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# CHAPTER ONE

# 1. INTRODUCTION TO SOIL AND WATER CONSERVATION

## 1.1 Why Conserve Soil?

Soil is the most fundamental and basic resource. Although erroneously dubbed as “dirt” or perceived as something of insignificant value, humans cannot survive without soil because it is the basis of all terrestrial life. Soil is a vital resource that provides food, feed, fuel, and fiber. It underpins food security and environmental quality, both essential to human existence. Essentiality of soil to human well-being is often not realized until the production of food drops or is jeopardized when the soil is severely eroded or degraded to the level that it loses its inherent resilience.

Traditionally, the soil’s main function has been as a medium for plant growth. Now, along with the increasing concerns of food security, soil has multi-functionality including environmental quality, the global climate change, and repository for urban/industrial waste.

World soils are now managed to:

1. Meet the ever increasing food demand,
2. filter air,
3. purify water, and
4. store carbon
5. to offset the anthropogenic emissions of CO2 (Table 1.1).

Soil is a non-renewable resource over the human time scale. It is dynamic and prone to rapid degradation with land misuse. Productive lands are finite and represent only *<*11% of earth’s land area but supply food to more than six billion people increasing at the rate of 1.3% per year (Eswaran et al., 2001). Thus, widespread degradation of the finite soil resources can severely jeopardize global food security and also threaten quality of the environment. Conserving soil has many agronomic, environmental, and economical benefits. The on- and off-site estimated costs of erosion for replenishing lost nutrients, dredging or cleaning up water reservoirs and conveyances, and preventing erosion are very high and estimated at US$ 38 billion in the USA and about US$ 400 billion in the world annually (Uri, 2000; Pimentel et al., 1995). In the Ethiopia, the estimated cost of soil loss due to soil erosion water was to be 32.2 million Ethiopian Birr, which according to Sutcliffe (1993) constitute 1.1% of the 1990 agricultural GDP.

The need to maintain and enhance multi-functionality necessitates improved and prudent management of soil for meeting the needs of present and future generations. The extent to which soil stewardship and protection is professed determines the sustainability of land use, adequacy of food supply, the quality of air and water resources, and the survival of humankind. Soil conservation has been traditionally discussed in relation to keeping the soil in place for crop production. Now, soil conservation is evaluated in terms of its benefits to increasing crop yields, reducing water pollution, and mitigating concentration of greenhouse gases in the atmosphere.

**Table 1.1:** Multi-functionality of soils

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## 1.2 The Term Erosion and its Application

The word *erosion* is of Latin origin being derived from the verb *erodere* - to eat away, to excavate. The term erosion was first used in geology to describe the forming of hollows by water, the wearing away of solid material by the action of river water (Penck 1894), while surface wash and precipitation erosion was called *ablation*.

*Erosion* shall be used for the disruption of the soil mantle - the *pedosphere*, or the underlying rock base – the *lithosphere* by the action of matter of exogenous origin, i.e. by *external geomorphic factors.* In the broadest sense of the word these factors include *water, snow, ice, air (wind), weathered debris, organisms,* and *man.* These factors may be classified as biotic, i.e. relating to life, and *abiotic*. Most authors include within the term erosion only that destruction of the soil that is caused by abiotic factors, the activity of which is attributable to mechanical action, i.e. kinetic energy. Applying broader criteria, this type of erosion may be called *mechanical erosion,* i.e. *corrasion.* But erosion also includes chemical action which is connected also with the mechanical action of water. This type of erosion may be referred to as *chemical erosion,* i.e. *corrosion.*

In addition to these *two* main forms of erosion caused by abiotic factors*,* the *organogenic* aspects of *erosion* may be distinguished and subdivided into *phytogenic*, *zoogenic* and man-made, i.e. *anthropogenic* *erosion.* The first two factors do little more than nibble at the soil andsubstrate hence *arrosion*. As far as erosion caused byman and animals is concerned, only that part of the activity caused by the natural factor is considered to constitute erosion.

In all situations several types of erosion always occur simultaneously or in some chronological sequence, forming patterns which are typical of a particular area. The decisive factors are the climate, the relief, the nature of the surface, and the activity of organism, especially the activity of man which has been responsible in recent years for an increasing specific influence on *erosion systems.*

Through erosion the surface of the earth is constantly being sculptured into new forms. The shapes of continents are continuously changing, as waves and tides cut into old land while silt from rivers builds up new land. As rivulets, streams, and rivers cut their channels deeper, gullies become ravines and ravines become valleys. The Grand Canyon, more than 1500 m deep, was produced by erosion probably within the past 5 million years. The overall effect of the wearing down of mountains and plateaus is to level the land; the tendency is toward the reduction of all land surfaces to sea level.

Erosion is but one of a number of landscape-modelling factors. By its action the Earth’s surface is either *being worn down* or *degraded*, or it is *being raised* or *aggraded* by deposition. The result of this process is a general *levelling* of the Earth’s surface-planation, and a condition of this levelling effect is the *disintegration* of matter in elevated regions of the Earth’s crust. Disintegration involves the weathering of rocks - the first stage of the process of soil formation.

## 1.3 Soil Erosion and its Component

There are two main types of erosion: *geologic and accelerated erosion. Geologic erosion* is a normal process of weathering that generally occurs at low rates in allsoils as part of the natural soil-forming processes. It occurs over long geologic timehorizons and is not influenced by human activity. The wearing away of rocks andformation of soil profiles are processes affected by the slow but continuous geologicerosion. Indeed, low rates of erosion are essential to the formation of soil. Incontrast, soil erosion becomes a major concern when the rate of erosion exceeds acertain threshold level and becomes rapid, known as *accelerated erosion*. This typeof erosion is triggered by anthropogenic causes such as deforestation, slash-and burnagriculture, intensive plowing, intensive and uncontrolled grazing, and biomassburning.

### 1.3.1 Water Erosion

On a global scale, water erosion is the most severe type of soil erosion. It occurs in the form of splash/interrill, rill, gully, tunnel, streambank, and coastal erosion. Different forms of erosion are discussed in detail in next subtopic. Runoff occurs when precipitation rates exceed the water infiltration rates. Both raindrop impact and water runoff can cause soil detachment and transport. Unlike wind erosion, water erosion is a dominant form of erosion in humid, and sub-humid, regions characterized by frequent rainstorms. It is also a problem in arid and semiarid regions where the limited precipitation mostly occurs in the form of intense storms when the soil is bare and devoid of vegetal cover. One of the spectacular types of water erosion is the concentrated gully erosion which can cause severe soil erosion even in a single event of high rainfall intensity.

### 1.3.2 Wind Erosion

Wind erosion is a widespread phenomenon, especially in arid and semi-arid regions. It is a dominant geomorphic force that has reshaped the earth. Most of the material carried by wind consists of silt-sized particles. Deposition of this material, termed as “loess”, has developed into very fertile and deep soils. The thickness of most loess deposits ranges between 20 and 30 m, but it can be as thick as 335m (e.g., Loess Plateau in China). Excessive wind erosion due to soil mismanagement has, however, caused the barren state of many arid lands. Anthropogenic activities set the stage for severe wind erosion by directly influencing soil surface conditions through deforestation and excessive tillage.

### 1.3.3 Mass Movement

In mass movement of soil - slides, slips, slumps, flows and landslides - gravity is the principal force acting to move surface materials such as soil and rock. When natural slope stability is disrupted, a range of complex sliding movements may occur. As a rule of thumb, rapid movements of soil or rock that behave separately from the underlying stationary material and involve one distinct sliding surface are termed landslides. Such movement is rarely the result of a single factor, but more often the final act in a series of processes involving slope, geology, soil type, vegetation type, water, external loads and lateral support.

Generally mass movement occurs when the weight (shear stress) of the surface material on the slope exceeds the restraining (shear strength) ability of that material. Factors increasing shear stress include erosion or excavation undermining the foot of a slope, loads of buildings or embankments, and loss of stabilising roots through removal of vegetation. Vegetation removal and consequent lower water use may increase soil water levels, causing an increase in pore water pressure within the soil profile. Increased pore water pressure or greater water absorption may weaken inter-granular bonds, reducing internal friction and therefore lessening the cohesive strength of the soil and ultimately the stability of the slope.

## 1.4 History of Soil Erosion

Accelerated erosion is as old as agriculture. It dates back to the old civilizations in Mesopotamia, Greece, Rome, and other regions in the Middle East (Bennett, 1939). The collapse of great ancient civilizations in Mesopotamia along the Tigris- Euphrates Rivers illustrates the consequences when lands are irreversibly degraded. Lessons from the past erosion and consequences for the demise of ancient civilizations have been amply cited and discussed in several textbooks. Indeed, Hugh Hammond Bennett, recognized as the “Father of Soil Conservation” in the U.S., described in his well-known textbook in detail the historical episodes and consequences of severe erosion (Bennett, 1939). Knowledge of the historic erosion is critical to understanding the severity and consequences of erosion and developing strategies for effective management of present and future soil erosion.

## 1.5 Soil Erosion in Ethiopia

### 1.5.1 Magnitude of Soil Erosion

Ethiopia is said to be the water tower of African countries; the soil material carried by water is transported to other countries via its rivers. Of all sub-Saharan African countries, Ethiopia has the largest degradation problems. Ethiopia has been very recently referred to be the most extremely eroded land on earth. A rather more conservative estimate indicated that Ethiopia is losing a total of one billion tons of fertile surface soil annually to oceans and seas due to erosion. The average annual soil loss due to erosion from farm land in Ethiopia is 42 t/ha (Hurni, 1993). At this rate, all the top soil can be washed away within 100-150 years. The annual production loss due to erosion amounts to 1-2 % (Hurni, 1978). Other land use types have less soil erosion. The overall annual soil loss due to erosion amounts to approximately 1493 millions tons (Table 1.2). This estimate rates into account, however, only the amount of soil transported out of the country by its large rivers crossing its international boundaries like the Blue Nile (Sudan), Wabi Shebelie (Somalia), Baro (Sudan), Tekezie (Sudan), Omo etc.

Table 1.2: Estimated rate of soil loss on slopes in Ethiopia dependent on land cover (Hurni, 1987)

|  |  |  |  |
| --- | --- | --- | --- |
| Land cover type | Area (%) | Estimated soil loss | |
|  | t/ha/year | Mt/year |
| Cropland | 13.1 | 42 | 672 |
| Perennial crops | 1.7 | 8 | 17 |
| Grazing and browsing land | 51.0 | 5 | 312 |
| Totally degraded | 3.8 | 70 | 325 |
| Currently uncultivable | 18.7 | 5 | 114 |
| forests | 3.6 | 1 | 4 |
| Wood and bush land | 8.1 | 5 | 49 |
| Total country | 100 | 12 | 1493 |

The rate of erosion loss from the Ethiopian highlands is estimated at over 100 tons/ha/year (EHRS, 1984). The highlands of Ethiopia (> 1500 m.a.s.l) cover 45% of the country’s total area or 54 million ha of lands. The EHRS (1984) report indicated that of these lands.

* 50% (27 million ha) is significantly eroded
* 25% (13.5 million ha) is seriously eroded
* 4.4% (2.4 million ha) of formerly cultivated land have been severely eroded as to reach the point of no return
* Only about 20% (11.1 million ha) is relatively free from the risks of accelerated erosion.

### 1.5.2 Causes of Soil Erosion in Ethiopia

The most important reasons or causes for the extremely aggravated/accelerated soil erosion and runoff water quite unique to Ethiopia are:

1. The rugged topography and mountainous geomorphic features that are common rather than exceptional characteristics of the country’s landscape.
2. The erratic and torrential typical tropical rains common in most of the highlands of the country, Ethiopia.
3. The indiscriminate clearing of forest vegetation.
4. Improper land use patterns and plans attributed to lack of sound land capability classification maps, that is:
   1. Plowing/cultivating of lands on steeply sloping areas
   2. Plowing soils too poor to support cultivated crops and/or plowing soils in areas with too little rainfall to support continuous crop production.
   3. Breaking up large blocks of lands susceptible to erosion
   4. Improper cropping practices and use of soil exposing crops
   5. Lack of pooper crop rotation programs
   6. Complete crop residue removal from the farmlands while the surface is not protected from heavy rains by vegetation crops
   7. Overgrazing of range lands/pastures
   8. Very low fertilizer inputs
5. Absence of proper soil and water conservation practices/measures
6. In some areas pressure on the land resulting form over population
7. Highly erodible soils.

## 1.6 Consequences of Soil Erosion

Accelerated soil erosion causes adverse agronomic, ecologic, environmental, and economic effects both on-site and off-site. Not only it affects agricultural lands but also quality of forest, pasture, and rangelands. Cropland soils are, however, more susceptible to erosion because these soils are often left bare or with little residue cover between the cropping seasons. The on-site consequences involve primarily the reduction in soil productivity, while the off-site consequences are mostly due to the sediment and chemicals transported away from the source into natural waters by streams and depositional sites by wind.

### 1.6.1 On-site Problems

The primary on-site effect of erosion is the reduction of topsoil thickness, which results in soil structural degradation, soil compaction, nutrient depletion, loss of soil organic matter, poor seedling emergence, and reduced crop yields. Removal of the nutrient-rich topsoil reduces soil fertility and decreases crop yield. Soil erosion reduces the functional capacity of soils to produce crops, filter pollutants, and store C and nutrients. One may argue that, according to the law of conservation of matter, soil losses by erosion in one place are compensated by the gains at another place. The problem is that the eroded soil may be deposited in locations where either no crops can be grown or it buries and inundates the crops in valleys.

### 1.6.2 Off-site Problems

Water and wind erosion preferentially remove the soil layers where most agricultural chemicals (e.g., nutrients, pesticides) are concentrated. Thus, off-site transport of sediment and chemicals causes pollution, sedimentation, and silting of water resources. Sediment transported off-site alters the landscape characteristics, reduces wildlife habitat, and causes economic loss. Erosion also decreases livestock production through reduction in animal weight and forage production, damages water reservoirs and protective shelterbelts, and increases tree mortality. Accumulation of eroded materials in alluvial plains causes flooding of downstream croplands and water reservoirs. Soil erosion also contributes to the projected global climate change. Large amounts of C are rapidly oxidized during erosion, exacerbating the release of CO2 and CH4 to the atmosphere (Lal, 2003).

Wind erosion causes dust pollution, which alters the atmospheric radiation, reduces visibility, and causes traffic accidents. Dust particles penetrate into buildings, houses, gardens, and water reservoirs and deposit in fields, rivers, lakes, and wells, causing pollution and increasing maintenance costs.

**Table 1.3** Some of the erosion-induced soil degradation processes

Impact.tif

A number of changes in physical, chemical, and biological processes occur due to the accelerated soil erosion (Table 1.3). These processes rarely occur individually but in interaction with one another (Eswaran et al., 2001). For example, compact soils are more prone to structural deterioration (physical process), salinization (chemical process), and reduced microbial activity (biological process) than un-compacted soils. Some processes are more dominant in one soil than in another. Salinization is often more severe in irrigated lands with poor internal drainage than in well-drained soils of favorable structure.

# CHAPTER TWO

# 2. THE HYDROLOGICAL BASIS OF SOIL EROSION

## 2.1 The Hydrologic Cycle

Hydrology is the study of the occurrence and movement of water on and beneath the surface of the Earth, the properties of water, and its relationship with the living and material components of the environment. The role of water is central to most natural processes. Water transports sediment and solutes to lakes and oceans, thereby shaping the landscape. The global energy balance is influenced strongly by the high capacity of water for storing thermal energy and the large amount of heat required to change water from liquid to vapor and vice versa. The abundance of water in the atmosphere and oceans makes it an important regulator of climate. Water vapor is the most important of the greenhouse gases. Life depends on water.

Water movement from the atmosphere to the oceans and continents occurs as precipitation, including rain, snow, sleet, and other forms. On the continents, water may be stored temporarily, but eventually returns to the oceans through surface and groundwater runoff or to the atmosphere through evapotranspiration.

## 2.2 Hydrological Establishment of Soil Erosion

The processes of soil erosion are closely related to the pathways taken by water in its passage through the vegetation cover and over the ground surface. There base thus lies in the hydrological cycle. During a rain storm part of the water reaches the ground directly, either because there is no vegetation or because it passes through gaps in plant canopy (by dripping off leaves). This component of the rainfall is known as direct through fall. Part of the rain is intercepted by the canopy, from where it is either returns to the atmosphere by evaporation or finds its way to the ground by dripping from the leaves, a component termed leaf drainage, or by running down the plant steams as steam flow.

The action of direct through fall and leaf drainage produces rain splash erosion. The rain that reaches the ground may be stored in small depressions or hollows on the surface or it may infiltrate into the soil, contributing either to soil moisture storage, to lateral movement down slope within the soil as sub-surface or interflow or, by percolating deeper, to ground water. When the soil is unable to take in more water, the excess contributes to runoff on the surface, resulting in erosion by overland flow or by rills and gullies.

The rate at which water passes in to the soil is known as infiltration rate and this exerts a major control over the surface runoff water is drawn into the soil by gravity and by capillary forces, whereby it is attracted to and held as a thin molecular film around the soil particles. During a rain storm, the spaces between the soil particles become filled with water and the capillary forces decrease so that the infiltration rate starts high at the beginning of a storm and declines to a level that represents the maximum sustained rate at which water can pass through the soil to lower levels. This level, the infiltration capacity or terminal infiltration rate, corresponds theoretically to the saturated hydraulic conductivity of the soil.

If rainfall intensity is less than the infiltration capacity of the soil, no surface runoff occurs and the infiltration rate equals the rainfall intensity. If the rainfall intensity exceeds the infiltration capacity, the infiltration rate equals the infiltration capacity and the excess rain forms surface runoff. As a mechanism for generating runoff, however, this comparison of rainfall intensity and infiltration capacity does not always hold. In the case of sandy soil, the important control for runoff production is not infiltration capacity but limiting soil moisture content (or the reason runoff occurs is that these soils are prone to the development of a surface crust). When actual moisture content is below this value, pore water pressure in the soil is less than the atmospheric pressure and water is held in capillary form under tensile stress or suction. When the limiting moisture content is reached and all the pores are full of water, pore water pressure equates to atmospheric pressure, suction reduces to zero and surface ponding occurs.

This explains why sands those have low levels of capillary storage can produce runoff very quickly even though there infiltration capacity is not exceeded by the rainfall intensity. Once water starts to pond on the surface it is held in depressions and runoff does not begin until the storage capacity of this is satisfied. On agricultural land, depression storage varies seasonally depending on the type of cultivation that has been carried out and the time since cultivation for the roughness to be reduced by weathering and raindrop impact.

## 2.3 Characteristics of Rainfall

### 2.3.1 Forms of Precipitation

Precipitation may occur in any of a number of forms and may change from one form to another during its descent. The forms of precipitation consisting of falling water droplets may be classified as drizzle or rain. Drizzle consists of quite uniform precipitation with drops less than 0.5 mm in diameter. Rain consists of generally larger particles. Precipitation may also occur as frozen water particles including snow, sleet, and hail. Snow is composed of a grouping of small ice crystals known as snowflakes. Sleet forms when raindrops are falling through air having a temperature below freezing; a hail stone is an accumulation of many thin layers of ice over a snow pellet. Of the forms of precipitation, rain and snow make the greatest contribution to our water supply.

### 2.3.2 Rainfall Causes Water Erosion

The amount of rainfall is directly proportional to the amount of water erosion. But in statistical terms the correlation between them is poor. The same total quantity of rainfall on different occasions result in widely differing amount of erosion. Example: 20 mm in 20 minutes of duration on Thursday and another 20 mm in 30 minutes of duration on Friday cause different amount of erosion. Other more specific measures are required to describe the ability of rainfall to cause erosion.

#### 2.3.2.1 Depth of Rainfall

Depth of rainfall in mm is measured as the distribution of rainfall per unit time in terms of a day, month, year, etc. Rainfall is expressed in terms of depth of total water which would stand on an area. For example, 1 cm deep sheet of rainwater, spread over an area of 1 sq km represents 104 m3 of volume of rainwater.

#### 2.3.2.2 Intensity of Rainfall

Intensity of rainfall is the rate at which rainfall occurs and is measured in terms of depth per unit time. It is generally calculated from the data obtained from a weighting or siphon type of recording rain gauge. It is given by the slope of the curve of time versus cumulative depth (mass curve) obtained from a recording rain gauge. The common unit of measurement for intensity of rainfall is mm/h.

### 2.3.3 Analysis of Rainfall Data

#### 2.3.3.1 Design Rainfall

For the design of soil and water conservation structures, rainfall recorded for several years is required. The discharge selected in the design of such structures depends upon the frequency of occurrence of the design discharge or the design rainfall. The design discharge can be determined by either direct measurement or analysis of several years of discharge records, or indirectly by analyzing rainfall data of the given station.

#### 2.3.3.2 Determining Design Rainfall

The value of the design rainfall depends upon season, duration selected and catchment area. In design procedure, the frequency, duration selected and the season depends upon the type of problem under consideration. For drainage or conservation purpose, the critical season is when there is maximum rainfall, long duration and higher frequency. For irrigation purpose, we are interested in seasons of minimum rainfall and lower frequency.

#### 2.3.3.3 Intensity, Duration, and Frequency of Rainfall

One of the most important rainfall characteristics is rainfall intensity, usually expressed in millimeters per hour. Very intense storms are not necessarily more frequent in areas having a high total annual rainfall. Storms of high intensity generally last for fairly short periods and cover small areas. Storms covering large areas are seldom of high intensity but may last several days. The infrequent combination of relatively high intensity and long duration gives large total amounts of rainfall. These storms do much erosion damage and may cause devastating floods.

Intense rainstorms of varying duration occur from time to time with the probability of the heavy rainfalls varies with the locality. The first step in designing a water-control facility is to determine the probable recurrence of storms of different intensity and duration so that an economically sized structure can be provided. For most purposes it is not feasible to provide a structure that will withstand the greatest rainfall that has ever occurred. The higher the design rainfall selected the less will be the failure of the structure. It is, however, often more economical to have a periodic failure than to design for a very intense storm. Where human life is endangered, however, the design should handle runoff from storms even greater than have been recorded. For these purposes, data providing return periods of storms of various intensities and durations are essential. This return period, sometimes called recurrence interval, is defined as the period within which the depth of rainfall for a given duration will be equaled or exceeded once on the average.

#### 2.3.3.4 Hydrologic Frequency Analysis and Recurrence Interval

A frequency must be computed to each measured rainfall in an observed data. The data can be ranked in ascending or descending order. For soil and water conservation works, we are interested with a frequency of maximum rainfall and the descending order is used. But for irrigation we use ascending order and obtain the frequency of minimum rainfall.

For a descending order the procedure is as follows:

1. Arrange the n data of rainfall (p) in a descending order, that is, the highest rainfall at the top and the smallest rainfall at the bottom
2. Attach rank number (r) to each rainfall (Pr, r = 1, 2, 3 - - -, n)
3. Divide the rank number by the total number of observations plus 1 (n + 1) to obtain the frequency of exceedence.

F (P> Pr) = r/ (n+1) ---------------------------------------------------- (2-1)

Thus, the frequency of non-exceedence = 1- F (P> Pr)

F (P< Pr) = 1- r/ (n+1) ------------------------------------------------- (2-2)

**Example 2.1** Calculate the frequency of observed rainfall based on depth ranking and return period.

**Solution**. Frequency based on depth ranking is calculated as shown in the following table

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| No. | Observed data(P) | Data in descending order | Rank( r) | F(P> Pr)  r/n+1 | F(P< Pr)  1- r/(n+1) | Return Period  T = n+1/r |
| (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| 1 | 1.0 | 10 | 1 | 0.09 | 0.91 | 11.1 |
| 2 | 0.4 | 8.5 | 2 | 0.18 | 0.82 | 5.6 |
| 3 | 5.7 | 6.6 | 3 | 0.27 | 0.73 | 3.7 |
| 4 | 8.5 | 5.7 | 4 | 0.36 | 0.64 | 2.8 |
| 5 | 6.6 | 5.0 | 5 | 0.45 | 0.55 | 2.2 |
| 6 | 0.3 | 2.5 | 6 | 0.55 | 0.45 | 1.8 |
| 7 | 10.0 | 1.7 | 7 | 0.64 | 0.36 | 1.6 |
| 8 | 5.0 | 1.0 | 8 | 0.73 | 0.27 | 1.3 |
| 9 | 2.5 | 0.4 | 9 | 0.82 | 0.18 | 1.2 |
| 10 | 1.7 | 0.3 | 10 | 0.91 | 0.09 | 1.1 |

n + 1 = 11

**Return Period, T:** It is the time interval in years during which a certain amount of rainfall is likely to be equaled or exceeded. It is computed as:

T = 1/F, where F is the probability (frequency) of occurrence.

The frequency of exceedence is often used to determine return periods, T= 1/F (P>Pr).

The higher the rainfall taken as a design rainfall, the lesser it occurs and the higher the return period.

**P**

**F**

**T**

**P**

**P**

**Duration, t**

Figure 2.1:Rain fall, duration, frequency relationships

### 2.3.4 Raindrop Size and Terminal Velocity

#### 2.3.4.1 Raindrop size

Since by far the largest portion of precipitation occurs as rain, and since rainfall directly affects soil erosion, the characteristics of raindrops are of interest. Raindrops include water particles as large as 7mm in diameter. The size distribution is any one storm covers a considerable range and this size distribution varies with the rainfall intensity. Not only does the higher-intensity storm have more large-diameter rain drops, but it also has a wider range of raindrop diameters.

#### 2.3.4.2 Terminal Velocity

Three forces on a falling raindrop (Figure 2.2): a gravity force due to its weight, a buoyancy forcedue to the displacement of air by the drop, and a drag forcedue to friction between the drop and the surrounding air. If the drop is a sphere of diameter D, its volume is (π/6) x D3 so the weight force is

-------------------------------- (2-3)

and the buoyancy force is

-------------------------------- (2-4)

Where  and  are the densities of the water and air, respectively. The friction drag force is given by

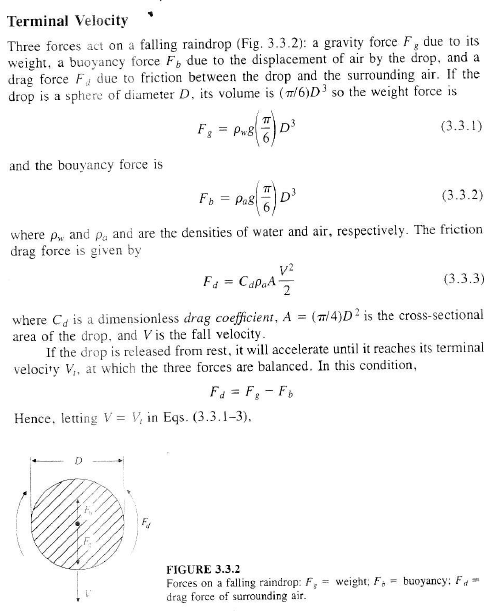


Whereis a dimensionless drag coefficient,(π/4) is the cross-sectional area of the drop, and V is the final velocity.

If the drop is released from rest, it will accelerate until it reaches its terminal velocity Vt, at which the three forces are balanced. In this condition

------------------------------------- (2-5)

Hence, letting V = Vt in Eq. (2-3 to 3-5)



Fg

Fb

Figure 2.2: Forces on a falling raindrop: Fg = weight; Fb = buoyancy; Fd = drag force of surrounding air.

  =  − ------ (2-6)

Which, solved for, is:

--------------------------------------- (2-7)

Table 2.3 Drag coefficients for spherical raindrops of diameter, at standard atmospheric pressure (101.3 KPa) and 20oC air temperature.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Drop diameter D (mm) | 0.2 | 0.4 | 0.6 | 0.8 | 1.0 | 2.0 | 3.0 | 4.0 | 5.0 |
| Drag coefficient Cd | 4.2 | 1.66 | 1.07 | 0.815 | 0.671 | 0.517 | 0.503 | 0.559 | 0.660 |

**Example 2.2** Calculate the terminal velocity of a 1-mm-diameter raindrop falling in still air at standard atmospheric pressure (101.3 KPa) and 20oC air temperature.

**Solution.** The terminal velocity is given by Eq. (2-7) with  = 0.671 from Table 2.3. at 20oC, 998 kg/m3, and = 1.20kg/m3 at pressure 101.3 KPa.



= 

= 4.02 m/s

Values of  similarly computed for various diameters are plotted in figure 2.4. It can be seen that the terminal velocity increases with drop size up to a plateau level of about 5 mm drop size, for which the terminal velocity is approximately 9 m/s.

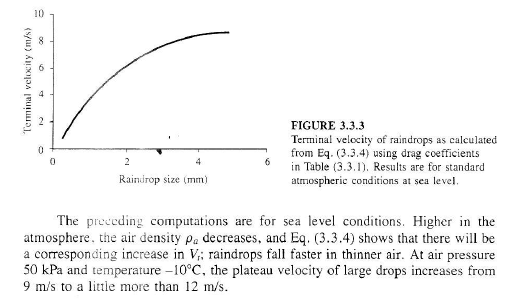


Figure 2.4: Terminal velocity of raindrops as calculated from Eq. (2-7) using drag coefficients in Table (2.3). Results are for standard atmospheric conditions at sea level.

### 2.3.5 Momentum and Kinetic Energy

The erosivity power of rainfall depends on two parameters derived from combinations of more than physical property, the kinetic energy of the rain and its momentum. If the size of raindrops is known and also their terminal velocity, it is possible to calculate the momentum of the falling rain, or its kinetic energy, by a summation of the values for individual raindrops. In the past this indirect calculation method has given better results than attempts to measure directly the momentum of kinetic energy of falling rain.

## 2.4 Water Entry and Movement in Relation to Erosion

### 2.4.1 Introduction to Infiltration

Infiltration is the passage of water into the soil surface and is distinguished from percolation, which is the movement of water through the soil profile. Infiltration is of particular interest, for if water is to be conserved in the soil and made available to plants, it must first pass through the soil surface. If the infiltration rate is high, less water will pass over the soil surface and erosion will be reduced. Infiltration directly affects deep percolation, groundwater flow, and surface runoff contributions to the hydrologic balance on a watershed. Accounting for infiltration is fundamental to understanding and evaluating the hydrologic cycle.

The term infiltration refers specifically to entry of water into the soil surface. Infiltration rate has the dimensions of volume per unit of time per unit of area. These units reduce to depth per unit time. Infiltration should not be confused with hydraulic conductivity nor with soil capillary conductivity. Infiltration is the sole source of soil water to sustain the growth of vegetation and of the ground water supply of wells, springs, and streams.

### 2.4.2 Factors Influencing Infiltration

Many factors influence the process of infiltration. The movement of water into the soil by infiltration may be limited by any restriction to the flow of water through the soil profile. Although such restriction often occurs at the soil surface, it may occur at some point in the lower ranges of the profile. The most important items influencing the rate of infiltration have to do with the physical characteristics of the soil and the cover on the soil surface, but such other factors as soil water, temperature, and rainfall intensity are also involved.

***Initial Soil Moisture Content:*** The antecedent soil moisture content has considerable influence on the initial rate and the total amount of infiltration. Both of the quantities decrease as the soil moisture content rises. The wetter is the soil initially; the lower will be its initial infiltrability.

***Soil Factors:*** Soil functions essentially as a pervious medium that provides a large number of passageways for water to move into the surface. The effectiveness of the soil as an agent for transporting water depends largely on the size and permanency of these channels. In general, the size of the passageways and the infiltration into the soil are dependent on (1) the size of the particles that make up the soil, (2) the degree of aggregation between the individual particles, and (3) the arrangement of particles and aggregates.

***Condition of the Soil Surface and Vegetation:*** Surface sealing can be greatly reduced by vegetation. In general, vegetative cover and surface condition have more influence on infiltration rates than do the soil type and texture. The protective cover may be grasses or other close-growing vegetation as well as mulches. A soil surface with vegetation cover favors a greater infiltration than a bare soil as the vegetation cover encourages slow movement of water over the surface. When infiltration rates are determined for soil protected by vegetation and the vegetation is removed, surface sealing occurs and infiltration drops much for the latter case.

***Other Factors:*** Other factors affecting infiltration include land slope, raindrop size, duration of rainfall, depth of water table, and water temperature (a special case being frozen soil).

***Organic Matter:*** The addition of organic matter increases infiltration rate substantially. Organic matter improves structure of soil. Hence infiltration capacity will be increased and also runoff will be minimized.

## 2.5 Runoff Phenomena

Runoff, also known as overland flow or surface flow, is the portion of water from rain, snowmelt, and irrigation. Runoff occurs only after applied water: (1) is absorbed by the soil, (2) fills up the soil pores and surface soil depressions, (3) is stored in surface detention ponds if in place, and (4) accumulates on the soil surface at a given depth. The components of water balance for runoff to occur are:

Runoff = INPUT – OUTPUT

### 2.5.1 Types of Runoff

#### 2.5.1.1 Surface Runoff:

It is that portion of rainfall which enters the stream immediately after the rainfall. It occurs when all losses are satisfied and if rain is still continued, with the rate greater than infiltration rate, then excess water makes a head over the ground surface (surface detention) which tends to move from one place to another, known as overland flow. This overland flow joins the stream channel or oceans, termed as surface runoff.

#### 2.5.1.2 Sub-surface Runoff:

That part of rainfall, which first leaches into the soil and moves laterally without joining the water-table, to the streams, rivers or oceans, is known as sub-surface runoff. Some time sub-surface runoff is treated as surface runoff due to reason, that it takes very little time to reach the river or channel in comparison to ground water.

#### 2.5.1.3 Base flow:

It is delayed flow and is defined as that part of rainfall, which after falling on the ground surface, infiltrated into the soil and meets to the water-table. The movement of water in this type of runoff is very slow. It takes a long time to join the rivers or oceans. Sometimes base flow is also known as ground water flow.

***Total’s Runoff = Surface runoff + Base flow (Including sub-surface runoff)***

### 2.5.2 Factors Affecting Runoff

The effect on runoff and its volume, from an area mainly influenced by following two factors:

1. Climatic factors (characteristics of rainfall), and
2. Physiographic (watershed) factors.

#### 2.5.2.1 Climatic Factor

The climatic factors of the watershed, is mainly associated with the characteristics of precipitation, which includes:

***Duration of Rainfall:*** The total runoff is related to duration for a given intensity. Rainfall duration is directly related to the runoff due to the fact that infiltration capacity of the soil goes down with the duration of rainfall till it attains a constant value. As a result of this even a mild intensity of rainfall, may yield a considerable amount of runoff. The higher the duration, the lower will be the intensity.

***Rainfall Intensity:*** The intensity of rainfall has a dominating effect on runoff yield. If rainfall intensity is greater than infiltration rate of the soil, the surface runoff varies rapidly, while in case of low intensity rainfall, there is reverse trend of the same. Thus, intense storms produce very quick (higher runoff) runoff than gentle storms.

***Rainfall Distribution:*** Runoff from a watershed depends very much on the distribution of rainfall. The rainfall distribution for this purpose can be expressed by the distribution coefficients. The distribution coefficient may be defined as the “ration of maximum rainfall at a point to the mean rainfall of the watershed. If all other conditions are the same, greater the value of distribution coefficient, greater will be the peak runoff and vice-versa.

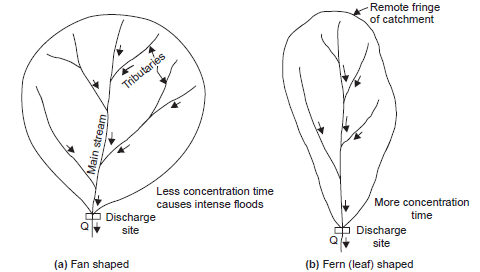
***Other climatic factors:*** The other climatic factors, such as temperature, wind velocity, direction of prevailing wind, relative humidity, annual rainfall, etc. affects the water losses from the watershed area to a great extent and thus affects the runoff. If the losses are more, the runoff will be less and vice-versa.

#### 2.5.2.2 Physiographic Factor

Physiographic factor consists of both the watershed as well as channel characteristic. The watershed characteristics which affect the runoff are listed below:

***Size of watershed:*** Regarding the size of watershed, as the size of the watershed increases both the rate and volume of runoff increases. The larger the watershed area, the higher the volume of runoff produced. However as size increases both amount of runoff and rate per unit area decreases i.e. large watershed takes longer time for draining the total runoff to the outlet and peak flow expressed as depth, will be smaller and vice-versa.

***Shape of watershed:*** The shape of watershed has great effect on runoff. There are two types of watersheds shape in which one is fan shape and other is fern shape. The fan shape (compact) watershed tends to produce higher peak rate of runoff than fern shape (long and narrow); due to the fact that in former one all part of the watershed contribute the runoff at the outlet simultaneously, comparatively in little period of time. In the long, narrow watersheds runoff does not concentrate as quickly as it does in the compact case.



**Figure 2.4:** Fan-and fern-shaped catchments

***Slope of Watershed:*** The slope of the watershed has an important role over runoff. But its effect is complex on runoff. It controls the time of overland flow and concentration of rainfall in the drainage channel. For example in case of sloppy watershed, the runoff velocity will be more, which results into higher runoff and vice versa.

***Land use:*** The land use pattern or land management practices have great effect on the runoff rate. For example, an area which is under forest, where a thick layer of mulch of leaves, and grasses etc. has been accumulated, reduces the surface runoff due to the fact that more rain water is absorbed by soil. While in a barren field, just the reverse trend is obtained.

***Soil Moisture:*** The runoff depends upon the amount of soil moisture presents in the soil at the time of rainfall. If rain occurs over the soil which has more soil moisture, the infiltration rate becomes less it results in more runoff yield. Similarly, if the rain occurs after a long dry spell of time, the soil is dry and it can absorbs huge amounts of rain water. In this condition even intense rain may fail to produce any appreciable runoff. But on the other hand, if the rain occurs in the rainy season, runoff has reverse effect.

***Soil Type:*** In the watershed, surface runoff is greatly influenced by the soil type, as infiltration capacity varies with the type of soil.

***Topographic Characteristics:*** Topographic features affecting rate and volume of runoff are slope of the upland areas, the degree of include the topographical feature i.e. undulating nature of the watershed. Undulate land has a greater runoff than the flat land because of the reason that runoff water gets additional power to flow, due to slope of the area.

### 2.5.3 Methods of Predicting Runoff

Some of the reasons we study runoff peaks and volumes are:

🖝 To quantify the volume and rate of water to be handled by water management facilities

🖝 To predict soil erosion and transport of surface pollutants

The methods of predicting runoff are runoff rates, runoff volume and temporal distribution of runoff.

#### 2.5.3.1 Estimating Peak Rate of Runoff

Components of runoff that are required to be estimated are runoff volume and runoff rate. Design runoff rate is the capacity to be provided in a structure that must carry runoff. The capacity to be provided in a structure that must carry runoff may be termed the design runoff rate. Structures and channels are planned to carry runoff that occurs within a specified return period. Temporary strictures are usually designed for a runoff that may expected to occur once in 10 years; expensive, permanent structures will be designed for runoffs expected only once in 50 or 100 years.

***Rational Method:*** The Rational Method is the most common method of predicting design peak runoff rate Eqs. (2.8). Peak runoff rate is defined as the maximum runoff to be used as a capacity for a given structure that must carry the runoff. Mathematically, the rational method relates the peak discharge (q, m3/sec) to the drainage area (A, ha), the rainfall intensity (i, mm/hr), and the runoff coefficient (C)

 **-------------------------------------------** (2-8)

Where q = design peak runoff rate in m3/s,

C = runoff coefficient, ratio of the peak runoff rate to the rainfall intensity, dimensionless

i = rainfall intensity in mm/h for the design return period and for a duration equal to the “time of concentration” of the watershed.

A = watershed area in ha

**Time of Concentration (T­c):** The time of concentration of a watershed is the time required for water to flow from the most remote (in time of flow) point of the area to the outlet once the soil has become saturated and minor depressions filled. It is assumed that, when the duration of a storm equals the time of concentration, all parts of the watershed are contributing simultaneously to the discharge at the outlet and the cumulative runoff provides a maximum runoff which is referred to as peak runoff.

For estimating time of concentration, the length of flow is divided by an estimated velocity of flow to obtain the travel time. The sum of the travel times for overland flow (sheet runoff) and for all channel flow equals the time of concentration. For such estimates the flow path is taken from the most remote point in the watershed to the outlet. In small watersheds of a few hectares, where a well defined channel does not exist, runoff occurs mostly as overland flow.

**Computation of** **Time of Concentration (T­c)**

There are several empirical relations for computing time of concentration. Kirpich (1940) developed an equation for computing the time of concentration, Tc.

**Kirpich Formula**

 ----------------------------------------- (2-9)

Where Tc = time of concentration in minutes.

L = maximum length of flow in meters.

S = the watershed gradient in m/m or the difference in elevation between the outlet and the most remote point divided by the length, L.

***Runoff Coefficient, C:*** The runoff coefficient, c is defined as the ratio of the peak runoff rate to the rainfall intensity. C is the measure of the proportion of the rain which becomes runoff. It is a dimensionless term, varies from 0 to 1 depending on land use and soil types.

 = Peak runoff rate --------------------------------- (2-10)

Rainfall intensity

On a corrugated iron sheet, the runoff coefficient; C value is nearly close to 1.0. On a well defined sandy soil, where 9 to 10th of the rain is soaked. C value on a given watershed area may differ due to the difference in practice. Therefore when a given area is not uniform (Figure 2.5) in values of C, the weighted mean must be calculated. The weighted runoff coefficient may be computed for a watershed divided into n number of sub-parts based on soil types and land use practices followed on them, having areas A1, A2, A3,---, An and their runoff coefficients are C1, C2, C3, - - -, Cn respectively, then the value of weighted runoff coefficient C of the watershed is given by:

C4

A4

A1

C1

C2, A2

C3 A3

Figure 2.5: Runoff coefficient for non-uniform watershed



 ------------------------------------------------------ (2-11)

Where A1, A2, - - -are watershed areas with the corresponding runoff coefficient values of *C1, C2*, - - -. The application of rational method is limited to areas less than 3200 acres.

Table 2.3 Values of runoff coefficient (C) for use in Rational method

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| S. No | Land Use and topography | Sandy loam | Clay and silt loam | Tight clay |
| 1 | Cultivated land |  |  |  |
|  | (i)Flat | 0.30 | 0.50 | 0.60 |
|  | (ii)Rolling | 0.40 | 0.60 | 0.70 |
|  | (iii) Hilling | 0.52 | 0.70 | 0.82 |
| 2 | Pasture land |  |  |  |
|  | (i)Flat | 0.10 | 0.30 | 0.40 |
|  | (ii)Rolling | 0.16 | 0.36 | 0.55 |
|  | (iii) Hilling | 0.22 | 0.42 | 0.60 |
| 3 | Forest land |  |  |  |
|  | (i)Flat | 0.10 | 0.30 | 0.40 |
|  | (ii) Hilling | 0.30 | 0.50 | 0.60 |
| 4 | Populated land |  |  |  |
|  | (i)Flat | 0.40 | 0.55 | 0.65 |
|  | (ii)Rolling | 0.50 | 0.65 | 0.80 |

***Rainfall Intensity, i:*** The rainfall intensity (i) is defined as the rate of fall of rainfall expressed as depth per unit time (mm/h or in/h). Intensity depends on duration of rainfall. Intensity is inversely related to duration. It can be expressed as the ratio of total amount of rainfall to its duration.

To use the rational method there are a few assumptions.

* Rainfall intensity and duration is uniform over the area of study
* In general, the maximum peak runoff rate occurs when the whole area of the drainage basin contributes.
* The storm duration must be equal to or greater than the time of concentration of the watershed for the whole area of the drainage basin to contribute runoff.

**Example 2.3** Compute the runoff coefficient of the watershed from the following data.

|  |  |  |  |
| --- | --- | --- | --- |
| Land use and topography | Cultivated land (flat, soil is sandy) | Pasture land  (rolling, sandy soil) | Populated with flat topography and tight clay soil |
| Area (ha) | 100 | 30 | 75 |

**Solution.** Using equation 2.11, the weighted runoff coefficient is given by



In which, the values of C1, C2 and C3 are obtained from the table 2.3 for given land use and topographical features of the watershed.

For Cultivated land, flat topography and, sandy soil A1 = 100, C1 = 0.30

Pasture land, rolling topography and sandy soil A2 = 30, C2 = 0.16

Populated land with flat topography and tight clay soil A2 = 75, C2 = 0.40

 =  = **0.32** **Ans**.

**Example 2.4** Calculate the time of concentration of 300 ha size watershed. The maximum length of drainage course is 350 m and average slope of it is 4m/100m.

**Solution.** Given that,

L = 350 m

S = 4/100

**∴** Time of Concentration, 



= **6.28 min. Ans**

***SCS Triangular Hydrograph Method:*** In this method, peak runoff is determined using the curve number approach. The assumption of uniform rainfall still applies. The hydrograph takes on a triangular shape shown in Figure 2.6b with equal peak and flow volume as in the rational method. This can be seen below.

Rainfall rate, i

Q

Runoff hydrograph

Tb = 2.67Tp

Tp

Tr = 1.67Tp

I

D

D/2

TL = 0.6TC

(b)

D

C = q/i

Rainfall rate, i

I

TC

Time

Peak runoff rate, q

Q

(a)

Rate and rainfall and runoff

Figure 2.6: Rainfall and runoff with assumptions: (a) for the rational equation and (b) for the SCS triangular hydrograph method of runoff estimation.

The area under the hydrograph equals the volume of the direct runoff related to the geometry of triangular hydrograph.

 = 

Where Tp and Tr = time of peak and recession time, respectively in hours

q = peak discharge in m3/s

Peak runoff rate is calculated by

q = 0.0021QA/Tp----------------------------------- (2-12)

Where Q = runoff volume in mm depth (from the curve number)

q = runoff rate in m3/s

A = watershed area in ha.

Tp = time of peak in hours

In this method, the “time to peak” does not equal the time of concentration as in the rational method, in this method time to peak Tp equals

Tp = D/2 + TL = D/2 + 0.6Tc -------------------------- (2-13)

Where Tp = time to peak (hours)

D = duration of excess rainfall

TL = time of lag

Tc = time of concentration

It is assumed that the total time (Tb) of flow is 2.67Tp and the recession time (Tr) of the hydrograph is 1.67 Tp.

Time of concentration equal to TL/0.6 is the longest travel time and may be calculated using the SCS Lag formula discussed earlier

Tc = L0.8 [(1000/CN) – 9]0.7 / [4407(Sg) 0.5] --------------- (2-14)

Where TC = time of concentration in hours,

L = Longest flow length in m,

S = watershed slope in m/m,

CN = runoff curve number

#### 2.5.3.2 Runoff of Volume

It is often desirable to predict the total volume of runoff that may come from a watershed during a design flood. Total volume is of primary interest in design of flood control reservoirs.

##### 2.5.3.2.1 SCS Method of Runoff Computation

The Soil Conservation Service (1972) developed a method for computing abstractions from storm rainfall. For the storm as a whole, the depth of excess precipitation or direct runoff Q is always less than or equal to the depth of precipitation I; likewise, after runoff begins, the additional depth of water retained in the watershed, G, is less than or equal to some potential maximum retention S. There is some amount of rainfall Ia (initial abstraction; it consists of interception losses, surface storage & infiltration losses before ponding begins) for which no runoff will occur, so the potential runoff is P-Ia. The hypothesis of the SCS method is that the ratios of the two actual to the two potential quantities are equal, that is,

Actual runoff = Actual retention

Potential runoff Potential retention

------------------------------------------- (2-15)

From the continuity equation

--------------------------------------- (2-16)

Ia = initial abstraction,

Q = direct rainfall or actual runoff,

G = Continuing abstraction or actual retention

Combining (i) and (ii) to solve for Q gives:

------------------------------------------ (2-17)

Which is the basic equation for computing the depth of excess rain fall or direct runoff from a storm by the SCS method.

By study of results from many small experimental watersheds, an empirical relationship between Ia and S has been obtained:

Ia = 0.2S

On this basis,

--------------------------------------- (2-18)

Where Q = direct runoff in inches

I = storm rainfall in inches

S = maximum potential difference between rainfall and runoff in inches.

Thus, *S* becomes the parameter which accounts for the differences in soil surface conditions, land use and management, and antecedent water content. It reflects the land use conditions through the CN, which is equal to:

Among the factors that influence CN are hydrologic soil group, land use, soil management, cropping system, conservation practices, and antecedent water content. The values of CN vary from 0 to 100 depending on the soil and surface conditions. Values of CN decrease with increase in surface vegetative cover. Bare soils without crop residues have the largest CN values whereas undisturbed soils covered by dense vegetation have the smallest CN values. Soils based on their infiltration characteristics and runoff potential are classified into four main hydrologic groups: A, B, C, and D. A hydrologic soil group refers to a group of soils having the same runoff potential under similar rainstorms and surface cover conditions. Important factors which determine the runoff potential include infiltration capacity, drainage, saturated hydraulic conductivity, depth to water table, and presence of impermeable layer.

**Characteristics of the hydrologic groups**

Group A: High infiltration (low runoff Potential) Sand, loamy sand, or sandy loam.  Infiltration rate > 0.3 inch/hr when wet.

Group B: Moderate infiltration (moderate runoff). Silt loam or sandy loam.  Infiltration rate 0.15 to 0.3 inch/hr when wet.

Group C: Low infiltration (moderate to high runoff). Clay loams, shallow sandy loam, soils low in organic content, and soils usually high in clay.  Infiltration rate 0.05 to 0.15 inch/hr when wet.

Group D: Very low infiltration (high runoff Potential) Soils that swell significantly when wet, heavy plastic clays, and certain saline soils. Infiltration rate 0 to 0.05 inch/hr when wet.

**Example 2.3**Estimate the runoff amount that is produced by a watershed of 2 km2 receiving an average precipitation of 50 mm per day. The watershed is under three different uses. Half of the watershed consists of agricultural lands with crops planted in straight rows under good condition, a third of the watershed consists of residential area with 30% of impervious surface from houses and paved driveways, and the rest of the watershed is under woods with dense litter cover. The soils are part of the hydrologic group B.

**Solution.**

Impervious area: 0*.*30 × 98 = 29*.*4

Pervious area: 0*.*70 × 61 = 42*.*7

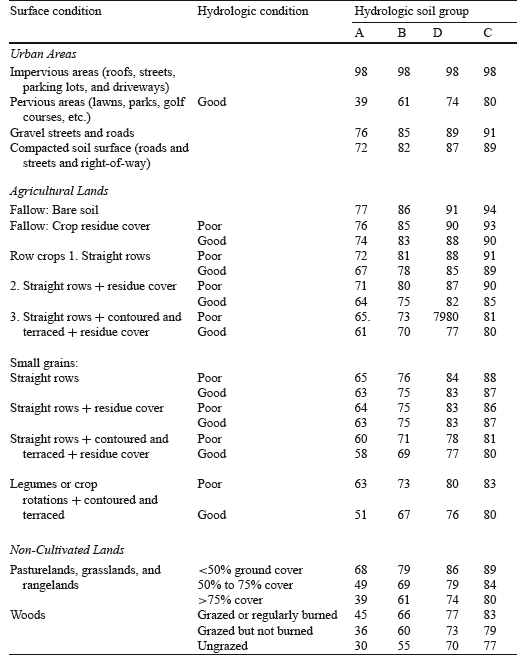
|  |  |  |  |
| --- | --- | --- | --- |
| Land use | Fraction of area | Average curve number | Weighted curve number |
| Row crops in good  condition | 0.500 | 78 | 39 |
| Residential Area | 0.333 | 29.4 + 42.7 = 72.1 | 24 |
| Woods | 0.167 | 55 | 9.2 |
|  |  |  | Total = 72.2 |

Compute S using the weighted CN value:

Next, compute runoff depth:

Runoff in terms of volume is computed as:

**Table 2.5:** Runoff curve numbers for selected surface conditions for different soil hydrologic groups (After USDA-SCS, 1986)



# CHAPTER THREE

# 3. SOIL EROSION BY WATER

## 3.1 Water Erosion:

It is the detachment and transport of soil from the land by water running rapidly over the exposed land surface, including rainfall and runoff from melted snow and ice. The rate of water erosion progress is totally based on the factors such as land slope, soil types, density of vegetative cover, amount and rainfall rate (intensity). Types of water erosion include interrill (raindrop and sheet) erosion, rill erosion, gully erosion and stream channel erosion. Sometimes water fall erosion is also included in water erosion. Water erosion is accelerated by farming, forestry, grazing, and construction activities.

## 3.2 Processes and Mechanics of Erosion

Water erosion is a complex three-step natural phenomenon which involves *detachment*, *transport*, and *deposition* of soil particles. The process of water erosion begins with discrete raindrops impacting the soil surface and detaching soil particles followed by transport and deposition. The three processes of erosion act in sequence. Detachment and transport of soil particles are the primary processes of soil erosion,

There are three steps to accelerated erosion by water are listed below and shown in Figure 3.1:

1. **Detachment** or **loosening** of soil particles caused by flowing water, freezing and thawing of the topsoil, and/or the impact of falling raindrops.

Detaching forces include:

* + - * + Raindrop/rain splash
        + Flowing water
        + Animal’s hooves
        + Human activities such as cultivation operation
        + Wetting and drying

1. **Transportation** of soil particles by floating, rolling, dragging, and/or splashing.

The main transporting agents are:

* + - * Surface runoff
      * Sub surface runoff
      * Gravity

1. **Deposition** of transported particlesat some place lower in elevation.

|  |
| --- |
| **Mechanics: detachment, transportation, deposition** |
|  |
| Figure 3.1 The three-step process of soil erosion by water starts with the impact of raindrops on soil. |

## 3.3 Forms of Water Erosion

### 3.3.1 Rain Splash Erosion

The action of raindrops falling on soil particles is understood by considering the momentum of a single raindrop falling on a sloping surface. The transference of momentum to the soil particles has two effects. First, it provides a consolidating force, compacting the soil, and second, it imparts a velocity to some of the soil particles, launching them into the air. On landing, they transfer their own down slope momentum to others particles and the jumping process is repeated.

The factors affecting the direction and distance of soil splash are:

* + - * Presence of wind,
      * Land slope
      * Soil surface conditions
      * Vegetative cover and mulches

It gives a start for the other forms of erosion.

### 3.3.2 Sheet Erosion

Sheet erosion involves the removal of a uniform thin layer of soil by raindrop splash or water run-off. This thin layer of topsoil often disappears gradually, making it difficult to monitor because the damage is not immediately perceptible. This insidious process is often overlooked until the subsoil is exposed.

Raindrop action on bare soil disrupts aggregates, dislodges soil particles and compacts the erodible soil surface. If rainfall exceeds infiltration, a surface film of water forms, building up into flows 2-3 mm deep. Continuing rainfall causes turbulence within the flow that may increase the water's erosive effect up to 200 times.

Loss of the finest soil particles, to which the bulk of plant-available nutrients and organic matter adhere, affects the productivity of the land. Erosion may also result in removal of seeds or seedlings and reduce the soil's ability to store water for plants to draw upon between rainfall events. Soil deposited off-site through this type of erosion causes crop and pasture damage, water-quality deterioration and stream, dam, lake and reservoir sedimentation.

Generally, repeatedly cultivated soils, fallow soils or soils that are bare through overgrazing by stock or pest animals are particularly vulnerable.

### 3.3.3 Rill Erosion

If rainfall exceeds infiltration, a surface film of water forms (see sheet erosion). Rill erosion results from a concentration of this surface water into deeper, faster-flowing channels, which follow depressions or low points through fields. The shearing power of the water can detach, pick up and remove soil particles making these channels the preferred routes for sediment transport. Rill erosion often occurs with sheet erosion and is commonly seen in fields of recently cultivated soils following high-intensity rainfall. It is easily identified as a series of little channels or rills up to 30 cm deep.

Rill erosion is often described as the intermediate stage between sheet and gully erosion. Rill erosion is common on agricultural land free from vegetation and so is often seen in cropping areas after tillage. Following intense rainfall cultivated top soils overlying denser cohesive sub soils often exhibit rill erosion. Texture-contrast (duplex) soils are susceptible, as are poorly managed pasture areas where overgrazing occurs. Rill erosion is often a preliminary step to gully erosion and under the right climatic and topographic conditions can extend into gully erosion, exposing subsoil and sometimes bedrock.

### 3.3.4 Gully Erosion

It is the advance and last stage of water erosion. In other words, gully erosion produces channels larger than rills, as the advance stage of rill erosion. These channels carry water during and immediately after rains. Compared to rills, gullies cannot be obliterated by tillage. When the rills has been formed in the field and is avoided by farmers, it increases in its size and shape with commencement of further rainfall. The amount of sediment from gully erosion is usually less than from rill and interrill erosion, but the nuisance from having fields divided by large gullies has been the greater problem. In tropical areas, gully growth following deforestation and cultivation has led to severe problems from soil loss, and damage to buildings, roads and airports (Aneke, 1985).

The rate of gully erosion depends primarily on the runoff-producing characteristics of the watershed, the drainage area soil characteristics; the alignment, size, and shape of the gully; and the slope in the channel (Bradford et al., 1973).

### 3.3.5 Stream Bank Erosion

Stream bank erosion is the direct removal of banks and beds by flowing water. Typically, it occurs during periods of high stream flow. It is sometimes confused with gully erosion as this has similarities with seasonal or ephemeral streams.

Erosion of stream or river banks through lateral (side) erosion and collapse often causes high sediment loads in creeks and rivers. The problem is often initiated by heavy falls of rain in catchments with poor vegetation cover, causing excess run-off. The resultant high volume and velocity runoff will concentrate in the lower drainage lines or streams within catchments. When the stress applied by these stream flows exceeds the resistance of the local soil material, stream bank erosion occurs. As the sediment load increases, fast-flowing streams grind and excavate their banks lower in the landscape. Later, the stream becomes overloaded or velocity is reduced, and deposition of sediment takes place further downstream or finally in dams and reservoirs. Stream bank erosion is exacerbated by the lack of riparian zone vegetation and by direct stock access to streams.

### 3.3.6 Tunnel Erosion

Water scouring or seeping through susceptible sub soils can form underground channels. Tunnelling often accompanies poor vegetative cover, sheet erosion and increased surface run-off.

Tunnel erosion is initiated by water moving into and through dispersive sub soils. It often results from water accumulating and moving along cracks or channels or into rabbit burrows and old tree root cavities. Dispersive clays are the first to be removed; steadily the route enlarges as more water moves through. Tunnels require an adequate gradient to initiate the runoff speed necessary to drive free water through the soil. As the tunnel increases in size, parts of the tunnel roof collapse resulting in potholes and gullies.

Such erosion leads to loss of productive capability, deposition of infertile subsoil in lower more fertile landscapes and high sediment loads in streams or rivers. In the worst cases tunnels provide a hazard by collapsing, restricting safe access and forming gullies.

## 3.4 Factors Affecting Soil Erosion

The rainfall, runoff, wind, soil, slope, plant cover and conservation measures etc. are the factors which affect the rate of soil erosion from a particular place or region. They are grouped under the following three heads, energy, resistance and protection

**Energy:** it includes the potential ability of rainfall, runoff and wind to cause erosion and these factors which directly affect the power of erosive agents such as reduction in length of runoff or wind blow through the construction of terraces, bunds etc in case of water erosion and windbreak, shelterbelt in case of wind erosion

**Resistance:** the mechanical and chemical properties of soil are the resistance factors. They may encourage infiltration rate of the soil and thereby reduction in runoff and finally decrease of soil erodibility. The cultivation decreases the erodibility of clay soil, but increase for sandy soil.

**Protection:** the plant cover intercepts the falling of raindrop before they reach the ground surface and thus reduces their impacts on the soil. The plant covers also reduce the runoff and wind velocity. Different plant covers provide different degrees of protection. Therefore, it is important to know the rate of soil erosion so that a suitable plant cover can be developed. If the soil properties such as nutrients, texture and thickness of soil remain unchanged throughout the time, then it is assumed that the rate of soil formation is in balance.

Water erosion is the removal of soil from the land's surface by the depressive action of rainfall and runoff. The factors controlling soil erosion are the erosivity of the eroding agent, the erodibility of the soil, the slope of the land (topography) and the nature of the plant cover. Of these, the vegetation, and to some extent the soil and topography may be controlled. Climatic factors are beyond human control.

The major factors affecting water erosion can be summarized according to the descriptive equation:

E = f(C,T,V,S,P)

Where,

* + - * E = Rate of erosion
      * C = Climate
      * T = Topography
      * V = Vegetation
      * S = Soil
      * P = Management practice

The erosion factors stated above contain two types of variables. Those that can be controlled and those that are directly uncontrollable. Climate, slope and certain physical characteristics of the soil cannot be directly controlled. Their effects, however, may be modified indirectly. For example, the use of bunds and terraces can reduce the length of slope.

### 3.4.1 Energy/Climatic Factors

#### 3.4.1.1 Rainfall Erosivity Indices

Erosivity may be defined as the potential ability of rain to cause the erosion. The most suitable expression of the erosivity of rainfall is an index based on the kinetic energy of rainfall. Thus the erosivity of a rainstorm is a function of its intensity and duration, and of the mass, diameter and velocity of raindrops. To compute erosivity requires an analysis of the drop-size distributions of rain. The drop-size characteristics vary with the intensity of the rain, with the median drop diameter by volume (d50) increasing with rainfall intensity. The relationship between median drop size and intensity is not constant; both median drop size and drop-size distribution vary for rains of the same intensity but different origins.

It is possible to derive general relationships between kinetic energy and rainfall intensity. Based on the work of Laws and Parsons (1943), Wischmeier and Smith (1958) obtained the equation:

 -------------------------------------3.1

Where I is the rainfall intensity (mmh-1) and KE is the kinetic energy (J m-2 mm-1). Many researchers consider the drop-size distribution of rainfall described by Marshall and Palmer (1948) as representative of a wide range of environments. The equivalent formula for calculating kinetic energy is:

 --------------------------------------3.2

For tropical rainfall, Hudson (1965) gives the equation:

 ----------------------------------3.3

To compute the kinetic energy of a storm

1. A trace of the rainfall from an automatically recording rain gauge is analyzed
2. The storms divide into small time increments of uniform intensity.
3. For each time period, knowing the intensity of the rain, the kinetic energy of the rain at rain intensity is estimated using an equation from Table 3.1.
4. This kinetic energy is multiplied by the amount of rain received, given the kinetic energy for that time period.
5. The sum of the kinetic energy values for all the time periods gives the total kinetic energy for the storm (Table 3.1).

**Example 3.1** Calculate the kinetic energy for the following storm given in Table 3.1.

**Solution.** Kinetic energy, KE values computed using the formula for tropical rainfall given in eq. (3-3)

Table 3.1 Calculation of kinetic energy for the particular storm provided in columns 1 and 2

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Time from start  of storm (min) | Rainfall  (mm) | Intensity  (mmh-1) | Kinetic energy  (Jm-2mm-1) | Total kinetic energy (col.2\*col.4)(J/m2) |
| 0-14 | 1.52 | 6.08 | 8.83 | 13.42 |
| 15-29 | 14.22 | 56.88 | 27.56 | 391.90 |
| 30-44 | 26.16 | 104.64 | 28.58 | 747.65 |
| 45-59 | 31.5 | 126.00 | 28.79 | 906.89 |
| 60-74 | 8.38 | 33.52 | 26.00 | 217.88 |
| 75-89 | 0.25 | 1.00 | - | - |
|  |  |  |  |  |

**Erosivity Indices**

**Wischemierindex *(EI30)***

🟔 To be valid as an index of potential erosion, an erosivity index must be significantly correlated with soil loss. Wischmeier and Smith (1958) found that soil loss by splash, overland flow and rill erosion is related to a compound index of kinetic energy (E) and the maximum 30- minute intensity (I30), known as **EI30 index**.

🟔 This index, **EI30**, is open to criticism.

🖝 First, being based on estimates of kinetic energy using eq. 3.1, it is of suspect validity for tropical rains of high intensity as well as for high altitudes and for oceanic areas like the Marshall Islands, where rainfall energies are rather low.

🖝 Second, it assumes that erosion occurs even with light intensity rain, whereas Hudson (1965) showed that erosion is almost entirely caused by rain falling at intensities greater than 25mmh-1. Its use is recommended only for bare soil conditions. With sparse and dense plant covers they obtain better correlations with soil loss using the maximum 15-and 5-minute intensities respectively. In order to overcome the likelihood of overestimating soil loss from high-intensity rainfall, the recommended practice with the EI30 index is to use a maximum value of 28 Jm-2mm-1 for the E component for all rains above 76.2 mmh-1 and a maximum value of 63.5mmh-1 for the I30 term (Wischmeier & Smith 1978).

**Example 3.2** Calculate the value of erosivity index (EI 30) from example 3.1.

**Solution**. The maximum 30-minute rainfall and intensity is calculated from Table 3.1 as follows:

Maximum 30-minute rainfall = 26.16 + 31.50

= 57.66 mm

Maximum 30-minute intensity = 57.66 mm/0.5 hr

=115.32mmh-1

Total kinetic energy = total of column 5

= 2277.24 J/m2

EI30 = 2277.74 x 115.32

= 262,668.98 Jmm/m2.hr

**Hudson index (KE > 25)**

As an alternative erosivity index, this is to compute for a single storm. KE ≥ 25 means summing the kinetic energy received in those time increments when the rainfall intensity equals or exceeds 25mmh-1 (Table 3.1). It is highly correlated to the soil loss especially for tropical rainfall as compared to EI30. Stocking and Elwell (1973) reworked Hudson’s data, taking accounts of more recent data, and suggested that EI30 was the better index after all.

**Example 3.3** Use the KE ≥ 25 method to compute the erosivity index using the rainfall data in example 3.1.

**Solution.** Compute the total energy KE for rainfall intensities≥ 25 mm/hr from Table 3.1.

Total kinetic energy for rainfall = total of lines 2, 3, 4, and 5 in column 5 intensity ≥ 25 mmh-1

= 391.90 + 747.65 + 906.89 + 217.88

= 2,264.32 J/m2

Calculating erosivity value for individual storms over a period of 20-25 years, mean monthly and mean annual data can be obtained. Since the EI30 and KE>25 indices yield vastly different value because of the inclusion of I30 in the former, the two indices cannot be substituted for each other.

#### 3.4.1.2 Runoff Erosivity

Similar to the rainfall erosivity, runoff erosivity is the ability of runoff to cause soil erosion. Raindrops impacting soil surface loosen up, detach, and splash soil particles, while runoff carries and detaches soil particles. Interaction among rain, runoff, and soil particles results in erosion. Rain has more erosive power than runoff.

The kinetic energy (*E*) of a rain of mass equal to *m* and terminal velocity (*v*) equal to 8 m/s is (Hudson, 1995)

Assuming that 25% of the rain becomes runoff and the runoff velocity is 1m/s, the *E* of runoff is

Thus, the *E* of rain is 256 times greater than that of runoff.

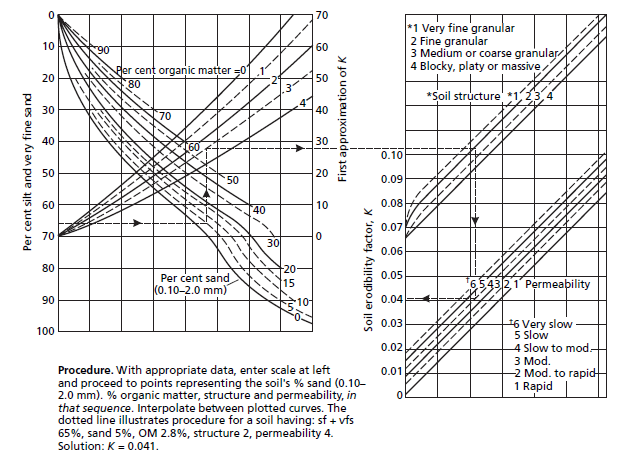
The capacity of runoff to scour the soil and transport particles increases with runoff amount, velocity, and turbulence. Runoff carries abrasive soil materials which further increase its scouring capacity.

### 3.4.2 Soil Erodibility, K

Erodibility defines the resistance of the soil to both detachment and transport. It reflects the fact that different soils erode at different rate when the other factors that affect erosion are kept the same. Although a soil’s resistance to erosion depends in part on topographic position, slope steepness and the amount of disturbance, such as during tillage, the properties of the soil are the most important determinants.

Erodibility varies with soil texture, aggregate stability, shear strength, infiltration capacity and organic and chemical content. Soil properties affect the infiltration capacity and the extent to which soil particles can be detached and transported. For example, clay particles are more difficult to detach than sand, but clay is more easily transported. Texture is the dominant property determining erodibility, but soil structure, organic matter, water content, and density or compactness, as well as chemical and biological characteristics of the soil also influence erodibility.

Direct measurements of K values require considerable time and equipments which is costly to perform. Many attempts have been made to devise a simple index of erodibility based on either the properties of the soil as determined in the laboratory or the field. Thus it is not surprising that these attempts lastly develop a more universally accepted index, one most commonly used is the K value. Where K values are determined from field measurements of erosion, they are valid. Estimates of the K value may be made (to use a nomograph to K value from Figure 3.2) if the grain-size distribution, organic content, structure and permeability of the soil are known.



**Figure 3.2** Nomograph for computing the *K* value (metric units) of soil erodibility for use in the Universal Soil Loss Equation (after Wischmeier et al. 1971)

### 3.4.3 Vegetation

Vegetation creates a surface obstruction in falling of raindrop as well as flowing of surface runoff. A good vegetative cover completely negates the effects of rainfall on soil erosion. The vegetation affects the soil erosion in respect of the following points.

1. **Interception and protection from raindrop impact:** A part of rainfall is intercepted by the vegetative foliage and never reaches the soil surface but it is return back to the atmosphere through evaporation known as interception. This part of precipitated rainfall does not contribute to the runoff. In addition, vegetative foliage reduces the impact of falling raindrop on the land surface, there by both the surface runoff as well as soil erosion are reduced.
2. **Reducing surface runoff velocity**: The vegetative cover is a direct hindrance in flowing path of the surface runoff. It reduces the runoff velocity. At the meantime the flow acquire more time to pass the length of travel. These two effects greatly reduce the erosive capacity of surface runoff.
3. **Holding soil in place:** The root system of vegetation also affects the soil erosion and runoff. Water goes down the soil along with the root. In addition, root system makes the soil porous and thus increases the absorption of water.
4. **Improving soil structure with roots, plant residue, and increased biological activity in the soil:** Regarding the biological points of view, vegetation also provides a great effect on soil erosion. A soil which is under thick forest cover, the earthworm, beetles and other lives makes the soil more permeable by making the channel in the soil. This reduces both surface runoff and soil erosion.
5. **Increasing transpiration rates**: Vegetation also by increasing the transpiration effect reduces the surface runoff and soil erosion.

These vegetative influences vary with the species, climate, season, soil type and degree of maturity of the vegetation, as well as the type of vegetative residue left from the previous crop, like roots, stems, or leaves.

### 3.4.4 Topographic Effect

Topographic features those influence erosion are slope steepness, length, size and shape of the watershed.

***Degree of slope:*** A flat land has not the problem of soil erosion while the sloping lands are predominantly affected by the erosion. As the land slope increases from mild to steep, erosion increases in more proportion. That signifies on steep slopes, runoff water is more erosive, and can more easily transport detached soil down slope. as the land slope increases four times, the velocity of runoff increases twice [] and kinetic energy increase 4 times and transportation of the particles increases many times. The splashing erosion and the possibility of soil displacement in downward direction also increase with the increase in land slope as given below.

………… (1)

Where Q = volume of particles carried away, A = coefficient and V= velocity of flow.

Therefore, increase of velocity by 2 times helps to carry 64 times more material.

***Length of slope:*** Another topographical factor is length of land slope or slope length factor has a direct relation to the soil loss. Slope length is defined as the distance from the point of origin of overland flow to the point where the slope decreases significantly for deposition to occur or to the point where runoff enters a defined channel. On a long slope there is larger build up of surface runoff and its velocity and depth. This leads to scour erosion which does not occur on a shorter length of slope, or where the effective down-hill slope is reduced to the distance between channel terraces.

***Slope shape:*** the shapes of slope have bearing on erosion potential. The base is more susceptible than the top because runoff has more momentum and more concentrated as it approaches the base. The slope may be roughly convex or concave. On convex slope, the effect is magnified and on concave slope it is reduced. In convex slope, the steepness increases toward the bottom, whereas it flattens toward the bottom in concave shape. In the previous case, the surface horizon is gradually removed from the steepest part of the slope, the sediment carried by runoff, settles down at the bottom. But with intense rains and high velocity flows, the water may concentrate in the concave parts and starts gullying. Apart from that, somewhere complex shaped slopes are also present, which may have either convex shape at the upper end or concave shape at the bottom or opposite. The order of soil erosion is: convex > complex > concave.

### 3.4.5 Man Induced Factors

The activity of human beings to fulfil different purposes can induce soil erosion danger

Some typical examples are:

* + Overgrazing of grasslands
  + Cleaning of the vegetation cover.
  + Poor farming system e.g. Plowing up and down
  + Removal of crop residue and animal dung from farm fields.
  + Badly designed and constructed culverts, canals, drains, etc.
  + Badly sited paths, roads and cattle tracks.
  + Badly designed and constructed conservation measures.

# CHAPTER FOUR

# 4. SOIL EROSION ASSESSMENT AND MEASUREMENT

## 4.1 Erosion Hazard Assessment

Erosion hazard assessment objective is to identify areas whose productivity is threatened by excessive soil loss. Aims dividing the area into regions similar to their degree of erosion hazard and to plan conservation practices.

## 4.2 Generalized Assessments

The erosion factors forming the erosion susceptibility and those of erosion hazard as distinguished as

* + climate
  + relief and slope
  + soil profile and parent material
  + existing erosion
  + natural vegetation and cultivated plants
  + land management (tillage, parceling, conservation)

### 4.2.1 Erosivity Mapping:

This explains the aggressivity of rainfall. Erosion risk reconnaissance mapping is done by studying the distribution of erosivity. Basically all efforts at mapping erosivity have stemmed from assessment of rainfall characteristics, particularly in the EI30 factor developed by Wischmeier (1959). In Africa, Hudson (1971) found the index KE>25 based on the total kinetic energy of rainfall above a certain threshold (25 mm/h) necessary to initiate erosion to be more appropriate. The greatest difficulty in developing erosivity an erosivity index lies in the paucity of stations recording rainfall intensity with those that exist often being remote from eroded areas or localities where erosion risk is to be assessed.

### 4.2.2 Erodibility mapping:

The parallel approach to erosivity estimation is to map soil eroidibility. This needs understanding of the soil characteristics like organic matter, texture, structure, infiltration. Source: of information, from maps, field survey, satellite images

## 4.3 Semi-detailed Assessments

**Soil erosion survey:** Three types of erosion survey can be distinguished: static, sequential and dynamic.

**Static** surveys consist of mapping, often from aerial photographs, the sheet wash, rills and gullies occurring in an area. Erosion hazard is estimated by calculating simple indices such as gully density.

**Sequential** surveys evaluate change by comparing the results of static surveys undertaken on two or more different dates.

**Dynamic** surveys map both the erosion features and the factors influencing them and seek to establish relationships between the two.

## 4.4 Detailed Surveys

Detailed surveys of erosion are usually carried out in the field at pre-selected points to give information on the extent and severity of erosion. They are also used as checks on semi-detailed surveys carried out from aerial photographs and satellite imagery. Observations are made using quadrant sampling over areas of 1m2 for depth of ground lowering and 100m2 for the density of rills and gullies.

## 4.5 Measurement of Soil Erosion

Data on soil erosion and its controlling factors can be collected in the field or, for simulated conditions, in the laboratory. Whether field or laboratory studies are used depends on the objective. For realistic data on soil loss, field measurements are the most reliable, but because conditions vary in both time and space, it is often difficult to determine the chief causes of erosion or to understand the processes at work. Experiments designed to lead to explanation are best undertaken in the laboratory, where the effects of many factors can be controlled. Because of the artificiality of laboratory experiments, however, some confirmation of their results in the field is desirable.

Experiments are usually carried out to assess the influence of one or more factors on the rate of erosion. In a simple experiment to study the effect of slope steepness, it is assumed that all other factors likely to influence erosion are held constant.

### 4.5.1 Field measurements and experiments

Field measurements may be classified into two groups: those designed to determine soil loss from relatively small sample areas or erosion plots, often as part of an experiment, and those designed to assess erosion over a larger area, such as a drainage basin.

#### 4.5.1.1 Erosion Plots (Bounded plots)

Bounded plots are employed at permanent research or experimental stations to study the factors affecting erosion. Each plot is a physically isolated piece of land of known size, slope steepness, slope length and soil type from which both runoff and soil loss are monitored. The number of plots depends upon the purpose of the experiment but usually allows for at least two replicates.

The standard plot is 22 m long and 1.8m wide, although other plot sizes are sometimes used. The plot edges are made of sheet metal, wood or any material that is stable does not leak and is not liable to rust. The edges should extend 150–200mm above the soil surface and be embedded in the soil to a sufficient depth so as not to be shifted by alternate wetting-and-drying of the soil. At the down slope end is positioned a collecting trough or gutter, covered with a lid to prevent the direct entry of rainfall, from which sediment and runoff are channeled into collecting tanks. For large plots or where runoff volumes are very high, the overflow from a first collecting tank is passed through a divisor, which splits the flow into equal parts and passes one part, as a sample, into a second collecting tank (Figure 4.1).

#### 4.5.1.2 Changes in Ground Level

The simplest way of measuring changes in ground level over time is to use what is technically known as an erosion pin but, in reality, is a 250–300 mm long nail, 5 mm in diameter, driven through a washer into the soil. The head of the nail should be some 20–30mm above the soil surface, the washer flush with the surface and the base of the nail sufficiently far into the ground not to be disturbed by changes in soil volume due to wetting-and-drying. Periodic measurements of the gap between the head of the nail and the washer indicate the extent to which the surface has been lowered; where the washer has become buried, the depth of the material above the washer indicates the depth of deposition. Measurements need to be taken over many years before a consistent pattern of ground lowering can be separated from shorter-term fluctuations in level due to changes in soil volume. A large number of pins, usually installed on a grid system, is needed to obtain representative data over a large area.

A disadvantage of erosion pins is that they can be easily disturbed by livestock and wildlife or stolen by the local population.

**Collecting Tank**

Meteorological station

**Runoff Plot**

**Figure 4.1:** Typical layout of erosion plots at a soil erosion and conservation research station (after Hudson 1965).

### 4.5.2 Catchments Sediment Yield

The sediment yield of a catchment is obtained from measurements of the quantity of sediment leaving a catchment along the river over time. Recording stations are established at the exit point for the automatic measurement of discharge, using weirs and depth recorders, and suspended sediment concentrations in the river water. Water samples are taken at set times with specially designed integrated sediment samplers, or the sediment concentration is monitored continuously by recording the turbidity of the water. With measurements made at set times, there is a need to extrapolate the data to cover the period between samples.

## 4.6 Soil Erosion Prediction Models

Modeling water and wind erosion is important to understanding the processes governing soil erosion, predicting runoff and soil erosion rates, and identifying or choosing appropriate measures of erosion control. Modeling permits the:

1. Understanding of the driving processes,
2. evaluation of on-site and off-site impacts on soil productivity and water and air pollution on large scale,
3. identification of strategies for erosion control, and
4. assessment of the performance of soil conservation practices for reducing water and wind erosion.

Well-developed and properly calibrated models provide good estimates of soil erosion risks. Soil erosion results from a complex interaction of soil-plant-atmospheric forces. Thus, modeling soil erosion requires a multidisciplinary approach among soil scientists, crop scientists, hydrologists, sedimentologists, meteorologists, and others. Models must be able to integrate processes, factors and causes at various spatial and temporal scales.

Numerous models of differing prediction capabilities and utilities have been developed. The advent of technological tools such as remote sensing and GIS has significantly enhanced the usefulness of soil erosion models.

Modeling soil erosion involves integration of complex and variable hydrological processes across large areas to understand the magnitude of soil erosion. There are empirical and process-based models to estimate soil erosion at various scales (e.g., plot, watershed, and field).

### 4.6.1 Types of Erosion Models

There are basically three types of erosion models

1. **Physically based:-** Based on mathematical equations to describe the processes involved in the model, taking account of the laws of conservation of mass and energy.
2. **Stochastic:-** Based on generating synthetic sequences of data from the statistical characteristics of existing sample data; useful for generating input sequences to physically based and empirical models where data are only available for short periods of observation.
3. **Empirical:-** Based on identifying statistically significant relationships between assumed important variables where a reasonable data base exists. Three types of analysis are recognized:
4. ***Black-box,*** where only main inputs and outputs are studied;
5. ***Grey-box,*** where some detail of how the system works is known;
6. ***White-box,*** where all details of how the system operates are known.

### 4.6.2 Application of USLE Models

Various models exist nowadays that vary from simple empirical to process-based. The empirical ones are simple and cheap to use, however need to be adapted if we need to use them for a conditions different from ours. The Universal soil loss equation which is developed by Wischemeir and Smith (1978) is most widely used throughout the globe.

One of the models developed to estimate rill and inter rill erosion and sediment yield is USLE. It is empirical model statically established based on the observed data which are usually easier to use and computationally efficient (Schwab et al., 1993). The USLE is designed to predicate long-term average annual soil erosion from alternative combination of crop system and management practice in association with specific soil type, rainfall patterns, and topography.

The equation can be expressed as

A=RKLSCP

Where A= Computed soil loss per unit area, K= soil erodibility, R= rain fall erosivity, L= the slope length, S =slope steepness factor, C=cover management factor and P= erosion control practice.

#### 4.6.2.1 Soil Erodibility Factor (K)

Texture, organic matter continent, structure, and permeability are the main variables, which explain 85% of the observed soil erodibility variance (Lal, 1994). Soil erodibility can be obtained by two methods by using empirical equation (Wischmeir et al., 1978) and by observing soil color on the field as (Hurni, 1985) suggested (for the information refer table 4.1). As this table indicates the susceptibility to erosion would placed as the following manner; when ordered from higher erodible to lower one hold the following order these are the erodibility of yellow color soil > red > brown > black.

#### 4.6.2.2 Topographic Factor (L and S)

L and S calculated by equation developed by (McCooL et al., 1989)

Length factor (L) = (λ/22)m,

Where L=slope length factor

λ=Slope length in meter

m=dimensional exponent

m = (sinθ)/ {(sinθ) + 0.269 (sinθ) .8 + 0.05}

θ = tan-1(s/100), where s= field slope

McCool et al., (1987) as Schwab et al., (1993) quoted present a set of S factor based on slope steepness.

S = 3 (sinθ).8 + 0.56, for slope shorter than 4m and S<9

S = 16.8 sinθ - 0.5, for slope longer than 4m and s>9 present

S = 10.8 (sinθ).8 + 0.03, for slope longer than 4m and s<9 percent

Table 4.1: The Universal soil Loss Equation (USLE) adapted for Ethiopia (Hurni, 1985).

SOURCE: WISCHMEIER AND SMITH, 1978

ADAPT IONS: R CORRELATION: HURNI, 1985

K VALUES FROM BONO AND SELER, 1984: AND WELGEL, 1985

S EXTRAPOLATION: HURNI, 1982

EQUATION: A\* R\* K\*L\* S\* C\* P (TONS PER MA PER MA PER YR)

1. R: RAINFALL EROSIVITY

ANNUAL RAINFALL (MM) 100 200 400 800 1200 1600 2000 2400

ANNUAL FACTOR R 48 104 217 441 666 890 1115 1340

1. K: SOIL ERODIRILITY

SOIL COLOUR BLACK BROWN RED YELLOW

FACTOR K 0.15 0 .20 0.25 0.30

1. L: SLOPE LENGTH

LENGTH (M) 5 10 20 40 80 160 240 320

FACTOR L 0.5 0.7 1.0 1.4 1.9 2.7 3.2 3.8

1. S: SLOPE GRADIENT

SLOPE (%) 5 10 15 20 30 40 50 60

FACTOR S 0.4 1.0 1.6 2.2 3.0 3.8 4.3 4.8

C: LAND COVER

DENSE FOREST: 0.001 DENSE GRASS: 0.01.

OTHER FOREST: SEE GRASS DEGRADED 0.05

BADLANDS: 0.05 FALLOW HARD: 0.05

BADLANDS SOFT: 0.06 FALLOW PLOUGHED 0.60

SORGHUM. MAIZE: 0.10 ETHIOPIAN TEF: 0.25

CEREALS. PULSES: 0.15 CONTINUOUS FALLOW 1:00

1. P: MANAGEMENT FACTOR

PLOUGHING UP AND DOWN: 1.00 PLOUGHING ON CONTOUR: 0.90

STRIP CROPPING: 0.80 INTERCROPPING: 0.80

APPLYING MULCH: 0.60 DENSE INTERCROPPING 0.70

STONE COVER 80%: 0.50

STONE COVER 40%: 0.80

#### 4.6.2.3 Rain Fall Erosivity

Rain fall erosivity considered the effect of the energy rain fall and over land flow on rill and in trill erosion. It is calculated by the equation used by (Hurni1985) developed for Ethiopian condition and calibrated from monthly data of 6 (SCPS) soil conservation project station. The correlation between USLE and R factor expressed as in cm-2h-y- mean annual rain (p in mm). This equation is

R = 0.55p - 4.7

#### 4.6.2.4 Land Cover Factor (C)

It includes the effect of cover, crop sequence, and density, length of growing season, tillage practice and timing with regard to period of erosive rain. For C factor only vegetation crop cover will vary. This concerns soil conservation techniques including tillage practice.

**4.6.2.5 Management Factor (P)**

Generally the p factor obtained by multiplying different sub factors such h as contouring tillage, terracing. Stripe, cropping and mulching, etc. This p factor equals 1 if there is no conservation P=Pc X Ps X Pt

Where P = management factor,

Ps = strip cropping

Pc = countering practice and

Pt = Terrace factor

## 4.7 Soil Loss Tolerance

Soil loss tolerance is defined as the maximum permissible rate of erosion at which soil fertility can be maintained over 20-25 years. Theoretically, soil erosion should be maintained at a rate that equals or is below the natural rate at which new soil forms. Unfortunately, it is difficult to recognize when this balance exist. Although rates of soil loss can be measured, rates of soil formations are so slow that they cannot be easily determined.

Rates of soil formation through out the world range from 0.01 to 0.07 mm yr-1. The fastest rates are exceptional, however, and the average is about 0.1 mm yr-1. In general, deep, medium textured, moderately permissible soils that have subsoil characteristics favorable for plant growth are assigned lower tolerances. Recommended tolerance values of specific soils are used as a guide for soil conservation planning (Table 4.2). The USLE is used to estimate the actual soil loss and to evaluate how changes in practices can be applied to reduce soil loss to below the other tolerance level.

Table 4.2 Recommended values for maximum permissible soil loss

|  |  |
| --- | --- |
| Meso-scale | kg/m2 per year |
| Deep fertile loamy soil | 0.6-1.1 |
| Thin highly erodible soil | 0.2-0.5 |
| Very deep loamy soils | 1.3-1.5 |
| Soil depth: 0-25 | 0.2 |
| 25-50 | 0.2-0.5 |
| 50-100 | 0.5-0.7 |
| 100-150 | 0.7-0.9 |
| Over 150 cm | 1.1 |
| Very erodible areas (e.g. mountains) | 2.5 |
| Macro-scale (e.g. drainage basins) | 0.2 |
| Micro-scale (e.g. construction sites) | 2.5 |

# CHAPTER FIVE

# 5. GULLY EROSION

## 5.1 Introduction

Gullies are highly eroded natural drainage channels. Gully is flow channels greater than rills in width and depth. They are one of the most destructive forms of soil erosion on a landscape. Gullies spread fast and destroy large tracts of land, and eventually engulf the entire land mass of the area. Thus, the spread of gullies needs to be checked and brought under control at the early stage of their growth.

Gully is a situation where the system is transferred from a series of Meta stable state to unstable state and the force required to replace back to its original position is much higher than the sum of forces of a series of Meta stably states applied to it.

## 5.2 Development of Gully

### 5.2.1 Factors for Gully Formation

The shear stress of flowing water and critical shear stress of the soil are two prominent factors affecting gully erosion. The shear stress of flow is responsible for continued detachment of channel bed and sides and transport of eroded materials along the well defined ephemeral channels. Grassed waterways reduce gully formation, but when the flow shear stress exceeds the critical stress of the soil and plant roots, the cover fails and shear stress of the flow rapidly increases, enlarging the gullies and causing severe soil erosion. Bare and freshly plowed soils have the lowest critical shear stress and thus are the most susceptible to gully erosion. Critical shear of soil is a function of soil texture, bulk density, clay content, dispersion ratio, tillage, plant roots, residue cover, and soil slope.

Shear stress of runoff *<* Critical shear of soil = No gully formation

Shear stress of runoff *>* Critical shear of soil = Gully formation

### 5.2.2 Causes of gully formation:

1. **Climate change** – if rainfall is greater than the usual that is if there is high rainfall, there will be high runoff and then high tendency of gully formation. If there is less precipitation there will be less vegetation (roughness decrease) and then high runoff high gully formation
2. **Landuse change** – if there is clear off forest there will be decreasing of roughness and change in structure of the soil. Intrinsic for internal condition of the gully self development. Due to this there will be:
3. Change in flow velocity: the velocity of runoff will increase
4. Change in slope: improper landuse system can change the topography of the land.

Many gullies are caused by accelerated erosion resulting from misuse of the land. The major causes of gully formation are:

* + - * Improperly designed and badly maintained roadside ditches
      * Up and down slope cultivation of steep land
      * Unprotected graded terrace or diversion ditch outlets
      * Unrepaired bunds, terraces, diversion ditches, etc.
      * Improperly sited, constructed and/or designed waterways
      * Badly sited cattle tracks or paths

### 5.2.3 Main Process of Gully Formation

The main processes in the development of a gully are waterfall erosion and channel erosion.

1. ***Waterfall erosion*:** is when water falling over the edge of a gully or bank of a ditch forms deep and rapidly extending gullies. The falling water undermines the edge of the bank, which caves in.
2. ***Channel erosion:*** is essentially the scouring away of the soil by concentrated runoff as it flows over unprotected depressions.

### 5.2.4 Stages of Gully Development

Stage 1 - ***Formation stage*:** Channel erosion as a function of concentrated flow and slope could develop piping.

Stage 2- ***Development stage*:** cut back and expansion of the sides of the gully upstream movement of gully head and enlargement of the gully in width and depth and also elongation in length. Especially C - horizon soil is weakly weathered and is highly under risk. Sometimes there could be deposition in floor of the gully where there is gentle slope of gully bed.

Stage 3- ***Healing stage*:** healing or cover (restore) stage start at vegetation to grow because of enlarged area and stabilized side.

Stage 4**-** ***Stabilization stage:***stabilization stage stable gradient and vegetation begin to grow in sufficient abundance to anchor the soil and permit development of new top soil

## 5.3 Damages Caused by Gully Erosion

* Gullies cut up farm fields and cause difficulty in farming and use of farm machinery
* Gullies reduce actual farm size
* Deep gullies cause water to drain from the soil and in some areas lower the ground water table
* Sediment from eroding gullies deposited on bottom land may destroy its value
* Sediments from gullies increase the cost of maintaining highways, rail roads, pipelines and other public utilities

Gullies undermine bridges, railways, roads and other structures and forces them to collapse It is difficult to estimate the soil loss from gully expansion.

## 5.4 Classification of Gullies

**U- Shape gully:** This is vertical shape gully for soft unstable silty soil. They formed on relatively flat lands. The catchment areas of such gullies are generally large, therefore large size runoffs occur with low velocities of flow. The runoff enters the gully at its head and also from the low elevation spots on its side.

**V- Shape:** When sub soil is less permeable than the top soil. A continuously flowing runoff through several rills gets converted in to a single channel, which in due course of time because of continued soil erosion, forms a V-shape gully.

# CHAPTER SIX

# 6. WIND EROSION AND CONTROL

## 6.1 Introduction

Wind erosion, also known as eolian erosion, is a dynamic process by which soil particles are detached and displaced by the erosive forces of the wind. When wind blows across the cultivated bare field having top soil as loose, dry and finely divided, it produces a large effect on soil erosion. In wind erosion not only the top soil is removed but the soil fertility is also reduced. The formation of sand dunes and extension of desert is the result of wind erosion. Regarding the soil loss, wind and water erosion play an equal important, no difference between them.

Wind erosion, cannot be divided into several types like the water erosion but it can varied up to some extent. It is generally occurs at a slow rate called geologic rate under natural vegetation as well as normal soil conditions.

## 6.2 Wind Erosion Processes

Wind detaches and transports soil particles. Transported particles are deposited at some distance from the source as a result of an abrupt change in wind carrying capacity. The three dominant processes of wind erosion, similar to those of water erosion, are: *detachment, transport, and deposition* (Figure 6.1). The mechanics and modes of soil particle movement are complex. Deposition of suspended particles depends on their size and follows the Stoke’s Law. Large particles settle down first followed by particles of decreasing size. Smaller particles remain suspended forming the atmospheric dust.

### 6.2.1 Types of Soil Movement

Three types of soil movements are **suspension, saltation, and surface creep** (Figure 6.2). The mode of transport of soil particles during wind erosion isgoverned by the particle size. All types generally take place simultaneously.

#### 6.2.1.1 Suspension:

Small soil particles (*<*0.1 mm) are transported in suspension in the air as dust or haze, and they are too small to overcome the upward current of the wind stream. Soil particles float and remain scattered in air until the upward wind force drops below the threshold level of the weight of the suspended particles. Soil particles deposit on the soil surface when their weight surpasses the declining upward wind force or when it rains.

**Figure 6.1:** Three main processes of wind erosion

**Processes of Wind Erosion**

**Detachment**

**Transport**

* Primary and secondary soil particles are detached by the erosive forces of the wind.
* Particles collide, abrade, and break into smaller particles.
* Detachment and movement of soil particles depends on the wind threshold velocity.
* Threshold velocity is the minimum amount of velocity needed to move soil particles.
* Detachment occurs when soil is dry and bare.
* The detaching capacity of wind is a function of friction velocity and size of erodible particles.
* Dry aggregates made up of fine particles are harder to detach than those of coarse particles with weak contact points.
* Particle transport is a function of wind velocity, surface roughness, particle size, and percent of detached particles.
* Well-aggregated and moist or wet soils are unaffected by wind erosion regardless of particle size and wind velocity.
* Turbulence and gusts produce different range of wind velocities above the soil surface with variable particle carrying capacity.
* Transport capacity increases rapidly from the windward edge of eroded and bare soil.
* The total soil removal is equal to the fifth power of the friction velocity.
* Soil deposition occurs when the gravitational force is greater than the upward forces of wind holding the soil particles in air.
* Any obstacle (e.g., windbreaks) that causes a sudden decrease in wind velocity promotes deposition.
* Rain during wind storms also contributes to deposition.
* Change in soil conditions from dry to wet also captures saltating and creeping soil particles.
* Vegetation intercepts floating particles, which adhere to leaves and branches and deposit in the soil surface with rain.
* Transported loess material is accumulated in piles or dunes on the leeward side of the field.

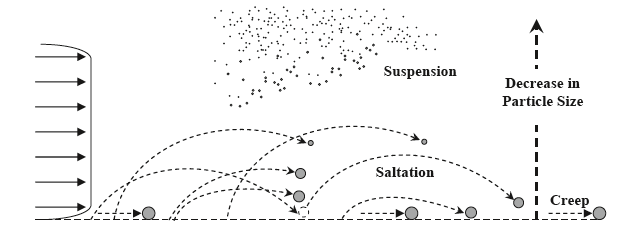
**Deposition**

#### 6.2.2.2 Saltation:

Soil particles with 0.1 to 0.5 mm in diameter move downwind by bouncing and saltating along the soil surface. Particles can jump as high as 1 m, depending on their size, wind velocity, and surface roughness. Coarse particles are lifted no more than 1 cm. Velocity of soil articles is half or one-third the wind velocity. During saltation, particles abrade and become suspended.

#### 6.2.2.3 Surface Creep:

Soil particles with diameters between 0.5 and 2 mm creep or roll along the soil surface due to their large size. Creeping particles may also collide with larger and non-creeping particles (e.g., pebbles). By consecutive abrasion, creeping particles with decreasing size can be transported by saltation. Surface creep transport accounts for about 1/3 of wind erosion.

**Figure 5.2:** The three types of soil movement in wind erosion

### 6.2.2 Deposition of Soil Particles

After initiation and transportation of soil particles in wind erosion, the next step is deposition. Deposition of suspended soil particles depends upon the particle’s weigh and wind velocity in which particles weight is directly related to the gravitational force. Deposition of soil particles occurs when gravitational force is greater than the resisting forces holding the particles in the air. It may also be taken place when wind velocity decreases near the ground surface due to surface roughness.

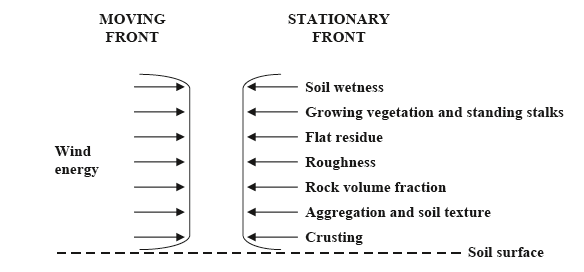
## 6.3 Factors of Wind Erosion

Wind erosion is the result of a combination of many factors associated with climate, soil, land surface, and management conditions (Table 6.1). Wind velocity, soil surface water content, surface vegetative cover, surface roughness (e.g., ridge height), aggregate stability, field length, rock volume fraction, and soil texture are the most sensitive parameters influencing wind erosion.

**Table 6.1:** Four interactive factors affecting wind erosion dynamics

|  |  |  |  |
| --- | --- | --- | --- |
| Climate | Land Surface Properties | Soil Properties | Land Use and  Management |
| * Wind speed, duration, direction, and turbulence * Wind shear velocity * Precipitation and temperature * Radiation and evaporation * Air humidity, viscosity, and pressure * Freezing and thawing | * Field slope * Length, width, and orientation of the field * Terrain roughness * Non-erodible materials (e.g., rocks, stones). * Residue orientation (e.g., flat, standing) | * Particle size distribution and particle density * Aggregate size distribution * Aggregate stability, strength, and density * Water content * Bulk density and crusting * Soil organic matter content * CaCO3 concentration | * Management * Type of land use (e.g, forest, rangeland, and pasture) * Type of cultivation (e.g., no-till, plow till, rotations) * Fallow or bare soil * Afforestation or windbreaks |

There are two opposing forces that take place during soil erosion (Figure 6.3). The force of wind which tends to move everything away faces an opposing front, which is the natural resistance of the soil that offsets the wind energy until the threshold level of resistance is overcome by the wind force at which point erosion is set in motion. For example, high winds increases soil transport, whereas well-aggregated soils decrease the availability of loose particles for erosion. The net effect of the opposing forces determines the rate of soil erosion. The wind is a moving force whereas the forces of soil resistance are stationary.



**Figure 6.3:** Forces defining the rate of wind erosion (After Fryrear et al., 1998)

### 6.3.1 Wind Erosivity

Wind erosivity refers to the capacity of wind to cause soil erosion. Wind in interaction with precipitation and air temperature is the driving force of wind erosion. Wind is dynamic and composed by eddies that change rapidly in intensity and direction. Amount of rainfall and temperature fluctuations determine rates of evaporation.

The wind velocity must be near 8 m/s at 2 m above the soil surface for the soil particles to be displaced by wind. Fast winds cause more erosion than slow winds. Wind velocity changes on an hourly, daily, and seasonal basis. The air movement near the soil surface is small because of the drag force between air and soil surface. The drag force increases with increase in surface roughness. A rough surface changes the wind profile. Wind blowing over a flat and smooth surface is shifted to a new level when it reaches a rough surface. Wind velocity increases with height above the soil surface due to decrease in drag forces.

The wind velocity at any given distance above the soil surface with crop canopy cover is computed using the semi-logarithmic model derived from the first momentum of eddy function as

where *U*(*z*) is the wind velocity at height Z, µ\* is the friction velocity, *K* is the vonKarman constant equal to 0.4, *d* is the aerodynamic displacement height equal to 0.7 × height of roughness element, and *Z*0 is the aerodynamic roughness parameter assumedto be equal to 0.13 × height of roughness elementor 0.15 × height of roughness element.

**Example 6.1**.Determine the wind velocity at 10 and 20 m above the soil surface if the wind velocity at the 5 m height is 4 m/s for a field with crop height of 2 m. Assume *z*0 is equals to 0.15 the height of crops.

Given: height of roughness element (crop height) = 2 m

Velocity at 5 meter is = 4 m/s

Z0 = 0.15 X height of roughness element = 0.15 X 2 m = 0.3 m

D = 0.7 X height of roughness element = 0.7 X 2 m = 1.4 m

***Z5***

***U5m***

***Z10***

***Z20***

***U10m***

***U20m***

***Soil surface***

So we can calculate the value of velocity friction

U\* = 0.644 m/s

Since U\*, *d* and *Z*0 remain the same with height above the surface, the wind velocity is estimated as per the above equation

The *U*20 *>U*10*>U*5 indicates that velocity increases with height above the soil surface.

Threshold wind velocity refers to the velocity required to entrain a soil particle. The threshold velocity required to initiate soil movement varies with soil surface and vegetative cover conditions. It increases with increase in soil particle size. Particles that are fine and loose are entrained more easily than coarse particles under the same wind velocity. A greater wind velocity is needed to break away and move particles in undisturbed and surface covered soils.

### 6.3.2 Soil Erodibility

It is the ability of the surface soil to resist the erosive forces of wind. Intrinsic soil properties such as texture, structure, and water content in interaction with surface roughness and living and dead vegetative cover define the rate at which the soil is detached and eroded. Any soil that is dry and loose with bare and flat surface is susceptible to wind erosion. Dry loose soil material *<*0.84 mm in diameter occurring on the soil surface, known as loose erodible material, is the fraction that is readily transported by wind.

## 6.4 The Effects of Wind Erosion

Wind erosion may have the following impacts:

* Soil fertility is reduced because of the loss of the plant nutrients that are concentrated on fine soil particles and organic matter in the topsoil. This reduces the soils capacity to support productive pastures and sustain biodiversity.
* The erosion of light-textured topsoil can expose dense clay sub soils. These smooth and bare areas, called clay pans or scalds can cover hundreds or even thousands of hectares. The buildup of soil particles against obstacles may bury fences and roads.
* Sand grains transported by strong winds can damage vegetation in their path by sandblasting.
* Air pollution caused by fine particles in suspension can affect people's health and cause other problems.

## 6.5 Wind Erosion Control

Proper land use and moisture conservation practices are the main constraints which help in wind erosion control. The principal measures to control the wind erosion, are broadly classified into following two major groups. These are as:

1. The measures to reduce the surface wind velocity, and
2. The measures to improve the soil characteristics.

Both of the aforesaid objectives may easily be achieved by vegetative measures, as it reduces the surface wind velocity and at the same time also improves the soil aggregates.

### 6.5.1 Measures to Reduce the Surface Wind Velocity

#### 6.5.1.1 Vegetative Measures

Vegetation is the most effective means of wind erosion control. It retards the wind velocity near the ground surface and control soil loss from the land surface. In addition, cultivated crops also hold the soil against attractive force of wind and reduce the soil erosion.

Vegetal cover on the ground surface has a great effect on distribution of wind velocity above the land surface. The velocity profile near the ground surface is sharply modified due to vegetation, known as roughness height of the vegetation. But above this height the velocity profile becomes constant.

The vegetative measures could again be classified as:

* 1. Temporary vegetative measure,
  2. Permanent vegetative measures.

##### 6.5.1.1.1 Temporary vegetative measures:

Temporary measurements are the crop management practices to provide a vegetative cover on the soil surface. It includes the growing or crops which are more effective for erosion control than the interilled crops. The root system of harvested crops holds the soil particles and the stalks or stubble left in the file also reduce the effect of wind currents, and thus wind erosion get reduced.

The effectiveness of crops is dependent upon the stage of growth, density of cover, row direction, width of rows, kinds of crops and climatic conditions. Pasture or meadow tends to accumulate more soil from neighboring cultivated fields.

In addition, good crop rotations that maintain the soil structure and conserve the moisture, also play a key role in wind erosion control. Vegetations used for the purpose of wind erosion control, should have ability to grow in rapid speed against the wind and able to withstand for a long time. It should also provide a dense vegetative cover during critical seasons of the year so that an uniform obstruction can be formed to the wind as much as possible and reduction in the surface wind velocity from an abundance of crop residue may be achieved.

##### 5.5.1.1.2 Permanent vegetative measures:

It consists of planting the trees, shrubs and grasses for protecting the eroded lands against wind erosion. The wind break and shelterbelt are most effective permanent vegetative measures, are generally used for controlling the sever wind erosion. These are described below:

**Wind break and shelterbelt**: The term wind break is defined as any types of barrier, either mechanical or vegetative used for protecting the areas like buildings, orchards or farm steads etc. from winds

**Shelterbelt:** A shelterbelt is a longer barrier than the wind breaks. It consists of rows of trees or plant hedges (shrubs). It is mainly intended to provide protection for soil and crops grown on the sheltered side and to trap air-borne soil particles conservation of soil moisture and for the protection of filed crops. The benefit will depend on the frequency and direction of the damaging winds. Use meteorological records of wind direction to decide placement of shelter belts.

Shelterbelt is more effective for redacting the wind movement than the wind break. In addition to control the wind erosion, wind breads or shelterbelt also provide others advantages such as provides fuels, reduce evaporation and protect the orchards from hot and cold winds. However, they have some disadvantages also, for example, affects the crop yields of the adjoining fields by their shade, root completion and also by harboring bird population. The closely planted shelterbelt also creates air conditions which tends to increases the susceptibility of fungus disease in some fruits.

#### 6.5.1.2 Primary and Secondary Tillage Practices:

Tillage practices such as ploughing etc. could be adopted for controlling wind erosion. These practices must be carried out before the start of the wind erosion. The tillage practices are generally used for moisture conservation as it is helpful in controlling the wind erosion.

The main objective of primary and secondary tillage operation in wind erosion control is to produce a rough and cloddy surface to resist the wind velocity. In order to obtain the maximum roughness, the land should normally be tilled as soon as after a rain as possible.

In tillage operations, the small ridges formed, normal to the direction of prevailing wind are effective in wind erosion control. Because it create an obstruction in flowing path and also change the direction between the ridges, causes soil deposition.

#### 6.5.1.3 Use of Crop Residues:

Use of crop residues on exposed soil surface is an effective measure of controlling the wind erosion, especially when it is combined with rough soil surface. This practice is known as stubble mulching. Crop residues acts in two ways, first it reduces the wind velocity over the land surface and second traps the eroding soils. Short stubble is less effective than long stubble. From field study, it has been reported that a mixture of straw and stubble provides more protection against erosion than equivalent amount of straw or stubble used separately. For higher wind velocity greater quantity of crop residues are required. From experiment, it was found that effect of various quantities of crop residues on soil loss varies inversely as the 0.8 power of the weight of plant residues for the soil aggregates fraction less than 0.42 mm in diameter.

#### 6.5.1.4 Strip Cropping:

Tillage practices may be quite effective as an emergency control measure. Soil blowing, usually takes place in a small area where the soil is loose or is exposed for a long duration than in other parts of the field. When the entire field starts to blow, the surface should be kept in a rough and cloddy condition as soon as possible. This can be accomplished by making the widely spaced strips throughout the field, and crops are grown on these strips. The main advantages of strip cropping are:

i. It provides a protection to the field against blowing wind.

ii. Makes a limited length of soil erosion equal to the width of field’s strip.

* + 1. The soil becomes able to conserve more moisture content.

iv. Provide a large possibility of earliest harvesting.

#### 6.5.1.5 Structural or Mechanical Method:

Mechanical or structural method for controlling the wind erosion consists of some mechanical obstacles, constructed across the prevailing wind which reduces impact of blowing wind on the soil surface. These obstacles may be fences; walls, stone packing etc. are in the nature of semi-permeable or permeable. The semi-permeable barriers are more effective because of diffusion and eddying effects on its downstream face. Terraces and bunds are also obstructed the wind velocity and control the wind erosion, considered as mechanical barriers.

### 6.5.2 Measures to Improve the Soil Characteristics:

The main soil factors which help in controlling the wind erosion are given as under:

1. By conserving the soil moisture to improve the vegetative growth, and
2. By conditioning of the top soil to improve the aggregation.

#### 6.5.2.1 Conserving the Soil Moisture:

The conservation of soil moisture, particularly in arid and semi-arid regions where rainfall is too less is most important for wind erosion control and for crop growing. The moisture conservation can be done by increasing infiltration, reducing evaporation and preventing unnecessary plant growth. This can also be accomplished by adopting the various practices such as terracing, contouring, mulching and selecting suitable crops. The moisture conservation measures either they are biological or engineering have an indirect effect on wind erosion control Among all these measures mulching is one of the most suitable practice and is successfully used for controlling the wind erosion. Crop residues are a common form of mulch are used to conserves the soil moistures and reducing the wind erosion. The grater the amount of mulch spread on the surface, the large quantity of moisture is conserved in the soil.

#### 6.5.2.2 Conditioning of the Top Soil:

The wind erosion is greatly influenced by the top soil condition regarding the detachment of soil particles. An effective method of conditioning the top soil against wind erosion is the adoption of tillage practices that produce the non-erosive soil aggregates. These aggregates over the top soil surface tends to reduce the striking effect of wind and results into reduction of wind erosion. The crop management practices, such as tillage, crop rotation and addition of manures also has a great effect on wind erosion control as it develop a good soil structure, able to with stand against wind velocity.

# CHAPTER SEVEN

# 7. SOIL AND WATER CONSERVATION MEASURES

## 7.1 Strategies for Erosion Control

A general aim of erosion control measures is to obtain maximum sustained level of production from a given area of land whilst maintaining soil loss below the threshold level.

In addition to this a need to control erosion may be:

* To reduce loss of nutrients from agricultural lands (natural or artificial nutrients)
* To prevent pollution of water bodies (rivers, lakes, underground) due to animal waste, industrial wastes & other contaminants.
* To reduce rate of sedimentation of dam reservoirs, canals, ditches. Before constructing a dam, erosion control structures are constructed as terraces to prevent transport of soils from the upper catchment to the upstream of the dam for deposition.
* To limit crop damage due to water and wind.

As a consequence of processes and mechanics of erosion described in section 6.1, there are four basic principles for erosion control:

* Dissipate the power of the rain, by intercepting with vegetation, mulch or other materials i.e covering the soil to protect it from rain drop impact.
* Minimize the rate of runoff by increasing infiltration to the soil and by maximizing the use of water by plants
* Prevent runoff generating excessive power by controlling slope, and stopping the accumulation and concentration of flows, and
* Increase the resistance of the soil by increasing its structural strength by raising fertility (via organic cycling), improving aggregate stability of soil and incorporating sound tillage practices.

## 7.2 Types of Erosion Control Measures

There are three types of erosion control measures.

1. Agronomic
2. Soil management
3. Mechanical /Physical measures.

The agronomic measures are ways of affording protection of the soil. Soil management practices control erosion by increasing resistance of soil to erosion. Agronomic and soil management measures, are referred to as biological measures, reduce erosion due to detachment and transport. But mechanical measures reduce soil erosion due to transport only. Vegetated water ways and terraces are important physical control measures.

### 7.2.1 Agronomical Practices to Control Erosion

Agronomic measures/Biological conservation measures/ for soil conservation can be defined as a set of conservation practices, which by the adequate cover of the soil surface favor the recirculation of organic matter and nutrient, as well as the establishment of vegetative barrier across the slope, prevent soil moisture loss, improve soil properties and maintain, restore the productivity and stability of the agro ecosystem. Wherever possible biological control measures must be interacted with physical structures and mutually benefit one from the other. In general it can be called as conservation farming which can improve the stability, productivity, sustainability and equitability of cropping systems in dry lands. It includes several practices aim at improved vegetation cover and improved soil structure for erosion control.

Principles of Agronomical Measures

1. ***Reducing rain drop impact: -*** first and above all agronomical measures prevent soil erosion by protecting the soil surface from the direct impact of rain drop. Organic matter from vegetation helps the formation of elastic soil aggregates that absorbs the kinetic energy of rain drops without being smashed and soils which are rich in organic matter have higher pores that enhance infiltration.
2. ***Increasing the time of concentration:-***vegetation provides resistance to the flow.
3. ***Reducing both the velocity and the volume of overland flow***.

The agronomical measures include mulching and crop management practices to control the soil erosion. The use of these measures are entirely dependent upon the soil types, land slope and rainfall characteristics.

#### 7.2.1.1 Mulching

Mulching is the covering of the soil with grass, crop residues such as straw, maize stalks, palm fronds or standing stubble. The cover protects the soil from raindrop impact (soil detachment and crusting) & evaporation, and reduces the velocity of runoff and wind.

Mulching reduces soil erosion by:-

* Intercepting the falling raindrops over the land surface and thus dissipating their kinetic energy.
* Increasing the infiltration capacity of the soil by maintaining the upper soil surface more permeable.
* Controlling sheet erosion: mulching reduces the velocity of surface runoff by the obstacles e.g. leaves, stems, roots.
* Maintaining the soil cool and must which favors good vegetation cover
* Conserving the soil moisture by reducing evaporation in dry seasons.

#### 7.2.1.2 Crop Management Measures

In crop management practices, the soil loss is minimized or conserved by adjusting the ***cropping system*** and ***cropping pattern***. A cropping system refers to the type and sequence of crops grown and practices used for growing them. It encompasses all cropping sequences practiced over space and time based on the available technologies of crop production. Cropping systems have been traditionally structured to maximize crop yields. Conserving soil and water and maintaining long-term soil productivity depend largely on the management of cropping systems, which influence the magnitude of soil erosion and soil organic matter dynamics. While highly degraded lands may require the land conversion to non-agricultural systems (e.g., forest, perennial grass) for their restoration, prudently chosen and properly managed cropping systems can maintain or even improve soil productivity and restore moderately degraded lands by improving soil resilience. Crop diversification is an important option in sustainable agricultural systems.

##### 7.2.1.2.1 Crop Rotation

Crop rotation is the practice of growing different crops one at a time in a definite sequence of the same piece of land. This is a system of farming in which the same piece of land is kept under cultivation for years, but the crops grown are changed on a rotational basis with a definite sequence.

Rotations which include high above- and below-ground biomass producing forages and crops reduce soil erosion hazard. Growing cereals and legumes alternatively with row crops provides a dense and permanent vegetative cover that stabilizes the soil underneath, reducing soil erosion hazard.

Crop rotations that include alfalfa, clover, or perennial grasses are recommended to improve soil structure, macro-porosity, reduce soil compaction, and increase soil organic matter content. Growing perennial crops in rotation with row crops eliminates tillage and reduces wheel traffic. Deep-rooted (*>*1 m) legumes or grass species loosen relatively compact or impermeable soil horizons, ameliorate plow pan formation, improve soil porosity, promote infiltration rate, and reduce runoff and soil erosion. Proliferation of roots and reduced soil disturbance under perennial crops promotes soil aggregate stability and strength.

##### 7.2.1.2.2 Intercropping

Intercropping is a multiple cropping system where two or more crops are grown simultaneously on the same field. The different crops can be planted in alternating rows or sections. Intercropping mixes different plant species with contrasting height, foliage, biomass, and other agronomic characteristics. It is a recommended system for soil and water conservation.

Intercropping with legumes or deep-rooted plant species absorbs nutrients from deeper soil horizons and reduces N deficiencies among neighboring and succeeding non-legume crops.

##### 7.2.1.2.3 Cover Crops

Cover crops are any covers grown as a conservation measure either during the off-season or as ground protection under trees. To be effective, the cover crops must be quick to establish, provide an early canopy cover, be aggressive enough to suppress weeds and posses a deep root system to improve the macro-porosity of the soil.

##### 7.2.1.2.4 Strip Cropping

Strip cropping refers to the practice of growing crops in alternate strips of row crops or forage/grass. This cropping system is an effective practice to reducing soil erosion because it breaks sloping landscapes in wide segments with diverse vegetative cover which intercepts runoff and promotes water infiltration, thereby reducing runoff and soil erosion. Strip cropping is often integrated with rotations where strips are planted to different crops each year.

##### 7.2.1.2.5 Contour Farming

Contour farming is the practice of tilling, planting, and performing all cultural operations following the contour lines of the field slope. This practice contrasts with up- and down-slope farming, which is the least desirable practice on highly erodible sloping lands. Furrows in an up- and down-slope direction become channels of concentrated runoff, forming rills or even gullies. Contour farming is being adopted in modern agriculture across the world for soil erosion control. Contouring creates furrows perpendicular to the predominant field slope. These furrows retard the runoff velocity, reduce the runoff transport capacity, enhance water infiltratibility, reduce sediment transport, and discharge excess runoff at non-eroding velocities. Furrows on the contour create irregular field surface which reduces runoff velocity.

##### 7.2.1.2.6 Contour Strip Cropping

This cropping system involves planting row crops in strips on the contour of the field slope. It provides added erosion control and plant and crop diversity because it combines contour- and strip-cropping. Strip-cropping on the contour is more effective than contouring alone for reducing soil erosion in fields with severe erosion hazard.

##### 7.2.1.2.7 Multiple Cropping

The aim of multiple cropping is to increase the production from the land while providing protection of the soil from erosion. The method involves either sequential cropping, growing two or more crops a year in sequence, or intercropping, growing two or more crops on the same piece of land at the same time. Many schemes involve the mixture of the two. Relay cropping is a type of cropping system where two crops are planted with a little overlap. Intercropping is a combination of two or more crops at the same time in the same plot.

### 7.2.2 Soil Management Practices

In soil and water conservation soil management practices refers to those practices done on the soil which reduce soil erosion to a safe amount. These are practices which increase infiltration rate, increase amount of organic matter; help the safe disposal of runoff water from the field.

Soil management practices can be grouped into two:

**Cultivation practices**: - these practices include farm operations that would improve yields. Most of these measures are integrated with physical structures for soil and water conservation.

**Fertility improvement practices**: - include all practices aimed to increase the amount and quality of organic matter content into the soil by improving plant and animal residues.

#### 7.2.2.1 Conservation tillage

Tillage is a mechanical manipulation of soil to provide favorable environment for good germination of seeds and crop growth; to control the weeds: to maintain infiltration capacity and aeration. The effect of tillage is the function of its several effect on soil such as aggregation, surface sealing, infiltration & resistant to erosion.

Conservation tillage is any tillage system which has its primary objective of reducing soil and water loss relative to conventional or excessive tillage. It can be achieved by minimum or zero tillage which are done in association with mulching or stubble mulching.

#### 7.2.2.2 Application of organic manure and mineral fertilizers

Manuring reduces soil erosion by increasing formation, stability, and strength of aggregates due to the addition of organic matter. Organic matter-enriched aggregates are less susceptible to slaking and have higher inter- and intra-aggregate macro-porosity, which results in higher water infiltration rates.

**Farmyard manure**: - are a decomposed mixture of cattle dug and urine, straw and litter used as bedding & any remnants of straw and plant stalks fed to cattle.

**Composted manure**: - is reduced natural product consisting of a partially decomposed mixture of organic residue; crop residues, vegetable refuse and litter usually mixed with animal dung and some soil. Compost is used for fertilizing and conditioning the soil.

**Green manure**: - is the practice of ploughing or turning into the soil undecomposed green plant for the purpose of improving physical structure as well as fertility of the soil.

**Fertilization** is the application of organic matter or synthetic origin in to the soil supply elements essential to the growth of plants.

Applying organic manure and mineral fertilizers in to the soil reduces soil erosion by:

* Increasing the permeability of the soil to water thus decreasing runoff loss.
* Increasing the density of the vegetative cover which interim decreases rate of surface run off and increases water penetration.
* If organic manures are used as a top dressing protects the soil from beating rains & decreases evaporation loss of water.
* Decreases soil erodibility by improving soil physical properties of by improving the water holding capacity of the soil promoting granulation, and improving porosity.

#### 7.2.2.3 Agroforestry

Agroforestry is a land management system that combines trees and/or shrubs with agricultural crops and livestock production on the same piece of land. It is an emerging technology for effective soil and water conservation. In a broader sense, agroforestry comprises a wide range of practices that involve establishing an managing trees intentionally around or within croplands, pasture lands, and farm animal grounds with the purpose of controlling soil erosion, developing sustainable agricultural production systems, improving wildlife habitat and rural landscape, mitigating environmental pollution, and increasing farm economy through harvesting of tree-based specialty products.

### 7.2.3 Mechanical Erosion Control Measures

Mechanical or engineering structures are designed to control runoff and soil erosion in fields where biological control practices alone are insufficient to reduce soil erosion to permissible levels. Because construction of engineering structures involves soil disturbance, change in landscape features, and some removal of land from production, biological practices such as residue mulching, no-till, reduced tillage, cover crops, riparian buffers, and grass filter strips must be the first choice for controlling soil erosion. Biological measures are also less expensive than engineering structures. Vegetative cover moderates erosion in a natural and ecological manner. Plants interact with the soil beneath in a mutual relationship while reducing soil erosion. Their roots increase soil shear strength and water infiltration and reduce detachment of soil particles. The canopy cover intercepts and changes the erosive raindrops into non-erosive streams of water through fall. Dense stands retard runoff velocity and increase the infiltration opportunity time, thereby reducing runoff.

Mechanical structures are companion practices designed to improve the performance of biological conservation practices. On severely gullied terrains, biological practices must be supplemented by mechanical structures.

These structures are designed to:

* intercept and reduce runoff velocity,
* pond and store runoff water,
* convey runoff at non-erosive velocities,
* trap sediment and nutrients,
* promote formation of natural terraces over time,
* protect the land from erosion,
* improve water quality,
* enhance biodiversity of downstream water,
* prevent flooding of neighboring lands,
* reduce sedimentation of waterways, streams and rivers,
* create recreational opportunities, and
* provide diverse ecosystem services.

Nowadays, bioengineering techniques are increasingly being combined with traditional mechanical structures for controlling erosion.

A number of mechanical and engineering structures are available, some of which are permanent and others temporary. Permanent structures are built for long term erosion control and are established for a long-term use. Such permanent measures include terraces, drop structures, spillways, culverts, gabions, ripraps, and ditches. In contrast, temporary measures include contour bunds, sand bags, silt fences, surface mats, and log barriers. The choice of mechanical measures depends on the severity of erosion, soil type, topography, and climate.

#### 7.2.3.1 Level Soil Bunds

A level soil bund is an embankment constructed along the contours (points of the same elevation), made of soil, with a collection channels or basin at its upper side. Soil which is eroded between two bunds is deposited in behind the lower bund. Whenever the basin or space behind the bund is full of sediment, the bund should be raised until forming terrace. In this way, a bench terrace will develop in the course of years (3-7 years based on slopes and type of soils)

The bund reduces and stops the velocity of runoff and consequently reduces soil erosion and steady decline in crop yields. They are impermeable structures, unless provided with spillways, intended to retain all rainfall, and hence, contributing to increase the moisture retention capacity of the soil profile, water availability to plants, and increase the efficiency of fertilizer application if any. In terms of increased productivity, the water retention effect alone can give significant increases in crop yields, particularly in drier areas. Through their water retention effect, the bunds may allow some crop yield even in drought years.

**Disadvantages and constraints**

1. Labor intensive activity:-labor availability (capital investment or incentives may be required) may be a problem for construction and maintenance of bunds,
2. Spacing taken out production by the bunds if too narrow spaced (2 -10% depending on slope and intervals),
3. Rodents or other pests may be harbored by bunds.

Most of disadvantages would be compensated by accurate design and modifications as required

**Technical specifications**

**Slope range:** soil bunds are suitable within a 3-30% slope range. However, in dry zones, above 5-15% slops and soils with limited infiltration capacity (crusted, shallow, etc.) it is recommended to provide soil bunds with spillways (check dams-spillway, lateral spillways, revegetated outlets, etc.) for higher slops, stone faced or stone bund and bench terraces are preferred.

**Type of soils:** soil texture and soil depth influence the design and construction of soil bunds. The first involves their spacing apart and need to apply excess water disposal devices. Where soils have a loose texture and high infiltration rate the bunds may be spaced further apart than those on heavy soils with low infiltration. However, loose texture is not easy to compact and thus, bunds should be of bigger dimensions. In heavy soils, some temporary water logging problems may affect the crops. In this case, spillways are needed to evacuate excess water. Knowledge of the soil depth is required as the vertical interval between the bund should not exceed twice the top soil depth. If this is exceeded then the resulting terrace will be partly exposed to the subsoil.

**Spacing apart soil bund:** as the water flows through a sloping land, it attains erosive velocity. The bund should be spaced to intercept the erosive velocity. Again, the spacing should not be too close to interfere with the farming operations. Different relationships are given:

C.E. Ramser’s formula.

V.I = vertical interval between the bunds in meter,

S = land slope in percent

The above formula does not take into account soil and rainfall characteristics and its applicability cannot be generalized. When the above formula is used for soils with high infiltration rate and good conservation practices such as contour farming, growing of cover crops etc then 25% extra spacing can be used. On the other hand, in a soil of low infiltration capacity and unfavorable conservation measures, the spacing should be reduced by 15%. For high rainfall areas, the interval should be reduced and vice-versa.

Cox’s Formula. M.P.Cox, a water management specialist of USAID gave the following formula

Where X = rainfall factor, Y = infiltration and crop cover factor. The value of X and Y are given in table 7.1 and 7.2 respectively.

Table 7.1 Value of Rainfall factor, X

|  |  |  |
| --- | --- | --- |
| Rainfall condition | Value of X | Annual rainfall in cm |
| Scanty | 0.8 | < 64 |
| Moderate | 0.6 | 64 - 90 |
| Heavy | 0.4 | > 90 |

Table 7.2 Value infiltration and crop cover factor

|  |  |  |
| --- | --- | --- |
| Infiltration rate | Cover crop during critical period | Value of Y |
| Below average < 3 cm/h | Low coverage | 1 |
| Average or above > 3 cm/h | Good coverage | 2 |
| One of the above factor is favorable and the other is unfavorable | | 1.5 |

**Dimension:** the dimension of the bund should be such that they are sufficiently large and robust to withstand intense rainstorms and accommodate runoff or allow its partial evacuation safely. It is recommended that animals should not trample over the structures at least up to the end of the first rainy season, when bunds naturally compact and are stabilized by natural vegetation.

* **The height** would normally depend from the vertical interval. However, under the dryland conditions, a minimum of 60 cm height after compaction is recommended.
* **Top width** of the bund is 30 cm on stable soil and 50 cm on unstable soil. Based width also vary with the soil texture and hence its stability. For unstable soils (sandy loams) the width of the bunds at the base should be 1.2 -1.5 m (embankment gradient 1:1) and for stable soils (clay loams, sandy clay loams) the width at the base should be 1-1.2 m (embankment gradient 1:2).
* **The collection ditch or** excavated area behind the bund embankment varies with scope and type of design variation of bund construction.
* **Length of bund** would depend from many factors, mostly slope, presence or absence of collection ditches, in-built spillways and need for cattle pathways, presence of traverse slopes within plot, etc. as a general rule should not exceed 50-80 meters to allow the passage of drought cattle from one plot to the next one. Length can be higher in case of gentle and uniform slopes and for bunds along farm boundaries and reinforced at sensitive points with stone walls.

**Layout of bunds:** the bunds are laid out along the contour using a line level fixed to a string attached to two poles or, in case irregular slopes, using an A-frame (water level can be also used). The layout should take into account the technical requirements of spacing and dimensions of the structures, but also farmers’ suggestions and cultural practices (particularly ploughing).

**Construction Phase:** after layout is completed with the approval of the farmers, construction should start at the top of the sub-catchment or field.

* Scrape the soil from the place where the embankment is placed and grasses removed for better merging of piled soil. Excavated soil (from ditch-channel, etc.) is piled downwards, 10-15 cm from the border of embankment (berm). Layers of soil should be regularly shaped and properly compacted until reaching the desired height.
* If applied, ties are left at regular intervals within the trench and the compacted embankment is shaped properly based upon the stability of the soil
* The last most important operation is to check that
* The top of the embankment through its entire length is perfectly level
* The bottom of the trench within ties is perfectly level in case of bunds with channels
* The bottom of the channel for bunds without ties is perfectly level

**Stone faced and reinforced soil bunds**

Stone faced soil bunds are soil bund further strengthened on one or both side of their embankment with a stone wall or riser. In some instances, the reinforcement may take place only along the depression points or, as emphasized here, to protect the entire length of the bund. The strengthening of soil bunds with stones throughout their entire length is recommended wherever farmers tend to increase the spacing between structures and stones are available.

**Technical specifications**

**Slope range:** the slope range may increase up to 35-45% slope compared to soil bunds alone. However, on such extreme slope range, the spacing apart bunds should be guided by standard technical recommendations (relationship between slope, vertical interval and soil depth). Besides, above 30% slope the stone riser of the downstream embankment should have a deep foundation (30 cm).

**Type of soils:** in all type of soils, excluding sandy soils. For soil depth and textures same as for soil bund. Stone should be available from the field itself or from adjacent areas.

**Spacing apart**: the spacing may be slightly wider than for soil bunds, particularly up to 15% slope.

#### 7.2.3.2 Level Stone Bunds

Level stone bunds are an embankment made of stone constructed along the contour across sloping lands, without a collection channel or basin at its upper side. Soil which is eroded between two bunds is deposited behind the lower bund. Stone bunds are either impermeable structure if their upstream side is sealed with soil or semi-permeable if not. However, the deposition of eroded soil along the bund will decrease its permeability after few rains. Whenever the bund has trapped enough sediment, the bund should be raised. In this way, a bench terrace will develop in the course of years (3-7 years) based on slopes and type of soils).

The function of stone bunds is identical to soil bunds. They are preferred to soil bunds in areas having abundant stones and are recommended for slopes higher than 15-30% for their superior stability and resistance against runoff.

**Technical specifications**

**Slope range:** slope range between 5-50%, following the relationship between vertical intervals, bund height and slope % shown in the Table 7.3.

**Type of soils:** stone bunds will be constructed in areas with stoniness>15% and <50% and with soil depth of at least 50-100cm. for shallower soils, stone bunds can still be constructed but would not form a bench terrace. In this case they should be considered as semi-permeable structures, which reduce runoff velocity and erosion.

Table 7.3 recommended height, vertical interval, and distance apart for stone bunds

|  |  |  |  |
| --- | --- | --- | --- |
| Ground slope (%) | Height of bunds (m) | Vertical interval (m) | Distance apart (m) |
| 5 | 0.5 | 1 | 20 |
| 10 | 0.5 | 1.5 | 15 |
| 15 | 0.75 | 2.2 | 12 |
| 20 | 0.75 | 2.4 | 10 |
| 25 | 1 | 2.5 | 8 |
| 30 | 1 | 2.6 | 8 |
| 35 | 1 | 2.8 | 6 |
| 40 | 1 | 2.8 | 5 |
| 50 | 1.15 | 2.8 | 4 |

**Dimension:**

* The top width of bunds should, for all heights, should not be at least 30-40 cm
* To counter the pressure from the soil which will accumulate in due course on the upper side, the lower face should at a grade of 1 (horizontal) to 3 (vertical), while the upper face, should not be steeper than 1 to 4
* Grade of soil bank (seal) on upper side: 1:2-5
* This grade may be used where large flat stones are available for construction. Smaller or slightly rounded stones will necessitate the construction of the face at a more gentle grade, 1:2 and 1:3 respectively.
* The foundation, placed at the lower side, has width of 30 cm and depth of 30 cm.

#### 7.2.3.3 Graded bunds

Graded bunds are laid out in areas where the land is susceptible to water erosion, the soil is less permeable, and area has water logging problems. A graded bund is designed to dispose of excess runoff safely from agricultural fields.

Graded bund is laid out with a longitudinal slop gradient leading to the outlet. The gradient can be either uniform or variable. The uniformly-graded bunds are suitable for areas where the bunds need shorter length and the runoff is low. The variable graded bunds area required where bunds need longer lengths, owing to which the cumulative runoff keeps getting higher towards the outlet. In this type of bund, variations in the grade are provided at different sections of the bund to keep the runoff velocity within the desired limits, so as not to cause any soil erosion or landslides.

**Design of graded bunds**

Graded bunds are designed in the same way as the broad-base terraces, except for the cross section of the bund. similar to the broad base terrace s, at steep slopes, a trapezoidal or a parabolic channel is provided, along the bund, and at less steep slopes, only the bund is provided allowing the water to flow along the bund in the strip itself.

The design of graded bund requires the determination of vertical and horizontal spacing, provision of suitable grade to the channel or to the bund, and computation of cross-section of the channel and the bund. The peak runoff rate is generally determined by the rational formula and the velocity of runoff by the Manning’s formula. It is always safe to provide a freeboard on the bund, which is recommended to be 15 to 20% of the design depth.

The following are the recommended limits of dimensions for cross-sections of bunds:

Height: more than 45 cm

Top width: 30 to 90 cm depending on the height of the bund. A greater depth requires more width.

Bund grade: sufficient to dispose of excess runoff safely and quickly

#### 7.2.3.4 Level Fanya Juu Bunds

A level fanaya juu (throw uphill in swaili language) bund is an embankment constructed along the contours, made of soil (or soil strengthen with a stone riser), with a collection channel or basin at its lower side. Runoff velocity is reduced but overflow may overtop the bund and accumulate (with some sediments) inside the downstream channel.

Main advantages are as for the soil bunds. However, another main advantage is that fanaya juu bunds bench more rapidly than level bunds. By raising the bund, a bench terrace will develop in the course of fewer years (3-5 years based on slope type of soils).

With regards to moisture deficit areas, fanaya juus are only suitable for upper limits of semi-arid environment (rainfall 700-900 mm) and deep soils (over 75 cm), and on slopes <15%, above which soil and stones bunds are proffered. A main problem is that fanya juus do not accommodates much runoff, especially during heavy showers that characterize drylands. In this case, fanya juu bund can easily be destroyed in series.

Another disadvantage is that spillways are difficult to insert (small upper side embankment for anchoring- overflow may be too high for next plot and bund-rill erosion and breakages).

**Technical specification**

**Criteria of spacing and layout:** similar to soil bunds. In addition fanya juus should have

* The embankment should be preferable higher common standards, with perfectly accurate layout and protection with stone-faced embankment on downstream side or both.
* To decrease the possibility of breakage, the spacing should be reduced by 10-20% compared to soil bunds.

**Dimension:**

* The height would normally depend from the vertical interval. A minimum of 60 cm height after compaction is recommended. This height should be referred to the upstream difference of elevation between the embankment and the ground.
* Top width of the bund is 30 cm on very stable soil and 60 cm on unstable soil.
* Space between the berm and the channel/ditch is minimum 25 cm.
* Base width also vary with the soil texture and hence stability.
* For unstable soils (sandy loams) the width of the bund at the base should be 1.4-1.7 m (embankment gradient 1:1) and supported by stone riser,
* For stable soils (clay loams, sandy clay loams) the width at the base should be 1.2-1.4 m (embankment gradient 1:2).
* The collection ditch or excavated area below bund embankment vary with the size of the fanya juu embankment:
* Deep and narrow ditches (approx. 60 cm width X 50 cm deep),
* For unstable soils, 70 cm width X 50 cm deep ditch is preferred
* Ties should be placed at 3-6 m interval based upon distance apart and type of terrain, i.e. closer spacing if infiltration rate are slow in order to better control lateral movements of runoff. The height of the ties is 15 cm lower than the total depth of the ditch to facilitate lateral movements of water within the collection ditches.
* Length of fanya juu: in dryland they should not exceed 50-70 m to allow the passage of drought cattle from one plot to the next one.

#### 7.2.3.5 Terraces

Terraces are earthen embankments established across the dominant slope partitioning the field in uniform and parallel segments. These structures are often combined with channels to redirect runoff to a main outlet at reduced velocities. Terraces have been used since the dawn of agriculture in many parts of the world (e.g., China, the Himalayas, Peru, Bolivia) for growing crops in hillsides. Graded terraces are slightly inclined along the dominant slope and accompanied by waterways and outlets to dispose of the runoff water. The tile outlet terraces collect, pond, and convey runoff in underground tile lines. Terracing is similar to contouring and decreases the P value of the USLE by half as compared to strip cropping. The LS factor is reduced considerably by terraces because it is defined by terrace spacing rather than by the field slope.

Terraces provide the greatest benefit to soil and water conservation when used in conjunction with: (1) proper cropping and tillage systems such as no-till, reduced tillage, residue mulching, crop rotation, contour strip cropping, and soil conservation buffers, and (2) other soil conservation structures such as grassed waterways, drainage channels, underground outlets, sediment control basins, drop structures, and gabions.

##### 7.2.3.5.1 Functions of Terraces

Terraces are constructed to achieve numerous functions. The main goal is to conserve soil and water. By decreasing the slope length, terraces not only allow the farming of steep slopes while reducing soil erosion risks. In mountainous areas, farming of hillsides would be nearly impossible without terraces. The loosening of soil during terrace construction increases the topsoil depth and facilitates crop establishment. In dry regions, terraces are used to increase plant available water storage and groundwater recharge.

Terraces are important to:

* slow runoff velocity and reduce formation of peak runoff rates,
* reduce the slope length of the hillsides by splitting the field into narrow bands,
* reduce soil erosion and concentrated runoff,
* promote soil water storage by slowing and retaining runoff and promoting infiltration,
* reduce wind erosion by increasing soil water content and increasing surface roughness,
* facilitate surface irrigation in relatively level soils and increasing crop production, and
* improve water quality by allowing removal of sediment and chemicals from runoff.

##### 7.2.3.5.2 Types of Terraces

There is no unique classification system of terraces. The American Society of Agricultural Engineers (ASAE) (2003) has grouped terraces based on *alignment, cross* *section, grade,* and *outlet*. In general, there are four main types of terraces: *broad-base, narrow-base, bench*, and *steep backs lope terraces*. Most terraces possess four sections: *wide segment* (between ridges), *cut-, front-,* and *back-slope* *segments*. Terraces are termed continuous if they cover large areas of the field and discontinuous if they are small and localized. Some terraces are transitional and can be removed when necessary. Choice of terraces depends on the dominant use (e.g., erosion control, water conservation).

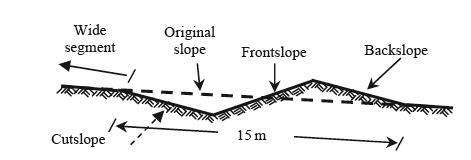
When water conservation is a major concern, broad-base and drainage terraces are preferable to absorb and store rainwater. In soils prone to erosion, however, bench terraces or traditional terraces are appropriate. Terraces are most suited to terrains with slopes *>*5%. On sloping lands, terraces are primarily installed to grow crops without causing excessive soil erosion. In large mechanized farms and relatively gentle slopes, broad-base terraces are the preferred type. Drainage type terraces are used in regions with high precipitation and poorly drained soils whereas absorption type terraces are preferred in regions with limited precipitation and permeable soils.

Among the factors that determine the design and layout of terraces are:

* field topography,
* climate (rainfall, wind),
* soil type,
* tillage and cropping system,
* cost of construction,
* accessibility to heavy equipment,
* population density, and
* land ownership.

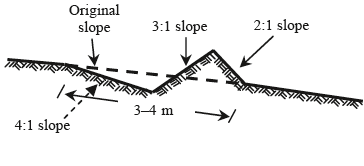
Terraces are designed to modify the original topography. The bed width of the terraces becomes narrower with increase in slope gradient and length. Narrow beds are more susceptible to high surface runoff velocity and soil erosion. Proper design of terraces is critical with increase in slope gradient. Rills start in the upper portions of the terrace and develop into gullies cutting through the lower terraces, especially when terraces remain bare and are improperly designed.

**Broad-base terraces.** These terraces are used in long and uniform fields with slopes *<*5% and thus all the sections of the terraces are farmed (Figure 7.6). They are also known as channel terraces because the channels are all cultivated and are common in regions with flat and abundant land, and where heavy equipment is available. Channels are gently graded to outlets for runoff disposal. These terraces are appropriate for regions where both soil erosion and drainage are required. Sheet and rill erosion between terraces are higher on broad base than on narrow base or grass backslope terraces in sloping fields.



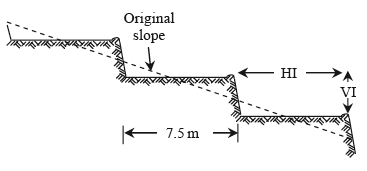
**Figure 7.6** Cross sectional view of lower portion of a broad-base terrace. The broad-base consists of lower and upper section. The lower section confines the channel and ridge (about 15m wide) while the upper section confines the wide segment (about 30m wide) (After ASAE, 2003)

**Narrow-base terraces.** These terraces are used in shallow and sloping lands unlike broad-base terraces and have a steep narrow ridge. The ridges are not farmed but are maintained and managed with permanent vegetation cover (Figure 7.7). These terraces cause lesser soil disturbance than other types of terraces. Narrow terraces are common in regions with limited land and with steep slopes,



**Figure 7.7** Cross sectional view of lower portion of a narrow-base terrace. The ridge is steeper than that in broad-base terrace (After ASAE, 2003)

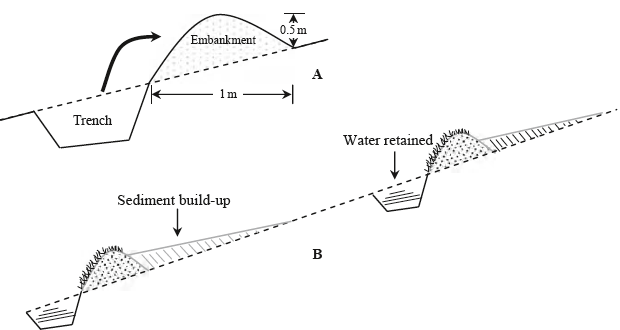
**Bench terraces.** These terraces are widely used throughout the world, particularly in hilly terrains. Bench terraces established on slopes *>*10% have steep back slopes. The width of the bench and the height of steps are variable depending on the field slope (Figure 7.8). A width of 7.5m is used in moderately sloping lands. Bench terraces are a series of strips constructed across the slope at equidistant vertical intervals and separated by steep banks of stones and grassed revetments.



**Figure 7.8** Cross sectional view of a bench terrace. The HI signifies the horizontal interval and VI the vertical interval

There are two types of bench terraces: *conservation* and *upland terraces*. *Conservation terraces* are also referred to as irrigation or level bench terraces and areused for flood irrigation (e.g., rice) and water storage. *Upland terraces* are used forrain-fed and irrigated crops and are gently sloped outwardly for allowing drainage.Bench terraces are more suited to large fields with mechanized agriculture underhigh-value crops.

***Fanya juu terraces*** are used as alternative to bench terraces in some parts of the world particularly in regions with rugged topography (e.g., East Africa). *Fanya juu* terraces consist of embankments and ditches built by digging a trench on the field contour and throwing the excavated soil uphill (Figure 7.9A). The embankment must be seeded to grass for proper stabilization. The trench is about 50 cm wide and 50 cm deep, resulting in about 50 cm high by 100 cm embankment. The distance between these terraces is a function of the field slope and can be 20–30m wide in gently sloping lands and about 5 m in fields with steep slopes. The embankments accumulate sediment above and create natural terraces over time (Figure 7.9B).

****

**Figure 7.9** A *fanya juu* terrace built from earth embankments (**A**) at construction and (**B**) after various years

***Steep back slope terraces.***These terraces are all farmed except the back slope section which is permanently vegetated. The front slope is wide for equipment maneuvering and is not as steep as in the narrow-base terraces. These terraces are used for slopes *<*15%.

***Individual terraces.***These terraces are small and round and are commonly used for planting individual plants. They are appropriate for growing tree crops or other perennials.

#### 7.2.3.6 Cutoff Drain

A cutoff drain is a channel used to collect runoff from the land above and to divert it safely to a waterway, river, cultivated field, gully or reservoir. Besides, by diverting excess runoff, a cutoff drain protects the land below from erosion. In the drylands, cutoff drains may be used mainly for the following purposes:

1. Protect cultivated land from runoff generated from sparse forest land or degraded grassland, steep slopes, etc..
2. Divert additional water to cultivated plots.
3. Divert additional water to SS dams cropped areas inside gullies.
4. Divert additional water into reservoirs for irrigation and/or domestic uses (including water supply for livestock).

**Technical specifications**

**Site selection:** a cut of drain can be constructed in different soils and type of slopes. However, it is preferable to avoid the following:

* Very steep slopes (>50%): it is difficult to dig and size the channel properly. Find below the catchment a break of slope where to construct your cutoff drain.
* Sandy, sodic and heavy expanded clays.
* Avoid areas with numerous hard rock outcrops areas (difficult to layout, construct and maintain the correct gradient).
* Avoid large catchments (>50 ha) or make several cutoff drains instead (relay cutoff drains).

#### 7.2.3.7 Grassed Waterways

Grassed waterways are the natural or manmade water courses covered with erosion resistant grasses for safe disposal of runoff from field, terraced areas, diversion channels, spillways or other structures. The grassed waterways should be fully established with grasses before water is turned on them.

Functions

1. Outlets for diversions and terraces
2. Outlets for farm ponds
3. Outlet for emergency spillways
4. Disposal of water collected by road ditches or discharge through culverts, and
5. Carry runoff from natural drains and prevent formation of gullies.

**Design of grassed waterways**

The waterway is design for an expected runoff from a rainfall of 10 year recurrence interval. The design includes the shape, grade, design velocity and cross section of the channel.

**Shape:** the shape depends upon the field condition and type of construction equipment. Generally parabolic triangular and trapezoidal shapes are used. Natural waterways have shapes very close to parabolic. Trapezoidal channels after a long use gradually approximate the shape of parabola. When a V-ditcher is used for construction, triangular shaped waterways are constructed. V-ditcher in combination with a buck scraper can construct a trapezoidal waterway.

**Channel grade and velocity:** the topography of the land largely influences the channel grade. The channel grade influences the flow velocity. If the land slope is very high, channel should not run down the general slope to produce erosive velocity. The maximum slope should not exceed 1% and preferably it should be within 0.5%. The slope should be checked for maximum non-erosive velocity under various conditions by using Manning’s formula. The following values of non erosive velocity should be used (Table 7.5)

Where waterways are not lined by vegetation, the following values of critical velocity can also be used (Table 6.6). The critical flow velocity is defined as that velocity of flow, at which neither silting nor scouring takes place.

Table 7.5: Non-erosive velocities in grassed waterways

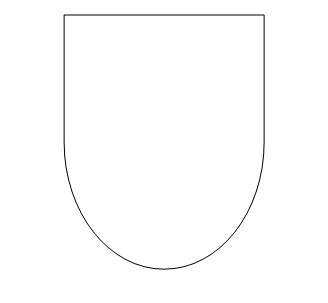
|  |  |  |
| --- | --- | --- |
| No. | Cover condition | Permissible velocity in m/s |
| 1 | Sparse cover | 0.9 |
| 2 | Vegetation to be established by sodding | 0.9-1.2 |
| 3 | Dense, vigorous and established quickly | 1.2-1.5 |
| 4 | Well established sod of excellent quality | 1.5-1.8 |
| 5 | Well established quality and conditions under which flow cannot take place at lower velocity | 1.8-2.5 |

Table 7.6: critical velocity of flow for unlined waterways

|  |  |  |
| --- | --- | --- |
| No | Nature of soil | Critical velocity in m/s |
| 1 | earth | 0.3 to 0.6 |
| 2 | Ordinary laterite (Morrum) | 0.6 to 0.9 |
| 3 | Hard laterite | 1.2 to 1.5 |
| 4 | boulders | 1.5 to 1.8 |
| 5 | Soft rock | 1.8 to 2.4 |
| 6 | Hard rock | >3.0 |

Cross-section of waterway: the shape can be parabolic, triangular or trapezoidal. For different shapes (Figure 7.10), the cross-section A, wetted perimeter P and top width T can be obtained by using the following formula.

Figure 7.10: Types of Waterways



**Design steps:** The following can be one of the procedures.

**Step-1:** Determine the peak runoff rate generated from the area and to the waterway. The area to be drained can be obtained from the contour map. The peak runoff rate is estimated using rational runoff formula.

**Step-2:** Fix the permissible velocity of flow (V) for the type of vegetated grass waterway.

**Step-3:** Compute the cross-section of the waterway, . It should be kept in mind that the catchment area and the peak runoff increase toward the outlet. Therefore, the cross-sectional area should increase downwards.

**Step-4:** Determine the different dimensions of the channel to get the cross-sectional area computed above.

**Step-5:** calculate the hydraulic radius R from the known values of A and P. .

**Step-6:** Compute the slope S of the waterway using Manning’s formula.

**Step-7:** If the available condition permits the slope, it is alright. Otherwise modify the slope as less as possible. Recalculate the velocity and discharge with the changed slope. If they are satisfied, design is final. Otherwise with new dimensions of the cross-section the waterway has to be redesigned.

**Problem 7.2:** Design a trapezoidal shaped grass waterway to carry a peak discharge of 4 m3/s along slope of 0.5%, side slope 2:1 and Manning’s n=0.048.

Solution: We assume a bottom width b= 2m, A = bd + zd2 = 2d +2d2, where, d=depth of channel.

From Manning’s formula,

By trial and error, d=1m (approx). Then

Velocity of flow, =1.07 m/s

For well established vegetation, this is non-erosive velocity.

This section meets the discharge requirement. A freeboard of 15 cm should be provided. Finally the dimension are: b = 2m , height = 1.15 m, and side slope 2:1.

## 7.3 Principles of Gully Control

Gully control is always difficult and expensive. The cost of reclamation usually exceeds the value of the land. Rather, it is very much a case of prevention being better than cure. Limited resources in manpower, money and materials can usually be better employed in preventing future gullies than in curing existing ones. Therefore, it is best, economical and easier to prevent the formation than to control it once it has been formed.

For adequate control of gully, the following principles should be adopted:

1. diagnose the cause and source of gully erosion
2. treat the gully according to the cause

When designing strategies to control gully erosion, it is not possible to treat the gullies in the same way. Treatment depends on the size of the gully and the catchment area. Generally large gullies are expensive to control than small gullies. One form of economical sound treatment is partial control method. i.e where the objective is not to reclaim or restore the gully at once, but to prevent it before getting worse.

### Types of Gully Control Measures

#### 7.3.1.1 Control by Vegetation:

It is learnt from experiencethat “in gully control a bag of seed is more important than a bag of cement”. The purpose of growing vegetation is twofold. First, it provides a soil cover and second protects the gully against scouring. It also reduces the flow velocity by increasing the hydraulic resistance of the channel section; thereby reduce the scouring and transporting ability of runoff. Thus the vegetation makes a favorable situation to control the gully. While doing so, it is important at the same time to exclude livestock from trampling or interring the gully and avoid overgrazing, at least until the vegetation are fully stabilized.

#### 7.3.1.2 Control by Structural Measures:

These measures are taken depending upon the size and age of gullies. For example, medium and large gullies cannot be controlled by vegetation measure alone. They need structural measures for a quick reclamation. These include:

1. **Filling and shaping:** it is the filling of gullies by soil and giving a certain gradient. It is only applicable in small gullies at their early stages as the measure is not economically feasible on large gullies. During filling the soil has to be compacted so that it is not susceptible to the impact of the rain and filling should be taken before the rainy season to avoid sever soil erosion before the work is completed.
2. **Diversion and retention of excess water:** it is temporary diversion of excess runoff above the head of the gully. Diversion ditches are constructed above the gully head, across the slope to interrupt the runoff coming from up slope area. The capacity of the ditch should be large enough to carry all the water yielded from contributing catchment area. This diversion ditch should be formed at a distance equals to 3 to 6 times the depth of the gully from the head of the gully.
3. **Watershed rehabilitation:** it includes application of improved crop management practice s on the arable land, and soil and water conservation measures such as construction of terrace, alley cropping, etc so that improve the infiltration rate and reduce the runoff velocity in the catchment. And, avoid formation of gullies, too.
4. **Application of small structures for gully control:** the purpose of these structures is for reducing and stabilizing the channel gradient and to get sufficient time for vegetation growth.

The kinds of structures are:

1. Temporary structures

-check dams

1. Permanent structures

-silt trap dams

-regulating dams

-drop structures, etc

**I. Temporary Structures**

They are used to provide protection for just long enough to give vegetation to start in the gully. The objective is to slow down the water and cause deposition of silt. Therefore, there is no need for the structures to be water tight. These include check dams which are small structures constructed across the bed of a gully to collect enough soil and water to ensure the growth of vegetation, and to check channel erosion until sufficient stabilizing vegetation are established. Check dams can be various types based on material upon which they made and their function.

1. **Rock fill dams (wire bolsters) (loss rock fill):** they are porous structures constructed across the bed of the gully from loose rocks. The head of flow will be reduced by releasing of part of the water through the pores thereby reduce the discharge of flow because discharge of water flow is a function of head of. It is a simple but effective methods when there is plenty of loose rock available in the nearby. To build the dam, loose rocks are anchored in a place by galvanized wire netting of a fairly stout gully 2 m or more in width which is laid out across the gully bed. Loose rock is packed on one-half of the width of the netting and the other half is warped over the stone and lace to the other edge.
2. **Netting dams:** another use of wire netting is to form small check dams, usually near the top end of gullies. Wooden posts are driven into the bed of the gully, and used to support a strip of wire netting which forms a low wall across the bed of the gully. The height should be only 0.5 m and the lower edge of the netting is buried. Light brush or straw is piled loosely against the upstream side of the netting wall form a barrier which is porous but slows down the flow and causes a build-up of sediment on the upstream side.
3. **Brush wood dam:** they are constructed from small wood branches of up to 2 to 3 cm in diameter. They are packed as rightly as possible across the direction of flow. They can be anchored by vertical wooden posts and horizontal stacks. They are not, however, long lasting and cause a number of trees to be cut for the purpose.
4. **Log dam:** it can be used in an area where available of timber is not a problem. In construction, one method is to use logs in the same way as the brush wood dam but to make a much more substantial structure. Two rows of vertical posts are driven into the bed of the gully and extending up sides to above flood level, and then logs are packed in between. The vertical posts should be at least 100mm dia., 2 m long and spaced about 1m apart in each row, with the two rows of posts 0.5m apart. The second method is to make a simple structure consisting only of a single row of vertical posts driven in side by side to form a wall of logs.

### Construction Design of Check Dams

The purpose of construction design is to construct or design the most economical one with the least input used. As rock fill dams are economical and easy type of check dams to construct, more will be discussed to such type. Some design criteria are:

* The sides of the dame should not be very steep. It is usually 1:1.5 i.e. 1.5 unit horizontal to 1 unit vertical
* The bottom width of the super structure (super structure is the structure above the ground) should be wide and 0.6 times the height of the structure. The middle and top of the structure is 0.4 and 0.4 of the height respectively.
* The dam should properly be keyed across the base of the gully for anchorage of the structure to the surface. The key trench has a depth 0.5 to 1 m and width of 1 to 1.5 m. the structure is anchored not only on the bottom but also on the side.
* The voids should be filled with small stone, and the upstream and downstream of the side of the dam should be covered by larger stones because it is needed to overcome the fluctuation of water level.
* An adequate spillway and apron should be provided.
* The spacing between successive check dams and the height of the dams should be properly planned.
* The gully banks on the downstream should be protected from splashing.
* Construction materials should be good quality.

**Spillway design**

Spill way is sloped or vertical end structure which is constructed at the middle of the dam for conveying maximum flow safely. Spillway should be designed to pass maximum expected flow once in 25 years. In the absence of any data, water marks on the side will indicate or estimate the peak flow. A free board of 25 cm should always be provided in the design. The length of the spillway should be smaller than the width of the gully.

**Apron design**

Apron is a structure constructed at the bottom of the check dam having a width equal to half the height of the water fall (spillway). Apron is used to dissipate energy of the water comes from spillway and is constructed from large stones or concert. A sill about 50 cm is provided to encourage the hydraulic jump to take place in the apron.

**Spacing of check dam**

Check dams are spaced by starting from the mouth of the gully upstream to the gully head. In general, the number of check dams increase with the gradient of a gully. The spacing also depends on the objective of the dam. If the main purpose of the dam is maximum sediment trap, few higher and widely spaced check dams are required. On the other hand, if the objective is to stabilize the gully gradient, closely spaced and lower dams are required.

The common rule in practice in deciding the spacing of check dams is that the next dame upstream is setup at the toe of the sediment deposit of the dam downstream. The future material carried by flowing water fills the check dam spillway level is called the compensation gradient and this gradient of gullies is not more than 3 percent.

Spacing of check dams can be obtained by different approaches

1. Using formula

|  |  |  |
| --- | --- | --- |
| Where | S = | a spacing between two check dams (m) |
|  | H = | effective height of check dam-it is the height from the base of the dam up to the spillway crest (m) |
|  | G = | the average percent slope of the gully channel (gully gradient) |

1. another approach is by finding the number of check dams

|  |  |  |
| --- | --- | --- |
| where | a = | The total vertical distance, calculated from the average gully gradient and horizontal distance between the first and the last check dam in the portion of the gully bed |
|  | b = | Compensation gradient multiplied by total horizontal distance from the first to the last check dam |
|  | H = | effective height of check dam-it is the height from the base of the dam up to the spillway crest (m) |

**II. Permanent gully control structures**

In many situations, vegetative control or temporary structures are unable to control the advancement of gully or stabilize it. This may be due to large drainage area, badly eroded gully not suitable for establishment of vegetation, high intensity of rainfall and very steeply sloped catchment. Material for temporary structure may not be locally available at cheap cost. High degree of safety and permanence may be required as the advancement of gully may endanger human habitation.

Permanent structures halt the advancement of gully heads, stabilize its grade and help growing of vegetation to change it to a vegetated waterway. They are made of masonry, concert, and earth and are in general costly. Proper investigation and engineering investigation are required for construction of the structures. The structures are required to meet the following functions:

1. they should handle the peak runoff at safe velocity
2. they should be able to stabilize the gully
3. they should store water for irrigation and other purposes
4. the sediment flow should be controlled

**Some of the permanent structures are listed below**

* Gabions:
* Chute Spillways:
* Drop Structure:
* Pipe Spillways: