters besides lethality. Toxic effect on cladocerans is examined on the basis of immobilization rate (the rate of organisms not to demonstrate swimming action). Halting swimming/moving does not necessarily mean it is dead. In this case, median effective concentration (EC_{50}) is used as the endpoint. Median inhibitory concentration (IC_{50}) is used as the endpoint, when inhibitory effect is examined. LC_{50}, IC_{50}, and EC_{50} are often determined by dose-response curve according to probit fitting or logit fitting (Casarett et al. 2001). These two plots give very similar value and are practically interchangeable for determination of LC_{50}, IC_{50}, and EC_{50}, while a marginal difference can be seen at higher or lower values, such as LC_{20} and LC_{80} (Fig. 6.4). Lowest-observable-effect-concentration (LOEC) and no-observable-effect-concentration (NOEC) are obtained by a statistical test such as Dunnett's procedure (Dunnett 1955).

A pollutant renders sublethal symptoms to aquatic organisms at lower concentrations. Histopathological abnormalities (e.g., dysplasia of filament cartilage of gills, glycogen depletion, or renal lesion of fish) and behavior alteration (e.g., swimming velocity of water flea, rostrum raising, and frantic swimming of fish)

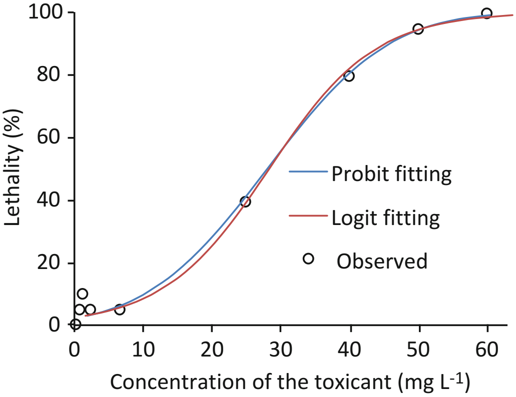

Fig. 6.4 Example of regression analysis of dose-response curve with probit model fitting and logit model fitting. Fitting curve was derived from the same data. The observed value was indicated with open circles (Data are modified from Mori et al. (2015))

are observable (Spies et al. 1996; Baillieul and Blust 1999). Reproductive toxicity is also an important endpoint of sublethal toxicity to aquatic organisms (e.g., Arcand-Hoy and Benson 1998; Fort et al. 2001).

The bioassay manual issued by USEPA (1978) describes a pithy, important, and yet pleasant notion for the selection of endpoints: “There are many effects other than death that can be and have been used. The possibilities are only limited by man’s ingenuity, time, and money.”

Test organisms of bioassays are favorable to be of significance to the local environment. Having a local/regional point of view, test organisms suited for Asian watershed have not been extensively developed. Bioassays with local organisms predict the impact on the ecosystems more relevantly, rather than foreign organisms. Criteria for suitable organism for bioassay are easiness to maintain in the laboratory, manipulable body size, reasonable sensitivity, constant and facile availability, and cost-effectiveness. Size does matter in such a way that small size of the animal makes the procedure easy under a limited laboratory space. Since the assays are carried out by an ordinary laboratory worker, the test organisms should not be too vulnerable to the laboratory condition. Test organisms with leveled quality must be available as the need arises with cheap price.

Meeting these criteria, a few papers have reported the utilization of local organisms suited for Southeast Asian aquatic environments in bioassays. Alkassasbeh et al. (2009) utilized common carp (*Cyprinus carpio*) to conduct a toxicity evaluation of landfill leachates. They used fries (immature fish) of which body length was approximately 3.8 cm. The fries were obtained from a local carp breeder. Common carp is easy to maintain and handle in a laboratory and is naturally distributed widespread in the world. Genetic evidence indicates evolutional differentiation of two subspecies of carp, *C. c. carpio* (European/Central Asia) and *C. c. haematopterus* (East/Southeast Asia) (Kohlmann et al. 2003). European/Central Asian carp and East/Southeast Asian carp were domesticated in very early days in history. How early was it? There is evidence that the Romans have already domesticated carp which became the ancestors of today’s carp in the Danube River (Balon 1995). Amazingly, *C. c. haematopterus* have been cultivated as early as 4000 years ago during the Shang dynasty in China (Chia-nan 2015). The carp in North America were introduced from Europe in the late nineteenth century as foodstuff and became popular in game fishing (US National Park Service 2015). Today, people recognize carp in North America as an invasive species. The East/Southeast Asian subspecies of carp is a good candidate to assess freshwater toxicity to fish in Southeast Asian environments, although Suliasih et al. (2010) reported that common carp exhibit less sensitivity to landfill leachate than the other candidate fish, *Rasbora sumatrana*, as mentioned below.

Suliasih et al. (2010) and Budi et al. (2015) used a battery test consisting of the freshwater fish, *R. sumatrana*; the freshwater prawn, *Macrobrachium lanchesteri*; and tomato, *Solanum lycopersicum* for toxicity identification evaluation (TIE) of a landfill leachate. *R. sumatrana* is distributed in Malay Peninsula, Borneo, Sumatra, Thailand, and Cambodia (Shukor et al. 2008). It is easily procured at local aquarium shop as ornamental fish and as a feed for carnivorous fish; and it is easy to maintain in the laboratory. The authors used adult *R. sumatrana* of which size is ~4.5 cm long and ~0.5 g in weight. In their study, in order to carry out TIE, the period of fish mortality testing was as short as 24 h (USEPA 1991), instead of 94-h test as suggested in OECD test guideline 203 (OECD 1992). These two studies used a riceland prawn, *M. lanchesteri*, instead of the popularly used cladocerans (e.g., USEPA 1991). *M. lanchesteri*, locally known as "*udang gantung*" (meaning hanging prawn), is sold at local aquariums as feed for carnivorous fish and sometime as foodstuffs and is distributed in Thailand, peninsular and state of Sabah in Malaysia, Laos, and Brunei (ZipcodeZoo 2015). The size of the prawn was ~2.5 cm long and ~0.1 g in weight, thus convenient to utilize. As it is procured readily and cheaply, it is a good candidate for the test organism in the area. Suliasih et al. (2010) exposed the prawn for 24 h to the dilution series of the leachate and determined the LC_{50}. Toxicity of a landfill leachate was successfully characterized by the phase I tests of TIE. They concluded that the leachate contained toxic compounds with various chemical characteristics. Tongbai et al. (2012) utilized *M. lanchesteri* to examine the toxicity of the organophosphate pesticide, chlorpyrifos. They tested the inhibitory effect of the pesticide on acetylcholinesterase (AChE) activity of the prawn extracts as well as the lethality test and examined neurotoxicity to riceland prawn. These domestic freshwater species are favourable candidates in regard to their local significance in Southeast Asian watershed.

OECD Guidelines for the Testing of Chemicals, Sect. 2, is a tool for assessing toxicity to biotic systems in the environment. It has test numbers with 3 digits starting from 200. Sects. 1 and 3 in the guidelines are on chemical properties, and Sect. 4 is for human health. Sect. 5 of OECD Guidelines is for other tests. Currently, 41 tests are available in the Sect. 2 (Table 6.1). These cover from aquatic to terrestrial organisms and broad kingdoms of organisms, including earthworms, insects, frogs, and avians; and not only on acute toxicity but also on longer exposure, soil respiration, and reproductive toxicity.

An approach of risk evaluation by chemical analysis becomes more challenging, since recent chemical pollution is characterized by wide variety of chemical species, relatively low amount, and broad spatial distribution. Each chemical in environmental samples is identified and quantified by chemical analysis. In order to identify and quantify hazardous metals, atomic absorption spectrometry (AAS) is sufficient. The number of organic compounds is so large, and thus separation of chemicals is usually necessary. Organic toxicants in samples are usually concentrated with solid-phase extraction (SPE) and fractionated utilizing a C_{18} reverse-phase cartridge and then analyzed with high-performance liquid chromatography (HPLC), gas chromatography-mass spectrometry (GC-MS), or liquid chromatography-mass spectrometry (LC-MS). Other SPE cartridges such as styrene-divinylbenzene copolymer (Sep-Pak PS-2) or Oasis HLB are often used alternatives for C_{18}. It is not realistic to analyze all chemicals contained in the environmental samples. Toxicity data for many chemicals identified are usually not available. Remember that millions of chemicals are registered annually. Interactions of chemicals (additive, synergism, and antagonism) are not largely understood. Toxic effect of chemicals on organism

Table 6.1 List of OECD guidelines for the testing of chemicals (Sect. 2: Effects on Biotic Systems)

No.	Test name	No.	Test name
201	Freshwater Alga and Cyanobacteria, Growth Inhibition Test	221	*Lemna* sp. Growth Inhibition Test
202	*Daphnia* sp. Acute Immobilisation Test	222	Earthworm Reproduction Test (*Eisenia fetida/Eisenia andrei*)
203	Fish, Acute Toxicity Test	223	Avian Acute Oral Toxicity Test
204	Fish, Prolonged Toxicity Test: 14-Day Study	224	Determination of the Inhibition of the Activity of Anaerobic Bacteria
205	Avian Dietary Toxicity Test	225	Sediment-Water *Lumbriculus* Toxicity Test Using Spiked Sediment
206	Avian Reproduction Test	226	Predatory mite (*Hypoaspis (Geolaelaps) aculeifer*) reproduction test in soil
207	Earthworm, Acute Toxicity Tests	227	Terrestrial Plant Test: Vegetative Vigour Test
208	Terrestrial Plant Test: Seedling Emergence and Seedling Growth Test	228	Determination of Developmental Toxicity of Dipteran Dung Flies (*Scathophagastercoraria* L. (Scathophagidae), *Musca autumnalis* De Geer (Muscidae))
209	Activated Sludge, Respiration Inhibition Test (Carbon and Ammonium Oxidation)	229	Fish Short Term Reproduction Assay
210	Fish, Early-life Stage Toxicity Test	230	21-day Fish Assay
211	*Daphnia magna* Reproduction Test	231	Amphibian Metamorphosis Assay
212	Fish, Short-term Toxicity Test on Embryo and Sac-Fry Stages	232	Collembolan Reproduction Test in Soil
213	Honeybees, Acute Oral Toxicity Test	233	Sediment-Water Chironomid Life-Cycle Toxicity Test Using Spiked Water or Spiked Sediment
214	Honeybees, Acute Contact Toxicity Test	234	Fish Sexual Development Test
215	Fish, Juvenile Growth Test	235	*Chironomus* sp., Acute Immobilisation Test
216	Soil Microorganisms: Nitrogen Transformation Test	236	Fish Embryo Acute Toxicity (FET) Test
217	Soil Microorganisms: Carbon Transformation Test	237	Honey Bee (*Apis mellifera*) Larval Toxicity Test, Single Exposure
218	Sediment-Water *Chironomid* Toxicity Using Spiked Sediment	238	Sediment-Free *Myriophyllum spicatum* Toxicity Test
219	Sediment-Water *Chironomi*d Toxicity Using Spiked Water	239	Water-Sediment *Myriophyllum spicatum* Toxicity Test
220	*Enchytraeid* Reproduction Test	240	Medaka Extended One Generation Reproduction Test (MEOGRT)
		241	The Larval Amphibian Growth and Development Assay (LAGDA)

depends on the concentration of chemicals and species of organisms. Therefore, it is hardly predictable from chemical composition.

Bioassays possess several advantages over chemical analysis. They allow evaluating comprehensive toxicity of the samples, and characterization of the toxic action to test organisms. Chemical analysis data does not necessary predict the toxicity. Sometimes, bioassay is cost-effective as compared to chemical analysis. In addition, bioassays do not require special equipment in general. Nevertheless, bioassays also possess disadvantage over chemical analysis. The test result is not able to provide information of influential toxicity factors in the water sample. Some bioassays take long periods to obtain the results. Chemical analysis, bioassay, and biomonitoring are complementary to each other for risk evaluation of chemical in aquatic ecosystem.

It is required to handle a large number of water samples in order to conduct a watershed-wide risk evaluation. According to a case to watershed-wide examination of water by conventional method, Many samples through entire watershed were analyzed in Langat River (Selangor, Malaysia) (Juahir et al. 2011). Currently, it is difficult to say that the characteristics of bioassays are satisfactory to conduct a high-throughput toxicity test. A high-throughput procedure and cheaper running cost of bioassay are needed. As high-throughput bioassay requires a large number of organisms, ethics is also an issue in addition to the availability. Water sampling is also a practical difficulty. Comprehensive sampling of the watershed is not easy, and correcting some liters of water for each sampling site and processing in the laboratory are painstaking job. Due to these difficulties, watershed-wide risk evaluation utilizing bioassays have not been standardized yet. To make watershed-wide chemical risk evaluation realistic, several assignments should be cleared. To reduce the laborious effort to collect samples, minimization of sampling scale and accordingly optimization of bioassay for small volume are also requested. Bioassays are still time-consuming and costly. Maintenance of test organisms can be a burden. Alternative tests that take place in living organisms should be developed to solve these assignments. At the same time, they are ethically more apt than sacrifice organisms. To date, automation of the bioassay has not been applied. The automation may be a critical step for high-throughput toxicity evaluation. The development of toxicity-oriented biosensors would aid the development of high-throughput toxicity testing.

6.3 Biosensors for Environmental Toxicity Assessment

Biosensor is an analytical device which combines a biological recognition element material with a transducer to translate the biological signal to electric signal. This signal comes from a change in concentration of proton, release and uptake of gases, light emission, absorption, etc. brought about by the metabolism of the target compound by the biological recognition element (Lei et al. 2006; Malandain et al. 2005). Biosensors are the offspring of the combination between biotechnology and modern electronic. The biological element responds to the analyte, and the

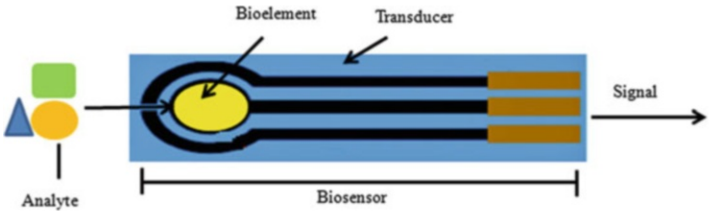

Fig. 6.5 Basic components of a biosensor with electrochemical transducer

transducer converts the biological signal to signals such as current, potential, and absorption that can be detectable by using optical and electrochemical method. Several transducers have always been explored in fabrication of a biosensor such as electrochemical (amperometric, potentiometric), thermal, piezoelectric, surface aquatic wave, and optical method (Lei et al. 2006; Su et al. 2011). Basic components of an electrochemical biosensor are shown in Fig. 6.5.

Toxicity biosensors are routinely used for the detection of environmental toxicants (Rogers 2006; Lei et al. 2006). Various biological matrices such as enzymes, antibodies, DNA, receptors, organelles, and microorganisms have been commonly used in the development of toxicity biosensor (Lei et al. 2006). Among these biological sensing elements, enzymes are the most popularly utilized recognition element, because of their unique specificity and sensitivity (Rogers 2006). However, the enzyme biosensor possesses several drawbacks, e.g., enzyme purification needed, high cost, and time-consuming. The in vitro operating environment could degrade enzyme activity (Rogers 2006; D'Souza 2001). In the meantime, the specific binding between antibody and antigen can be applied in immunosensor. The immunosensor can detect low concentration of analyte such as drugs, toxins, pesticides, herbicides, explosives, etc., while DNA biosensors have also been often developed for the detection of toxicants in environmental samples. The advantages of both antibody and DNA as the sensing elements are: good specification, high sensitivity, and good reproducibility (Rogers 2006; Lei et al. 2006). However, the antibody and DNA are low in stability, high cost, complicated (for DNA extraction) and time-consuming.

Another biological sensing element very commonly used to detect environmental toxicant is microorganism. A basic microbial biosensor is designed by immobilizing microorganism cell on a transducer surface to recognize toxicant in the environmental samples. The microorganisms such as algae, bacteria, and yeast are frequently used in the fabrication of toxicity biosensor, since they can be massively produced through cell culturing. Other advantages of the use of microorganism in the recognition sensing element are: the ability to detect a wide range of chemical substances, amenability to genetic modification, and broad operating pH and temperature range, making them ideal as biological sensing materials (Su et al. 2011). Compared to other cells from higher organism including plants, animals, and human beings, microorganism cells are easier to be mutated and have better viability and stability. The biosensor-based microbial cells greatly simplify the fabrication process and enhance the performance of biosensors (Su et al. 2011; D'Souza 2001). Microbial cells consist of numerous enzymes and cofactors/coenzymes, endowing themselves with the ability to respond to a number of chemicals, which can be utilized as the signal for sensing purposes. However, microbial-cell biosensors are non-specific in detecting a specific type of toxicant, giving it a drawback.

The toxicity biosensor is usually fabricated via direct contact between microbial cell and the transducer. Therefore, immobilization of microorganism onto the transducer plays an important role in the development of the toxicity biosensor (D'Souza 2001). Many immobilization methods of microorganism involve adsorption, encapsulation, entrapment, covalent binding, and cross-linking technique (Lei et al. 2006; D'Souza 2001). Besides these methods, many novel immobilization techniques have been reported in the recent years in order to improve the performance and stability of the toxicity biosensor. Futra et al. (2014) have developed a microencapsulation technique, which is combined with cellulose nitrate membrane for the immobilization of *Aliivibrio fischeri* for the detection of heavy metals. Futra et al. (2015) proposed a natural polymeric film alginate modified cellulose membrane for the adsorption of GFP *Escherichia coli.* The GFP biosensor was applied to detect single and mixed toxicants in water samples. Ooi et al. (2015a) described an encapsulation strategy using *k*-carrageenan matrix for the immobilization of roGFP2 *Escherichia coli.* Yu et al. (2005) developed a sol-gel for the entrapment of *Moraxella* spp. cells. The resulting toxicity biosensor demonstrated improving cell activity and stability. Conducting polymer has also attracts great attention for its application in the immobilization of microorganism, due to its unique electrochemical properties (Ahuja et al. 2007).

The detection of toxicants in the environmental samples using toxicity biosensors has been successfully developed using various biological elements including DNA, antibody, enzyme, and microorganism. In this part, all the biological elements (DNA, antibody, enzyme, and microorganism) will be reviewed. Deoxyribonucleic acid (DNA) is anion polyelectrolyte, which is the carrier of genetic information and the foundation material of biological heredity. DNA consists of four bases type including adenine, thymine, cytosine, and guanine (Harteis and Schneider 2014). All of these bases will be coupled via hydrogen bonding to form double-strand DNA. The basic for genetic analysis of organism is based on the base pairs adenine/thymine and cytosine/guanine via hybridization reaction. The DNA sequences differ in living organisms and this criteria provides practical way to identify, evaluate, and diagnose various diseases (Harteis and Schneider 2014; Kerman et al. 2004).

Whole-cell biosensors are commonly utilized in evaluation of microbial habitat and provide measurements of the bioavailable fraction of toxicant compound. It is routinely used for the screening of toxicity in the environmental samples and also often used in early warning toxicity of aquatic system (Lei et al. 2006; Belkin 2006). It could produce measurable gene product encoded by reporter gene, which comes from natural microorganism or introduced by genetic manipulation. The reporter genes often used to evaluate environmental toxicity including *lacZ* gene from *Escherichia coli*, *lux* gene from *Vibrio fischeri*, and *gfp* genes from *Aequorea victoria* (Sorensen et al. 2006; Shin 2011). The biosensor based on microorganism is usually sensitive to various toxicants and is very suitable for the evaluation of environmental toxicity, because enzyme and cofactor needed by microorganism for the detection of toxicant are available inside the cell of microorganism (Lei et al. 2006). The main advantages of microbials as sensing elements are its capability in detecting a wide range of chemicals and its amenability to genetic modification (Shin 2011). Microorganism-based toxicity biosensors have been developed to detect heavy metals, pesticides, and organic compounds. The summary of toxicity biosensor based on various microorganisms for the detection of toxicants is shown in the Table 6.2.

Optical toxicity biosensor based on bacterium has been reported by using marine bacterium *Aliivibrio fischeri* (Futra et al. 2014) and *Escherichia coli* transformed with green fluorescence protein (GFP) genes (Futra et al. 2015) for the detection of heavy metals in water samples. The optical biosensor was designed using microencapsulated alginate microsphere modified CNM (Futra et al. 2014) and alginate film functionalized CNM (Futra et al. 2015) transduced with spectrofluorimetric method. These biosensors were successfully utilized for the evaluation of trace metals with a low detection limits (at ppb to ppm level) and wide linear range. Ooi et al. (2015a, b) also developed a simple and easy optical biosensor based on GFP *Escherichia coli* using *k*-carrageenan as matrix immobilization which is used for the monitoring of sodium dodecyl sulfate in the drinking water and metaloids in water samples. This biosensor also obtained a low detection limit at ppm to ppb levels, with high reproducibility and stability. Eltzov et al. (2015) and Souiri et al. (2012) proposed other toxicity biosensors based on *Escherichia coli* bacteria that are constructed by using alginate bead (Eltzov et al. 2015) and ITO functionalized with PAH(PSS-PAH) (Souiri et al. 2012) for the detection of heavy metals in the water samples. These toxicity biosensors also demonstrated a low detection limit at pM level, with good reproducibility.

Electrochemical toxicity biosensor based on bacteria is also commonly used for the detection of heavy metal and benzene derivatives. The electrochemical biosensor was designed using alginate functionalized cellulose sulfate-PMCG (Schenkmayerova et al. 2015) and reported a low detection limit at uM level. An integrated electrochemical biosensor platform fabricated based on *Arthrospira platensis* bacteria immobilized on gold electrode via physical adsorption (Tekaya et al. 2013) evaluated toxicity based on the alkaline phosphatase activity (APA) from the cyanobacterium. This enzyme activity will be inhibited in the presence of heavy metals, conductivity was taken after addition of the substrate. The biosensor has obtained a low detection limit at fM level, with rapid response time.

Algae have been widely employed for the detection of heavy metals and pesticides in water via a simple optical biosensor based spectrofluorimetry. The optical-fluorescent biosensor developed using *Anabaena torulosa* was fabricated with pHEMA modified cellulose nitrate membrane and without pHEMA (Wong et al. 2013a, b) and designed using *Chlorella vulgaris* based on silica matrix (Nguyen-Ngoc et al. 2009). The optical biosensor based on algae have also achieved a wide linear range and a low detection limit at ppb level.

Table 6.2 The microbial biosensor recently used for the evaluation of various toxic materials

Material used for biosensor fabrication	Microorganism	Type of Biosensor	Toxicants	LOD	References
Alginate microspheres-CNM	*Escherichia coli* GFP	Fluorimetric	Cu(II)	0.04 ppb	Futra et al. (2015)
			Pb(II)	0.32 ppb	
			Pb(II)	0.46 ppb	
			Zn(II)	2.80 ppb	
			Ag(I)	720 ppb	
			Ni(II)	400 ppb	
			Co(II)	250 ppb	
Alginate film-CNM	*Aliivibrio fischeri*	Fluorimetric	Cu(II)	6.40 ppb	Futra et al. (2014)
			Cd(II)	1.56 ppb	
			Pb(II)	47 ppb	
			Zn(II)	320 ppb	
			Ag(I)	18 ppb	
			Ni(II)	2800 ppb	
			Co(II)	1700 ppb	
k-Carrageenan	*Escherichia coli* GFP	Fluorimetric	Sodium dodecyl sulfate	1.7 ppm	Ooi et al. (2015b)
Cellulose nitrate membrane	*Anabaena torulosa*	Fluorimetric	Cu(II)	1.19 ppb	Wong et al. (2013a)
			Pb(II)	0.03 ppb	
			Cd(II)	0.10 ppb	
			2,4-D	0.03 ppb	
			chlorpyrifos	0.03 ppb	

pHEMA-CNM	*Anabaena torulosa*	Fluorimetric	Cu(II)	1.41 ppb	Wong et al. (2013b)
			Cd(II)	0.25 ppb	
			Pb(II)	0.50 ppb	
			2,4-D	0.24 ppb	
			chlorpyrifos	0.12 ppb	
Physically adsorbed on GE	*Arthrospira platensis*	Conductometric	Hg(II)	0.01 fM	Tekaya et al. (2013)
Alginate bead	*Escherichia coli*	Fluorimetric	Cu(II)	1.00 pM	Eltzov et al. (2015)
			As(II)	0.01 pM	
			Zn(II)	0.01 pM	
Silica matrix	*Chlorella vulgaris*	Fluorimetric	Cd(II)	25 ppb	Nguyen-Ngoc et al. (2009)
			Paraquat	1.0 ppb	
Alginate- CS-PMCG	*Gluconobacter oxydans*	Amperometric	2-phenyl-ethanol	1.0 µM	Schenkmayerova et al. (2015)
ITO-PAH(PSS-PAH)- bacteria	*E. coli* strain PHL818	Impedimetric	Cd(II)	1.0 pM	Souiri et al. (2012)
			Hg(II)	1.0 pM	
Alginate-acrylic	*Lentinus sajor-caju*	Potentiometric	Permethrin	1 µM	Arip et al. (2013)
AFM-PVA gel	*Saccharomyces cerevisiae*	Potentiometric	BOD	1 ppm	Chiappini et al. (2010)

Note: *CNM* cellulose nitrate membrane, *pHEMA* poly(2-hydroxyethyl methacrylate), *GE* gold electrode, *CS* cellulose sulfate, *PMCG* poly(methylene-co-guanidine), *ITO* indium tin oxide, *PAH* poly-(allylamine hydrochloride), *PSS* poly-(sodium-4-styrenesulfonate), *AFM* acetate film membrane, *PVA* polyvinyl alcohol

Apart from algae, fungi have also been exploited for electrochemical biosensor constructed for the detection of pesticide and organic pollutant environmental samples (Arip et al. 2013; Chiappini et al. 2010). For instance, Arip et al. (2013) have proposed *Lentinus sajor-caju* based on encapsulated alginate grafted on acrylic microspheres and measured with potentiometry technique. The fungi biosensor demonstrated a wide linear response, with low detection limit at μM level; this contributed for the fungi to have high ability to degrade permethrin to yield the degradation product of 3-(2,2-dichlorovinyl)2–2-dimethylcyclopropanecarboxylic acid. Produced weak acid could be easily detected by the plasticizer-free H^+ selective membrane. Microbial biosensor for organic pollutant based on BOD and CO_2 production was also exploited using acetate film functionalized PVA gel and used for the immobilization of *Saccharomyces cerevisiae* (Chiappini et al. 2010). The proposed microbial biosensor was successfully utilized for the detection of BOD in a low detection limit at ppm level, with satisfactory result.

6.4 Future Prospect

Toxicity biosensor has employed various biological molecules as sensing element such as DNA, antibody, enzyme, and microorganism and is used for the detection of various environmental toxicants. It has also utilized various matrices for biomolecule immobilization to enhance and to improve analytical performance of toxicity biosensor. The toxicity biosensor can play an important role in biological early warning system for real-time toxicity detection and water quality assessment. Therefore, developing a simple and sensitive optical biosensor based on visual test and color change can be handy even for unskilled users making it easier for environmental toxicity testing. In the meantime, electrochemical biosensor is needed to create a simple and compatible electronic kit as assessment tool for environmental toxicity. From the literature, it is clear that toxicity biosensor has great potential and plays a helpful role in the detection of environmental toxicity in biological and aquatic system. Toxicity biosensor for the evaluation of environmental toxicity will continue to show advances with improvement in recognition elements such as antibody, DNA, enzyme, natural microorganism, and gene modification of microorganism. From the previous reports, the immobilization matrix used for the development of electrochemical toxicity biosensor always utilized semiconducting polymer and natural polymer. Therefore, conducting polymer and molecularly imprinted polymer can be good candidates as the immobilization matrix. Further research work is also still required to explore the potential of nanosensors and other novel approaches which could be used to assess environmental safety and also to improve environmental quality.

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Chapter 7
Epidemiological Approaches to Characterize Human Health Risks from Environmental Exposure in a Watershed

Kayo Ueda and Hirohisa Takano

Abstract Water quality has impact on human health. Contamination of drinking water by microorganisms and chemicals can cause various diseases, such as diarrhea, infectious diseases, and cancer. Recently, there has been increasing attention in health risk of water-related diseases because climate change is expected to alter rainfall, surface water availability, and water quality. Epidemiological studies have been used to evaluate health risks including water-related diseases at population level. Collecting accurate information on exposure and health outcomes is a key component to obtain valid effect estimates. The section describes basic elements of epidemiological methods, including study design, health outcome measures, and exposure assessment, especially focusing on health risk of water-related diseases.

Keywords Epidemiology · Exposure assessment · Health outcomes · Association

7.1 Introduction

Water quality has impact on human health. Contamination of drinking water by microorganisms and chemicals can cause various diseases, such as diarrhea, infectious diseases, and cancer. There have been histories in which environmental contamination of metals and chemical substances around watershed posed a threat to human health: Itai-itai disease caused by cadmium poisoning in Japan, contamination of groundwater by arsenic in Bangladesh, and chemical mixtures leaking in Elk River of the USA (Manuel 2014). WHO International Agency for Research on Cancer (IARC) evaluated the carcinogenic effects of chemical contaminants in water using epidemiological and experimental studies (IARC 2013). Besides, microorganism-contaminated waters may cause waterborne diseases, such as cholera (by *V. cholerae*), gastroenteritis (by viruses), and liver failure (by hepatitis A virus). Recently, there has been also increasing attention in health risk of waterborne

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diseases because climate change is expected to alter rainfall, increase floods, and affect surface water availability and water quality (Levy et al. 2016). It is anticipated that climate change can have a greater impact on coastal and watershed areas. And that is likely to threaten human health.

Watersheds are linked with human health mainly through aquatic contaminants and are considered as a conceptual framework for the study of human health (Kolok et al. 2009). Various human activities, including agriculture, mining, drilling, timbering, and urban development, affect water quality of watershed areas (Jordan and Benson 2015). The impairment of water quality consequently brings negative impacts on human health. For example, chemical substances used in agriculture and industry along the watershed can contaminate groundwater and/or surface water either directly or indirectly through deposition in watersheds. This may cause chronic diseases, such as cancer, through drinking water. Microbial contamination from sewage systems in drinking water also causes outbreaks of waterborne gastrointestinal diseases (Gertler et al. 2015).

Epidemiology is the study of disease occurrence (health outcomes) and the determinants of disease. Epidemiological approaches have been used to evaluate environmental health risks by "observing" exposure and outcomes among people in the real world, while toxicological approaches are characterized by random exposure assignment. Collecting accurate information on exposure and health outcomes is a key component to obtain valid effect estimates for epidemiological studies. Epidemiological approach is a tool for taking effective measures to control the emerging health problems.

The section describes basic elements of epidemiological methods, including study design, health outcome measures, and exposure assessment, especially focusing on health risk of water-related diseases. Exposure assessment with consideration of watershed is also discussed.

7.2 Study Design

A study design may be chosen according to the study objectives. There are two main types of epidemiological studies: observational studies and intervention studies (Table 7.1). In an intervention study, the investigator assigns the subjects to an

Table 7.1 Main types of epidemiological study design

Observational (nonexperimental) studies
Descriptive studies
Analytic studies
Cross-sectional studies
Case-control studies
Cohort studies
Intervention (experimental) studies
Individual level, household level
Aggregated level (community trials)

exposure (or an intervention) and observes what happens to them. On the other hand, in an observational study, the investigator just observes what happens to the subjects. Selecting a study design may rely on ethical and practical issues such as costs or data availability (Morgenstern and Thomas 1993).

Observational studies are further classified into descriptive studies, cross-sectional studies, case-control studies, and cohort studies. In a descriptive study, the patterns of disease occurrence in relation to person, place, and time are described without regard to causal or other hypotheses. The main object of descriptive studies is to figure out the distribution of disease occurrence and make hypothesis of the potential cause of diseases. In a cohort study, a group of people who share a common characteristic (cohort) is followed up over time. Information on the exposure of interest is obtained at the starting point, and the incidence of the disease (outcome) in the exposed individuals is compared with the incidence in those not exposed (Fig. 7.1, upper). In a case-control study, identifying "cases" who have a disease (outcome) of interest and appropriate "controls" without the disease is the starting point. Then, the exposure is compared between cases and controls to examine the exposure associated with the diseases (Fig. 7.1, lower). In a cross-sectional study, a sample of individuals is selected and collected the information on both the exposure and outcome of interest at a particular point in time.

Intervention studies are classified by the level of assignment (Table 7.1). There are many studies focusing on whether improvement of drinking water and sanitation decreases risks of diarrhea (Wolf et al. 2014). In those studies, interventions include the use of water filters, provision of high-quality piped water, and sewer connections to improve water quality.

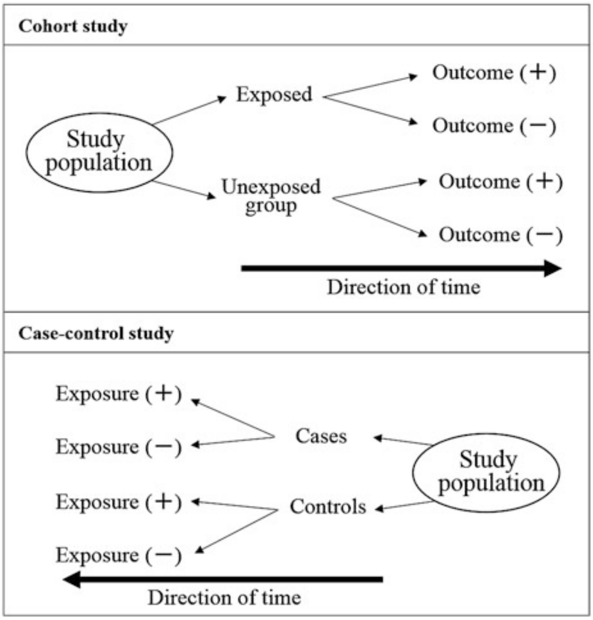


Fig. 7.1 Outline of a cohort study and case-control study

7.3 Exposure Assessment

Exposure is defined as contact between an agent and a target, where contact takes place on an exposure surface over an exposure period (IPCS 2004). Exposure assessment is a fundamental component of health risk assessment and epidemiological studies for environmental hazards. Especially, exposure assessment is used to identify exposure-incidence (dose-response) relationships. Epidemiological studies focus on how much the temporal or spatial variability in exposure level would change the frequency of the outcomes. Methods of exposure assessment are generally determined by the health outcomes of interest (Villanueva et al. 2014). For example, cancer generally has a long latency period, and, consequently, long-term exposure (several years or decades) has to be evaluated. When investigating the source of gastrointestinal infection, on the other hand, it is important to capture the temporal variation in exposure over shorter period covering the relevant time windows.

There are three exposure routes, which are inhalation, ingestion, or dermal uptake. Environmental agents including microorganisms and chemicals enter into human body through a medium, such as water, food, or air. Some substances can take multiple pathways. For example, there are several possible exposure pathways for pesticide: agricultural-related exposure, residential pesticide use, and drinking water. Agricultural-related exposure can be estimated using distance to agricultural fields. Information on residential use and drinking water can be obtained from questionnaires.

To obtain accurate and comprehensive exposure information, there are several approaches. Direct methods utilize the information from personal monitoring and biological markers, while indirect methods use the information from environmental monitoring, exposure models, and questionnaires as a proxy of personal exposure. Previous epidemiological studies have generally relied on exposure estimates from environmental monitoring and individual questionnaires. For example, past epidemiological studies relied on the information of arsenic concentration in the drinking water as the surrogate of exposure. However, there was substantial uncertainty in exposure because water consumption varies by individuals and intake from food contaminated with arsenic was neglected. Personal monitoring is considered to provide more accurate estimates of the subject's true exposure. Biological monitoring measures the internal dose of chemicals and its metabolites in biological samples, such as blood, urine, and other body tissues. Significant progress has been also made in the use of biological monitoring to assess the exposure of individuals (Nieuwenhuijsen et al. 2006). In an example of exposure assessment of arsenic, arsenic contents were measured in blood, urine, hair, or finger/toe nails. While arsenic levels in urine/blood, with a half-life of a few days, are a marker of current exposure, those in hair and nails reflect chronic exposure (Quansah et al. 2015). However, biological monitoring has a few limitations: generally reflecting only recent exposure (especially blood and urine samples), availability of adequate samples, and financial cost. Because it is not feasible to take measurement from each subject especially in a large-scale epidemiological study, this method is often used in case-control studies. Recent studies have used modeling based on geographic distribution of contaminants, hydrological modeling of underground plumes of contaminants (Gallagher et al. 2010), and land use information (Aschebrook-Kilfoy et al. 2012). Application of satellite remote sensing is also explored for early detection of waterborne diseases. In an example of study in the Bay of Bengal, sea-surface temperature and sea-surface height derived from satellite data were used to monitor the timing and spread of cholera (Lobitz et al. 2000).

7.4 Health Outcome Measures

Health outcomes refer to health events or changes in health status that occur within a population. In the epidemiological studies in watershed areas, those include various diseases: gastrointestinal infection caused by microorganisms, cancer which can be caused by chemical substances and heavy metals, and injuries/deaths due to natural disasters around watershed (like floods). Recent studies have paid more attention on cardiovascular diseases, neurodevelopmental problems, endocrine disruption, and perinatal health.

Information on the health outcomes can be obtained from various sources. Mortality data is generally derived from death certificates in many countries. Hospital records can be used to capture the occurrence of specific diseases. Cancer registration can provide the information on the incidence and characteristics of specific cancers in various segments of the resident population and on temporal variations in incidence although the formation of a cancer registry in a developing country is a challenge because of the difficulties that need to be overcome for reasonable completeness and quality of data (Parkin and Sanghvi 1991). Population surveys and individual questionnaires are also utilized to collect the information on individuals' health status.

There are a few measures of diseases frequency in epidemiology (Table 7.2) incidence and prevalence. Incidence refers to the number of individuals who experience a specific health event or new cases of a specific disease during a particular time period. Prevalence refers to the total number of individuals in a population who have a disease or health condition at a specific period of time.

An intermediate endpoint or a marker can be also used as a surrogate of health outcome for chronic diseases, such as cancer and cardiovascular diseases. Because these diseases progress slowly and its occurrence is generally rare, it is necessary to

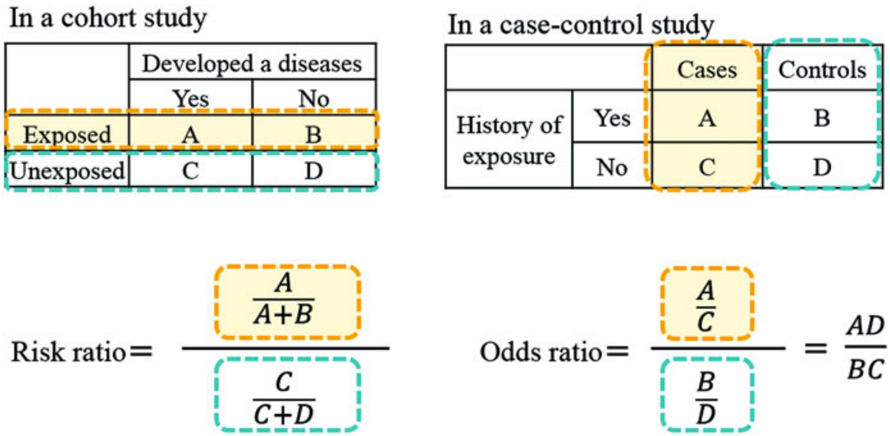
Table 7.2 Measures of frequency in epidemiological studies

	Incidence rate	Incidence proportion (Risk, cumulative incidence)	Prevalence
Definition	The frequency of new cases (diseases or health condition) in a population, but take into account the sum of time that each participant remained under observation and at risk of developing the outcome under investigation	The proportion that a particular disease or health condition has occurred over a given time	The proportion of the population that has a particular disease or health condition at a point in time
Numerator	Number of new cases	Number of new cases in a specified period of time	Number of individuals who have a disease or a health condition at a point of time
Denominator	Total person-time at risk during the follow-up period	Number of diseases-free persons at the beginning of that time period	Population at the same point in time
Units	Time^{-1}	Unitless	Unitless
Range	0–infinity	0–1	0–1

wait for a long time to collect information on disease occurrence. When using an intermediate endpoint in an epidemiological study, it is necessary to validate the assumption that the association between exposure and intermediate endpoint reflects the association between exposure and the chronic disease of interest.

7.5 Measures of Association

A measure of association is used to compare the association between a specific exposure and health outcome and to quantify its association. There are several measures of association: risk difference, risk ratio, rate ratio, and odds ratio. Risk difference is defined as the difference in risk between exposed and unexposed groups. Figure 7.2 shows an example of how to calculate a risk ratio and odds ratio in epidemiological studies. A positive risk difference means there is excess risk due to the exposure against the health outcome. A risk ratio and rate ratio are measures of the strength of the association between the exposure and the outcome. A risk ratio or rate ratio of 1 means that there is no difference in risk among the two groups. A risk ratio or rate ratio greater than 1 means an increased risk for the exposed group. A risk ratio or rate ratio less than 1 means that



In a cohort study

	Developed a diseases	
	Yes	No
Exposed	A	B
Unexposed	C	D

In a case-control study

		Cases	Controls
History of exposure	Yes	A	B
	No	C	D

$$\text{Risk ratio} = \frac{\frac{A}{A+B}}{\frac{C}{C+D}}$$

$$\text{Odds ratio} = \frac{\frac{A}{C}}{\frac{B}{D}} = \frac{AD}{BC}$$

Fig. 7.2 An example of calculating risk ratio and odds ratio

perhaps exposure actually protects against disease occurrence. The interpretation of odds ratio is the same as risk/rate ratio. Odds ratios are generally used in case-control studies.

7.6 Issues in Environmental Epidemiology Around Watershed

As described above, major challenge in environmental epidemiology is exposure assessment. Exposure of each person may be modified by factors such as activity patterns, which determine encounters with various sources of exposure, bioavailability of the agent in time and place, and the rate at which exposure occurs (Hatch and Thomas 1993). Although new methods have been developed to assess how people are exposed to environmental factors, validation of such methods should be considered. Besides, environmental epidemiology often requires large sample sizes to detect risk factor effects with sufficiently small statistical error (Morgenstern and Thomas 1993). This may make infeasible to apply accurate but expensive exposure assessment methods for large population.

Watershed is an important unit of area which characterizes the exposure in environmental epidemiology. The communities within a watershed area share the exposure through drinking water sources and other anthropogenic activities along the watershed. On the other hand, the data on health outcomes are often collected by administrative unit (districts, municipalities) or by hospitals which have different geographic boundaries from watershed. It is necessary to understand the distribution of exposure and health outcome in watershed areas and to accumulate epidemiological evidence on human health risks in watershed areas.

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Part IV

Management of Environmental Risk in a Watershed

Chapter 8
Environmental Scan and Framework of Watershed Risk Assessment in Malaysia

Lubna Alam, Mazlin Mokhtar, Goh Choo Ta, Khai Ern Lee, and Mohd Talib Latif

Abstract Water is not only a resource, it is a life source; therefore, the water should be healthy, secure, and sustainable for people. Watersheds are nature's boundaries for surface water supplies, and thus, the quality of the drinking water at a consumer's tap depends on the quality of watershed. The risk assessment which is a process used to define the probability and magnitude of adverse effects of an environment from stressors can be used to estimate the costs and benefits of changes in a watershed in terms of risk. This chapter describes the source of pollution and the framework for assessing risk in Malaysian watershed.

Keywords Pollution status · Chemical contamination · Risk assessment · Risk Management

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8.1 Overview of Water Pollution in Malaysia

Water pollution is considered to be a grievous issue in Malaysia influencing the sustainability of water resources, affecting the plants, organisms, people's health, and country's economy. The adequate water resource in the catchment in Malaysia is not able to assure the satisfactory supply to all users, and the river pollution (Fig. 8.1) is responsible for the situation (Bao 2010). There is a long history of river water pollution in Malaysia, and the trend is shown in Fig. 8.2. Out of the 473 rivers

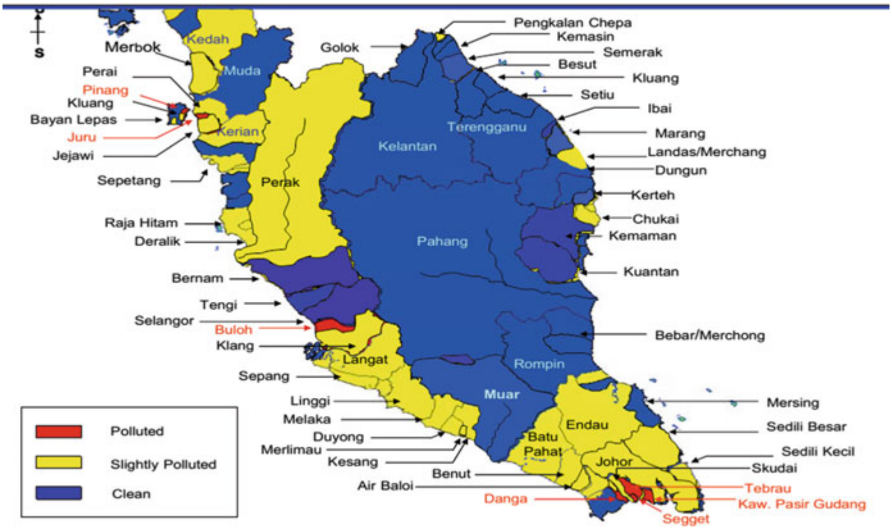

Fig. 8.1 Map showing the river pollution status in Malaysia (*Source*: Afroz et al. 2014)

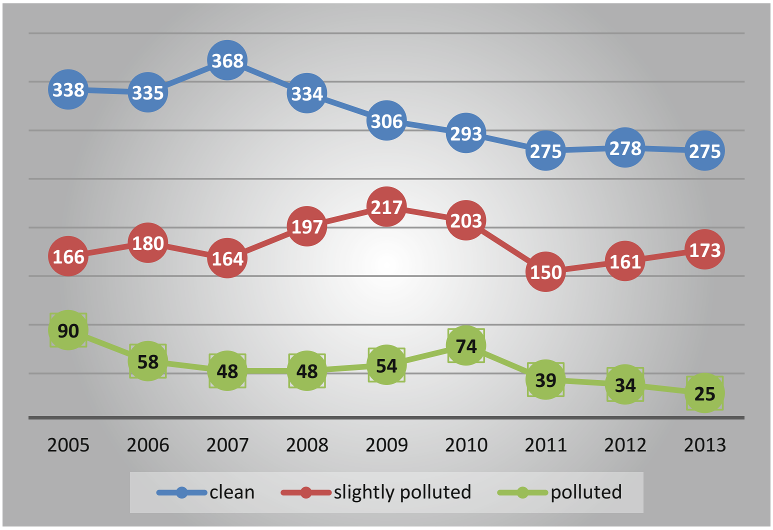

Fig. 8.2 Malaysian River water quality trend based on WQI (*Source*: EQR 2013)

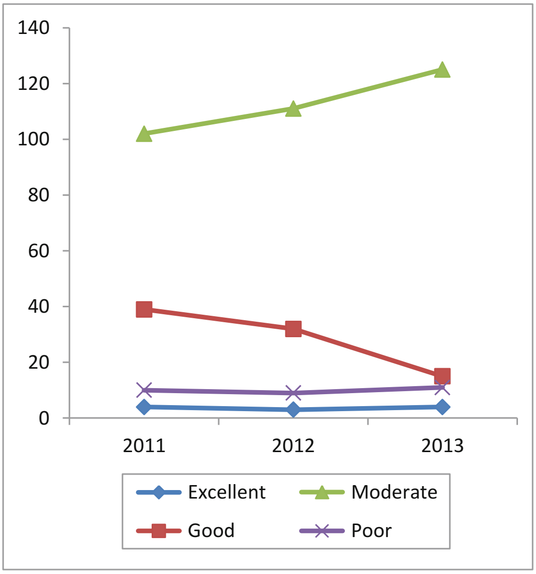

Fig. 8.3 Trend of marine water status in coastal area of Malaysia (*Source*: EQR 2013)

monitored by the Department of Environment (DOE) in 2013, 58.1% were stated to be clean, 36.6% were slightly polluted, and another 5.3% were found to be polluted (EQR 2013).

However, in case of groundwater, the department of environment has monitored 78 wells in peninsular Malaysia, 12 wells in Sarawak, and 15 wells in Sabah in the year 2013. The results demonstrated that all stations were within the National Guidelines for Raw Drinking Water Quality values except for arsenics (As), iron (Fe), manganese (Mn), total coliform, and phenol.

To identify the quality of marine water status and to determine the degree of pollution from both land-based sources as well as the seas, the Department of Environment is carrying out the marine water quality program since 1978 for Peninsular Malaysia and since 1985 for Sabah and Sarawak. Based on the observation of the year 2013, four (4) stations (2.6%) identified as excellent, 15 stations (9.7%) as good, 125 stations (80.6%) as moderate, and 11 stations (7.1%) as poor. The trend in terms of Marine Water Quality Index (MWQI) from 2011 to 2013 demonstrated that the number of excellent, moderate, and poor water quality stations had increased, while the number of good stations had decreased (Fig. 8.3).

In case of estuary, among 76 monitored stations, one (1) station (1.3%) has been identified as excellent, 7 stations (9.2%) as good, 54 stations (71.1%) as moderate, and 14 stations (18.4%) as poor. The quality of estuarine water, in terms of Marine Water Quality Index (MWQI), showed a slight increase in the moderate category from 69.6% in 2012 to 71.1% in 2013. The stations with poor quality increased from 12 in 2012 to 14 in 2013. There was a decline from eight (8) in 2012 to seven (7) in 2013 for stations in the good category. Meanwhile, for the excellent category, the figures remained unchanged in 2013 as compared to 2012 (EQR 2013) (Fig. 8.4).

Lakes are important source of water in Malaysia with their multipurpose functions. According to the National Hydraulic Research Institute of Malaysia, there are over 90 lakes in the country covering an area of at least 100,000 ha and hold about

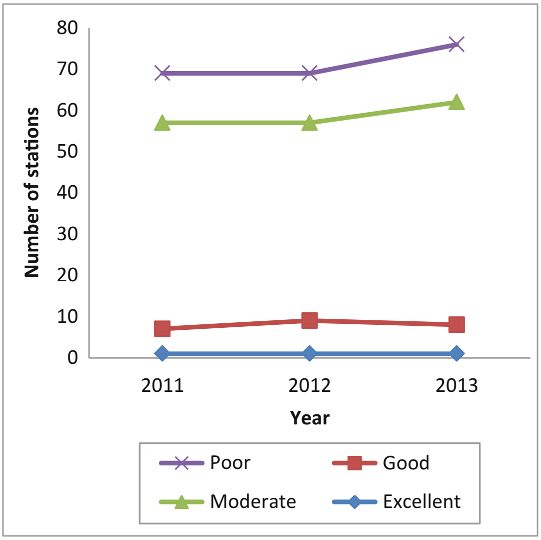

Fig. 8.4 Trend of estuary water status in coastal area of Malaysia (*Source*: EQR 2013)

31 billion cubic meters of water. A joint study carried out by the Academy of Sciences Malaysia (ASM) and the National Hydraulic Research Institute of Malaysia (NAHRIM) initiated in October 2004 to provide a baseline appraisal of the current state of the country's lakes and reservoirs. 56 (62%) of 90 lakes studied were nutrient-rich or eutrophic with a poor condition and reached levels for serious concern. The summary of issues facing some selected lakes in Malaysia is listed in Table 8.1.

8.2 Source of Water Pollution

The sources of Malaysian water pollution can be categorized into point and nonpoint sources. Based on the Environmental Quality Report of the year 2013, a total of 1,475,444 water pollution sources have been identified. These sources included pollution from 4595 manufacturing industries, 10,336 sewage treatment plants, 1,262,185 individual septic tank, 3629 communal septic tank, 602 animal farm (pig farming), 508 agro-based industries, 879 wet markets, and 192,710 food services establishments.

Unexpected floods are becoming common occurrences in Malaysia over the last few years mainly because of changes in rainfall pattern (Sulaiman et al. 2014; WECAM 2013; Baharuddin 2007; Tam et al. 2014; IPCC 2014). The short duration heavy rainfall as well as continuous rainfall generally overflow the rivers and flooded the river side area or sometimes the whole basin (DID 2009; Ya'acob et al. 2014; Hueya et al. 2011). For instance, the Gombak River, which was flooded frequently over the last few years, passes through the industrial areas of Kula

Table 8.1 Summary of issues facing selected Lakes in Malaysia

Lake	Unplanned catchment develop	Pollution	Proliferation of aquatic weeds	Endangered/ declining biodiversity	Alien invasive species	Sedimentation	Declining fish catch	Absence of an overall ILBM based management plan	Impairment of lakeside community values	Absence of a Central management authority
Timah Tasuh	+	+	+	NA	NA	+	NA	+	NA	+
Terip				NA	NA		NA	+		
Bukit Merah	+	+	+	+	NA	+	NA	+		+
Loagan Bunut	+	+	NA	+	NA	+	+	+	+	
Kenyir	+	+			+	+	+	+		
Chini	+	+	+	+		+	+	+	+	+
Pedu/ Muda	+	+	NA	NA	NA	NA	NA	+	NA	+
Putra jaya	+	+	+	NA	NA	+	NA	+	NA	

Source: Abdullah et al. (2010)

Lumpur. A study on Gombak River in terms of pollution level of nitrates, chlorides, and phosphates over the period of 1997–2009 highlighted that several steps should be taken to improve the health of the river (Sulaiman et al. 2014).

The Department of Irrigation and Drainage Malaysia reported that every year flood affected about 29,000 kilometers land throughout Malaysia (Lawal et al. 2014), and the industrial areas were also within the flood affected area. For instance, flood in Penchala River through excessive rainfall at Petaling Jaya industrial area increased the level of chemical pollution in the river (Sulaiman et al. 2014). In the study, it was also reported that more than 4.82 million populations were struggling with flood all over Malaysia that will damage around RM915 million (Lawal et al. 2014).

A study on the Pinang River in Penang Island, Malaysia, showed that manufacturing industries contributed significantly both in the economic development (i.e., 46% in 2000) of the area and the level of pollution of the Pinang River. The study also reported that the level of pollution of the river increased during rainy season when the runoff was higher, and due to flood the runoff might be also higher from nonpoint sources of pollution (Yunus and Nakagoshi 2004).

The study on Semariang mangrove area, Kuching, Sarawak, Malaysia, revealed that the diversity and richness of fish species were less in the flood mitigation channel along with the high level of suspended solids and low level of dissolved oxygen (Nyanti et al. 2012). Similarly, a study on subtropical mangrove forest reported that the level of TN (total dissolved nitrogen), TP (total dissolved phosphorus), COD (chemical oxygen demand), and DOC (dissolved organic carbon) in the water was higher in the mangrove forest during flood (Wang et al. 2010).

Industrial pollution is considered as one of the major sources of chemical contamination of surface water in Malaysia. However, in order to achieve the status of developed country by 2020, Malaysia has focused seriously on the industrial expansion. It was also reported that massive industrial expansion occurred in the west coast of Peninsular Malaysia because the coast is now one of the busiest shipping lanes in the world (Yap et al. 2002). Therefore, the surface water of the rivers in the Peninsular and the Strait of Malacca were contaminated with heavy metals. It is also believed that the discharges from manufacturing and agro-based industries were the major sources of chemical pollution of the surface water (Yap et al. 2002). Moreover, the approval of a few projects by the Malaysian Industrial Development Authority (MIDA) in 1998 contributed significantly to the toxic heavy metal pollution of the surface water (Yap et al. 2002). Another study highlighted that there were several reasons behind the chemical pollution of surface water and sediment in all over Malaysia, but industrial discharges were the highest contaminator because of less focus on the effluent treatment. It was also reported that the lack of highly efficient and economic treatment seriously contributed to the surface water pollution by chemicals (Ho et al. 2012). The industrial discharges were considered to be a potential source of chemical pollution in the Langat river even though the industrial discharges reduced to 9.09% in 2013 compared to 84.09% in 2002 (Farid et al. 2016). Another study revealed that the Semenyih River was slightly polluted with NH3-N, TSS, COD, and NO3, whereas it is extremely contaminated with PO4 and FC (Al-Badaii et al. 2013).

Inland river systems provide almost 95% water resources in Malaysia, but the surface water was contaminated with chemical due to heavy industrialization (Muyibi et al. 2008). Moreover, Malaysian Department of Environment (DOE) reported that about 2292 industries were the significant water polluters in Peninsular Malaysia, and among the industries, 928 food and beverage industries were the highest (40%) polluters followed by the 324 rubber industries (14.1%). Similarly, Selangor state possessed the maximum polluter industries, i.e., 414 followed by Johor state, i.e., 384 industries (Muyibi et al. 2008).

A study observed the heavy metal concentrations in the Gombak and Penchala River of Malaysia over the period of 1998 to 2009 and reported that the absolute concentration of metals in Penchala is higher than the Gombak. The reason might be the better management of Gombak River in Kuala Lumpur than the Penchala River in the city Petaling Jaya (Ismail et al. 2013).

Another study on aquatic ecosystem of Malaysia reported that it was under severe threat in terms of physical and chemical stress due to rapid industrialization and urbanization since 1970s. For example, among many rivers in Malaysia, Juru River was one of the highly contaminated river in Northwestern Peninsular Malaysia, and it was mainly contaminated with Cd, Cu, Pb, and Zn. Malaysian Department of Environment (DOE) also ranked it "very polluted" in 1994 based on the water quality index, and it was believed that the pollution of the Juru river was severe because of the Prai Industrial Estate (Al-Shami et al. 2010).

A very recent study on Semenyih River in the Peninsular Malaysia also highlighted the antibiotic resistance due to degradation of water quality. It was reported that the water quality of the river degraded mainly through the industrial discharges, urban runoff, rural sewage, and domestic wastewater (Al-Badaii and Shuhaimi-Othman 2014). Similarly, the study on the tropical Terengganu River basin, northeast coast of Peninsular Malaysia, showed a different level of chemical contamination such as increasing arsenic (As) and decreasing cadmium (Cd) in the upstream to downstream, respectively. Moreover, the level of Hg contamination in the surface water of the Terengganu River was higher than the Mekong and Amazon Rivers but lower than the Central Africa River (Sultan et al. 2011).

The monitoring of DOE over the period of 2000 to 2004 showed that manufacturing industries (37.9%) and the domestic waste (52.6%) were the main sources of surface water pollution in Malaysia, and among the manufacturing industries, food and beverage industries (23.7%) were the highest polluters of surface water. DOE also reported that out of 120 river basins in Malaysia, 60 (i.e., 50%) river basins were clean, 47 (i.e., 39%) were slightly polluted, and 13 (i.e., 11%) were seriously polluted (Muyibi et al. 2008).

The emerging fisheries sector of Malaysia is under severe threat because of chemical contamination both in the surface water and sediment. Through several studies, it has been reported that the chemical contamination such as polycyclic aromatic hydrocarbon (PAHs) in the rivers, coastal areas, and oceans was mainly due to poor management of the industries (Zakaria et al. 2002). Therefore, though the aquaculture production has increased from 73,262 tons in 1981 to 581,043 tons in 2010, the chemical-contaminated fish has also enhanced the health risk of human being because of their consumption of those contaminated fishes (Mirsadeghi et al. 2011; Retnam et al. 2013). For instance, the Strait of Malacca that provided almost 70% fish production of the country was contaminated with trace elements in several ways especially due to industrial pollution (Agusa et al. 2005; Alina et al. 2012).

It was also reported that the level of vanadium (V) in the west coast of Malaysia was higher than the east coast indicated oil contamination in the water due to massive industrial activities along the coast as well as transportation of ships (Agusa et al. 2005; Alina et al. 2012). Hence, in June 2008 European Union (EU) stopped importing fisheries product from Malaysia because of health hazards, and the country made losses of almost RM600 million. However, in 2007 Malaysia export fisheries product to EU and earned almost $190 million (Retnam et al. 2013).

There were several studies upon the chemical contamination fish in Malaysia, and the level of contamination varies among the aquatic locations mainly because of industrial setup. One of the studies reported that the concentrations of the heavy metals such as copper (Cu), cadmium (Cd), zinc (Zn), lead (Pb), and nickel (Ni) were different of tilapia fish between the Langat River and Engineering Lake, Bangi, Selangor, Malaysia (Taweel et al. 2013). Similarly, a study on the Kuantan estuary revealed that the water quality of the river water degraded due to increase industrialization and urbanization in Pahang (Jalal et al. 2012).

Another study also confirmed that the fishes were contaminated by heavy metals in different coasts of Malaysia, and it possessed serious health risk of human being because of intake of mercury and methyl mercury through it. In the same study, it was reported that fishes were contaminated by the polychlorinated biphenyl (PCB) and methyl mercury through the industrial discharges in Malaysia (Hajeb et al. 2009; Yap et al. 2003).

Though fish is the main dish of the Malaysians during their meal, these fishes are largely contaminated with chemicals due to industrial and agricultural activities. In Malaysia, both the inland and sea water, fishes are containing mercury, arsenic, cadmium, etc. though the level of these heavy metals were reported below the risk level of FAO/WHO 2004 as well as Food Act 1983 and Food Regulations 1985 (Alina et al. 2012). However, in low-level concentrations of these heavy metals, a particular fish may become toxic through increasing toxic level of these chemicals by bioaccumulation in their body that may be a serious risk of human exposure (Alina et al. 2012). Another study examined 34 species of marine fishes in the coast of Cambodia, Indonesia, Malaysia, and Thailand and reported that the mean concentration of chemicals in the fishes of Malaysia were the highest in terms of V, Cr, Zn, Pb, and Bi (Agusa et al. 2007).

8.3 Health Risk Associated with Water Pollution

In Malaysia both the state authority and the concession companies following the privatization exercise of 1987 are responsible of drinking water supply at household level. Although the water is examined regularly in the drinking water treatment plants before being supplied to the household level through pipeline, there are possibilities of biological and chemical contamination into the water supply during transfer and storage. Lead in drinking water is a serious public health concern, and the risk from exposure to lead-contaminated drinking water affects the nervous system of both adults and children. Gradual exposure of lead in drinking water is responsible of insomnia, confusion, impaired concentration, and memory problems. A study assessed the risk of exposure to lead in tap water at the Sunway residential area, Malaysia, (Nalatambi 2009) and reported that lead and copper concentration increased in the tap water due to decade-old water distribution pipe. Similarly, Lim et al. (2012) reported that the concentration of lead in stagnant water of household's taps had actually exceeded the National Standard for Drinking Water Quality (NSDWQ), i.e., 10 μg/L in Seri Kembangan, Selangor, Malaysia. The Hazard Quotient (HQ) values were found, i.e., 0–0.0647. The HQ values were less than one in the whole population, indicating the non-carcinogenic risk associated with exposure to lead in tap water (Lim et al. 2012).

Higher concentration of ammonia (i.e., 2.27 mg/L) and manganese (i.e., 0.46 mg/L) in Langat River during 2009 crossed the standard set by the Ministry of Health Malaysia. The higher concentration of ammonia and manganese in the river was due to the sewerage and effluent discharge as well as urban waste disposal that had been very problematic for the drinking water treatment plants to treat. However, the fluctuations in the concentrations during 2005–2009 indicated improper treatment of domestic and latex effluent or sewage before dumping to the rivers (Hasan et al. 2011).

Sewage treatment plants, small and medium industries, housing estates, townships, palm oil plantations, and industries in the downstream of Langat River Basin are the main sources of bisphenol A (BPA) (i.e., 1.3–215 μg/L) in the raw water, and the concentration was six times higher near the sewerage and effluent outlets. Although BPA in drinking water is responsible of endocrine disruptor of humans, in the tap water at Langat River Basin, the concentration of BPA was very low, i.e., 3.5–59.8 μg/L (Santhi et al. 2012).

Moreover, tap water is not fully clean and may contain microorganisms though it is treated in the plants before being supplied to the household level in Klang Valley, Malaysia. Tap water requires full boiling before drinking as the water supply could be contaminated with microbes from water pipe corrosion. On the other hand, the tap water is chlorinated before supplying to households. After boiling, concentrated level of chlorine in the water may pose a great health issue, with unknown signs and symptoms. High chlorine in tap water may also cause degenerative diseases or toxicity (Azlan et al. 2012a). carcinogenic risks associated with the ingestion and dermal absorption of heavy metals in water from Langat river were evaluated probabilistically by performing 10,000 trails for Monte Carlo simulation where potential carcinogenic risk exists in case of Cd and As (Alam et al. 2015a).

Ministry of Health Malaysia in 2002 reported that in some Malaysian states the concentration of fluoride in drinking water crossed the Malaysian drinking water standard due to the artificial fluoridation of drinking water, and it contributed to the highest prevalence of dental fluorosis among the people. The highest fluoride level was found in Seri Serdang, Selangor, with a mean of 0.71 ± 0.12 mg/L, while the lowest mean was found in Kota Kinabalu, Sabah, at 0.08 ± 0.06 mg/L. The lowest level was a result of non-fluoridation of drinking water in Kota Kinabalu by the local health authorities. Kelantan, Terengganu, and Sabah are three states in Malaysia that does not have artificial fluoridation of drinking water because of higher cases of dental fluorosis among the population. A report indicated that 62.2% of the Malaysian public receives processed water with artificial fluoridation, and the level was at 0.5 mg/L–0.9 mg/L (Shaharuddin et al. 2009).

A study on the tap water of Kuala Lumpur reported no microbial contamination, and heavy metals such as Cu^{2+}, Pb^{2+}, Cr (total), Ni^{2+}, Cd^{2+}, Fe (total), and Mn (total) were under control. However, the concentration of Ba^{2+} in the first flush of tap water was 10 times higher than the standard of Malaysian drinking water (Ong et al. 2007). Similarly, the concentration of the inorganic elements in the tap water of Peninsular Malaysia was within the international standard limit; however, in some places iron and manganese did not comply with the standard (Azrina et al. 2011). Another study also reported the concentrations of iron (0.33 mg/L) and manganese (0.1 mg/L) in the tap water was higher than the standard limit in some places of Peninsular Malaysia (Azlan et al. 2012b).

Another study on Al concentration in drinking water found highest Al concentration with a mean of 1.59 ± 1.87 mg/L at Bandar Penwar, Kota Tinggi, Johor, Malaysia. Moreover, the overall mean concentration of Al in all estates with private water supply was 0.99 ± 1.52 mg/L. On the contrary, Al concentrations in all estates with public water supply were well within the NSDWQ limit except for one estate in Bandar Penwar which slightly violated the standard with the mean concentration of 0.41 ± 0.22 mg/L. (Siti Farizwana et al. 2011). Abdullah showed that the organic matter in tap water has a positive correlation with the formation of trihalomethane ($r = 0.380$, $P = 0.0001$) in Tampin, Negeri Sembilan, and ($r = 0.478$, $P = 0.0001$) in Sabak Bernam, Selangor (Abdullah et al. 2003).

Twenty-eight percent water samples collected from Mukim Parit Lubok and 70% from Parit Raja, Batu Pahat, Malaysia, recorded aluminum concentration above the standard limit set by the Ministry of Health, Malaysia, for drinking water guideline (0.2 mg/L). The mean value of Chronic Daily Intake (CDI) of aluminum in drinking water from Parit Raja (0.00707 mg/kg/day) was significantly higher compared to Mukim Parit Lubok (0.00164 mg/kg/day). Hazard Index (HI) calculation showed that all respondents had HI of less than one. Therefore, there was an unlikely potential for adverse health effects from Al intake in drinking water from both study areas (Qaiyum et al. 2011).

Similarly, Dzulfakar et al. (2011) recorded the mean concentration of aluminum in drinking water from Sungai Lembing (i.e., 0.11 ± 0.0634 mg/L) and from Bukit

Ubi, Kuantan (i.e., 0.12 ± 0.0462 mg/L). The mean value of Chronic Daily Intake (CDI) in Sungai Lembing (0.0035 ± 0.0028 mg/kg/day) was lower than Bukit Ubi (0.0037 ± 0.0021 mg/kg/day). The Hazard Index (HI) calculation showed all respondents had HI less than one. Hence, there was a potential health effects from aluminum intake in drinking water. The presence of aluminum in water distribution systems can be due to aluminum in the source water, aluminum leached from distribution system materials, and aluminum introduced to the water from aluminum-containing coagulants. Other factors that may affect aluminum concentration in drinking water are temperature, pH, and turbidity of the water (Dzulfakar et al. 2011). However, a study carried out to investigate environmental and human health risk due to pollution caused by toxic heavy metals at different places around the Langat River and elevated risk observed due to several chemicals, associated with the consumption of Tilapia fish collected from the river (Alam et al. 2015b).

8.4 Framework of Assessing Watershed Risk

Watershed risk assessment is a process that deals with collecting, organizing, analyzing, and presenting scientific information with the goal of improving decision making. A framework for assessing watershed risk in Malaysia has been designed by following the principles described in US-EPA guidance documents (EPA 1992, 1998). There are three principle phases of watershed risk assessment such as problem formulation, risk analysis, and risk characterization and three additional components such as planning, risk communication/management, and iterative monitoring/data acquisition. At the step of planning, the scientists and managers with input from stakeholders seek agreement on the focus, scope, and complexity of an assessment. In the problem formulation phase (Fig. 8.5), the available information on ecological resources potentially at risk, stressors, and observed or anticipated ecological effects is collected for describing the nature of the problem and identifying measurable characters of the ecological resources that can be used as indicators. A conceptual model describing interrelationships among resources, stressors, and effects is produced which helps to develop analysis plan which estimates the environmental exposure and effects of the stressors on the ecosystem.

The role of risk analysis phase is implementing the analysis plan formulated in problem formulation phase (Fig. 8.6). The characterization of exposure and characterization of effects are included in this phase. The steps in this phase are significantly more technical and quantitative than the problem analysis phase which extracts information on exposure profile and stressor-response profile through the exposure analysis and ecological response analysis.

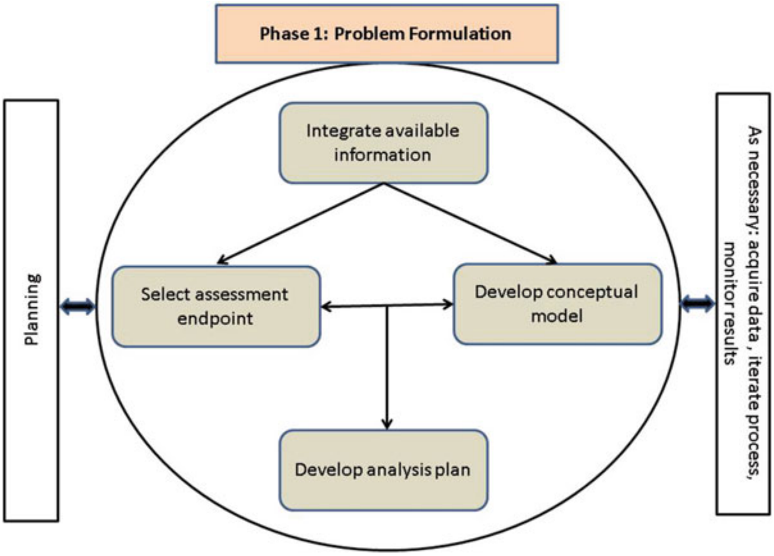

Fig. 8.5 Overview of problem formulation phase based on USEPA

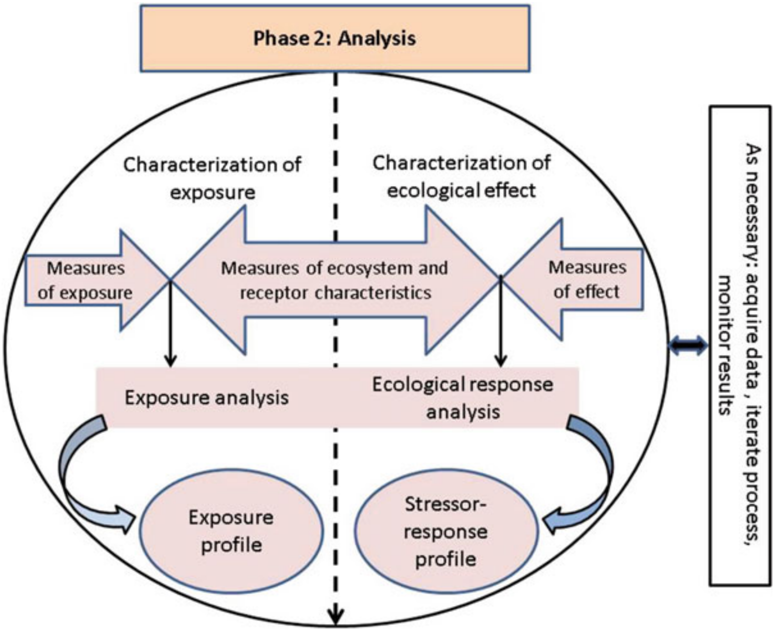

Fig. 8.6 Overview of risk analysis phase based on USEPA

Finally, the risk characterization phase (Fig. 8.7) includes two major steps (risk estimation and risk description) and evaluates the likelihood and significance of adverse effects due to exposure to stressors. The end product of this phase is the risk assessment, prepared for managers to support science-based decision making based on defensible assessment conclusions.

Eventually, at the risk management step, the science-based assessment findings are integrated with economic, social, legal, and political factors affecting management decisions. However, monitoring plays significant role in all phases which deals with the validation of the ecological risk assessment process, confirming predictions made during an assessment and providing additional data to develop exposure profiles or stressor-response profiles. The proposed framework integrating the three phases is presented in Fig. 8.8.

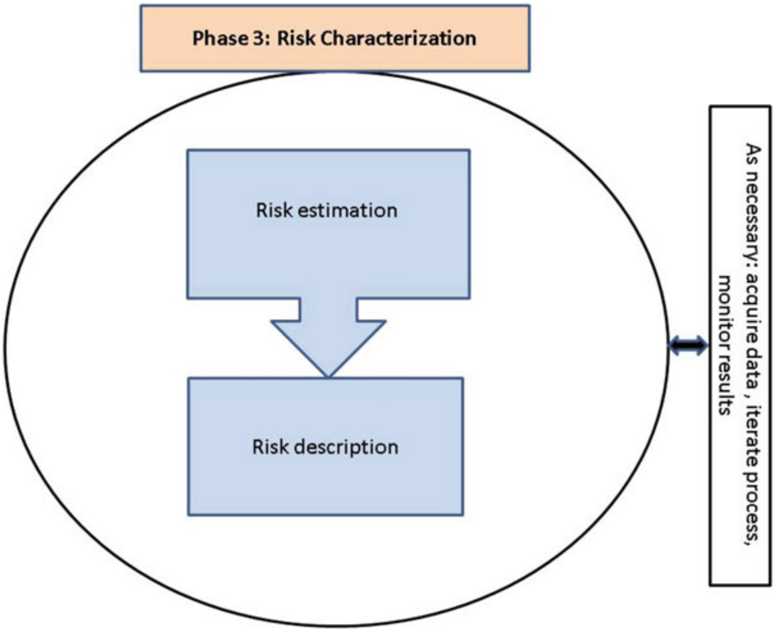

Fig. 8.7 Overview of risk assessment phase based on USEPA

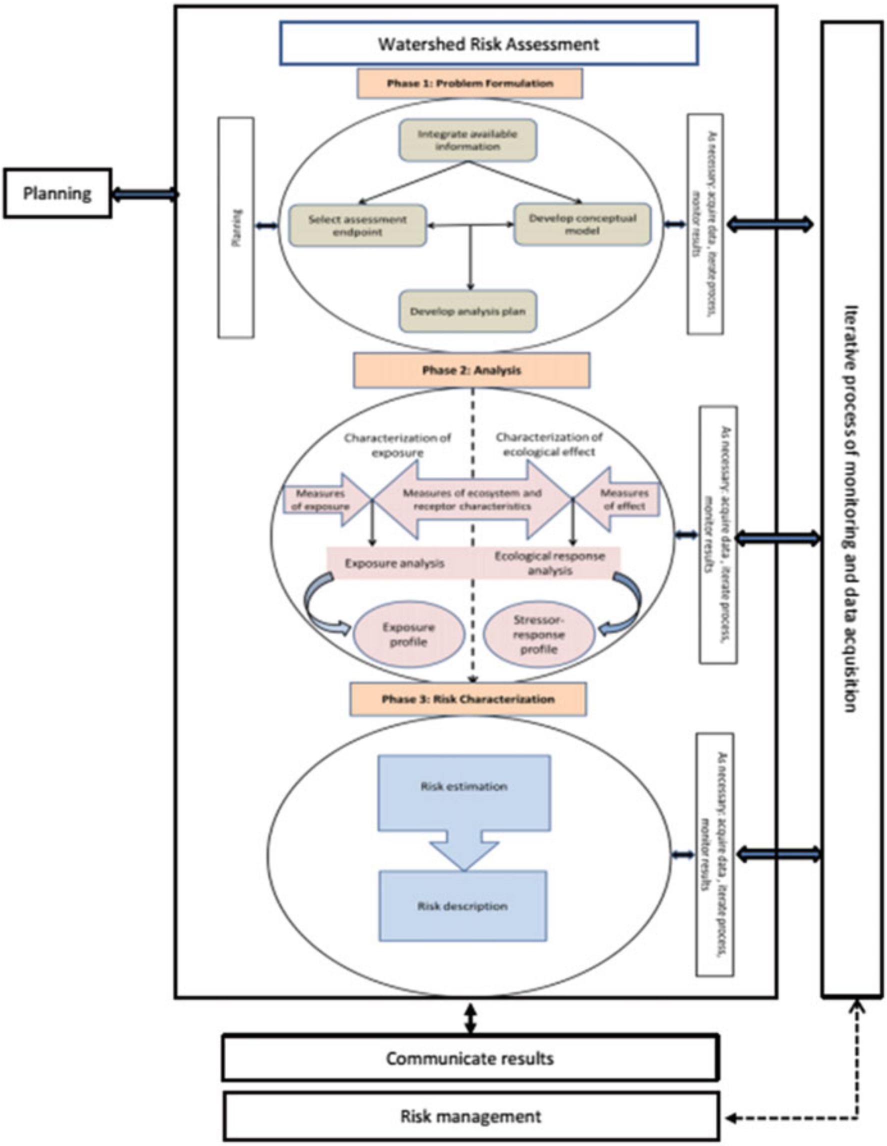

Fig. 8.8 Framework for watershed risk assessment

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Chapter 9
Institutional Arrangement and Legal Framework for the Management of Watersheds in Malaysia

Goh Choo Ta, Mazlin Mokhtar, Khai Ern Lee, and Lubna Alam

Abstract Due to inadequate planning, rapid development and urbanization have polluted watersheds. Hence, watersheds must be managed properly to ensure their sustainability, by taking into account the importance of landscape and ecology and different socio-economic conditions, culture and religion. Among others, one of the ways to enhance watershed management is via adequate institutional arrangement and legal framework. This chapter has selected Malaysia as a case study, and by focusing on the discharge of pollutants, this chapter demonstrates how both federal and state governments complement each other to strengthen the regulatory framework in preventing pollution in watersheds. While the federal government regulates the discharge from manufacturing processes, the state government regulates activities that are not covered by the federal government, such as aquaculture and farming.

Keywords Malaysia · Legal framework · Federal government · State government · Watershed management

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9.1 Introduction

A watershed is an area or ridge of land that drains into a river, stream, lake or any other body of water. A watershed provides ecological services and water resources for flora and fauna, as well as for human activities such as agriculture and cultivation. In general, a watershed has three main functions, namely, water capture, water storage and water release (Johnson and Bedell 2002). Within a watershed, water is transferred from the atmosphere into the soil (water capture), stored between soil particles (water storage) and then released into groundwater or out of the watershed (water release). A healthy watershed is essential to ensure good-quality and adequate water that fulfils the needs of those dependent on it.

Due to development and urbanization, watershed systems have been affected by changes in urban spatial patterns, altering water quality at local, regional and global scales (Alberti 1999). According to Hardy and Koontz (2010), watershed pollution sources vary among urban and rural areas. For example, watershed pollution occurring in a rural area is caused by excessive nitrate discharged from agricultural activities (Almasri and Kaluarachchi 2004). Nitrogen and other elements such as phosphorus from the excessive application of fertilizers can lead to eutrophication and groundwater contamination (Zhang et al. 2015). This example indicates that while crop yield from agricultural activity ensures sufficient food supply, it also has the potential to cause deterioration of water quality. Hence, conflict between agricultural production and environmental protection might occur.

Development is essential for advancing a nation and enhancing the quality of life. However, it is always seen as a trade-off between human needs and environmental protection. In this regard, the concept of ‘sustainable development’ was introduced in the Brundtland Report, *Our Common Future*, published in 1987, defined as the development that meets the needs of the present without compromising the ability of future generations to meet their own needs. In the case of excessive nitrate discharged from agricultural activities, farmers should optimize the use of fertilizers to avoid the occurrence of eutrophication, so that a balance between food security (crop production) and environmental protection (water quality) can be achieved. Similarly, development within a watershed should be managed and monitored to ensure watershed sustainability.

9.2 Watershed Management

Watershed management approaches might vary across districts, nations and regions. There is no single approach that can fulfil the needs of all watersheds, as each watershed is unique, with a different landscape and ecology and different socio-economic conditions, culture and religion. Nonetheless, the underlying principle for different watershed management systems should be the same or similar, i.e. watershed sustainability must be ensured, so that the services provided by the watershed are maintained in its original or improved condition. Based on six examples of watershed management cases (Table 9.1), the US EPA (Environmental Protection Agency) has identified four core principles of watershed management, namely: (1) watersheds are natural systems that we can work with; (2) watershed

Table 9.1 Examples of success cases in watershed management

Success cases	Brief description
Merrimack River Initiative, New England: Public and private partners collaborate to build watershed toolbox to aid management decision-making	A watershed toolbox was established via collaboration with different stakeholders. The toolbox consisted of (1) data management, (2) volunteer monitoring network, (3) emergency response, (4) education and outreach, (5) local involvement grants and (6) information access network
Boulder Creek, Colorado Watershed Project: Restoring multiple river corridor values and uses by choosing the most cost-effective strategies	Stream monitoring indicated that stream habitat was degrading and could be contributing to the buildup of ammonia concentration in the water. Hence, a physical habitat restoration programme was undertaken to restore complexity of the stream channel, stabilize streambanks, revegetate the riparian corridor, etc.
Occoquan Water Supply Protection: Looking at best use of land throughout watershed, enabling local governments to meet multiple objectives	By taking into account capability of treatment technology for wastewater treatment plants, as well as intensive data collection and model development, several counties in Virginia developed a comprehensive land use plan for the Occoquan Reservoir watershed. This included working with basin partners to study different land use development scenarios and how well they met multiple objectives such as improved transportation system, economic development and efficient provision of community services
North Carolina Statewide Framework: Innovative, cost-effective solutions through partnerships and leveraging	Through stakeholder collaboration, a pollutant trading programme was established. The discharger consortium agreed to fund development of tools to evaluate management alternatives and provide cost-share funds to implement best agricultural management practices
Cooper River Corridor Project: Corporate community takes the lead in ecological restoration	Three major chemical companies led the forming of the Cooper River Corridor Project and worked with various government agencies to identify and solve ecological problems in the region
Washington Statewide Framework: Improved database to support decision-making	A framework was designed to improve the basis for decision-making for watershed management. A strategic data collection plan was established under the framework with the aim of developing a common database that would facilitate decision-making

Source: US EPA (2015)

management is continuous and needs a multidisciplinary approach; (3) a watershed management framework supports partnering using sound science, taking well-planned actions and achieving results; and (4) a flexible approach is always needed (US EPA 2015).

In general, there are different ways of managing a watershed. It can be either a mandatory approach that requires compliance from relevant parties or a voluntary approach that is normally initiated by stakeholders or the community. In this chapter, we discuss the regulatory framework in Malaysia related to watershed management, particularly legislation that prevents the occurrence of pollution and contamination in waterbodies. Successful efforts by the federal government and state government complementing each other at preventing pollution are also described.

9.3 Regulatory Framework for Pollution Prevention in Watersheds: Federal Government

After the 1970s, Malaysia's mainly agricultural economy became more diversified with increased manufacturing activity. This was supported by various policies such as the New Economic Policy (1971–1990), Vision 2020 (1991–2020), the National Development Policy (1991–2000) and National Vision Policy (2001–2010). According to the Economic Report 2014–2015 published by the Ministry of Finance Malaysia, the manufacturing sector was projected to contribute 5.5% of the total gross domestic product (GDP) in 2015, while the agricultural sector was projected to contribute 3.1% of the total GDP in the same year (Ministry of Finance Malaysia 2014).

As the Malaysian economy became more manufacturing-based, the Government of Malaysia gazetted the Environmental Quality Act 1974 (hereinafter known as EQA 1974) for environmental protection and to prevent further deterioration of environmental quality by reducing and eliminating the negative impact of industrialization. The EQA 1974 covers different aspects of environmental protection; however, this chapter will focus only on pollution and contamination caused by environmentally hazardous substances, pollutants and wastes. According to EQA 1974, 'environmentally hazardous substances' means any natural or artificial substances including raw material, whether in a solid, semi-solid or liquid form, or in the form of gas or vapour, or in a mixture of at least two of these substances, or any living organism intended for any environmental protection, conservation and controlled activity, which can cause pollution. 'Pollutants' refer to any natural or artificial substances, whether in a solid, semi-solid or liquid form, or in the form of gas or vapour, or in a mixture of at least two of these substances, or any objectionable odour or noise or heat emitted, discharged or deposited, or is likely to be emitted, discharged or deposited from any source which can directly or indirectly cause pollution and includes any environmentally hazardous substances. Finally, 'waste' includes any matter prescribed to be scheduled waste, or any matter, whether in a solid, semi-solid or liquid form, or in the form of gas or vapour which is emitted, discharged or deposited in the environment in such volume, composition or manner as to cause pollution (Malaysia 1974).

Due to industrialization and GDP contribution by the manufacturing sector, Malaysia allows the use of different types of materials and processes by the industry. However, for the purpose of environmental protection, the emission, discharge and deposit of environmentally hazardous substances, pollutants and wastes are regulated by the Department of Environment (DOE). In this regard, EQA 1974 gives

DOE the mandate to prevent occurrence of pollution via control and prohibition. Section 21 of EQA 1974 gives the power to the Minister[1] to control industry activities by specifying the acceptable conditions for the emission, discharge and deposit of the environmentally hazardous substances, pollutants and wastes. If the Minister is of the opinion that the industry activities can cause harm to the environment, under Section 30 of EQA 1974, the Minister has the power, by order, either to prohibit the use of any materials for any process, trade or industry or to prohibit whether by description or by brand name the use of any equipment or industrial plant, within the areas specified in the order.

For the protection of waterbodies or watersheds, several regulations that prevent occurrences of pollution were gazetted under the provisions of EQA 1974. In this chapter, two selected regulations will be elaborated on – one on control and the other on prohibition. In order to control the loading of environmentally hazardous substances, pollutants and wastes into the environment, DOE can specify the acceptable conditions that industry should comply with. In this regard, DOE gazetted the Environmental Quality (Industrial effluent) Regulations 2009 to regulate discharge or release of industrial effluent into the environment. ‘Industrial effluent’ refers to any waste in the form of liquid or wastewater generated from the manufacturing process including the treatment of water for water supply or any activity occurring on any industrial premises (Malaysia 2009). According to these regulations, an owner or occupier of a premise shall design, construct and operate an industrial effluent treatment system and then monitor the discharge of industrial effluent. The acceptable conditions (standard limit) for the parameters in industrial effluent discharged by industry are shown in Table 9.2, except for the parameter of chemical oxygen demand (COD). Standard A in Table 9.2 refers to the standard limit of the parameters for effluent discharged into any inland waters within the catchment area, while Standard B refers to the standard limit of the parameters for effluent discharged into any other inland waters outside the catchment area. As far as COD is concerned, the regulations allow different standard limits based on the types of industry (Table 9.3). Certain premises are exempted from the Environmental Quality (Industrial effluent) Regulations 2009, for example, premises of mining activities. This is because the effluent discharged from mining activities is regulated under Mineral Development Act 1994 (Malaysia 1994).

Besides controlling emission, discharge and deposit of environmentally hazardous substances, pollutants and wastes, DOE also prohibits the use of certain substances. For example, DOE gazetted the Environmental Quality (prohibition on the use of controlled substances in soap, synthetic detergent and other cleansing agents) which prohibits the use of branched alkylbenzene sulphonates (BAS) in the manufacturing of soaps, detergents and other cleaning agents (Malaysia 1995). The BAS is used as surfactants, but BAS is not biodegradable (Scott and Jones 2000). Hence, extensive use of BAS will pose significant long-term effects on the environment.

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[1] ‘Minister’ means the Minister charged with the responsibility for environment protection.

Table 9.2 Acceptable conditions (standard limit) for the parameters in industrial effluent discharged by industry

	Parameter	Unit	Standard	
			A	B
(i)	Temperature	°C	40	40
(ii)	pH value	–	6.0–9.0	5.5–9.0
(iii)	BOD_5 at 20 °C	mg/L	20	50
(iv)	Suspended solids	mg/L	50	100
(v)	Mercury	mg/L	0.005	0.05
(vi)	Cadmium	mg/L	0 01	0.02
(vii)	Chromium, hexavalent	mg/L	0 05	0.05
(viii)	Chromium, trivalent	mg/L	0.20	1.0
(ix)	Arsenic	mg/L	0.05	0.10
(x)	Cyanide	mg/L	0.05	0.10
(xi)	Lead	mg/L	0 10	0.5
(xii)	Copper	mg/L	0.20	1.0
(xiii)	Manganese	mg/L	0.20	1.0
(xiv)	Nickel	mg/L	0.20	1.0
(xv)	Tin	mg/L	0 20	1.0
(xvi)	Zinc	mg/L	2.0	2.0
(xvii)	Boron	mg/L	1.0	4.0
(xviii)	Iron	mg/L	1.0	5.0
(xix)	Silver	mg/L	0.1	1.0
(xx)	Aluminium	mg/L	10	15
(xxi)	Selenium	mg/L	0.02	0.5
(xxii)	Barium	mg/L	1.0	2.0
(xxiii)	Fluoride	mg/L	2.0	5.0
(xxiv)	Formaldehyde	mg/L	1.0	2.0
(xxv)	Phenol	mg/L	0.001	1.0
(xxvi)	Free chlorine	mg/L	1.0	2.0
(xxvii)	Sulphide	mg/L	0.50	0.50
(xxviii)	Oil and grease	mg/L	1.0	10
(xxix)	Ammoniacal nitrogen	mg/L	10	20
(xxx)	Colour	ADMI[a]	100	200

Source: Malaysia (2009)

[a] *ADMI* American Dye Manufacturers Institute

Table 9.3 Acceptable conditions (standard limit) for COD in industrial effluent discharged by different types of industry

Industry	Unit	Standard	
		A	B
(a) Pulp and paper industry			
(i) Pulp mill	mg/L	80	350
(ii) paper mill (recycle)	mg/L	80	250
(iii) pulp and paper mill	mg/L	80	300
(b) Textile industry	mg/L	80	250
(c) Fermentation and distillery industry	mg/L	400	400
(d) Other industries	mg/L	80	200

Source: Malaysia (2009)

9.4 Regulatory Framework for Pollution Prevention in Watersheds: State Government

There are 13 states in Malaysia, jointly governed by the federal government and the respective state government. Under the Malaysian constitution, there are areas that are solely governed by the federal government (such as education and transport) or solely by the state government (such as land and forests) and areas that fall under the jurisdiction of both (such as irrigation and drainage). For watershed management in Malaysia, the federal government works closely with the state government because water-related issues affect water resources and water supply. In this chapter, we have selected the State of Selangor as an example of how the federal government and state government complement each other's efforts to prevent pollution in the watersheds. According to the Department of Statistics Malaysia (2014), compared to other states, Selangor recorded the highest economic growth in 2013. This implies that Selangor had undergone rapid development; hence, discharge of industrial effluent might be higher compared to other states.

The DOE, as one of the agencies under the federal government, monitors the status of the rivers throughout Malaysia and uses the water quality index (WQI) to classify rivers into three categories, namely, clean, slightly polluted and polluted. In 2014, throughout Malaysia, 244 (52%) rivers were classified as clean, 186 (39%) rivers classified as slightly polluted and 43 (9%) rivers classified as polluted (Department of Environment Malaysia 2015). In Selangor, in 2014, 20 (51%) rivers were classified as clean, 15 (39%) rivers classified as slightly polluted and 4 (10%) rivers classified as polluted (Department of Environment Malaysia 2015). Table 9.4 shows the river quality in Selangor. The river quality monitoring data produced by DOE is useful for the state government as it indicates its priority in watershed management.

Table 9.4 River quality in Selangor, Malaysia, 2014

River basin	River	Status
Selangor	Sg. Batang Kali	Clean
	Sg. Kanching	Clean
	Sg. Kerling	Clean
	Sg. Selangor	Clean
	Sg. Serendah	Clean
	Sg. Sembah	Slightly polluted
Buloh	Sg. Buloh	Polluted
Sepang	Sg. Sepang	Clean
Tengi	Sg. Tengi	Slightly polluted
Langat (Selangor/Putrajaya/N. Sembilan)	Sg. Chua	Clean
	Sg. Jijan	Clean
	Sg. Liu	Clean
	Sg. Semenyih	Clean
	Sg. Anak Chua	Slightly polluted
	Sg. Batang Nilai	Slightly polluted
	Sg. Langat	Slightly polluted
	Sg. Pajam	Slightly polluted
Bernam (Selangor/Perak)	Sg. Bernam	Clean
	Sg. Inki	Clean
	Sg. Slim	Clean
	Sg. Trolak	Clean
Bernam (Selangor/Perak)	Sg. Bernam	Clean
	Sg. Inki	Clean
	Sg. Slim	Clean
	Sg. Trolak	Clean
Klang (Selangor/Kuala Lumpur)	Sg. Penchala	Clean
	Sg. Semelah	Clean
	Sg. Ampang	Slightly polluted
	Sg. Anak Air Batu	Slightly polluted
	Sg. Batu	Slightly polluted
	Sg. Damansara	Slightly polluted
	Sg. Gombak	Slightly polluted
	Sg. Jinjang	Slightly polluted
	Sg. Keroh	Slightly polluted
	Sg. Klang	Slightly polluted
	Sg. Rasau	Slightly polluted
	Sg. Bunos	Polluted
	Sg. Toba	Polluted
	Sg. Untut	Polluted

Source: Department of Environment Malaysia (2015)

Table 9.5 Scheduled activities, parameters and standard limits for effluent discharges

Scheduled activity	Acreage/quantity/type	Parameter[a]	Standard limit (mg/L)
Fresh water aquaculture in ponds or cages	Area of farm in operation: fifty (50) hectares or more	NH_3-N	5
		BOD_5	50
		TSS	100
		TN	10
		TP	1
Marine prawn aquaculture in ponds	Area of farm in operation: ten (10) hectares or more	NH_3-N	5
		BOD_5	50
		TSS	100
		TN	10
		TP	1
Development or earthworks	Less than fifty (50) hectares	TSS	100
		O&G	10
Non-pig farming	(a) Livestock of chicken, duck, goose, turkey, guinea fowl, quail, pigeon, ostrich, emu and others involving twenty thousand (20,000) or more reared livestock	NH_3-N	200
		BOD_5	200
		COD	500
	(b) Livestock of cattle, goat, sheep, buffalo, deer and others involving two hundred and fifty (250) or more reared livestock	TSS	500
Pig farming	All farms irrespective of quantity of livestock reared	NH_3-N	200
		BOD_5	50
		COD	500
		TSS	100
Pets	Activities relating to dogs or cats, twenty (20) or more reared	NH_3-N	300
		BOD_5	50
		COD	500
		TSS	250
Mining-related activity	(a) Any type of washing of sand, earth and other substances irrespective of its quantity	TSS	50
	(b) Mining or quarrying involving an area less than two hundred and fifty (250) hectares	O&G	1

Source: Government of Selangor (2012)

[a] *NH_3-N*, ammoniacal nitrogen; *BOD_5*, biochemical oxygen demand (5 days) at 20 °C; *TSS*, total suspended solids; *TN*, total nitrogen; *TP*, total phosphorus; *O&G*, oil and grease; and *COD*, chemical oxygen demand

In order to manage water in a comprehensive and holistic manner, the Government of Selangor gazetted the Selangor Water Management Authority Enactment 1999. An entity known as Selangor Water Management Authority (*Lembaga Urus Air Selangor*, LUAS) was established under the Enactment. The objectives of LUAS are as follows:

1. To ensure water resources, river basins, coastal waters and their environment are preserved sustainably so as to support viable socio-economic development in the state
2. To implement functions as planner, implementor, coordinator, facilitator, researcher and enforcer in an effective, systematic and efficient way in water resources development and management
3. To create an encouraging environment for the participation of public and private sectors in water resources management by taking into account the interests of the public and state government as well as inculcating public awareness on the importance of preserving water resources
4. As a reference point and role model of excellent integrated water resources management for other Malaysian states and for foreign countries (LUAS 2015)

Section 79 under the Selangor Water Management Authority Enactment 1999 stipulates that no one shall discharge or deposit any pollutants without obtaining a licence from LUAS. In this regard, the Government of Selangor gazetted the Emission or Discharge of Pollutants (State of Selangor) Regulations 2012 to prescribe the scheduled activities that require licencing from LUAS. Table 9.5 shows the scheduled activities, parameters and standard limits permitted by LUAS. It is important to note that the scheduled activities (such as aquaculture and farming) under these regulations complement the DOE regulations, i.e. Environmental Quality (Industrial Effluent) Regulations 2009, because DOE regulates only industrial effluents generated from the manufacturing process.

9.5 Conclusion

In Malaysia, watershed management crosscuts between federal government and state government jurisdiction. This chapter, by focusing on the discharge of pollutants, demonstrates how both federal and state governments complement each other to strengthen the regulatory framework in preventing pollution in watersheds. While the federal government regulates the discharge from manufacturing processes, the state government regulates activities that are not covered by the federal government, such as aquaculture and farming.

It is hoped that the case presented in this chapter will be a helpful example for other countries in a similar setting.

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Chapter 10
An Integrated Approach for Stakeholder Participation in Watershed Management

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Abstract Water is an essential element for life. However, the rapid urbanization and industrial development in the past decades have put stress on water resources. Water resource management is intended to solve watershed problems on a sustainable basis, and these problems can be categorized into lack of water (quantity), deterioration in water quality, ecological effects, poor public participation, and low output economic value for investment in watershed-related activities. Involvement of stakeholders is of utmost importance to ensure no one is left behind in the sustainable management of water resources. Hence, an integrated approach has emerged as a shift from the structural approach to a nonstructural approach, that is, from engineering-based solutions to community-based solutions, aiming to induce policy-driven institutional change, particularly the coordination and integration of multiple stakeholders toward sustainable watershed management

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Keywords Water resource · Watershed · Integrated approach · Stakeholders · Sustainability

10.1 Introduction

Water is a key element for life. The rapid urbanization and industrial development over the past decades have given stress to water resources. According to the study conducted by ASEAN Secretariat (2005) in the Report on State of Water Resource Management in ASEAN 2005, the total available internal water resources for Malaysia are 630,000 mcm/year. It is estimated in 2025, the total demand for sector such as industry, agriculture, irrigation, and domestic will increase to the level of 14,504 mcm compared to 1622 mcm for the current demand. In Malaysia, the federal government initiates policies and remains in charge of governance of water resources, in consultation and cooperation with state governments. Although the government is traditionally being entrusted to address the increasing water demand and pollution issues by reviewing existing laws, restructuring water-related agencies, drafting new national water-related policy, initiating nationwide public awareness campaigns, and also enhancing research and development in the field of water resources management, other stakeholders should also play a vital role (Khalit 2008).

A watershed is an area of land, a bounded hydrological system, within which all living things are inextricably linked by their common water course and where, as humans settled, simple logic demanded that they become part of a community (USEPA 2012). There were 146 river basins monitored by the Department of Environment Malaysia whereby 80 were deemed clean, 59 slightly polluted, and 7 polluted. All of the seven polluted rivers were located in the industrial area which is Pinang and Juru River in Penang; Buloh in Selangor; and Danga, Tebrau, Segget, and Pasir Gudang in Johor (DOE 2006), and one of the major pollution sources identified in Malaysia by the Global Environmental Forum (1999) was manufacturing industries. Therefore, government should relinquish some of its responsibility on watershed management to relevant stakeholders. Stakeholders, namely, industries, communities, and NGOs, need to start taking initiatives to manage, protect, conserve, and restore watershed to ensure our water resources are sustainable for future needs (Chan 2005).

Watershed management is to solve watershed problems on a sustainable basis, and the problems can be categorized into lack of water (quantity), deterioration in water quality, ecological effects, poor public participation, and low output economic value for the investment in watershed-related activities (Grigg 1998). Watershed management has evolved through a number of stages from the starting point of focusing on forest-related hydrology issue with an only involvement of government forest department. The next stage focuses on converting their interest into land resources management-related activities that provide economic benefits to the government. However, involvement and contribution from other stakeholders have become an emerging subject to the success of integrated approach in watershed management. We recognized that sustainable watershed management involves cooperation between all stakeholders (Blomqvist 2003). Hence, this chapter aims to discuss how stakeholders can participate by working together in managing watershed through an integrated approach.

10.2 Integrated Approach in Watershed Management

Industrialization plays a vital role in driving the country economy through their activities, which could either be beneficial or harmful. Since the 1960s, Malaysia pursued rapid industrialization supported by foreign investment, but the result of industrialization was a raft of pollution problems, caused by industrial wastewater and other wastes, which became very apparent in the later decades. Water pollution is arguably the most fundamental environmental issue in Malaysia, since the country's pollution problems began with water pollution caused by industries. The government's environmental programs since then give high priority to control the pollution of watershed (Global Environmental Forum 1999). Upon the increasing magnitude of environmental problems and public scrutiny, industries should start taking up the responsibility and integrate sustainability principles into their management (Wu et al. 2013).

While complying with regulations in regard to watershed protection, many industries have adopted ISO 14001 Environmental Management System as their initiatives to protect the water resources. Some has even initiated corporate social responsibility (CSR) programs in protecting watershed from pollution (Chan 2014). One of the recent CSR programs, Canon Malaysia, has organized the river cleaning program in collaboration with other stakeholders, namely, the Institute for Environment and Development (LESTARI), Universiti Kebangsaan Malaysia, Selangor State Forestry Department, Department of Irrigation and Drainage Selangor, and Kajang Municipal Council. In conjunction with "World Water Day," Canon Malaysia staffs worked closely with other stakeholders not only cleaning up the riverbank but also educating the local communities in conserving the watershed. Such an industry-driven watershed management program would not have been a success without an integrated approach.

Watershed management efforts that are sectoral, technological, and centralized have proved inadequate, because these approaches failed to recognize and appreciate the intricacies and interrelations of ecosystems (Pereira 1973). Hence, an integrated approach has been suggested as a solution for watershed management (Bowden 1999). Working toward an integrated watershed management program often required participation, community-based, interactive, resilience thinking, adaptive management, transdisciplinarity, and social learning as appropriate means to address both real-world problems and the sustainability. And, an integrated approach should consist of four principles which are (1) embrace uncertainty, (2) engage stakeholders, (3) transdisciplinary, and (4) learning orientation (Kerkhoff 2014). Hence, the integration of best available knowledge and practice, reconcile values and preferences, as well as create ownership for problems and solution options are crucial in conducting a watershed management program.

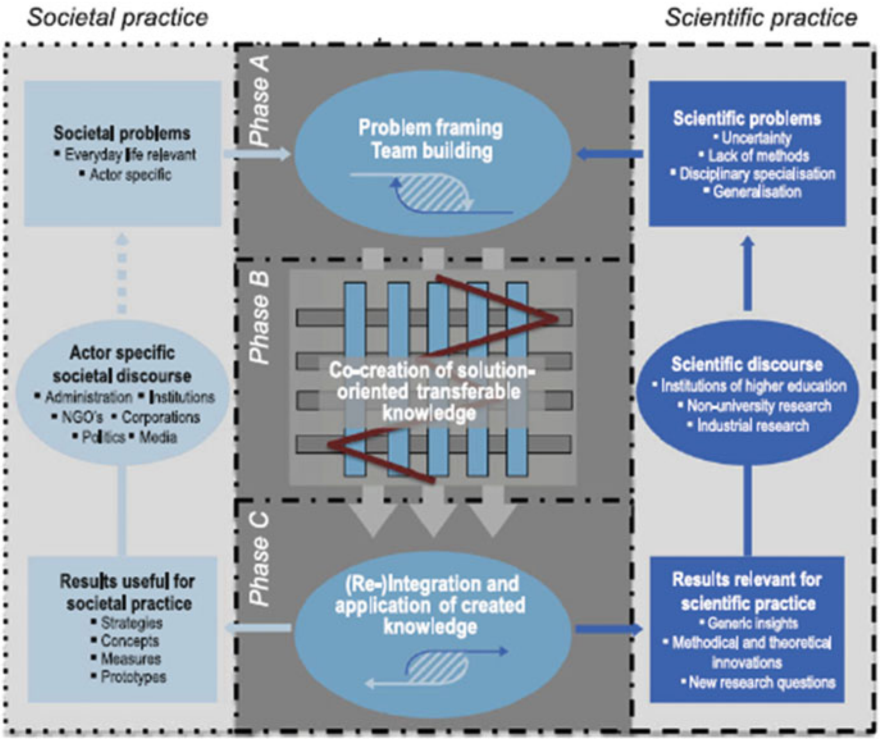

Fig. 10.1 Transdisciplinary process for an integrated approach (Lang et al. 2012)

An integrated approach that was proposed by Lang et al. (2012) in Fig. 10.1 will be adapted in this article as a guide to conduct a watershed management program. The process includes three phases:

Phase A – Collaboratively framing the problem and building a team
Phase B – Collaboratively producing solution-oriented and transferable knowledge
Phase C – (Re-)integrating and applying the produced knowledge in both scientific and societal practice

Phase A: Collaboratively Framing the Problem and Building a Team

To kick off a watershed management program, one should first identify a local-based watershed problem through engaging relevant stakeholders, e.g., industries, communities, government agencies, academia, and local authorities. Forming a team with these relevant stakeholders helps to understand the watershed problem and set an agreed-upon program, including the joint formulation of objectives and goals. The program team should next design a conceptual and methodological framework for the program which allows for the reintegration of insights into societal implementation as well as the scientific body of knowledge in managing watershed.

Phase B: Collaboratively Producing Solution-Oriented and Transferable Knowledge

The watershed management program should be goal- and solution-oriented and allow collaboration from different stakeholders to produce transferable knowledge in a functional and dynamic manner. A set of integrated methods should be adopted and applied to expedite the differentiation and integration of different knowledge input from the stakeholders throughout the process whereby the participation and responsibility of each stakeholder should be clearly defined to consider different levels of stakeholders' involvement in the program.

Phase C: Reintegrating and Applying the Produced Knowledge in Both Scientific and Societal Practice

As different perspectives, world views, values, and types of knowledge are integrated over the course of previous phase, this phase is to transfer the solutions formulated into practice by implementing evidence-based strategies and action programs as well as incorporating program results into the scientific body of knowledge. Likewise, this transdisciplinary process can trigger an intense learning process which can empower and motivate stakeholders to contribute more actively in the implementation of program for watershed management.

10.3 Challenges and Exemplary Strategies for Integrated Approach

However, this ideal-typical integrated approach which adapted a transdisciplinary process is also posing several challenges as postulated by Lang et al. (2012). In Phase A, collaboratively framing the problem and building a team for a program could be challenging whereby stakeholders engaged might not perceived a localized watershed issues as being problematic. In addition, the program team could be underrepresentation of relevant stakeholders causing it dominated by certain group of stakeholders during defining the program boundary and objectives. The lack of problem awareness or insufficient problem framing often faced by a program team formed by multiple stakeholders; hence, a preliminary study should be conducted prior to kick off a program to build problem awareness. During the team building, a stakeholder's mapping should be conducted to identify expertise and interest, and a joint leadership is also suggested as a strategy to promote participation.

In Phase B, collaboratively producing solution-oriented and transferable knowledge requires the integration across knowledge types, organizational structures, communicative styles, or technical aspects. Such form of integration often creates conflicts between stakeholders. Failure to integrate concepts and methods often creates barriers for members from practice to participate in this program. To address these challenges, a systematic comparison of concepts and methods should be conducted for the specification and explicit conflict reconciliation of different methods and concepts. Besides that, a demonstration project should be referred as a guided structure for the program to initialize actions first to stimulate learning-by-doing.

In Phase C, reintegrating and applying the produced knowledge in both scientific and societal practice require transferability and scaling up of the produced solution for the program. However, the impacts on the scientific and societal are difficult to assess due to the program characteristics of transdisciplinary process. Hence, a new methodology should be developed for the post program evaluation to determine the impact of the program.

10.4 Case Study

According to Darghouth et al. (2008), watershed management programs in the 1970s and 1980s focused on specific on-site and downstream physical outcomes, which aimed to prevent rapid water runoff, slow down siltation of reservoirs, and limit the incidence of potentially damaging flash flooding through engineering approaches. Targets were fixed in relation to physical outputs rather than economic and natural resource outcomes, and a top-down planning was generally adopted. As such, the investments were high and not always well justified. Furthermore, the impacts of physical infrastructures built and benefits generated often were not significant plus the ecological dimension had never been included in these programs. Adopting these approaches, it is hardly to put a sustainable management approach in a holistic way. The general result of this top-down planning approach was a total mass on side whereby local users often abandoned these old infrastructures. The need to improve the livelihoods of the poor upland population was not completely ignored, but the technical improvements for agricultural production introduced usually focused on costly vegetative and mechanized technologies. Watershed planning and management was based on land capability rather than on the capacities and needs of local communities. There was little involvement and participation of local communities and other stakeholders in planning and implementation of program, which often resulted in weak commitment to the program. Reyhan (2013) has summarized the watershed management from the 1970s to 1990s in Table 10.1.

Ever since the World Bank's Water Resource Strategy was founded, the Bank's commitment on the water portfolio has been turned around, and the outcome project rating is above the Bank average. The World Bank increasingly works with partners from different disciplines at the global, regional, and country levels, including the Global Water Partnership (GWP), International Commission on Irrigation and Drainage (ICID), International Water Association (IWA), UN-Water, Water Supply and Sanitation Collaborative Council (WSSCC), and World Water Council (WWC).

World Bank has conducted many watershed management programs to support local economies and protect natural resources at the same time, including financing critical economic infrastructure such as rural footpaths, sewerage, drainage, roads, and water supply. Working together with stakeholders, World Bank has initiated Participatory Watershed Management Project (PWMP) which was to improve the productive potential of natural resources and increase incomes of the rural households in selected watersheds in Jammu and Kashmir, India, using socially inclusive

Table 10.1 Watershed management from the 1970s to 1990s (Reyhan 2013)

Years	Main purpose	Applications	Results
1970s	To protect on-site and downstream resources and infrastructure of site	Physical measures designed to manage soil and water resources in medium or large river valleys	High government staff turnover and poor supervision resulted in inconsistent project management and unaccountable implementation arrangements
		To stabilize uplands through erosion control infrastructure	Projects often ignored crucial intersectoral linkages, resulting in lack of collaboration and communication across sectors
1980s	Beyond the engineering approaches acceptance of large-scale collaboration between national and international organizations	To protect soil, water, and vegetation resources.	The comparative failure of the "engineering-led" approach was clear
		To decrease local community poverty ecological and institutional sustainability of the resources management	Lack of collaboration and communication across sectors
		To try watershed management approaches in dryland areas	
1990s	To resource, use productivity, livelihood improvements, and poverty reduction objectives in addition to resource conservation	To identify and execute interventions within an integrated farming systems approach, including lowland and upland agriculture, pasture, and forest management	To lead watershed management programs, to seek ways to build on existing social structures and institutions, and to support planning and implementation by community institutions the promotion of low-cost vegetative techniques for erosion control replaced or complemented the previous "mechanical" techniques that had relied on heavy construction and had proved expensive to build and difficult to maintain
		To adopt a participatory and demand-driven development approach, which was influenced by emerging theories of "farmer first"	

and institutionally and environmentally sustainable approaches and to support policy and institutional development in Jammu and Kashmir to harmonize watershed development projects and programs across the state in accordance with best practices. Throughout projects, the key lessons learned are (Darghouth et al. 2008):

- Cost-sharing among stakeholders is critical for ensuring ownership and continued operations of project-financed assets. Handouts and full subsidies are to be discouraged.

- Transparency of decision-making and resource allocation is important to ensure that all community members are fully aware of program activities and benefits. Several participatory planning tools, such as social mapping and village account displayed in central places, have been used successfully in this respect.
- As a land-based approach, the watershed development projects need to take into account marginal group (women, landless, nomadic tribes) who may not directly benefit from project interventions unless targeted efforts are made by the program to cater their unique needs.
- The proposed program should leverage its resources going beyond target watersheds and encouraging state-wise initiatives in capacity-building and policy reforms that will yield wider benefits (Reyhan 2013).

With early setbacks by the domination of engineering approaches, community-based approaches have emerged in an integrated approach for watershed management. There are some projects that have been held by the World Bank in Turkey in which its rural economy has been characterized by a high rate of poverty, especially in upland areas. The growing pressures on forests and pasture have reduced vegetative cover and diminished soil fertility and the carrying capacity of rangeland which has contributed to reductions in infiltration rates and to increases in peak river flows, flooding, and sedimentation problems. An integrated and participatory approach in watershed management has been implemented, and from 2004 the approach has been expanded to three major river basins. Hence, policy is now based on a community-driven approach to natural resource management, integrating forestry, soil and water conservation, and crop and livestock production. The government shares the cost of a mutually reinforcing package of resource use productivity-enhancing and conservation measures. This policy has driven institutional change, particularly the coordination and integration of the activities of different government departments and stakeholders in the development of watershed-based forest resource management plans (Darghouth et al. 2008; Reyhan 2013).

10.5 Concluding Remark

As the increasing developments are taking place, water resources have become an issue. The government has been putting a lot of efforts to conserving watershed. Nevertheless, support from all stakeholders is necessary for overall watershed management. An integrated approach is needed to ensure effective and sustainable watershed management. A transdisciplinary process was adapted in an integrated approach to conduct programs for watershed management. An integrated approach can be summarized into three phases which are co-framing the watershed problem, coproducing solution for the watershed management, and co-implementing solution for the watershed management. Transiting from the earlier engineering approaches, community-based approaches have emerged as an integrated approach that has induced policy-driven institutional change, particularly the coordination and integration of multiple stakeholders in the watershed management.

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Chapter 11
Transition of Hazardous Chemical Management and Environmental Risk Management and Evaluation in Japan

Nobumitsu Sakai and Minoru Yoneda

Abstract Japan has experienced many public nuisances in high economic growth period as the representative public nuisances are called “four big pollution diseases” which caused many patients and fatality. The government initiated antipollution measures from the late 1960s and enforced environmental quality standards and Total Pollutant Load Control System. These antipollution measures had obviously improved public nuisances and retrieved clean quality of life. Since the 1990s, environmental risk management and evaluation has been globally implemented, and Japan enforced some regulations such as Pollutants Restriction Transfer Register, screening assessment, etc. These regulations enable to prevent environmental risks of chemical substances. This chapter explains the transition of the hazardous chemical management and current system of environmental risk management and evaluation in Japan.

Keywords Four big pollution diseases · Total Pollutant Load Control System · Environmental risk management and evaluation · Pollutants Restriction Transfer Register · Screening assessment

11.1 Introduction

In high economic growth period in Japan (1950s–1973), economic activities were drastically and rapidly expanded, whereas hazardous chemicals were heavily discharged into environment. It caused many public nuisances as major ones are known as “four big pollution diseases,” and consequently it resulted in a serious social issue. The government eventually initiated antipollution measures from the

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late 1960s and enforced environmental quality standards (EQS) and Total Pollutant Load Control System (TPLCS). As a consequence, these enforcements apparently reduced public nuisances and health effects by hazardous chemicals. Since the 1990s, the government gradually recognized an importance of environmental risk management and evaluation and sequentially enforced some regulations and systems such as Pollutant Release and Transfer Register (PRTR) law, Safety Data Sheet (SDS), screening assessment under Chemical Substances Control Law (CSCL), etc. In addition, risk communications between people and enterprises are promoted, and databases of chemical substances are released in public for people to understand potential risks of chemical substances properly. Thus, the environmental risk management and evaluation systems in Japan have been widely developed to prevent environmental load, human health effects, and ecosystem destruction. This chapter explains the transition of the hazardous chemical management and environmental risk management and evaluation in Japan.

11.2 Transition of Hazardous Chemical Management

11.2.1 High Economic Growth and Public Nuisances

Japanese economy was rapidly grown up from the 1950s until 1973 when the first oil shock occurred, and the gross domestic product exceeded 10% in the late 1960s. The energy demand was also drastically expanded as it was increased about seven times in 1974 than that in 1955. On the other hand, many public nuisances caused by the economic growth emerged such as air pollution, water pollution, noise pollution, odor pollution, and so on. The representative public nuisances in Japan which resulted in many patients and fatality are called "four big pollution diseases" (Fig. 11.1).

1. Itai-itai disease (in Jintsu River basin in Toyama Prefecture Since the 1910s)

The cause was that mining companies discharged their wastewater containing cadmium produced after refining of zinc into upstream of Jintsu River. The river water and soil in Jintsu River basin were heavily polluted by cadmium, and local people consequently consumed vegetables and tap water contaminated by cadmium. It resulted in kidney disorder and osteohalisteresis, and the patients were suffered by massive pains of joints at the back, hands, and feet. Furthermore, due to the osteohalisteresis, their bones were easily fluctuated. As of 2011, the number of certified patients by government is 196 (Aoshima 2012).

2. Minamata disease (in Minamata city in Kumamoto Prefecture Since 1953)

The cause was that a company which manufactured acetaldehyde discharged their wastewater containing methylmercury into the river. The methylmercury was accumulated into fish, and the local people consumed the polluted fish. It resulted in numbness, tunnel vision, hearing impairments, and death. Furthermore, it could be

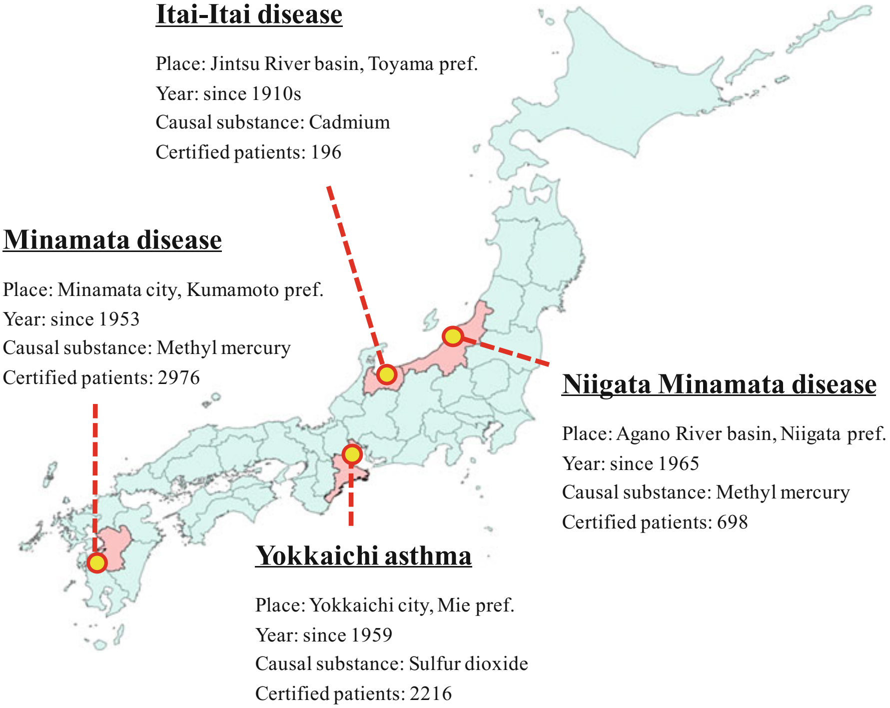

Fig. 11.1 Four big pollution diseases in Japan

transferred from mother to fetus via placenta, and consequently the baby was suffered by language disorder, movement disorder, or swallowing disorder. As of 2013, the number of certified patients by government is 2976 (The Japan Times 2013).

3. Yokkaichi asthma (in Yokkaichi city in Mie Prefecture Since 1959)

The cause was that sulfur dioxide was released from petrochemical complexes into the atmosphere. The local people inhaled the polluted air and were suffered by cough, sputum, bronchitis, asthma, etc. By 1988 when approvals by government had been terminated, the number of certified patients was 2216 (The Mainichi 2012).

4. Niigata Minamata disease (in Agano River basin in Niigata Prefecture since 1965)

This incident was as the same as the Minamata disease. As of 2012, the number of certified patients by government is 698 (Ministry of Environment 2011a).

Furthermore, Kanemi Yusho incident (Fukuoka Prefecture in 1968), photochemical smog (Tokyo Prefecture in 1970), hexavalent chromium pollution (Tokyo Prefecture in 1973), and other many public nuisances occurred throughout Japan during the high economic growth period. As a result, many people radically protested against them even if they were brought from industrial development.

Japanese government eventually initiated holistic antipollution measures from the late 1960s.

11.2.2 Enforcement of Environmental Quality Standards (EQS)

Through the four big pollution diseases, Japanese government recognized that the public nuisances occurred due to their belated measures and had to be thoroughly solved. Accordingly, they proposed to establish a new law to progress antipollution measures holistically and to clarify the responsibility of government, local municipality, and enterprise for the public nuisances. In 1968, Basic Law for Environmental Pollution Control was adopted. Article 9 in the law described that the government enforces EQS for air pollution, water pollution, soil pollution, and noise pollution to protect human health and maintain quality of life of people. This was the first law in Japan to introduce a concept of the EQS, and accordingly various EQS were enforced. Table 11.1 shows the transition of the EQS and laws in Japan.

11.2.3 Total Pollutant Load Control System (TPLCS)

Public nuisances after the enforcement of EQS were apparently decreased. However, air pollution in populated industrial areas and water pollution in closed river basin such as lakes and bays were not effectively improved. In addition, some enterprises intended to get past the EQS by undesirable ways just to comply with the standard. For example, in case of sulfur oxides in the atmosphere, the government enforced “K-value regulation” based on atmospheric diffusion theory in 1968. The K-value was decided in each region in accordance with polluted status by sulfur oxides. A formula of the regulation is as follows:

$$q = K \times 10^{-3} \times He^2 \tag{11.1}$$

q: Permissible hourly emission volume of sulfur oxides ($\mathrm{Nm^3/h}$)
K: Constant given for each area
He: Effective height of stack (m)

K has 16 ranks ranging from 3.0 to 17.5 as of 2013 (Ministry of Environment 1996), and He means a virtual stack height which includes a height of smoke ascent as shown in the following formula:

$$He = Ho + 0.65 \times (Hm + Ht) \tag{11.2}$$

Ho = Height of stack (m)
$Hm = 0.795 \times \sqrt{}(\mathrm{Q} \times \mathrm{V})/(1 + 2.58/\mathrm{V})$

Table 11.1 Transition of environmental quality standards and laws in Japan

Year	Environmental Quality Standard / Law	Remarks
1967	Public Nuisance Countermeasures Law	This law prescribed (1) air pollution, (2) water pollution, (3) soil pollution, (4) noise, (5) vibration, (6) subsidence and (7) odor as seven major public nuisances.
1969	Environmental Quality Standard for Sulfur Dioxide (SO_2)	Daily average $\leq$0.05 ppm
		Amendment in 1973:
		Daily average $\leq$0.04 ppm and Hourly values $\leq$0.1 ppm
1970	Environmental Quality Standard for Carbon Monoxide (CO)	Daily average $\leq$10 ppm and 8- hour –average $\leq$20 ppm
1971	Environmental Quality Standards for Water Pollution	Protection of the Human Health: 8 items such as Cd, Pb, Hg, As, etc. (as of 2013, 27 items)
		Conservation of the Living Environment in River, Lake and Sea: pH, SS, DO, COD, BOD, Coliform group, etc.
1971	Environmental Quality Standards for Noise	AA (Specified area): $\leq$50 dB(daytime), $\leq$40 dB (nighttime) A (mostly residential area) and B (mainly residential area): $\leq$55 dB (daytime), $\leq$45 dB (nighttime) C (Residential/Commercial/Industrial area): $\leq$60 dB (daytime), $\leq$50 dB (nighttime), etc.
1972	Environmental Quality Standard for Suspended Particulate Matter (SPM)	Daily average $\leq$0.1 mg/m^3 and Hourly values $\leq$0.2 mg/m^3
1973	Environmental Quality Standard for Nitrogen Dioxide (NO_2)	Daily average $\leq$0.2 ppm Amendment in 1978: Daily average: 0.04-0.06 ppm or below
1973	Environmental Quality Standard for Aircraft Noise	Region I (Residential area) $\leq$70 WECPNL Region II (Others) $\leq$75 WECPNL Amendment in 2007: Region I $\leq$57 dB, Region II $\leq$62 dB
1975	Environmental Quality Standard for Shinkansen Noise	Region I (Residential area) $\leq$70 dB Region II (Industrial area) $\leq$75 dB
1991	Environmental Quality Standard for Soil	10 items mostly from heavy metals (as of 2013, 27 items)
1993	Basics Environmental Law	This law is aimed to comprehensively and systematically promote policies for global environmental conservation. The Public Nuisance Countermeasures Law was abolished after this law was enacted.
1997	Environmental Quality Standards for Benzene, Trichloroethylene, Tetrachloroethylene and Dichloromethane	Yearly average $\leq$0.003 mg/m^3 in benzene, $\leq$0.2 mg/m^3 in trichloroethylene, $\leq$0.2 mg/m^3 in tetrachloroethylene and $\leq$0.15 mg/m^3 in dichloromethane
1997	Environmental Quality Standard for Groundwater	23 items mainly from organochlorine compounds and heavy metals (as of 2013, 26 items)

(continued)

Table 11.1 (continued)

Year	Environmental Quality Standard / Law	Remarks
1999	Environmental Quality Standard for Dioxines	Yearly average $\leq$0.6 pg TEQ/m^3 in air, $\leq$1 pg TEQ/L in water (except for sediment), $\leq$1000 pg TEQ/g in soil and $\leq$150 pq TEQ/g in sediment (since 2002)
2009	Environmental Quality Standard for Particulate Matter (PM2.5)	Yearly average $\leq$15 μg/mg^3 and Daily average $\leq$35 μg/mg^3

$Ht = 2.01 \times 10^{-3} \times \mathrm{Q} \times (\mathrm{T} - 288) \times (2.30 \times \log \mathrm{J} + 1/\mathrm{J} - 1)$
$J = 1 / \surd(\mathrm{Q} \times \mathrm{V}) \times \{1460–296 \times \mathrm{V}/(\mathrm{T} - 288)\} + 1$
Q: Quantity of emitted smoke at 15 °C (m^3/s)
V: Velocity of smoke emission (m/s)
T: Temperature of emitted smoke (K)

However, many enterprises intended to construct higher stacks with a height of more than 100 m because the K-value regulation allows higher smoke emission as the height of stacks is increased. Therefore, the emission of sulfur oxides was not effectively reduced by the regulation. Another similar issue occurred in water environment. Although a volume of effluents from industries was decreased by EQS on water quality, a volume of municipal sewage such as domestic sewage was not decreased because it was not enforced by the EQS. Furthermore, the industries intended to dilute their effluents so as to comply with the EQS. Therefore, the government proposed that the amount of emissions and effluents from whole pollution sources had to be restricted. As a consequence, a new enforcement TPLCS was applied in order to reduce the whole amount of pollutants. This regulation designated controlled regions and enforced stricter standards to facilities having high pollution load than the EQS. Furthermore, both new and additional facilities in the designated regions were enforced with further strict standards so that the enterprises refrained from further expansions. In the TPLCS, SOx (1974) and NOx (1981) in air environment as well as NOx and particulate matter from automobiles (2001) were regulated in populated industrial regions. Similarly, chemical oxygen demand (COD, 1980), phosphate (2002), and nitrogen (2002) in water environment were regulated in enclosed watersheds.

The TPLCS of sulfur oxides in both existing facilities and new or additional facilities is defined by the following formulae:

$$\text{Existing facilities} : Q = a \times W^b \tag{11.3}$$

$$\text{New or additional facilities} : Q = a \times W^b + r \times a \times \left\{ (W + W_i)^b - W^b \right\} \tag{11.4}$$

Q: Permissible hourly emission volume of sulfur oxides (Nm^3/h)
W: Total rated output of a facility constructed before a designated date decided by a prefecture (kL (crude oil equivalent) /h)
Wi: Total rated output of a facility constructed after a designated date decided by a prefecture (kL (crude oil equivalent) /h)

a: Coefficient decided by a prefectural governor to comply a reduction goal

b: Coefficient decided by a prefectural governor ranging from 0.8 to 1.0 in consideration of a distribution of facilities and their fuel consumptions

r: Coefficient decided by a prefectural governor ranging from 0.3 to 0.7 in consideration of a transition of constructions of facilities

The TPLCS of nitrogen oxides is defined by the following formulae:

Facilities constructed before a designated date decided by a prefecture:

$$Q = 0.51 \times \left\{ \sum (C \times V) \right\}^{0.95} \tag{11.5}$$

Facilities constructed after a designated date decided by a prefecture:

$$Q = 0.51 \times \left\{ \sum (C \times V) + \sum (C_i \times V_i) \right\}^{0.95} \tag{11.6}$$

Q: Permissible hourly emission volume of nitrogen oxides (Nm^3/h)

C: Coefficient decided by a prefectural governor to the former facilities

Ci: Coefficient decided by a prefectural governor to the latter facilities

V: Volume of gas emission from the former facilities (10^4 Nm^3/h)

Vi: Volume of gas emission from the latter facilities (10^4 Nm^3/h)

In the TPLCS of NOx and particulate matter from automobiles, Automobile NOx/PM Law was established in 2001 and introduced "Vehicle Type Regulation" which prohibited those which were registered in designated areas under the law and not compliant with the standards of nitrogen oxides and particulate matters driven inside the areas. In addition, those which were originally registered in non-designated areas but not compliant with the standards were prohibited to be registered there.

On the other hand, the TPLCS of COD, nitrogen, and phosphorus are defined by the following formulae:

$$\text{COD} : Lc = \left(C_{cj} \times Q_{cj} + C_{ci} \times Q_{ci} + C_{co} \times Q_{co} \right) \times 10^{-3} \tag{11.7}$$

$$\text{Nitrogen} : \text{Ln} = \left(C_{ni} \times Q_{ni} + C_{no} \times Q_{no} \right) \times 10^{-3} \tag{11.8}$$

$$\text{Phosphorus} : Lp = \left(C_{pi} \times Q_{pi} + C_{po} \times Q_{po} \right) \times 10^{-3} \tag{11.9}$$

Lc, Ln, and Lp: Permissible loading of COD, nitrogen, and phosphorus (kg/day)

Q_{co}, Q_{ci}, and Q_{cj}: Volume of specified effluent in each classified period (Table 11.2) COD (m^3/day)

Q_{no} and Q_{ni}: Volume of specified effluent in each classified period (Table 11.2) nitrogen (m^3/day)

Q_{po} and Q_{pi}: Volume of specified effluent in each classified period (Table 11.2) phosphorus (m^3/day)

C_{co}, C_{ci}, and C_{cj}: COD value specified by a prefectural governor (mg/L)

C_{no} and C_{ni}: Nitrogen value specified by a prefectural governor (mg/L)

C_{po} and C_{pi}: Phosphorus value specified by a prefectural governor (mg/L)

Table 11.2 Classification period quantity of effluent in classified period

Quantity of effluent in classified period (m^3/day)	COD	Nitrogen	Phosphorus
Quantity of effluent from existing plants before June 30. 1980	Q_{co}	Q_{no}	Q_{po}
Quantity of effluent from new/or expanded plants between July 1, 1980 and June 30, 1991	Q_{ci}		
Quantity of effluent from new/or expanded plants between July 1, 1991 and September 30, 2002	Q_{cj}		
Quantity of effluent from new/or expanded plants after October 1, 2002		Q_{ni}	Q_{pi}

Source: Ministry of Environment (2011b)

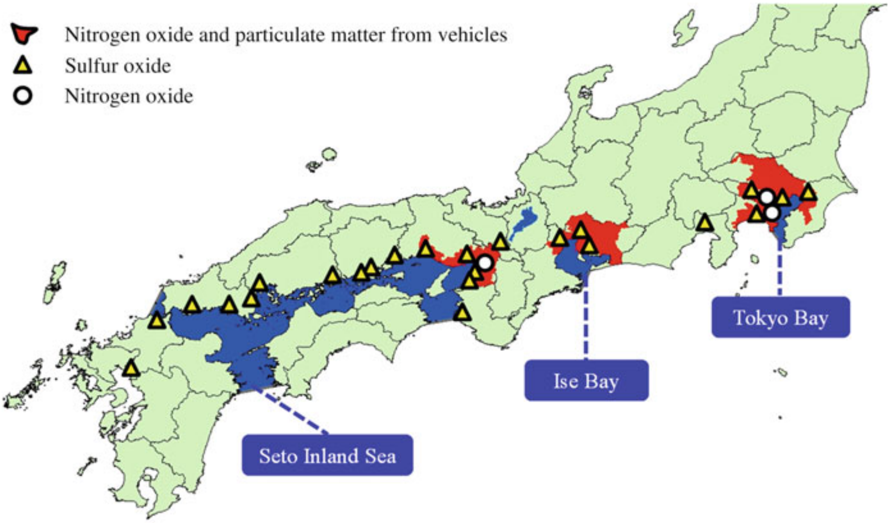

Fig. 11.2 Designated regions of TPLCS in the atmosphere and enclosed watersheds (Source: Ministry of Environment 1983, 2005, 2011b)

Figure 11.2 shows the designated regions enforced the TPLCS in the atmosphere and/or enclosed watersheds. According to the Ministry of Environment, sulfur oxides were enforced in 24 regions, nitrogen oxides were enforced in 3 regions (Tokyo Prefecture, Kanagawa Prefecture, and Osaka Prefecture), nitrogen oxides and particulate matter from automobiles were enforced in 3 regions (Tokyo metropolitan area, Aichi-Mie area, and Osaka-Hyogo area), and COD, nitrogen, and phosphorus were enforced in 3 enclosed watersheds (Tokyo Bay, Ise Bay, and Seto Inland Sea).

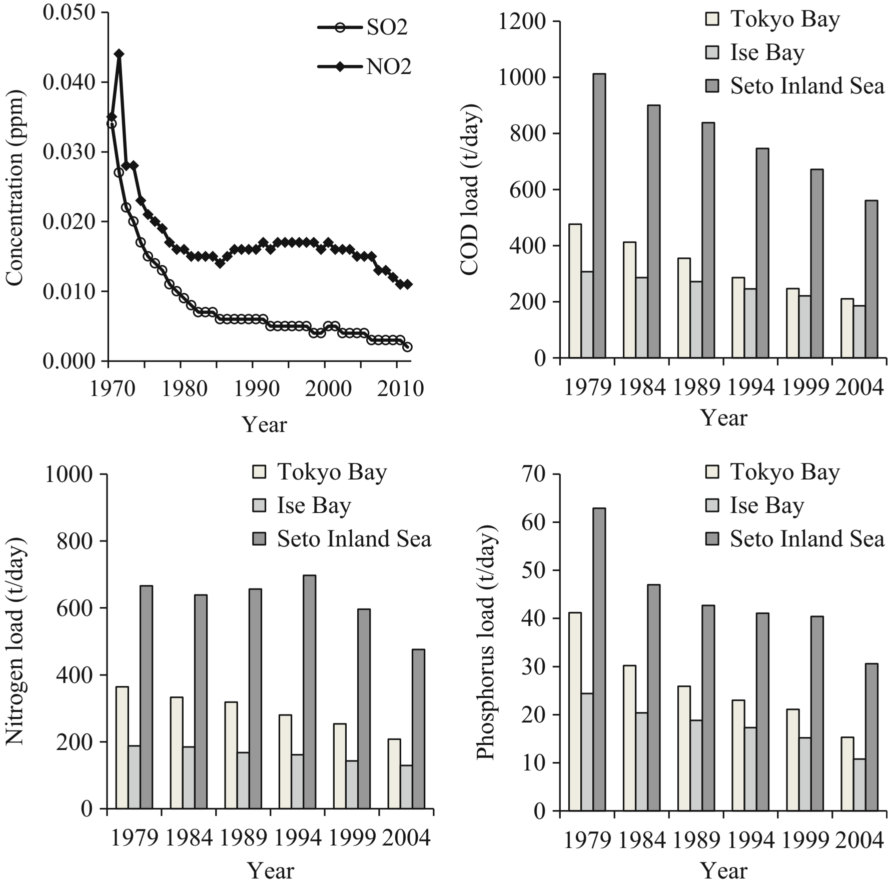

Fig. 11.3 Air and water monitoring results in designated regions of TPLCS

11.2.4 Achievement of Antipollution Measures

According to monitoring results by the Ministry of Environment (Ministry of Environment 2010, 2011c), concentrations of all sulfur oxides and nitrogen oxides in the atmosphere and COD, nitrogen, and phosphate in enclosed watersheds have been steadily decreased, compared to the 1970s (Fig. 11.3). The compliance rates of EQS in sulfur oxides and nitrogen oxides were almost 100% in 2011. As for COD, phosphate, and nitrogen, the TPLCS has been amended to stricter goals as their loadings are steadily decreased. Thus, these antipollution measures by the government have improved public nuisances enough to reduce health effects and conserve the quality of life, and they are still effective to maintain the improved environment.

11.3 Environmental Risk Management and Evaluation in Japan

11.3.1 From "Antipollution Measures" to "Environmental Risk Management and Evaluation"

Since the 1990s, serious public nuisances were apparently decreased in Japan as EQS and TPLCS have been effective to reduce high pollution loads. Nevertheless, we are exposed to various kinds of chemical substances in low concentration, and most of their potential adverse effects have not been clarified yet. It is suggested that there are over tens of millions of chemical substances and new chemical substances have been enormously developed so that all the chemical substances cannot be evaluated their toxicity. Therefore, a new concept and methodology are necessary to prevent adverse effects to human and biological system from them.

Globally, the importance of chemical management has been recognized since the early 1990s. In the Rio Declaration on Environment and Development at Earth Summit in 1992, Principle 15 was described that precautionary approach shall be widely applied to protect the environment. Similarly, Chapter 19 of Agenda 21 summarized the "Environmentally sound management of toxic chemicals including prevention of illegal international traffic in toxic and dangerous products" (UN 1992) so that chemical management was promoted worldwide since then. Furthermore, in World Summit on Sustainable Development (WSSD) held in 2002, paragraph 23 of Johannesburg Plan of Implementation was described:

> To sound management of chemicals throughout their life cycle and of hazardous wastes for sustainable development as well as for the protection of human health and the environment, inter alia, aiming to achieve, by 2020, that chemicals are used and produced in ways that lead to the minimization of significant adverse effects on human health and the environment, using transparent science-based risk assessment procedures and science-based risk management procedures, taking into account the precautionary approach. (UNEP 2012)

Accordingly, Japanese government has enforced some regulations for environmental risk management and evaluation, and the society has also implemented related activities since the late 1990s. This section explains those representative examples.

11.3.2 Pollutants Restriction Transfer Register (PRTR) and Safety Data Sheet (SDS)

In 1999, the Law for PRTR and Promotion of Chemical Management was enforced in order to promote self-management of chemical substances by enterprises and to maintain environmental conservation. This law introduced PRTR and SDS. Although the SDS was previously called as MSDS (Material Safety Data Sheet), it was redefined as SDS in consideration of Global Harmonization System (GHS) in 2011.

The PRTR is applied to chemical substances which are concerned to be hazardous to human health and biological systems and widely existing in the environment. Designated enterprises under the PRTR need to report their discharge amount of the designated chemical substances into the atmosphere, water, and soil to the government and also report their transfer amount of them as wastes from the enterprises. Accordingly, the government makes a statistics of the reported amount and publishes in public. As of 2013, the number of the designated chemical substances under PRTR is 462. In the Law for PRTR and Promotion of Chemical Management, these chemical substances are defined as Class I Designated Chemical Substances. Furthermore, 15 chemical substances out of them which have carcinogenicity, mutagenicity, and reproductive and developmental toxicity are defined as Specific Class I Designated Chemical Substances. The designated enterprises are defined as the following conditions:

1. Those which are classified in either of the 24 categories of business designated by cabinet order
2. Those which contract with more than 21 employees
3. Those which deal with either of Class I Designated Chemical Substances by more than 1 ton or of Specific Class I Designated Chemical Substances by more than 0.5 ton

The assembled data from the designated enterprises can be downloaded in the Ministry of Economy, Trade and Industry (METI), Ministry of Environment (MOE), National Institute of Technology and Evaluation (NITE), and so on. In addition, NITE publishes PRTR map which visualizes the assembled data as a distribution map and a concentration map. The distribution map shows the amount of releases and transfers of each chemical substance into the atmosphere or water by colorized prefectures or municipalities in 2001 onward. The concentration map visualizes daily average of estimated atmospheric concentration of each chemical substance by 5 km × 5 km mesh in 2001 onward. The estimated atmospheric concentration is calculated from assembled data from both designated and non-designated enterprises, yearly meteorological data, etc. with AIST-ADMER which has been developed by National Institute of Advanced Industrial Science and Technology (AIST).

As TPLCS of COD, nitrogen, and phosphorus is applied to three enclosed watersheds, watersheds can be considered as one of the most typical domains in the environment. Therefore, as a tool of the environmental risk evaluation of chemical substances, the assembled PRTR data can be applied to a watershed-based distribution map in order to evaluate the environmental risk of chemical substances in watershed level. Figure 11.4 shows an example of a watershed-based distribution map of toluene by colorized municipality located in Lake Biwa-Yodo River basin with a combination of the PRTR data and geographical information system (GIS). Since the GIS can visualize designated river basins and colorize each municipality based on the PRTR data, users can easily check the municipalities where toluene is heavily discharged into the atmosphere and water in Lake Biwa-Yodo River basin. This result can be also applied to simulate occurrence, distribution, or environmental fate of chemical substances and evaluate biological risks and

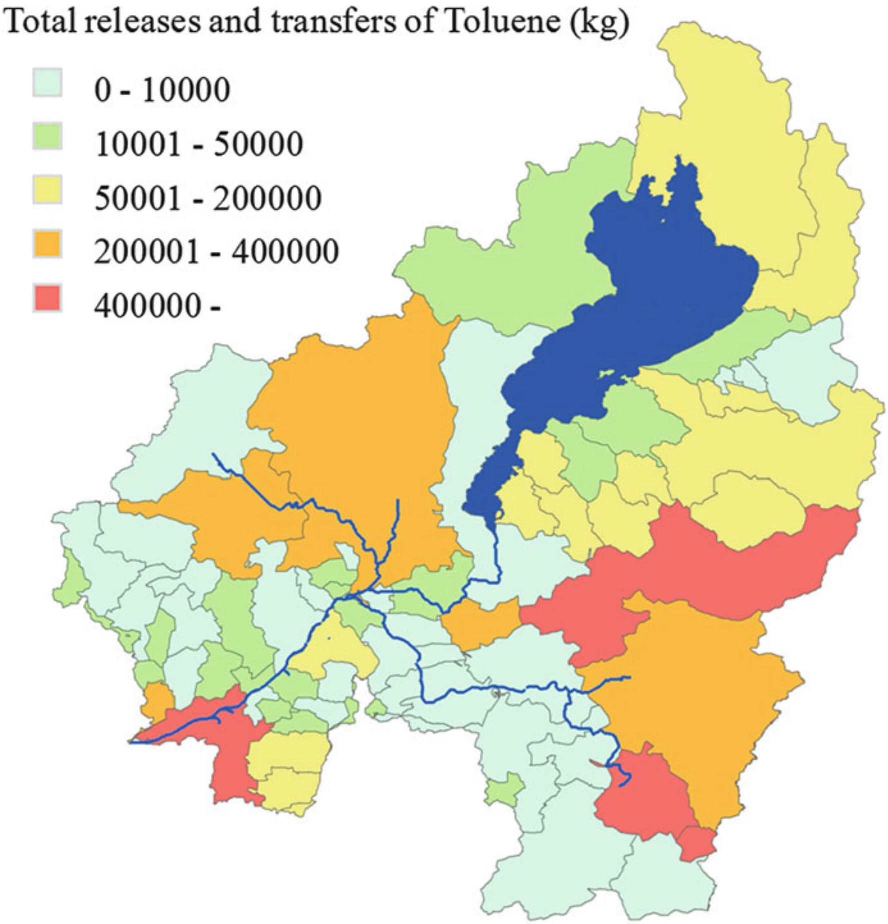

Fig. 11.4 Total releases and transfers of toluene in Lake Biwa-Yodo River basin

environmental load in a watershed level. Thus, the PRTR data is a helpful information as a tool for environmental management and evaluation.

SDS is aimed to ensure that manufacturers and importers can communicate through the sheet describing enough information of the chemical substances and mixtures in order to secure their safety use. The SDS includes information about the physicochemical properties of the chemical substance, its hazards, and instructions for handling, disposal, transport, etc. The SDS is prepared by a supplier of the chemical substance and provided to a recipient along the supply chain. The government enforces the SDS in Class I Designated Chemical Substance and Class II Designated Chemical Substance (100 substances). The SDS is applied to all enterprises which handle the designated substances.

In Japan, GHS Inter-ministerial Committee has been launched since 2001 to introduce GHS through translations of GHS-related UN documents into Japanese, publications of GHS Classification Manual and Technical Guidance, and classification of approximately 2618 chemical substances by GHS (as of October 2012). Furthermore, the Industrial Safety and Health Act was amended and enforced in 2006 in order to implement GHS-based labeling and SDS.

11.3.3 Chemical Substances Control Law and Screening Assessment

The Chemical Substances Control Law (CSCL) was established in 1973 as environmental pollution by PCBs pollution and its health effects emerged. This law is enforced to investigate safety of new chemical substances prior to manufacture or import. As of 2013, five categories (Class I Specified Chemical Substance (28 substances), Class II Specified Chemical Substance (23 substances), Monitoring Chemical Substance (38 substances), Priority Assessment Chemical Substances (162 substances), and General Chemicals (others)) are defined under the law.

In 2009, the CSCL was amended in a consideration of Johannesburg Plan of Implementation. The amended CSCL added a new screening assessment method for holistic management and evaluation of risks by chemical substances. The screening assessment is applied to all chemical substances except for Class I Specified Chemical Substance, Class II Specified Chemical Substance, and Monitoring Chemical Substance. After the screening assessment, those which are concerned their risks to human health and/or biological risk are designated as Priority Assessment Chemical Substances, and thereby various information on the chemical substances is investigated in order to conduct environmental risk evaluation effectively and efficiently by the government.

The screening assessment introduces a priority matrix classified by both hazardous class and exposure class as shown in Fig. 11.5. With this priority matrix, human health risk and biological risk are assessed in each chemical substance. In the hazardous class, the human health risk is assessed by four toxicity tests (i.e., general toxicity, reproductive/developmental toxicity, mutagenicity, and carcinogenicity) and classified into five classes. Similarly, the biological risk is assessed by acute toxicity test and chronic toxicity test and classified by five classes. In the exposure class, the amount of manufacture and shipment according to application reported from enterprises to the government is added up in each chemical substance and multiplied by emission factors according to application to estimate loading amount of the chemical substance into air and water. The loading amount is reduced by a factor in consideration of decomposition by sewage treatment plants and environment, and consequently the chemical substance is classified by six classes. The

			Hazardous Class				
			1	2	3	4	Out of Class
Category 1: Human health risk (Hazardous class is determined by a highest one among 4 toxicity tests)							
General Toxicity			-	$D \leq 0.005$	$0.005 < D \leq 0.05$	$0.05 < D \leq 0.5$	$D > 0.5$
Reproductive/Developmental Toxicity			-	$D \leq 0.005$	$0.005 < D \leq 0.05$	$0.05 < D \leq 0.5$	$D > 0.5$
Mutagenicity			GHS class 1A	GHS class 1B, 2			Out of GHS class
Carcinogenicity			GHS class 1A	GHS class 1B, 2	-	-	
Category 2: Biological risk			$PNEC \leq 0.001$	$0.001 < PNEC \leq 0.01$	$0.01 < PNEC \leq 0.1$	$0.1 < PNEC \leq 1$	$PNEC > 1$
Exposure Class	1	> 10000t	HIGH	HIGH	HIGH	HIGH	OUT OF CLASS
	2	1000t - 10000t	HIGH	HIGH	HIGH	MIDDLE	
	3	100t - 1000t	HIGH	HIGH	MIDDLE	MIDDLE	
	4	10t - 100t	HIGH	MIDDLE	MIDDLE	LOW	
	5	1t - 10t	MIDDLE	MIDDLE	LOW	LOW	
	Out of Class	≤ 1t	OUT OF CLASS				

Fig. 11.5 Summary of priority matrix

classified hazardous class and exposure class are applied to the priority matrix, and the chemical substance is accordingly classified by three classes (i.e., high, middle, or low). The Priority Assessment Chemical Substances are those which are classified high in both/either of the human health risk and/or the biological risk. Furthermore, those which are judged as high by experts, regardless of a result of the priority matrix, are also designated as the Priority Assessment Chemical Substances.

11.3.4 Risk Communication

In addition to the environmental management and evaluation implemented by the government, communications on the risk of chemical substances among people are also necessary to comprehend it correctly as their recognitions of the risk are different based on their experiences, aspects, or values. Therefore, the information of chemical substances should be shared among people, enterprises, and government to understand each other and cooperate to avoid any conflicts. When the risk communication is promoted and information on the risk is shared among them, they will be able to implement proper solutions against the environmental risk by their own judgments.

NITE website shows some examples of the risk communication in Japan. According to the website, popular events in 2010–2011 were dialogues between enterprises and local people, social visits to factories, luncheons and social gatherings for informal communications with local people, etc. The frequency of these events was mostly once in a year, and about 80% of enterprises held at least one event in a year. Thus, there are various opportunities of risk communications, and interests of people on the risk of chemical substances are enhanced through these events.

11.3.5 Database on Environmental Risk Evaluation

Evaluation reports on environmental risk of chemical substances can be downloaded from some databases provided by government websites in Japan. Here are the representative databases.

1. Profiles of the Initial Environmental Risk Assessment of Chemicals (MOE)

MOE has been evaluating environmental risks on chemical substances including unintentional products and natural products which are prioritized by experts and detected frequently in environmental monitoring since 2002. As of 2013, 209 chemical substances have been evaluated. The English website of the profiles is http://www.env.go.jp/en/chemi/chemicals/profile_erac/index.html.

2. Initial Risk Assessment (NITE)

The Initial Risk Assessment is an early-stage screening assessment in a multistage risk assessment of chemical substances. The risk of chemical substances to human health and organisms is evaluated in order to determine the necessity of further investigation, analysis, and assessment and to point out insufficient information and required action. NITE has evaluated 150 chemical substances mainly from PRTR-designated substances between 2001 and 2007. The English website of the Initial Risk Assessment is http://www.safe.nite.go.jp/english/risk/initial_risk.html.

3. Risk Assessment Documents (AIST)

The Risk Assessment Documents is a detailed risk assessment by AIST to promote environmental safety through science-based and sustainable solutions and to disseminate research findings and recommendations to the general public and policymakers. AIST has evaluated 25 chemical substances which are highly concerned about the risks to human health and biological systems between 2001 and 2007. The abstracts of the Risk Assessment Documents can be downloaded from http://unit.aist.go.jp/riss/crm/index_e.html.

4. Chemical Risk Information Platform (NITE)

The Chemical Risk Information Platform (CHRIP) is a database to provide hazardous information, regulations/laws in Japan, inventories/regulations in other countries, etc. about chemical substances which can be searched by Chemical Abstracts Service (CAS) Registry Number, substance name, or chemical structure, etc. The English website of CHRIP is http://www.safe.nite.go.jp/english/db.html.

11.4 Conclusions

Japan has experienced many public nuisances especially in high economic growth period, and the government restricted the discharge of hazardous chemical substances by EQS and TPLCS. Through these regulations, serious public nuisances and health effects had been steadily decreased. Since the 2000s, Asian countries have been rapidly developing their economies, whereas serious environmental pollutions emerged as the same as Japan. Therefore, we have to disseminate our previous incidents and transitions of our antipollution measures so as to prevent the same mistakes there. In that sense, an effective method of the prevention is environmental risk management and evaluation. In Japan, it has been gradually systemized through PRTR, SDS, screening assessment, etc. Furthermore, people and enterprises have gradually comprehended potential hazards and risks of chemical substances via risk communications and databases on environmental risks. Thus, industry-academia-government-citizen collaboration and cooperation are indispensable for environmental risk management to maintain the invaluable environment for future generations.

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Chapter 12
A History of Water Quality Monitoring System in Japan

Yoko Shimada

Abstract After serious water pollution problems caused health risks such as the "Minamata Disease," the water quality monitoring systems have been developed under the Basic Environment Law and the Water Pollution Control Law in Japan. Water qualities are being regularly sampled at about 9000 points in public waters (rivers, lakes, inland and coastal seas and groundwater) and analyzed by each prefectural government. Measurement results across the country have been stored for several decades. In this section, the history of the development of water quality monitoring system is explained with relation to the improvement in water environment in Japan.

Keywords Water quality standard · Monitoring system · Environmental policy

12.1 Introduction

Japan is blessed with abundant water resources. But serious water pollution has been caused by the rapid economic growth after World War II. The approaches to the water pollution problem in Japan have a long history. The establishment of water quality monitoring system has enabled to improve the water quality in public waters (rivers, lakes, harbors, coastal seas, etc.) and groundwater. This chapter shows the water quality monitoring system in Japan in relation to the environmental policy of Japanese government.

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12.2 Progress of Water Quality Monitoring System in Japan

In the industrial recovery period following World War II, water pollution became a serious problem in urban areas and caused pollution diseases such as the "Minamata disease." Japanese government and local authorities, therefore, began to take control measures. The Basic Law for Environmental Pollution Control was enacted in 1967 in the first place. Water Pollution Control Law was secondly enacted in 1970. The Environmental Agency was established in the next year. The Basic Law for Environmental Pollution Control was replaced by the Basic Environment Law in 1993, and the Environmental Agency was reorganized into the Ministry of the Environment in 2001.

Environmental quality standards were set up in 1971 by the Ministry of the Environment in line with the Basic Environment Law. They have been established as part of the Japanese government' s objectives: "standards that are to be followed," related to the setting of environmental parameters for water pollution, air pollution, soil pollution, and noise pollution to prevent health hazards and conserve the living environment.

Environmental quality standards for water pollution are target levels for water quality that are to be achieved and maintained in public waters (rivers, lakes, harbors, coastal seas, etc.) and groundwater. These standards are established to achieve two major goals: the protection of human health and the conservation of the living environment. Monitoring of the water quality of public waters started in 1971 along with the establishment of the water quality standards.

These policies for water pollution have locally improved the water quality. But the problem of water pollution has become more wide and complicated. The water quality of enclosed water areas such as basins, inland seas, and lakes has not improved yet, and the water contamination caused by toxic chemicals has surfaced. In view of these situations, groundwater and domestic wastewater pollution control measures and eutrophication control in enclosed water have reinforced with revisions of the Water Pollution Control Law and addition of the items of the water quality standards.

The item of the water quality standards has increased from 8 to 27 for the protection of human health and from 7 to 12 for the conservation of the living environment. Accordingly, the number of samples surveyed has increased. Tables 12.1 and 12.2 show water quality standards for the protection of human health and for the conservation of the living environment. Figure 12.1 shows the change of the number of samples surveyed for the water quality standard for the protection of human health.

Table 12.1 Water quality standards for the protection of human health

Item	Note
Cadmium	Set from the beginning (in 1971)
Total cyanide	Set from the beginning (in 1971)
Lead	Set from the beginning (in 1971)
Chromium(VI)	Set from the beginning (in 1971)
Arsenic	Set from the beginning (in 1971)
Total mercury	Set from the beginning (in 1971)
Alkyl mercury	Set from the beginning (in 1971)
Organophosphorus	Set in 1971 and erased in 1993
PCBs	Added in 1975
Dichloromethane	Added in 1993
Carbon tetrachloride	Added in 1993
1,2-dichloroethane	Added in 1993
1,1-dichloroethylene	Added in 1993
cis-1,2-dichloroethylene	Added in 1993
1,1,1-trichloroethane	Added in 1993
1,1,2-trichloroethane	Added in 1993
Trichloroethylene	Added in 1993
Tetrachloroethylene	Added in 1993
1,3-dichloropropene	Added in 1993
Thiuram	Added in 1993
Simazine	Added in 1993
Thiobencarb	Added in 1993
Benzene	Added in 1993
Selenium	Added in 1993
Nitrate nitrogen/nitrite nitrogen	Added in 1999
Fluorine	Added in 1999
Boron	Added in 1999
1,4-dioxane	Added in 2009

12.3 Outline of Water Quality Monitoring System in Japan

The water quality has been monitored at about 9000 points in public water areas across Japan (rivers, lakes, and seas) according to the water quality monitoring program set up by local governments all over Japan every year.

The number of monitoring points is 5375 for the items of the water quality standards and 7114 for the conservation of the living environment in FY2014 (Ministry of the Environment, Japan 1969). Local governments take water samples, measure their water quality, and compile data on the results of measurement in cooperation with the Ministry of Land, Infrastructure and Transport. The Ministry of the Environment gathers and analyzes these data and constructs the database of water quality of public water areas across Japan. This database has been used for

Table 12.2 Water quality standards for the conservation of the living environment

Item	Waters	Note
Hydrogen-ion concentration (pH)	Rivers, lakes and coastal waters	Set from the beginning (in 1971)
Biochemical Oxygen Demand (BOD)	Rivers	Set from the beginning (in 1971)
Chemical Oxygen Demand (COD)	Lakes and coastarl waters	Set from the beginning (in 1971)
Suspended Solid (SS)	Rivers, lakes and coastal waters	Set from the beginning (in 1971)
Dissolved Oxygen (DO)	Rivers, lakes and coastal waters	Set from the beginning (in 1971)
Total coliform	Rivers, lakes and coastal waters	Set from the beginning (in 1971)
Nomal-hexane extract substances	Coastal waters	Set from the beginning (in 1971)
Total nitrogen	Lakes and coastarl waters	Added in 1982
Total phosphorus	Lakes and coastarl waters	Added in 1982
Total zinc	Rivers, lakes and coastal waters	Added in 2003
Nonylphenol	Rivers, lakes and coastal waters	Added in 2012
n-alkylbenzenesulfonic acid and its salts	Rivers, lakes and coastal waters	Added in 2013

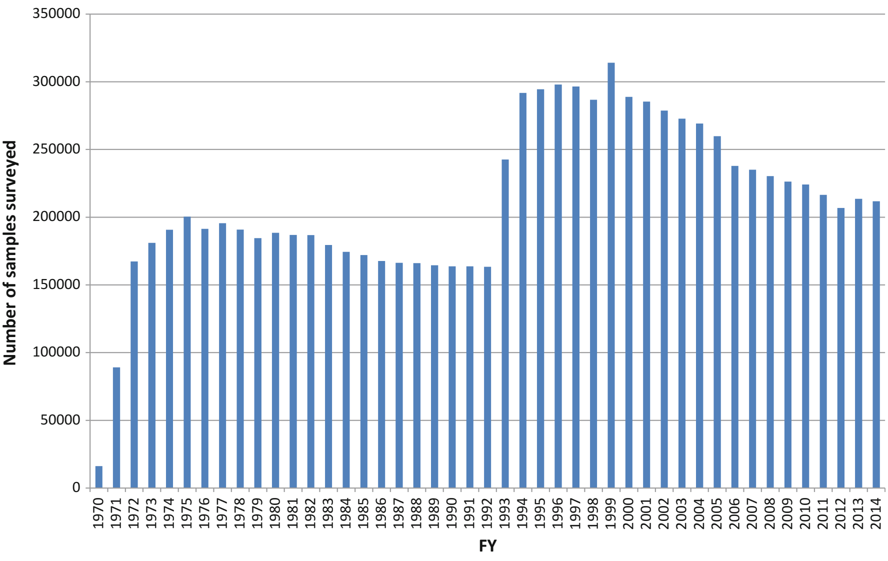

Fig. 12.1 Change of the number of samples surveyed for the water quality standard for the protection of human health

continual improvement of environmental conservation measures: environmental standards, effluent regulations, analytical method, survey method, and standards for processing survey data.

12.4 Results and Future Outlook

12.4.1 Results

As mentioned above, the water quality monitoring system in Japan has been build up for dealing with ever-growing complexity of water contamination problems. With this system, the water quality in public water areas across Japan (rivers, lakes, and seas) has been much improved. In terms of the compliance with the water quality standards for BOD and COD, typical indicators of water quality of organic contamination, the compliance rate was 92.0% for rivers, 55.1% for lakes, and 77.3% for seas (Ministry of the Environment, Japan 1969). Figure 12.2 shows the progress in compliance rate of water quality standard, BOD/COD.

12.4.2 Future Outlook (Ministry of the Environment, Japan 2011)

Though water quality in rivers and seas has been improved, water quality in enclosed water areas such as lakes and reservoirs is still low. The number of chemical

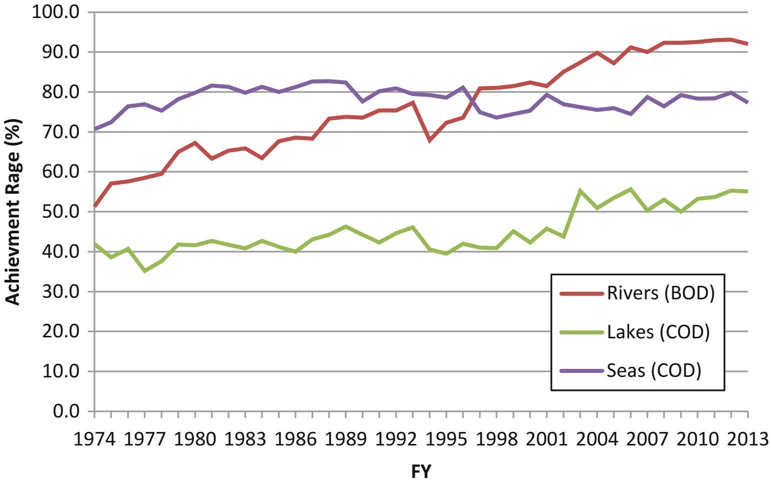

Fig. 12.2 Progress in compliance rate of water quality standard, BOD/COD

substances as “monitored substances” which have not been made directly into the environmental quality standards as of the present time but have been identified as needing further observation increases. Therefore, water quality monitoring will play a more important role from now on.

The Ministry of the Environment has put together the discussions about what future water environment conservation policy should be. In those discussions, it is indicated that gathering monitoring data concerning the water environment and utilizing for the future progress of environmental policy and researches should be very important for dealing with various problems with water environment. Specifically, there are three issues as follows:

1. Monitoring items

   It is necessary to gather monitoring data of not only water quality but also water quantity and aquatic life.
2. Efficient and concentrated monitoring

   Exact grasp on the environment of a target basin should be done by efficient and concentrated monitoring under cost restriction on the basis of the information about the geology, use of chemical substance, and utilization of water in the basin.
3. Integration of all monitoring data

   We should integrate the data and information concerning water environment which many organization, respectively, hold and make a common database.

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Chapter 13
Environmental Dynamic Model of Chemicals for Risk Evaluation

Minoru Yoneda

Abstract In order to estimate the amount of a chemical that humans take in from the environment, one must model environmental pathways leading from the source of the chemical to humans and assess exposure to representative human populations that accounts for the rate at which the body can absorb the chemical. While such models are assessed on various temporal and spatial scales, a watershed (drainage basin) in association with its corresponding air and soil is a suitable spatial scale. Furthermore, the precision of the model must be best suited for its intended use and other considerations, and uncertainty associated with the estimated results must be evaluated. Moreover, a simple multimedia model implemented using a fugacity model and systems analysis model with conventional environmental compartments demonstrated that fugacity models are advantageous in that they are essentially the same as common systems analysis models and make nonequilibrium conditions readily apparent.

Keywords Multimedia model · Pathways · Spatial scale · Systems analysis model · Fugacity model

13.1 Introduction

The following information is needed to evaluate the risks that chemicals pose to people.

- The type of toxicity possessed by the chemical substance
- The relationship between dose and adverse effects according to the type of toxicity
- Populations that may be exposed to the chemical substance
- The quantity of the chemical to which the population is actually exposed

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The circumstances are slightly different for assessing risk to an ecosystem. One must define the criteria that will be used to consider toxicity or adverse effects in the above information. Further, it must be taken into account that manifestations of adverse effects are not always caused by exposure but may be induced by conditions that threaten widespread environmental stress. This paper attempts to explain environmental fate models needed to quantitatively evaluate the risk of chemicals to humans in particular, but the same models can often be used for assessing the risk to ecosystems.

As mentioned above, the dose of a chemical substance must be known to assess its risk to people. To find the dose, it is necessary to estimate the concentrations of the chemical in various environmental media. Here, there is no need to estimate concentrations in media not required for predicting the dose, while concentrations of the chemical in media required for predicting the dose must be estimated at a precision dependent on the desired reliability of the risk assessment outcome. Hence, an environmental fate model for evaluating the risk of chemical substances includes numerous variations according to the type and properties of the target chemical, the target population, and the purpose of evaluation. In some cases, models are used solely to find chemical equilibrium concentrations in several media. In other cases, the model must estimate regional and temporal variations for concentrations in a number of foods. Practicable models may also be limited due to the amount of data available for risk assessment. In such cases, the model must not only specify the estimated results but must also note the uncertainty in the estimated results. As outlined above, there exist many environmental fate models used for risk assessment. In fact, numerous computer programs are available for determining the environmental fates of chemical substances. For example, the National Institute for Environmental Studies (NIES) provides the Grid-Catchment Integrated Environmental Modeling System (G-CIEMS) (http://www.nies.go.jp/rcer_expoass/gciems/gciems.html) that uses a geographical information system (GIS) to calculate the migration of chemicals released into the environment in detail through such media as air, water, soil, and sediment; and the Multimedia SimpleBox-systems Environmental Model (MuSEM) (http://www.nies.go.jp/rcer_expoass/musem/musem.html) is used to evaluate the environmental fates of chemicals and exposure levels using a Mackay Level III fugacity model (described later). The National Institute of Advanced Industrial Science and Technology (AIST) also provides models for estimating atmospheric levels of chemicals and assessing their exposure and systems for simulating the migration and accumulation of chemicals in various media (http://www.aist-riss.jp/main/modules/product/software/). A variety of similar programs are being used or have been proposed throughout the world, including a tool provided by the US Environmental Protection Agency (EPA). For information on the theoretical background and performance of these systems, as well as instructions on how they are used, please refer to the descriptions provided with the individual systems themselves. This paper describes only those aspects that form the basis for constructing the models. Through a thorough understanding of this theoretical foundation, one can effectively use the systems mentioned above.

13.2 Human Exposure

While the dose of a chemical is required for assessing its risk, generally the route of exposure is also an important factor for determining the degree of adverse effects in people. The nature and degree of effect that the chemical causes to a person may differ depending on whether the chemical was taken into the blood through the lungs (inhalation) or whether the chemical was absorbed into the blood from the digestive system after being metabolized by the liver (ingestion), even for the same quantity of chemical. Further, rather than being taken into the body via the lungs or digestive system, a chemical substance may also be absorbed through the skin (dermal absorption). It is important to be aware of this because chemicals may cause adverse effects in the body simply through such dermal absorption. Therefore, when creating an environmental fate model for a specific chemical substance, it is necessary to determine what exposure routes are important by considering the mechanism of the chemical's toxicity. If the mechanism of toxicity is uncertain for the target chemical, generally the dose should be evaluated for all routes, including inhalation, ingestion, and dermal absorption. Evaluation of a certain route may be omitted when it is clear that the dose via that route is extremely low, but when such information is not known, the dose should be assessed at least once for all routes.

The quantity of a chemical internalized via each route is sometimes expressed as "dose" and sometimes as "exposure." While these terms may have slightly different uses, they are often used nearly interchangeably and will not be particularly differentiated in this document. However, confusion between these terms may arise, as in the following case.

On university exams, students often write the following equation when asked to provide a formula for estimating the ingested quantity of a chemical present in a certain food.

$$\begin{aligned}&[\text{Concentration of chemical in food}]\,(\text{mg/kg}) \times [\text{food intake}]\,(\text{kg/kg} - \text{bw/day})\\ &\quad = [\text{chemical intake}]\,(\text{mg/kg} - \text{bw/day})\end{aligned} \tag{13.1}$$

Here, the quantity of food consumed is expressed as the daily intake per unit body weight (kg-bw). However, in order to express the actual quantity of the chemical absorbed by the body, it is necessary to include the rate at which the chemical is absorbed from the food, as in the following equation.

$$\begin{aligned}&[\text{Concentration of chemical in food}]\,(\text{mg/kg}) \times [\text{food intake}]\,(\text{kg/kg} - \text{bw/day})\\ &\quad \times [\text{absorption rate}]\,(-) = [\text{chemical intake}]\,(\text{mg/kg} - \text{bw/day})\end{aligned} \tag{13.2}$$

Thus, care must be taken as the quantities given in both Eqs. (13.1) and (13.2) may be expressed as exposure (or dose). The dose-response relationship used in risk assessment is frequently found using chemicals in a form that can be easily absorbed by the body, where the absorption rate is often a value approaching 100%. However, dose in the dose-response relationship is actually the exposure expressed in Eq. (13.2). In other words, this equation expresses the relationship between the quantity of the chemical actually taken into the body and a response in the body. However, when not enough is known about the absorption rate of a chemical, an absorption rate of 100% may be used when calculating exposure for risk assessment to be on the safe side. Thus, Eq. (13.1), which ignores the absorption rate, is often used to express exposure. For this reason, students often mistakenly express exposure using Eq. (13.1) even when it is essential to account for the absorption rate.

13.3 Exposure Pathways in the Environment

In order to clarify the level of environmental exposure based on each exposure route of a certain chemical substance, ideally one should evaluate all pathways that can lead from the source of the chemical released into the environment to each exposure route. In reality, however, this is not possible. We can broadly consider all environmental pathways that pass through the air, drinking water, food, and soil, as illustrated in the example of Fig. 13.1. However, simply indicating routes through food is not precise as there are limitless types of food, and it would be impossible to evaluate all such paths comprehensively. Therefore, foods are normally organized into general categories and assessed by their category. The method of determining these categories is dependent on the properties of the chemicals being evaluated and the available data. In Japan, we can use classifications in the Food Balance Sheet published by the Ministry of Agriculture, Forestry and Fisheries (MAFF), for example. Since this sheet provides the consumption per man-day for each food type and the proportions of each that are produced domestically and imported, it is possible to obtain approximate values indicating, on average, the amount of foods produced in a target region of Japan that are being consumed by Japanese people. MAFF has also published statistical data for the volume of each food type shipped by prefecture, which can be used when it is necessary also to consider the characteristics of a target region. Figure 13.1 illustrates pathways to human exposure when broad classifications are employed for food.

In Fig. 13.1, the pathways from air, water, and soil to foods have been greatly simplified. Naturally there exist routes by which chemicals are absorbed into foods directly from the soil and water, but in most cases, the chemical actually passes through media in many steps before reaching the food. However, these multiple steps can be combined and expressed with a single transfer coefficient, as shown in Fig. 13.2. The example of Fig. 13.2 illustrates how chemicals are transferred from the air, water, and soil to the food product cheese. Chemicals contained in the cheese are shown being transferred through multiple media in the upper drawing of Fig. 13.2 but are depicted as being transferred directly from soil, water, and air in the lower drawing of Fig. 13.2. The chemical transfers from air, water, and soil to foods depicted in Fig. 13.1 are actually simplified representations of these complex

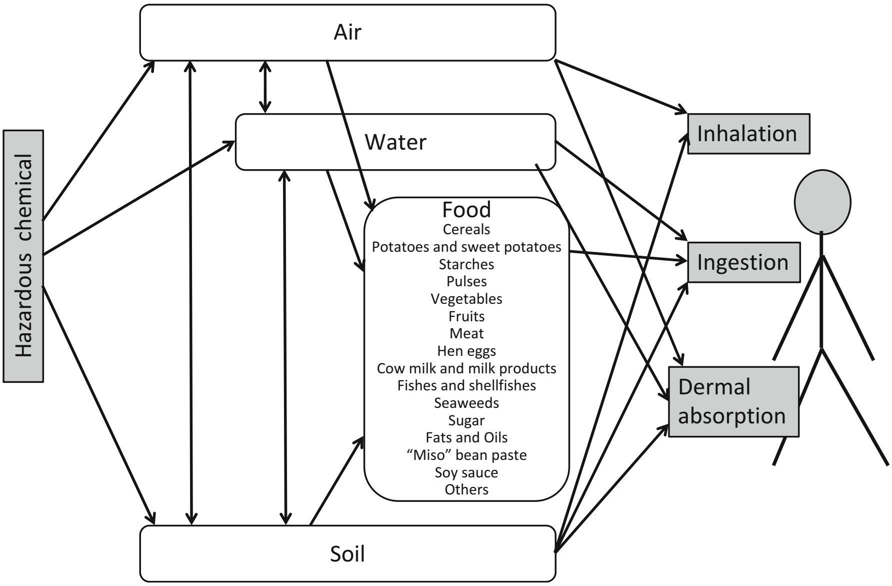
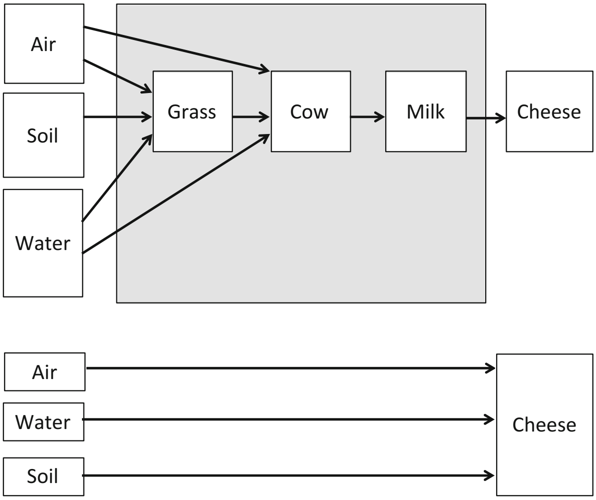


Fig. 13.1 Exposure pathways for toxic chemicals in the environment

Fig. 13.2 Transfer pathways from air, water, and soil to cheese (The upper drawing illustrates pathways through multiple media that lead to cheese. These pathways can be represented as transfer coefficients from air, water, and soil to cheese, as illustrated in the lower drawing)



transfers. Incidentally, there are also chemical transfers from plants and animals, which are the origin of food, to water and soil. In fact, these transfer pathways are important for estimating chemical concentrations in the target plants and animals. When estimating chemical concentrations in food, often the quantities of a chemical exchanged between soil/water and plants/animals is not large enough to generate significant differences in the amounts of the chemical present in the water and air, and, thus, transfers from plants and animals to water and soil can be ignored in a diagram depicting transfer paths to food. The transfer paths from food to water and soil have been omitted in Fig. 13.1.

Another issue in constructing environmental fate models to assess the risk of exposure to chemicals is defining the type of person or type of population whose risk of exposure is being evaluated. The US EPA has compiled a detailed list of standardized values for risk assessment specifying levels of exposure to various groups of people through various routes and pathways of exposure including air, water, soil, and food (U.S. EPA 2011). To ensure a conservative assessment, the region in which the target person resides is frequently selected from among regions with high exposure levels based on results estimated using the environmental fate model. Conversely, if a target person is not defined, the target space in the environmental fate model is not defined. Consequently, the development of the environmental fate model and definitions of target populations are often adjusted through trial and error based on how the two influence each another.

13.4 Temporal and Spatial Scales

As described above, exposure to certain people can often be roughly estimated by incorporating air, water, soil, and food in a model as exposure pathways, as illustrated in Fig. 13.1. However, transfer pathways to food are more complex in reality, as illustrated in Fig. 13.2. Further, depending on the temporal scale during which the target chemical migrates after being released from the source into the environment and the spatial scale for distribution at the source of release, air may be considered in terms of indoor air, air on a regional scale, air on a national scale, or air on a global scale; water may be considered in terms of pond water, river water, and groundwater for a specific watershed (drainage basin), water on a national scale, or water on a global scale; and soil may be considered in terms of sediment or soil around a pond, surface soil in a watershed, surface soil on a national scale, or surface soil on all land of the Earth. In general, the larger the spatial scale being considered, the longer the temporal scale to evaluate. Of the spatial scales, a national scale has natural political boundaries for air, water, and soil but is not physically valid as a target region. Still, a national scale is often suitable for use as the target region of risk assessment because statistics on the amounts of chemicals released into the environment are usually given by country. When considering transfers in the environment and exposure to humans of chemicals after being released into the environment, a single watershed is likely a suitable spatial scale for approximating the concentration in each environmental medium under steady-state conditions. This is because boundaries can be easily established for water, one of the principal media facilitating the transport of chemicals, when accounting for the processes of water being supplied from rainfall, flowing into rivers and groundwater, and flowing out of the watershed, without giving much thought to water exchanged with other watersheds. Further, it is preferable to have a moderate-sized spatial scale that has just enough randomness to average out the variations in the target region in order to approximate transfer rates in a dynamic steady state under the assumption that the amount of chemicals released into the environment is substantially equivalent to the amount of chemicals flowing out of the watershed. Thus, a single watershed may be suited to an analysis that meets these conditions. In addition, the topographical features of a watershed are often reflected in the distribution of inhabited areas, and, thus, the people under evaluation can often be represented by the resident group in a single model. By this token, watersheds are suitable as unit-spatial scales when creating environmental fate models for chemicals. The airshed (air basin) is a concept very similar to the watershed. These regions can be thought of as single coherent airspaces when considering air pollution or the like and may be thought of as a generally enclosed space or a space in which inflow and outflow can be evaluated qualitatively to some extent.

Within most terrain of urban settings, valid analysis can be performed by assuming the watershed and airshed are substantially aligned, as shown in Fig. 13.3. When a watershed is selected as the subject of land analysis, it is reasonable to establish the region overlapping this basin in a plan view as the airshed, except under special circumstances. Another issue is defining the altitude of the airshed. Often the airshed is set to the atmospheric boundary layer (up to approximately 1000 m) in which there is substantial convective airflow. However, when analyzing special conditions at fixed intervals, such as the generation of smog, it may be more appropriate to limit the airshed to a lower altitude, such as the surface boundary layer.

Similar problems arise for surface soil or groundwater. Determining how deep the analysis should cover is one issue related to surface soil and groundwater. While there is no particular established value, depth is often set by determining the distribution and penetration characteristics of the target chemical in soil. For example, most chemicals are present within 5 cm beneath the surface. Thus, the depth of analysis for surface soil can be set to 5 cm for chemicals that would not be transported lower by rainfall. However, for chemicals that easily penetrate the soil, the region of analysis may be set deeper and, in some cases, may even include groundwater tens of meters beneath the surface. It should be noted that, while the term “watershed” encompasses surface runoff into rivers and lakes, the equivalent term for groundwater is a “groundwater basin.” However, this can be misleading because the underlying groundwater basin does not always correspond to the surface runoff in the watershed. In general, the unconfined aquifer constituting the uppermost groundwater zone forms an unconfined groundwater basin that corresponds to the surface runoff in the watershed, but often a confined aquifer forms a confined groundwater basin unrelated to the watershed. As an example, when a mountain is present in the middle of surface runoff, dividing the area into two regions with separate watersheds, there is often confined groundwater that spans both regions. However, it is rare that the subterranean flow over such a vast region needs to be considered in the risk assessment of chemicals.

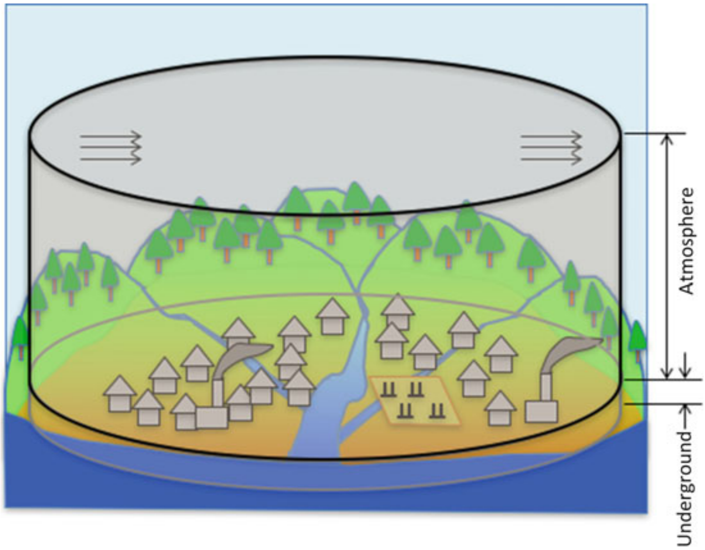


Fig. 13.3 An airshed (air basin) over a watershed (drainage basin)

13.5 Approaches to Model Precision and Uncertainty

When looking at human exposure to chemicals released into the environment, one approach is to create a model with as much detail as possible, as in the upper drawing of Fig. 13.2, while a black box approach is to represent transmission coefficients for a certain pathway with a single coefficient, as in the lower drawing of Fig. 13.2. As an example, the pathway in the upper drawing of Fig. 13.2 leading from water to pasture grass may involve multiple pathways leading to the grass in a certain region, including the pathway that river water follows to the grass to be absorbed thereby and the pathways through which groundwater and precipitation are absorbed in the grass. It is also possible to consider temporal variations and spatial distributions of chemicals in river water and groundwater using GIS software and data, for example. Thus, there is no limit to how precise the model can be made, but that does not mean it is desirable simply to make the model as precise as possible. The model precision should be set with consideration for the following points.

1. Are the temporal/spatial scales compatible with the intended use?

   For example, if the model is intended for estimating the average annual exposure of a certain chemical to all residents in a specific watershed, in most cases, it is meaningless to reproduce concentrations in river water of the watershed for temporal variations down to units of minutes or seconds. Even when the model is refined in this way, often the estimating precision is not improved. Spatially, it is sufficient to model just the target watershed and unnecessary to model all of Japan or the world. The model need only have sufficient precision to reproduce the temporal variation and spatial distributions for quantities of the chemical being evaluated.

2. What are the critical pathways of the target chemical?

   When looking at chemicals whose critical pathways are primarily foods brought in from outside the prefecture, it is pointless to estimate temporal variations of chemical concentrations in the basin's river water. The model must incorporate quantities and parameters necessary for simulating the critical pathways.

3. What environmental compartments must be considered in the model?

   When a chemical is primarily present in water and soil but has low volatility and, hence, is nearly nonexistent in the atmosphere, there is no need to employ a detailed atmospheric model. In such cases, an atmospheric model may be omitted from the fate model. It is preferable to ignore environmental compartments that are unessential in order to simplify the model.

4. What data is available?

   It is not pragmatic to use a model requiring a lot of unobtainable data. It is preferable to construct the model with only available data. However, some data is simply indispensable for estimating exposure of a target chemical. In such cases, one may create a model somehow using only available data while simultaneously evaluating uncertainty in the estimated results or may create a model incorporating unavailable data and perform sensitivity analysis, for example, to quantitatively evaluate uncertainty in the estimated results attributable to uncertainty in the data.

5. Will refining the model improve estimating precision?

   Futilely increasing the number of parameters in an effort to refine the model may result in a more refined model, but in the end, it is not possible to determine the values of all parameters. Consequently, the estimating precision of the target quantity is not improved and may in fact be worse. Unless the added parameters can produce a clearer theoretical explanation for the environmental fate of the chemical or can be expected to produce an obvious improvement in estimating precision, it is preferable to use a simplified model with as few parameters as possible.

6. Is the model useful?

   When creating a model that requires weeks to calculate and evaluate the fate of a certain chemical, even when using a supercomputer, such a model is not pragmatic for situations in which the government requires daily estimations on the same day. Thus, it is necessary to ensure that the model is useful to the user and for the intended application.

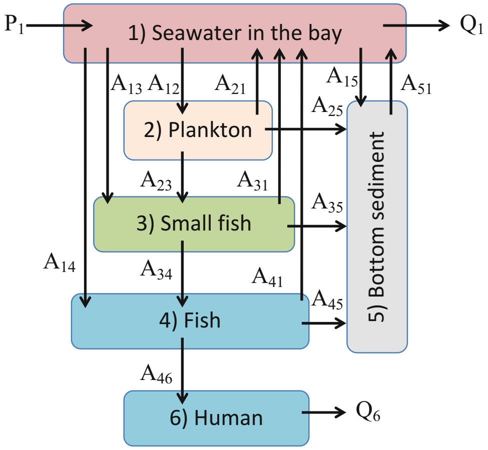
Therefore, one must select a suitable model with consideration for the points described above. This type of modeled environment for evaluating the fate of a chemical is called an "evaluative environment," in contrast to a "real environment" (Mackay 2001). The relationship between meticulousness in selecting a conceptual model and the estimating precision of the model is organized well in the approach of fugacity model levels used as environmental fate models for organic pollutants. Therefore, levels I–IV fugacity models are outlined below.

13.6 Fugacity Models

Fugacity models are a technique for finding distributions of organic chemicals, for example, in various media. However, rather than representing the concentration of an organic chemical in each medium using the units of each medium, which have differing significance and dimensions, fugacity models establish the units of a reference medium representing the chemical concentration and express the concentrations at equilibrium in other media in units of the reference medium. Commonly, air is set as the reference medium, with pressure (Pa) used as the units of concentration. Here, the values obtained by converting concentration (mol/m^3) in other media to pressure are known as fugacity. The fugacity of a medium expresses the escaping tendency of the organic chemical. The parameter for converting fugacity in a medium to the inherent concentration in the medium is called fugacity capacity. Mackay (2001) described the relationship between fugacity and fugacity capacity as being analogous to the relationship between temperature and heat capacity. Based on this analogy, the thermal energy per unit volume of a medium is equivalent to the concentration in the medium. Since the quantity of thermal energy present in a unit volume of a medium differs among different media, even at the same temperature, heat capacity represents the quantity of thermal energy stored per unit volume of a medium due to an increase in unit temperature. By analogy, fugacity capacity represents the number of moles of a substance actually stored in a unit volume of a medium due to an increase in unit fugacity (Pa). Thus, when the concentration of an organic chemical in a medium is at equilibrium, the magnitude of fugacity capacity represents the quantity of the organic chemical actually present in a unit volume of the medium. When the chemical is nearly nonvolatile, water may be used as the reference medium, while the aqueous concentration is used as the reference unit. In this case, the reference unit (aqueous concentration) equivalent to fugacity is called aquivalence. Fugacity models are fundamentally configured of mass balance equations based on the theory of chemical equilibrium. However, due to their advantages described later and their ability to produce more orderly expressions of mass balance equations, fugacity models are frequently used as environmental fate models for chemicals.

Fugacity models are divided into levels from level I to level IV based on how they treat steady state. In a system such as that shown in Fig. 13.4, level I denotes an equilibrium model of a conserved chemical in a closed system, i.e., a system having no input or output represented by P_1 and Q_1 in Fig. 13.4. This model defines the size of each environmental compartment, i.e., sets the regions for analysis, and one can calculate the concentration at equilibrium in each compartment by finding a parameter for converting concentration to fugacity, known as the fugacity capacity or the Z-value.

Fig. 13.4 Example of an environmental fate model



Level II is an instantaneous equilibrium model that assumes perfect mixing in the target regions and considers inflow and outflow for the target region and reactions such as chemical emissions and loss for the target chemical. The model can perform nonsteady-state computations that consider temporal changes due to advection and reactions but cannot always estimate realistic temporal changes since the intercompartmental transport is based on an instantaneous equilibrium model. However, a level II model can be used for approximating changes in the average concentration of environmental compartments (e.g., water, soil, and crops) within a watershed.

Level III is a model that finds steady-state solutions that do not assume equilibrium as in level II, where the distribution of chemicals in each compartment is based on the compartment's composition and size, but consider intercompartmental transport rates of the chemical. With this model, discretization is performed for each environmental compartment enabling assessment of spatial distribution in the same compartment. For example, while a level II model determines the distribution ratio of a chemical between air and soil from the chemical properties, the volume of air and soil, and the quantity of organic matter in the soil, a level III model determines the distribution ratio based on the balance between the rate at which the chemical evaporates into air from soil and the rate at which the chemical becomes deposited in soil from air. Here, level II models are sufficient when the intercompartmental transport rates of the target chemical are extremely high and time of transport can be ignored, while level III models should be used when the time required for intercompartmental transport processes cannot be ignored.

Level IV models are used to track the same intercompartmental transport of a target chemical in a level III model except in a nonsteady state and can vary the rate of advection of the chemical in a nonsteady state.

The level of model to be used among the fugacity models described above should be chosen with consideration for the conditions presented at the beginning of Sect. 13.5.

13.7 Example of an Environmental Fate Model Based on Mass Balance Equations

Figure 13.4 shows an example of an environmental fate model for chemicals constructed based on mass balance equations. The model illustrates the behavior of the chemical in a specific bay. For simplification, only migration of the chemical within the water system will be considered, while volatilization of the chemical into the atmosphere is assumed negligible. Media considered in the model are seawater in the bay, plankton, small and large fish, and bottom sediment, and the model simultaneously evaluates exposure to local residents. The following example estimates values for the parameters in the model of Fig. 13.4. When creating a model and estimating its parameters, consistency of units is imperative. Thus, it is desirable to confirm the consistency of units at every opportunity in the process of model creation. Here, provisional units will be assigned to each parameter for this purpose. Note that the following is merely one example of estimation, and the method of estimating parameters is not limited to the following example. Further, loss of the chemical by degradation is considered negligible in this example.

P_1: Inflow of chemical into bay seawater (mg/day)

Chemical inflow is found by multiplying the inflow of river water into the bay F_r (kg/day) by the chemical concentration in river water C_r (mg/kg)

$$P_1 = F_r \times C_r \tag{13.1}$$

Q_1: Outflow of chemical from bay (mg/day)

Chemical outflow is found according to the following equation from the exchange rate γ (−/day) of seawater inside the bay exchanged with seawater outside the bay, the volume of seawater in the bay V_1 (kg), the concentration of the chemical in bay seawater C_1 (mg/kg), and the concentration of the chemical in seawater outside the bay C_o (mg/kg).

$$Q_1 = V_1 \times \gamma \times (C_1 - C_o) \tag{13.2}$$

A_{12}: Chemical transfer rate from bay seawater to plankton (mg/day)

A_{12} is found from the chemical concentration in bay seawater C_1 (mg/kg), the seawater intake per unit quantity of plankton F_{12} (kg/day/kg), and the abundance of plankton in the bay V_2 (kg).

$$A_{12} = F_{12} \times C_1 \times V_2 \tag{13.3}$$

A_{21}: Chemical transfer rate from plankton to bay seawater (mg/day)

The concentration of the chemical in plankton detritus is proportional to the chemical concentration in the plankton C_2 (mg/kg) at a ratio of η_2 (−). Normally η_2 is a value smaller than 1. Assuming the rate of detritus per unit quantity of plankton F_{21} (kg/day/kg) is equivalent to the seawater intake per unit quantity of plankton F_{12}, A_{21} is found from the following equation.

$$A_{21} = \eta_2 \times C_2 \times F_{12} \times V_2 \tag{13.4}$$

A_{23}: Chemical transfer rate from plankton to small fish (mg/day)

A_{23} is calculated from the plankton intake per unit quantity of small fish F_{23} (kg/day/kg), and the abundance of small fish in the bay V_3 (kg), assuming small fish absorb the chemical from plankton at the rate 1.

$$A_{23} = C_2 \times F_{23} \times V_3 \tag{13.5}$$

A_{25}: Chemical transfer rate from plankton to bottom sediment (mg/day)

A proportion of plankton ζ_2 (−/day) from the abundance of plankton is assumed to die and sink into the bottom sediment over a unit time. However, it will be assumed that the abundance of plankton itself does not fluctuate since newly born plankton account for those that die off and sink and those that are eaten by small fish. Based on these conditions,

$$A_{25} = \zeta_2 \times V_2 \times C_2 \tag{13.6}$$

A_{13}: Chemical transfer rate from bay seawater to small fish (mg/day)

Based on the seawater intake per unit quantity of small fish F_{13} (kg/day/kg),

$$A_{13} = F_{13} \times C_1 \times V_3 \tag{13.7}$$

A_{31}: Chemical transfer rate from small fish to bay seawater (mg/day)

The concentration of chemical in waste from small fish is considered proportional to the concentration of chemical in the small fish C_3 (mg/kg) at a proportion of η_3 (−). Normally η_3 is a value smaller than 1. Hence, A_{31} is found from the following equation when the rate of waste per unit quantity of fish F_{31} (kg/day/kg) is equivalent to the seawater intake per unit quantity of small fish F_{13}.

$$A_{31} = \eta_3 \times C_3 \times F_{13} \times V_3 \tag{13.8}$$

A_{35}: Chemical transfer rate from small fish to bottom sediment (mg/day)

A proportion of small fish ζ_3 (−/day) from the abundance of small fish is assumed to die and sink into the bottom sediment over a unit time. However, it will be assumed that the abundance of small fish itself does not fluctuate since newly born small fish account for those that die off and sink and those that are eaten by other fish. Based on these conditions,

$$A_{35} = \zeta_3 \times V_3 \times C_3 \tag{13.9}$$

A_{34}: Chemical transfer rate from small fish to fish (mg/day)

A_{34} is calculated from small fish intake per unit quantity of fish F_{34} (kg/day/kg) and the abundance of fish in the bay V_4 (kg), assuming that fish absorb the chemical in small fish at a rate of 1.

$$A_{34} = C_3 \times F_{34} \times V_4 \tag{13.10}$$

A_{14}: Chemical transfer rate from bay seawater to fish (mg/day)

Based on seawater intake per unit quantity of fish F_{14} (kg/day/kg),

$$A_{14} = F_{14} \times C_1 \times V_4 \tag{13.11}$$

A_{41}: Chemical transfer rate from fish to bay seawater (mg/day)

It is assumed that the concentration of chemical in waste from fish is proportional to the concentration of chemical in fish C_4 (mg/kg) and that this ratio is η_4 (−). Normally η_4 is a value smaller than 1. Thus, A_{41} is calculated from the following equation when the rate of waste per unit quantity of fish F_{41} (kg/day/kg) is equivalent to the seawater intake per unit quantity of fish F_{14}.

$$A_{41} = \eta_4 \times C_4 \times F_{14} \times V_4 \tag{13.12}$$

A_{45}: Chemical transfer rate from fish to sediment (mg/day)

It is assumed that a proportion of fish ζ_4 (−/day) from the abundance of fish dies and sinks per unit time. However, it will be assumed that the abundance of fish itself does not fluctuate since newly born fish account for the numbers that die off and sink and the fish that are eaten by humans. Under these conditions,

$$A_{45} = \zeta_4 \times V_4 \times C_4 \tag{13.13}$$

A_{15}: Chemical transfer rate from bay seawater to bottom sediment (mg/day)

Assuming that a proportion of bay seawater ζ_1 (−/day) from the abundance of bay seawater sinks into (is absorbed by) bottom sediment per unit time.

$$A_{15} = \zeta_1 \times V_1 \times C_1 \tag{13.14}$$

A_{51}: Chemical transfer rate from bottom sediment to bay seawater (mg/day)

It is assumed that a proportion of the chemical ζ_5 (−/day) from the abundance of the chemical in bottom sediment is leached into the bay seawater per unit time. A_{51} is calculated from the following equation, where the quantity of bottom sediment in the bay is V_5 (kg) and the concentration of chemical in the sediment is C_5 (mg/kg).

$$A_{51} = \zeta_5 \times V_5 \times C_5 \tag{13.15}$$

A_{46}: Chemical transfer rate from fish to humans (mg/day)

If the amount of fish consumed per person is F_{46} (kg/day/kg), the number of humans eating fish from this bay is N_6 (persons), and the rate at which humans absorb the chemical in fish is 1.

$$A_{46} = C_4 \times F_{46} \times N_6 \tag{13.16}$$

Q_6: Rate of chemical discharge from humans (mg/day)

It is assumed that the chemical discharged from humans is proportional to the abundance of chemical in the body and the rate of discharge is η_6 (−/day). If the concentration of the chemical in a body is C_6 (mg/kg) and the average body weight per person is V_6 (kg/person),

$$Q_6 = \eta_6 \times C_6 \times V_6 \times N_6 \tag{13.17}$$

Based on the relationships of these transfer rates, the change per unit time in the quantity of chemical present in each medium is expressed by the following system of ordinary differential equations.

$$V_1 \mathrm{dC_1/dt} = P_1 - Q_1 - A_{12} - A_{13} - A_{14} - A_{15} + A_{21} + A_{31} + A_{41} + A_{51} \tag{13.18}$$

$$V_2 \mathrm{dC_2/dt} = A_{12} - A_{21} - A_{23} - A_{25} \tag{13.19}$$

$$V_3 \mathrm{dC_3/dt} = A_{13} + A_{23} - A_{31} - A_{34} - A_{35} \tag{13.20}$$

$$V_4 \mathrm{dC_4/dt} = A_{14} + A_{34} - A_{41} - A_{45} - A_{46} \tag{13.21}$$

$$V_5 \mathrm{dC_5/dt} = A_{15} + A_{25} + A_{35} + A_{45} - A_{51} \tag{13.22}$$

$$N_6 V_6 \mathrm{dC_6/dt} = A_{46} - Q_6 \tag{13.23}$$

While real phenomena is greatly simplified in Eqs. (13.18), (13.19), (13.20), (13.21), (13.22), and (13.23), the data can be further simplified by ignoring any terms found to be clearly insignificant compared to the other terms. Consider the following approximations, for example.

(a) In Eq. (13.18), all transfer rates other than P_1 and Q_1 can be ignored.
(b) In Eq. (13.19), A_{23} and A_{25} are minor compared to A_{12} and A_{21} and can be ignored.
(c) In Eq. (13.20), all transfer rates other than A_{23} and A_{31} can be ignored.
(d) In Eq. (13.21), all transfer rates other than A_{34} and A_{41} can be ignored.
(e) In Eq. (13.22), all transfer rates other than A_{15} and A_{51} can be ignored.
(f) In Eq. (13.2), the value of C_o is sufficiently smaller than C_1 to be negligible.

The validity of these approximations must be verified by finding the approximate value for each transfer rate. The following equations are derived from Eqs. (13.18), (13.19), (13.20), (13.21), (13.22), and (13.23) using the above approximations.

$$\mathrm{V_1 dC_1/dt} = \mathrm{P_1} - \mathrm{Q_1} = \mathrm{F_r} \times \mathrm{C_r} - \mathrm{V_1} \times \gamma \times \mathrm{C_1} \tag{13.24}$$

$$\mathrm{V_2 dC_2/dt} = \mathrm{A_{12}} - \mathrm{A_{21}} = \mathrm{F_{12}} \times \mathrm{C_1} \times \mathrm{V_2} - \eta_2 \times \mathrm{C_2} \times \mathrm{F_{12}} \times \mathrm{V_2} \tag{13.25}$$

$$V_3 dC_3/dt = A_{23} - A_{31} = C_2 \times F_{23} \times V_3 - \eta_3 \times C_3 \times F_{13} \times V_3 \quad (13.26)$$

$$V_4 dC_4/dt = A_{34} - A_{41} = C_3 \times F_{34} \times V_4 - \eta_4 \times C_4 \times F_{14} \times V_4 \quad (13.27)$$

$$V_5 dC_5/dt = A_{15} - A_{51} = \zeta_1 \times V_1 \times C_1 - \zeta_5 \times V_5 \times C_5 \quad (13.28)$$

$$N_6 V_6 dC_6/dt = A_{46} - Q_6 = C_4 \times F_{46} \times N_6 - \eta_6 \times C_6 \times V_6 \times N_6 \quad (13.29)$$

By substituting the equation for each transfer rate into the above system of ordinary differential equations, setting initial values, and performing calculations, temporal changes can be found for the concentration in each compartment C_i ($i = 1, 2, \ldots, 6$). In a compartment model, the method of solving a system of ordinary differential equations such as those in Eqs. (13.24), (13.25), (13.26), (13.27), (13.28), and (13.29) to calculate the concentration of each compartment is also called a system analysis method.

In the context of Eqs. (13.24), (13.25), (13.26), (13.27), (13.28), and (13.29), if the system reaches a quasi-steady state after sufficient time has elapsed, the concentration at steady state can be found for each medium by solving the system of linear equations produced by placing a "0" on the left side of each Eqs. (13.24), (13.25), (13.26), (13.27), (13.28), and (13.29). The system of linear conditions derived from Eqs. (13.24), (13.25), (13.26), (13.27), (13.28), and (13.29) is shown below.

$$C_1 = (F_r/(V_1 \times \gamma)) \times C_r = \alpha_1 \times C_r \quad (13.30)$$

$$C_2 = (1/\eta_2) \times C_1 = \alpha_2 \times C_1 \quad (13.31)$$

$$C_3 = (F_{23}/(\eta_3 \times F_{13})) \times C_2 = \alpha_3 \times C_2 = \alpha_3 \times \alpha_2 \times C_1 \quad (13.32)$$

$$C_4 = (F_{34}/(\eta_4 \times F_{14})) \times C_3 = \alpha_4 \times C_3 = \alpha_4 \times \alpha_3 \times \alpha_2 \times C_1 \quad (13.33)$$

$$C_5 = (\zeta_1 \times V_1/(\zeta_5 \times V_5)) \times C_1 = \alpha_5 \times C_1 \quad (13.34)$$

$$C_6 = F_{46}/(\eta_6 \times V_6) \times C_4 = \alpha_6 \times C_4 = \alpha_6 \times \alpha_4 \times \alpha_3 \times \alpha_2 \times C_1 \quad (13.35)$$

The significance of these equations is that one can estimate the approximate equilibrium concentration in fish and local residents, for example, when the concentration in bay seawater C_1 is known. When calculating concentrations in a compartment model, the method of finding the concentration in each medium at equilibrium from relational expressions of their concentration ratios is called a concentration factor method, and terms α_2, $\alpha_3 \times \alpha_2$, and $\alpha_4 \times \alpha_3 \times \alpha_2$ in the above equation are called concentration factors. Since the values of $\alpha_2 - \alpha_4$ are generally greater than 1, the concentration factors are larger values for animals higher up in the food chain. Concentration factors can also be estimated from the parameters used for finding each transfer rate. However, usually the actual ratio of chemical concentrations in seawater and fish is found directly through field studies and water tank experiments.

Note that while each medium is expressed as a single compartment in the above description, a medium may be represented by multiple compartments. Breaking a medium down into smaller compartments may be necessary, for example, when chemical concentrations differ greatly according to location owing to currents in the bay or according to the types of fish linked to exposure.

13.8 Example of an Environmental Fate Model Using a Fugacity Model

Equations (13.24), (13.25), (13.26), (13.27), (13.28), and (13.29) described above can be expressed as follows in a fugacity model.

$$(V_1/\rho_1)Z_1 df_1/dt = F_r \times C_r/(1000 \times M) - (\gamma \times V_1/\rho_1) \times Z_1 \times f_1 \tag{13.36}$$

$$(V_2/\rho_2)Z_2 df_2/dt = (F_{12} \times V_2/\rho_1) \times Z_1 \times f_1 - (\eta_2 \times F_{12} \times V_2/\rho_1) \times Z_2 \times f_2 \tag{13.37}$$

$$(V_3/\rho_3)Z_3 df_3/dt = (F_{23} \times V_3/\rho_2) \times Z_2 \times f_2 - (\eta_3 \times F_{13} \times V_3/\rho_1) \times Z_3 \times f_3 \tag{13.38}$$

$$(V_4/\rho_4)Z_4 df_4/dt = (F_{34} \times V_4/\rho_3) \times Z_3 \times f_3 - (\eta_4 \times F_{14} \times V_4/\rho_1) \times Z_4 \times f_4 \tag{13.39}$$

$$(V_5/\rho_5)Z_5 df_5/dt = (\zeta_1 \times V_1/\rho_1) \times Z_1 \times f_1 - (\zeta_5 \times V_5/\rho_5) \times Z_5 \times f_5 \tag{13.40}$$

$$(V_6/\rho_6)Z_6 df_6/dt = (F_{46}/\rho_4) \times Z_4 \times f_4 - (\eta_6 \times V_6/\rho_6) \times Z_6 \times f_6 \tag{13.41}$$

Here, fugacity f_i ($i = 1, 2, \ldots, 6$) represents the tendency of the chemical to escape from each compartment. Thus, the following equation is true when partial pressure of the chemical in a medium is expressed in units of Pa and concentration C_i ($i = 1, 2, \ldots, 6$) is expressed in units of mg/kg.

$$C_i = Z_i \times f_i \times W_i \tag{13.42}$$

Here, Z_i ($i = 1, 2, \ldots, 6$) is called the fugacity capacity or the Z-value and has units of mol/m^{3}Pa. Since $Z_i \times f_i$ is expressed in units of mol/m^3, a coefficient W_i (m^3 mg/kg/mol) is used for converting these units to mg/kg.

$$W_i = (1000 \times M)/\rho_i \tag{13.43}$$

Here, M denotes the molecular weight of the chemical, and ρ_i is the density (kg/m^3) of the medium in the ith compartment. Note that the density of waste from each medium in Eqs. (13.37), (13.38), and (13.39) is equivalent to the density of the bay seawater.

The fugacity capacity is generally determined according to the medium. Table 13.1 shows an example of values for fugacity capacity.

Fugacity models also define D-values, which are transport parameters related to the transport of chemicals between compartments i and j. Using D-values, Eqs. (13.36), (13.37), (13.38), (13.39), (13.40), and (13.41) above can be expressed as follows.

$$(V_1/\rho_1)Z_1 df_1/dt = F_r \times C_r/(1000 \times M) - D_{1o} \times f_1 \tag{13.44}$$

$$(V_2/\rho_2)V_2 Z_2 df_2/dt = D_{12} \times f_1 - D_{21} \times f_2 \tag{13.45}$$

$$(V_3/\rho_3)Z_3 df_3/dt = D_{23} \times f_2 - D_{31} \times f_3 \tag{13.46}$$

Table 13.1 Examples of fugacity capacities (Z-values)

Compartment (medium)	Fugacity capacity (mol/m ^{3}Pa)	Description of parameters
Air	$1/RT$	R: Gas constant (Pa m^3/mol K)
		T: Absolute temperature (K)
Water	$1/H$ or C^S/P^S	C^S: Aqueous solubility (mol/m^3)
		P^S: Vapor pressure of solute (Pa)
		H: Henry's law constant (Pa m^3/mol)
Soils, bottom sediments, particles, etc.	$K_P\ \rho_S\ /H$	K_P: Partition coefficient (L/kg)
		ρ_S: Density (kg/L)
Biota (fish, humans, etc.)	$K_B\ \rho_B\ /H$	K_B: Bioconcentration factor (L/kg)
		ρ_B: Density (kg/L)
Pure chemicals	$1/P^S v$	v: Molar volume of chemical (m^3/mol)

From Figure 5.5 in reference Mackay (2001)

$$(V_4/\rho_4)Z_4 df_4/dt = D_{34} \times f_3 - D_{41} \times f_4 \tag{13.47}$$
$$(V_5/\rho_5)Z_5 df_5/dt = D_{15} \times f_1 - D_{51} \times f_5 \tag{13.48}$$
$$(V_6/\rho_6)Z_6 df_6/dt = D_{46} \times f_4 - D_{6o} \times f_6 \tag{13.49}$$

Here, each D_{ij} (i, j = 1, 2, . . ., 6, with o, o representing an external domain) is a coefficient expressing the transport rate from compartment i to compartment j. The D-value consolidates the entire coefficient in Eqs. (13.36), (13.37), (13.38), (13.39), (13.40), (13.41) that is multiplied by the corresponding f_i (i = 1, 2, . . ., 6) and is essentially in the form of the product of volumetric flow rate (m^3/day) and the Z-value (mol/m^{3}Pa).

Thus, calculations in a fugacity model are basically the same as in a system analysis model based on mass balance. However, there are advantages in using fugacity models. For example, since fugacity models use fugacity (Pa) as a variable, the simultaneous equations can be expressed using the same units, even though concentration is expressed differently in air (e.g., mol/m^3), water (e.g., mg/L), and organisms (e.g., mg/kg). Accordingly, coefficients related to transfers have the same units, facilitating comparisons of intercompartmental transfer rates. Further, since all compartments have the same fugacity at equilibrium, any change in the magnitude of fugacity represents a deviation from equilibrium and the migration of matter in a closed system. Best of all, since approximate values for corresponding Z-values and D-values based on the nature of the medium have already been compiled in a database, calculations can be performed simply by inputting the basic sizes and temperatures of the compartments. Therefore, even generic software programs can be used with sites having a wide variety of conditions by expressing fundamental equations with fugacity models. Conversely, when dealing with special transfer principles or conditions, it is better to formulate such processes using mass transfer equations on a mass basis than imposing the use of fugacity models.

13.9 Conclusion

This paper has described only the fundamental aspects of environmental fate models used for the risk assessment of chemicals and ignores the various chemical reactions. In some cases, a more elaborate model must be created, such as when the fate of the chemical is influenced by the concentrations and ionic strengths of other chemicals. Further, the objectives of risk assessment must be considered when setting the size and number of compartments in order to create an effective and realistic model. While it seems likely that models such as G-CIEMS that link to GIS data will become a commonplace in advanced nations like Japan, risk assessment will still be needed in less developed countries where it is difficult to obtain even the minimum required basic data. In the latter case, it will be necessary to quantitatively evaluate uncertainty in estimated results based on low temporal and spatial resolutions resulting from the uncertainty in parameters and the low quantity of data. Further, a method of estimating the required parameters from basic information on target chemicals is strongly needed for situations requiring the risk assessment of an enormous number of chemicals. In this way, environmental fate models for assessing the risk of chemicals will continue to evolve and be applied in various forms and will likely be compiled in a software package. It will be essential to fully understand the basic principles of these models in order to apply the model best suited for one's purpose and to avoid misguided use.

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Chapter 14
Water Information Access 'Communication Pack': To Know Is to Care

Zarina Othman

Abstract Information is the first step to solutions towards awareness of the need for improved water management. Recognizing the right information to be communicated well to the community and the general public is invaluable in order to change behaviour and attitude for better and sustainable water quality and supply. The type of information and how this information is disseminated to the community need to be given considerable attention. This chapter focuses on water information access (WIA) and the framework in developing its 'communication pack' to be taken into consideration when communicating water issues to the public. It presents the framework or methodological research design that was adopted in designing the framework of the 'water information access' (WIA). The project identifies the prioritized information and the relevant communication methods that are needed to raise water information awareness among the community. These findings were incorporated in the WIA carnival in its aims to educate and promote water information awareness to the community.

Keywords Water information · Communication · Education · Awareness

14.1 Introduction

Information is the first step to solutions towards awareness of the need for improved water management. Recognizing the right information to be communicated well to the campus community and the general public in order to change behaviour and attitude for better and sustainable water quality and supply is invaluable. Information needs to be packaged in a simple and easy pack to understand forms to facilitate people from all walks of life to participate in water-related decisions (Othman et al. 2014). The forms and discourse of the language used to disseminate and engage

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public water discourse is an important consideration to achieve this goal. Thus, it is necessary that a framework 'communication pack' is developed for a potential educational training program that respective parties can undertake in communicating and promoting awareness on environmental water issue.

14.1.1 Water Information Awareness

Water-related problems need to be discussed and reflected upon in order for everyone to take action. The channel of communication and the form and quality of the language used to disseminate and engage the public water discourse is an important consideration to achieve this goal.

The keys to succeed in achieving the set goals comprise of several main factors. Emphases are to be given on the need (1) to research the issue, (2) to mobilize support and supporters, (3) to inform the public and (4) to lobby decision-makers. These are the keys that should contribute to the potential success in raising public awareness. One needs to realize that as humans, there are ways in which 'understanding' requires an involvement based on the Confucius belief (450 B.C) that:

> Tell me, and I will forget
> Show me, I may remember
> **Involve** me, I will **understand**

On the same note, one has to take into consideration of how an individual learns. Many researchers, such as Rosenblum (2010), highlight that our senses are our raw learning portals. They pose the question on how much information actually comes through each of our senses. According to researchers, 83% is through sight, 11.0% is through hearing, 3.5% is through smell, 1.5% is through touch and finally 1.0% is through taste. These are in alignment with the conventional educational theories like VAK (visual, auditory and kinaesthetic) and learning styles. This is supported by similar facts that we remember 0% of what we read, 20% of what we hear, 30% of what we see, 50% of what we see and hear, 80% of what we say and 90% of what we say and do.

14.1.2 Communication

Throughout the millennia, ways of communication have changed. Advancement of communication technology allows faster and more people mass communication. Every aspect of human behaviour is being used to get the message across: gesture, action, physique, dress, facial expression, timing, touch, etc. Behavioural change is a social outcome where every human is influenced by the behaviour of others around him or her, most often greatly than first expected. Change is not possible to happen in closed system but has to come as cultural change. Social learning theory states that people learn from each other all the time, by modelling the behaviour around them and by using individual human contact and communication to set their behaviour and attitudes.

A persuasive discourse (Othman et al. 2009) using the power of language is a tool in communication that can affect such changes in attitude, behaviour, beliefs and values of oneself. Words in language can be a form of therapy as language and emotions can be intertwined. The embedment of intentional discourse via certain communication strategies will churn out an effective mode of information transfer between the source of information and the receiver. In the case of this program, a knowledge transfer of prioritized information regarding environmental awareness, i.e. water resource management, is crucial to the access of information by the community.

In transferring information, one of the relevant theories, which can be taken into consideration when planning such programs, is Rogers’ Diffusion of Innovation Theory (Rogers 1983). According to Rogers, there are four innovations (or concept, ideas, information) to be adopted by people in a society. They are innovation, communication channel, time and the social system. The focus is on the communication channel, whereby mass communication and interpersonal communication play prominent role at different phases in the transfer of information process.

Cases of engagement with community members at large in promoting participatory water management are few and far between. Thus, efforts on information dissemination of water information access through communicating its environmental awareness have been initiated by a group of researchers in one of the local universities in Malaysia on one of the watersheds i.e. Langat River Water Basin. The research is labelled as WIA – water information access.

14.2 The Project Planning

The researchers explore the prioritization and selection of the appropriate type and amount of knowledge to be transferred, the language use for water discourse and the functionality and sustainability of the chain of communication for water information throughout the community. We distributed questionnaire to the community to identify the research knowledge gap between the researchers and the community. This is also to determine the validity and reliability of the constructs that had emerged through a discussion between the research team and members of the city council.

The project is planned based on the consideration of the primary aims to communicate and to raise awareness on water information. Figure 14.1 summarizes the project planning that was undertaken. This project planning forms the basis to creating the WIA carnival to promote the core focus of *To Know is To Care*.

The area of focus for this project is on the Langat River Water Basin. The Langat River Basin in Selangor is the main water source for those in Klang Valley that runs 200 km across the Klang Valley to the Straits of Malacca. It has several tributaries, among them are Sungai Semenyih, Sungai Lui and Sungai Beranang, and the most important river in the basin is Sungai Langat itself. Thus, this project designs the

Fig. 14.1 The WIA Project Planning

MyLangatRiver.com portal website at the initial stage of its project. Following this, the researchers engaged the district council, i.e. the MPKJ Kajang Municipal Council, as a counterpart and point of reference (POR). Our next step proceeded with the design of questionnaires that were distributed to communities of respective residential areas identified by the council.

We referred to a sampled questionnaire survey from the University of Georgia that surveyed on Water Issue in Georgia on Public Attitude in Georgia (UGA 2010). A workshop between the researchers and the municipal members was held to adapt the questions to suit our context and purpose of study. Subsequently, researchers had come up with various questions that were vetted and then coded into different parameters. The five parameters or constructs were derived based on the researchers' knowledge and municipal's knowledge and experience in dealing with the community. These parameters were (1) general issue/knowledge, (2) awareness, (3) water quality and quantity, (4) conservation management and (5) communication and information. These constructs had tallied with those in the Georgia survey. Questions were then devised as well as taking into consideration some relevant questions already in the Georgia survey. Each of the parameters had several items using the Likert scale of 1–4 from strongly disagree to strongly agree.

A pilot study was conducted as pilot studies are feasibility studies which are small-scale version or trial run done in preparation for the major study. A pilot study had also allowed the pretesting or 'trying out' of a particular research instrument. The pilot study was also to seek a preliminary data to identify the gap between what the respondents need to know as compared to what they already know. It was also conducted to identify which form of communication is necessary to ensure effective dissemination of information.

A community engagement took place in a face-to-face focus group discussion with selected samplings of residents. This had provided information on what the residents knew or were aware of with regard to water information. The training or educating came next in a form of WIA carnival that collated all findings based on the survey and interviews. It is with the planning of the carnival that a WIA communication pack template was conceived.

14.3 The Water Information

Based on the SPSS analysis, it is found that the construct of general issue or knowledge is more appropriate to be included as a profiling of the respondents. Thus, the four constructs of awareness, water quality, conservation management and communication and information appear as suited sample of constructs for the study on water information access with the construct of general issue or knowledge to be items for respondent profiling. It is in the interest of this study, however, to focus on the constructs of communication and information mainly. This is to relate to the need to prioritize type of water information and how this information should be communicated to the public in general.

The fact that the mean interpretation of awareness on water information access, water quality, communication and information is of medium level, it indicates that the respondents are less sensitive with water information access. And thus, a call to enrich the respondents with information targeting at a high level of mean score is in need. This also shows that these three constructs are those that need prioritization of information to relate to the respondents.

With regard to the recorded high-level mean score of water conservation management, respondents appear to have a high-level conservation management. This may be due to some control by the state governments or religious practice influence. As it is behavioural or action related (with the use of words such as I *changed*, I *adopted*, I *pumped*), the high mean scores may be influenced by practices the respondents know of other people or practices they have seen or watched and thus follow. But then again, whether by having high mean level of conservation management, it is worth investigating whether these practices are realized by respondents as measures that are conservation management by nature or otherwise.

14.3.1 Communicating Water Information

The respondents gain information access about water from public television, cable television, newspaper, social networks (Facebook, Twitter, websites, etc.), family and friends. Public television is the major source of information. This is not surprising as almost every household has a television nowadays. In addition, the widespread use of the Internet helps public to obtain information from social networking such as Facebook, Twitter, websites, etc. On the other hand, respondents informed that there is a lack of information about water from environmental group, local authorities, water agencies, schools or environmental groups. They believe that it is the responsibility of the school to be the main medium of dissemination of water information to the public because education begins since kindergarten. Other resources like exhibition, seminars and festivals are not popular among respondents because they are according to respondents too formal, not casual, boring and more of academic presentations.

It is interesting to note here that majority of the respondents stated that their sources of information in general mainly comes from the television. However, in receiving information about water, the Internet appears as the main source as compared to television and the radio. This does indicate the lack of information being transmitted through the most popular resource, i.e. the television. And the top five sources of information that respondents find attractive to learn from rank television primarily, followed by the Internet, campaigns, small group discussions and voluntary activities.

14.4 The 'WIA ComPack' Framework

Based on the findings and discussion of this preliminary result, a tentative framework to address the water information access and its discourse is drawn up as in Fig. 14.2. We label it as the 'WIA ComPack' (Water Information Access Communication Pack) framework.

The 'WIA ComPack' is based on the communication model that composites sender, message, channel and receiver. It is adapted to include a significant element, i.e. the language use or the discourse which highlights the choice of words; the sentence structure; the voice whether the message requires a voice of instruction, advice or directive; and the persuasive tones as some of its linguistics features. The 'message' box specifies the 'information', one that is selective for purpose of the targeted audience. The 'channel' box accentuates the forms or mode of communication where the intended information is to be conveyed. While the senders may

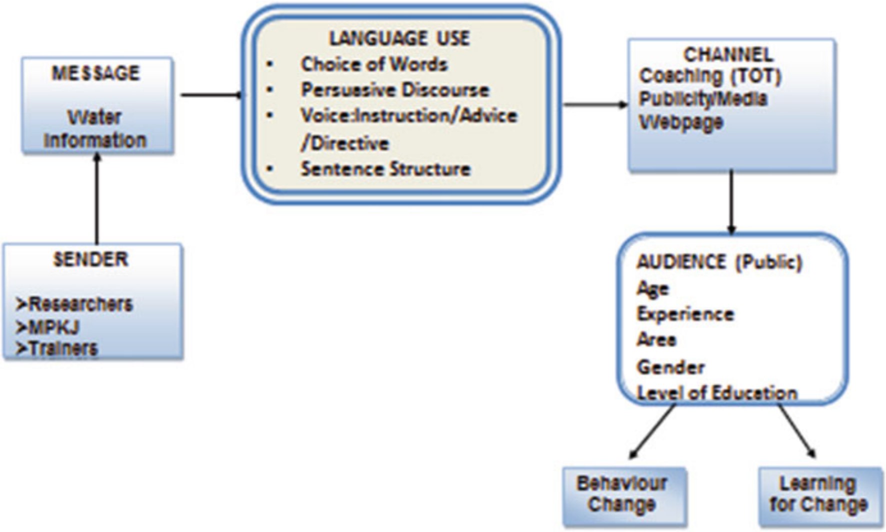

Fig. 14.2 The 'WIA ComPack' framework

perhaps be researchers (scientists, environmentalists), the receiver, i.e. the audience, will take into consideration variables such as age, experience, area of residents, gender and level of education. The insertion of the 'discourse' box prior to the 'channel' box is of importance as it indicates that the discourse will 'cushion' the message that is to be transmitted via the different modes of communication. Whether it is a poster, webpage or TOT sessions, the discourse used will be its frontiers. And another most important element that is as significant as the language use or discourse is the 'end product' of this project, i.e. the 'behaviour change' and the 'learning for change'. It is this outcome that is expected as it should indicate a rising awareness on water information within the community.

Based on the preliminary results of the survey, it appears that the best medium of communication is television. However, not much information on water has been disseminated through this means of communication. It is, thus, an area to focus on. Similarly, radio also has its potential and yet not utilized effectively to communicate water information to the public. This is the most apparent gap in terms of one of the many communication channels. Apparently, radio and television are means of media where respondents are exposed to information but not sufficiently on water information.

14.5 Conclusion

The study has to a certain extent unravelled the type of information that needs prioritization such as the level of awareness, the water quality and quantity as well as the communication and information. It has then opened doors for further investigation on the language use which needs to employ appropriate linguistics features to communicate this water information awareness to the public. Its discourse should aim to consider several aspects that would facilitate public to understand scientific or environmental terminologies by conveying knowledge, i.e. message or information through a 'layman's' language. Also, a more significant aspect is to deliver information in the correct tone of voice that contributes to a persuasive discourse that can lead to a behaviour change. Mass communication and interpersonal communication play prominent role at different phases in the transfer of information process; the discourse is the means in which these are possible. This element of social science, i.e. language, has at this point proven to be a potential invaluable aspect which scientists or environmentalists should not overlook its relevance to begin with.

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