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Lecture Note on Principles of soil Erosion & Modeling (MSRWM2092)

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1.1. Introduction

Soil Erosion: the word 'erosion' was derived from Latin word 'erodere', which is to mean 'to eat away' or 'to excavate'. The word was first used in geology for describing the eomorphologic processes that take place on the surface of the earth and rock systems like the terms 'hollow' created by water in rock systems. However, soil erosion is essentially a smoothening process, with soil and rock particles being carried, rolled or washed by the gravity, water, wind or other agents.

Definition: "***It is defined as detachment, transportation and deposition of soil particles from one place to another place under the influence of wind, water or gravity forces***".

Erosion is a physical process, characterized by significant variations in its intensity and frequency all over the world. Erosion varies upon many elements, among which the most significant are climate parameters precipitation and temperature, as well as other parameters such as geology, topography, vegetation cover and anthropogenic influences.

Soil erosion is a process of mechanical detachment of the soil under the influence of erosive agents such as water and wind that consists of a detachment of soil particles, transportation of detached soil and its deposition. The dominant geomorphic process for much of Earth`s land surface is soil erosion by water agent. The main influence on erosion processes are considered to have climate, soil, topography, vegetation cover and anthropogenic factors.

Soil erosion which is a global threat responsible for soil nutrient depletion, degradation of soil quality, destruction of soil structure and disruption of ecosystem; have reduced the availability of productive lands for cultivation which in turn has greatly reduced chances of food sufficiency and security.

Soil erosion is a three phase phenomena, consisting the detachment of individual soil particles from the soil mass and their transport by erosive agents such as running water and wind. When sufficient energy is no longer available with the erosive agents to transport the particles, then the third phase called as deposition takes place. The soil erosion may be defined as =detachment' transportation and deposition of soil particles from one place to another under influence of wind, water or gravity forces. Most of the time erosion takes place when the rains drops in the upstream moves to downstream through water, gravity and glacier and also wind in dry area.

Erosion is a natural process by which soil and rock material is loosened and removed. Erosion by the action of water, wind, and ice has produced some of the most spectacular landscapes we know. Natural erosion occurs primarily on a geologic time scale, but when man's activities alter the landscape, the erosion process can be greatly accelerated. Construction-site erosion causes serious and costly problems, both on-site and off-site.

Erosion is the wearing away of material by naturally occurring agents through the detachment and transport of soil materials from one location to another, usually at a lower elevation. Natural agents are mostly responsible for this phenomenon but the extent to which erosion occurs can be considerably accelerated through human activities.

The term **erosion** was first used in geology to describe the forming of hollows by water and the wearing away of solid material by the action of river water.

There are many **classifications of soil erosion**: by the intensity (Natural or Geologic and Accelerated), by the erosive agent (water and wind), by stage (Raindrop, Sheet, Rill Gully, Stream bank and Tunnel).

Water erosion is considered the most severe type of soil erosion where soil detachment and transportation is caused by two different phenomena, the first being the raindrop impact on soil and the second water runoff. **Water erosion** is "a function of forces applied to the soil by raindrop impact and surface runoff relative to the resistance of the soil to detachment".

A detachment of sediment from the soil surface was originally considered to be exclusively the result of raindrop impact, although the importance of overland flow as an erosive agent has later been recognized. Today, rainwater in the form of runoff is considered the main trigger of water erosion causing the transport of soil particles and its deposition on lower parts of the catchment.

"**Sediment delivery** is the amount of eroded material delivered to a particular location, such as from the eroding portions of a hill-slope (soil loss) or the outlet of a catchment (sediment yield)".

Soil loss refers to the sediment from the eroding portion of a hill-slope where overland flow occurs.

1.2. History of Soil Erosion

The history of soil erosion is an integral part of agriculture. All over the world, whenever human being started the agricultural operation in wider range; use of marginal lands, arid and semi-arid, steep lands etc.., there existed the problem of soil erosion. There are also threats of deforestation throughout the centuries for the hunting of agricultural land. Increased population also called for increased cattle herding which puts more area of land to grazing or small areas in overgrazing which calls for accelerated erosion.

Today erosion is almost universally recognized as **a serious threat to man's well-being**, if not to his very existence, and this is shown by the fact that most governments give active support to programs of soil conservation. The science of soil erosion was unknown before **80 years**.

From the record of past achievements, history tells us that civilization and fertility of soil are closely inter-linked.

The flourished civilizations of the Mesopotamians, Babylonins, Asorians, etc. declined as the fertility of their soils had declined. The declination of soil fertility had occurred due to uncontrolled accelerated erosion caused by human interference. Although this is clearly evident throughout 7000 years of history, an awareness of the problem developed very slowly. There are many articles which mention the threat of soil erosion in the centuries past. But more **attention** was given **very recently**.

1.3. Erosion in Ethiopia

1. In terms of soil loss due to erosion, estimates vary by location, which reflects the varying Ethiopian landscape and soil characteristics.
2. Hurni *et al.* (2010) measured soil erosion rates on test plots and estimated a loss of **130 to 170 tons per hectare per year** on cultivated land.
3. The average annual soil loss in Medego watershed in the north of Ethiopia was estimated at **9.6 metric tons ha/year** (Tripathi and Raghuwanshi, 2003).
4. The average annual soil loss due to erosion in the Chemoga watershed in the Blue Nile Basin was estimated at **93 metric tons ha/year** (Bewket and Teferi, 2009).
5. Shiferaw (2011) estimated soil loss in Borenaworeda in south Wollo using the Revised Universal Soil Loss Equation (RUSLE, which allows for spatial modeling of soil loss) and

found that annual soil loss ranged from **no loss in the flat plain areas to over 154 metric tons ha/year in some steeper areas**.

"A nation that destroys its soil destroys itself"

The major causes of erosion in Ethiopia are

1. Land history of exploitation and pressure on land: population puts pressure on the marginal land and causes land degradations.
2. The rapid population increases, deforestation: - forest clearing for agricultural use, fuel wood, fodder, and construction materials. Forest areas have been reduced from 40 percent a century ago to an estimated less than 3 percent today. The current rate of deforestation is estimated at 160,000 to 200,000 hectares (ha) per year, and fertile topsoil is lost at an estimated rate of one billion cubic meters per year.
3. Low vegetation cover and unbalanced crop and livestock production/ Increasing the number of livestock(overgrazing)
4. Policy and land tenure system:
   a. Inappropriate land use system and land tenure policies enhanced desertification and loss of Argo biodiversity.
   b. Ownership and user right: the absence of well-defined land legislation and ownership discourage farmers to invest on land conservation activity
   c. Land fragmentation and labor availability
5. The resettlement and investment program
6. Poor management: if the existing practice on different agricultural activities is not in proper way the land may be degraded. Utilization of dung and crop residues for fuel and other uses disturbs the sustainability of land resources.

In general, soil erosion in Ethiopia can be seen as a direct result of past agricultural practices on the highlands. The dissected terrain, the extensive areas with slopes above 16 percent, and the high intensity of rainfall lead to accelerated soil erosion once deforestation occurs. Also some of the farming practices within the highlands encourage erosion. These include cultivation of cereal crops such as teff and wheat which require the preparation of a fine tilth seedbed, the single cropping of field, and the down slope final plowing to facilitate drainage.

Areas severely affected by erosion

The most severely affected areas in Ethiopia are **north of the country**, and the **eastern highland**, with **wollo** and **tigray highland** and **Gondar**.

The magnitudes of erosion as varying between 16- 300 tons/ha/year and soil degradation caused by erosion and leading to decline in productivity and famine.

To reduce these problems, rural afforestation and conservation programs on farms and community lands have been practiced in Ethiopia.

In general, soil erosion in Ethiopia can be seen as a direct result of past agricultural practices on the highlands. The dissected terrain, the extensive areas with slopes above 16 percent, and the high intensity of rainfall lead to accelerated soil erosion once deforestation occurs. Also some of the farming practices within the highlands encourage erosion. These include cultivation of cereal crops such as teff and wheat which require the preparation of a fine tilth seedbed, the single cropping of field, and the down slope final plowing to facilitate drainage.

1.4. Major agents of erosion

Agents for Soil Erosion are Water, Wind, Ice (glaciers), Waves, and Gravity (mass wasting)

1. Water

Water results erosion because it has the power to detach the soil particles and carry them to somewhere else.

Water erosion refers to the detaching and transporting of the top soil by runoff. Runoff is basically caused due to rainfall. Therefore, water erosion is linked to the rainfall event in an area.

The factor that most influences soil erosion by water is the mean annual rainfall. In regions of very low rainfall, there can be very little erosion caused by rain due less runoff since canopy abstraction of the rainfall. At the other extreme, an annual rainfall of more than 1000mm usually dense forest vegetation that affords protective covers to the soil, which is a key factor in reducing water erosion. The most severe erosion will thus tend to be associated with the middle range of rainfall when the natural vegetation is undisturbed and with higher rainfall when the natural forest is removed.

2. Wind

- wind is another agent of soil erosion
- It has a great effect on bare soil where the vegetation is very sparse.
- When the wind blows, wind force act on the soil particles to detach and to move its direction.

Agents Active in Water Erosion

Two major agents active in water erosion are falling raindrop and running water. Both of these get the energy needed to detach and transport soil grains from the force of gravity. The agents of water erosion are: Raindrop and Running water.

Raindrops

It is now established that collision of rain drops on bare soil and resulting splash is the major cause of soil erosion by water. About 95% of soil is splashed by falling rain drops and runoff water erodes less than 5% of the soil.

1.5. Processes of Soil Erosion

Important Points:

1. When eroding agents have sufficient capacity to transport more quantity of materials than the materials supplied through detachment then erosion is termed as "detachment limited ". When materials supplied are greater than materials transported then erosion is termed as transport limited.
2. Two energy forms are involved in erosion process.
   a) Potential energy represented by PE = m.g.h,

   Where

PE =potential energy in joules, g= acceleration due to gravity,

m= Mass of body in kg, h = elevation Difference.

   b) Kinetic energy is the energy possessed by a substance by virtue of its motion and proportional to the product of the moving mass and half of the square of the velocity of the mass. Kinetic energy represented by KE = ½ mv^2, Where

KE = Kinetic energy,

m = mass of body in kg,

V = Velocity of running water or falling raindrops

A large amount of energy is lost against frictional resistance of soils surface. Only 3 to 4 % energy is remained with running water to detached soil particles.

In the course of soil erosion there are three major processes that occur.

A. Detachment of soil particles

This is the first phenomenon that should happen for soil erosion to occur. It refers to detachment of soil particles from the soil aggregate that was originally developed. Detachment of soil particles mainly occur because of the action of rain drops, runoff, wind, animal trampling and different activities of human beings.

The detachment of soil particles is generally caused due to the impact of raindrops wherein the particles are detached and splashed away. Large quantities of soil are eroded by simple process of splashing and it is considered to be the first step in erosion process. The soil loss due to splash is considered to be 50 to 90 times greater than the wash-off losses.

Rain splash is the most important detaching agent, the soil is also broken up by weathering processes, and tillage operations and by the trampling of people and livestock. All these processes loosen the soil, so that it is easily removed by the agents of transport.

The smaller the soil particle size, the larger the Kinetic energy required detaching; and vice versa.

B. Transportation of Particles

This is the second important phenomenon for the soil erosion occurrence. Once the soil particles are detach, running water or wind can easily remove them from their original place and carry them to somewhere else. The major transporting agents are runoff and wind. It is the process, under which soil particles dissolved in the running water are carried away from one place to another.

Transportation affected by:

i. **Velocity at which water is running**. It offers a force on the soil particles in the flow direction. At greater velocity comparatively large amount of soil particles are transported. In addition, large size soil particles are also easily transported at greater velocity.

ii. **Load present in the water**. Here load indicates the amount of soil/rock existing in the flowing water. Flowing water containing fewer loads, easily transports the soil mixed while in opposite case a reverse effect is observed.

iii. **Impediments/obstacles present in flow path** of water. Actually, these constraints **create an obstruction** in the path of water flow, as a result the velocity of water gets reduced, and thereby the **deposition of soil** particles over the channel bottom is caused. In other way, it can be said that, presence of obstacles, reduce the transportation of soil particles and vice-versa.

iv. **Carrying capacity of running water** also affects the soil transportation rate. A stream which has large **flow volume**, involves greater soil transportation and vice-versa.

Transportation Process

In water erosion, the process of soil transportation by running water is completed under the following forms:

2. **Solution :** The water soluble contents present in the water are transported by the water in solution form.
3. **Suspension**: Suspension process involves the transportation of finer soil particles, which present in suspension form in the flowing water
4. **Saltation and surface creep:** The saltation mechanism is responsible to transport the medium size soil particles, which are not able to stand in suspension form, but are mixed in water and flow over the stream bed in the form of mud. The saltation and surface creep share a major part of the sediment load, transported by the running water. The transportation of soil particles by the surface creep action is referred to the courser soil particles, which is activated through the actions of jumping, collusion and creeping.

C. Deposition/Sedimentation

The deposition of load mixed in the running water, is furnished under the following conditions:

I. When force, by which the load is transported from one place to another, is reduced to a greater limit, then the load present in the water tends to settle over the flow path. The reason is when the force which is acting in the direction of water flow for causing to transport the load, becomes very less than the resisting force acting in opposite direction, then presence of soil load in the water is more resisted and thus forcing to settle or deposit the materials over the flow path.

II. Presence of surface obstructions in the flow path of running water tends to cause the deposition of load present in the water. These obstructions may be stems of trees, shrubs etc. Actually these obstructions breakdown the velocity of running water, as a result the weight of soil load mixed in the flow becomes more effective to get deposit over the path.

III. The curves of meander or winding courses of stream also cause to deposit the soil load running along the flowing water, because at these points the flow velocity is reduced significantly, thereby deposition of soil load there

Soil particles that is carried by the water or wind be deposited, when the transporting agent is no more effective to carry them further distance. Mostly deposition in flat land, depressions and reservoir's.

Deposition affected by:

• When the force in the direction of water flow for causing to transport the load becomes very less than the resisting force acting in opposite direction, then presence of soil load in the water is more **resisted and thus forcing to settle or deposit** the materials over the flow path.

The severity of erosion depends upon the quantity of material supplied by detachment over time and the capacity of the eroding agents to transport it. Where the agents have the capacity to transport more material than it is supplied by detachment, the erosion is described as **detachment-limited**. Where more material is supplied than can be transported, the erosion is **transport limited.** The critical water velocity for detachment, transport and deposition of the soil particles is the function of particles size. The value of critical velocity increases with increase in the grain diameter.

A greater force is also required to move larger soil particles. The fine particles are harder to get erode by water flow, because of the cohesiveness of the clay minerals which comprise them. Once an individual soil particle comes in motion, it is continued until the velocity reduces below the threshold value.

Table 1 Role of the three main processes of water erosion

Detachment	Transport	Deposition
• Soil detachment occurs after the soil adsorbs raindrops and pores are filled with water. • Raindrops loosen up and break down aggregates. • Weak aggregates are broken apart first. • Detached fine particles move easily with surface runoff. • When dry, detached soil particles form crusts of low permeability. • Detachment rate decreases with increase in surface vegetative cover.	• Detached soil particles are transported in runoff. • Smaller particles (e.g., clay) are more readily removed than larger (e.g., sand) particles. • The systematic removal of fine particles leaves coarser particles behind. • The selective removal modifies the textural and structural properties of the original soil. • Eroded soils often have coarse-textured surface with exposed subsoil horizons. • Amount of soil transported depends on the soil roughness. • Presence of surface residues and growing vegetation slows runoff.	• Transported particles deposit in low landscape positions. • Most of the eroded soil material is deposited at the downslope end of the fields. • Placing the deposited material back to its origin can be costly. • Runoff sediment transported off-site can reach downstream water bodies and cause pollution. • Runoff sediment is deposited in deltas along streams. • Texture of eroded material is different from the original material because of the selective transport process.

1.6. Types of Soil erosion

In broad sense the erosion process can be classified in to two types:- geologic and accelerated erosion. They represent contrasting type of soil removed.

A. Geological erosion:

Erosion can occur naturally, transforming soil into sediment. This naturally occurring erosion devoid of man‘s influence is called **geological or natural or norm**al erosion. It represents erosion under the cover of vegetation. It takes place as a result of the action of water, wind, gravity and glaciers. It is a very slow process and responsible for soil formation as well as soil loss (means that loss of soil is compensated for by the formation of new soil under natural weathering process). Under this erosion type, the process of soil erosion is balanced by the process of soil formation, creating a state of equilibrium.

Geologic erosion refers to the formation and loss of soil simultaneously which maintain the balance between formation and various losses.

In its broadest sense it is a normal process, which represents the erosion of soil in its natural condition without the influence of human being. The geologic erosion is long time eroding process. The various topographical features such as existing of stream channels; valleys etc. are the results of geologic erosion.

B. Accelerated erosion:

When the process of soil erosion is influenced by human activities, it is **accelerated**. Such accelerated erosion is caused by removal of vegetation, and improper land use and management. When the vegetation is removed and land is put under cultivation, the natural equilibrium between soil building and soil removal is disturbed. The removal of surface soil takes place at much faster rate than it can be built up by the soil forming processes. This is known as accelerated soil erosion or abnormal erosion. It is destructive in nature and caused much land degradation. Only accelerated erosion is matter of concern for the agricultural land. The erosion can be classified as water, wind, and coastal erosion.

Accelerated erosion includes serious deterioration and loss of soil by the nature and human beings. Accelerated erosion is an excess of geologic erosion. It is activated by natural and man's activities which have brought about changes in natural cover and soil conditions. In usual course, the accelerated erosion takes place by the action of water, wind, gravity and glaciers. In which water causes the soil erosion through sheet flow, stream flow, wave action and ground-water flow .Similarly wind detaches and transports the soil particle and causing a general mixing of the soil at the surface. The gravity force causes the mass movement such as soil creep, rock creep, rock slide and subsidence of the soil surface. These are examples of accelerated erosion. In general accelerated erosion is simply known as soil erosion or erosion only.

1.7. Mechanics of Water Erosion

There are six types of soil erosion: **splash, sheet, rill, and gully**, and **stream and tunnel**. Splash erosion results when the force of raindrops falling on bare or sparsely vegetated soil detaches soil particles. Sheet erosion occurs when these soil particles are runoff is allowed to concentrate and gain velocity, it cuts rills and gullies as it with slope length and gradient, gullies become deep channels and gorges. The volume and velocity of runoff and the greater the resultant damage

1. Raindrop Erosion

Raindrop erosion is also known as **splash erosion**. Raindrop erosion is soil detachment and transport resulting from the impact of water drops directly on soil particles or on thin water surfaces. The impact of raindrops breaks the soil crust and splashes the soil particles away. The mass of each raindrop is directly proportional to its kinetic energy.

Rain drop erosion is:-

- It Is the first stage in the erosion process
- Results from the bombardment of the soil surface by raindrops
- Is the primary cause of soil detachment and soil disintegration
- Means that resettled sediment blocks soil pores resulting in surface crusting and lower infiltration.
- Raindrop erosion is soil detachment and transport resulting from the impact of rain drops directly on the soil particles or on thin water surface
- The effect is to give the surface a dimpled like appearance.
- Studies in America have shown that splashed particles may rise as high as 0.6 meters above the ground and move up to 1.5 meters horizontally.

2. Sheet (Inter-rill) erosion

Sheet erosion may be defined as: It is the removal of the fairly uniform layer of soil from the land surface by the action of rainfall and runoff.

Sheet erosion is the movement of soil particles by runoff flowing over the ground surface as un-concentrated thin sheet layer. The eroding and transporting power of sheet flow are dependent upon the depth and velocity of sheet flow for a given size, shape and density of soil particle.

It is caused by the unconfined flow of water running across the surface. Rarely possible to see or distinguish but accounts for large volumes of soil loss. Sheet erosion is often only recognized when eroded soil is deposited along a fence line, on lower fields, and when sub soil materials emerge on the upper soil surface.

Typically it results in the loss of the finest soil particles which contain the bulk of the available nutrients and organic matter.

Sheet erosion of soil is a conceptual or an idealized form of soil erosion, where the fertile top soil is removed in uniform layers under the action of runoff water or the overland flow. Such type of removal of the top soil in the form of a layer or a sheet is very difficult to visualize. Sheet erosion is affected by flow velocity, flow volume, and physical and chemical properties of soil, etc. In reality, the sheet flow is carried out by very small definable channels called the inter-rills. Raindrop detaches very thin layers of soil particles through splash and the detached particles are then carried through the inter-rills by a very thin layer of the overland flow. The soil erosion by inter-rills is dependent on the erosion that takes place through rills.

The eroding and transporting power of sheet flow are dependent upon the depth and velocity of sheet flow for a given size, shape and density of soil particle. Sheet erosion is:-

- ✓ Caused by the unconfined flow of water running across the surface
- ✓ Thin layers of soil are being removed by water acting over the whole soil surface;
- ✓ Is responsible for extensive soil loss in both cultivated and non-cultivated environments.
- ✓ Rarely seen/hard to distinguish but accounts for large volumes of soil loss.
- ✓ Difficult to observe in the field, sheet erosion is often only recognized when eroded soil is deposited along a fence line, on lower fields, and when sub-soil materials emerge on the upper soil surface.
- ✓ Typically results in the loss of the finest soil particles which contain the bulk of the available nutrients and organic matter.

3. Rill Erosion

It is sometime known as micro channel erosion. It is the removal of soil by running water with the formation of areas of small branching channels. There is no sharp time of demarcation where sheets erosion ends and more readily visible than sheet erosion. Rill of small depth can be ordinary form tillage.

It is regarded as a transition/Intermediate stage between sheet erosion and gully. Rills are small channels small enough to be obliterated by normal tillage operations. Occurs on recently cultivated soils where runoff water concentrates in streamlets as it passes downhill.

Rills frequently occur in relatively straight lines between crop rows or along tillage marks. Concentrated flow is able to detach and transport soil particles. Channels form up to 30cm deep

Prolonged occurrence of soil erosion through inter-rills, results widening of the inter-rills and formation small channels, called rills.

These rills carry both the overland flow from the inter-rill areas and the direct flow. In a channeled flow, the depth of flow is more, thus soil erosion is very high from the well-defined channels. Rills carry the sediment brought by the overland flow through its inter-rills, and have a controlling effect on the magnitude of soil erosion.

- Has greater scouring action than sheet flow and it removes soil from the edges and beds of the streamlets

4. Gully Erosion

It is removal of soil by excessive concentration of running water, resulting in the formation of channels ranging in size from 30cm to 10m.Gully is a steep – sided eroding watercourse which is an advanced stage of rill erosion.

Normal tillage operations cannot obliterate/destroy it as in the case of rill erosion. These channels carry water during and immediately after rains.

Gully erosion is responsible for removing vast amounts of soil, irreversibly destroying farmland, roads and bridges and reducing water quality by increasing the sediment load in streams. Water running into the gully either scours the face or undercuts the headwall resulting in gully migration. Believed to be a response to changed hydrological conditions

- Gully initiation is thought to be a response to excessive water in the local environment caused by the removal of perennial vegetation.
- Gully head forms as rill erosion deepens and widens creating a characteristic nick/scrach point or headwall.
- Water running into the gully either scours the face or undercuts the head wall resulting in gully migration.
- Widening of gully sides occurs by undercutting or slumping.
- Gully head shape indicates if erosion is due to scouring (forward slope) or dispersion (undercut).
- Some people call it " a land cancer"

Gully expansion can be undertaken through three directions

- Gully head cut/ Gully migration
- Gully bed erosion
- Gully side erosion/fall

Rills are small in size and can be smoothened by tillage operations. When rills get larger in size and shape due to prolonged occurrence of flow through them and cannot be removed by tillage operations, these are called gullies.

Large gullies and their networks are called ravines. Some of the major causes of gully erosion are steepness of land slope, soil texture, rainfall intensity, land mismanagement, biotic interference with natural vegetation, incorrect agricultural practices, etc.

5. Stream Channel Erosion

Stream channel [bank] erosion is the sourcing of material from the side and bottom of a stream or water channel a by running water. It is mainly due to removal of vegetation, over grazing or cultivation on the area near to the streams banks. But in general terms, it is caused due to watershed degradation.

It is movement of soil particles on the bed and banks of streams and channels due to concentration of runoff. Scouring, another facet of channel erosion, occurs along channels where eddies form as a result of sudden expansion, contraction or change in flow direction. Scouring may lead to rapid soil loss from the channel bed or side slopes.

6. Tunnel Erosion

Tunnel erosion appears as a series of tunnels that form beneath the soil surface

- It is both a chemical and physical erosion process
- Tunnel erosion is caused by the movement of excess water through dispersive (usually sodic) subsoil.
- Associated with changes in catchment hydrology or uneven saturation of clay subsoils.

1.8. Impacts/ Problems of Soil Erosion

Soil erosion is a worldwide problem. It affects the land from which soil is washed and damages the area downstream. Soil erosion is a hazard traditionally associated with agriculture in tropical and semi-arid areas and is important for its long-term effects on soil productivity and sustainable agriculture. It is, however, a problem of wider significance occurring additionally on land devoted to forestry, transport and recreation. Erosion also leads to environmental damage through sedimentation, pollution and increased flooding.

The effect of soil erosion can be divided into two.

On site effect of soil erosion

On-site, refers to the damage of soil erosion on the original places, where erosion is occurred. On-site effects are particularly important on agricultural land where the redistribution of soil within a field, the loss of soil from a field, the breakdown of soil structure and the decline in organic matter and nutrient result in a reduction of cultivable soil depth and a decline in soil fertility.

Erosion also reduces available soil moisture, resulting in more drought-prone conditions. The net effect is a loss of productivity, which restricts what can be grown and results in increased expenditure on fertilizers to maintain yields.

The loss of soil fertility through erosion ultimately leads to the abandonment of land, with consequences for food production and food security and a substantial decline in land value.

A. Loss of productive soil

Loss of any soil material from either forms of erosion calls concern, but top soil loss is the most important. Top soil is generally more friable and contains more organic matter and fertility than the sub soil.

The surface soil lost with runoff water consists of rich productive soil and frees or active organic matter. The eroded material, which is ultimately carried into the ocean and thus lost, consists of colloidal matter, clay, silt and the finest grades of sand .Only a small fraction of the eroded material ,however reaches the ocean. The coarser material is usually deposited on river beds or plains when the velocity of water reduces with the reduction of slope of the river bed. The soil deposited in a river bed reservoir is not unavailable for agricultural use.

B. Plant Nutrient Loss

Plant nutrients like nitrogen, phosphorous, potassium, etc. can easily be removed along with the soil from eroding surfaces. The colloidal clay and organic matter are the seats of most the soil's fertility. The loss of colloidal materials in suspension under water erosion and in the clouds of dust blown under wind erosion from eroding field's cause's considerable fertility. Top soil which contains higher concentration of available nutrients than sub soil is lost first by erosion. In this way eroding soils become progressively less fertile. Of course, a high proportion of nutrient elements in eroded soil may not immediately be useful to crops and may not become available for many years to crop.

C. Textural Change

The effect of wind erosion makes the finer soil grains to be carried great distances in suspension .this selective removal makes originally sandy soil sandier. However medium-or fine-textured soil may not be altered seriously because the water or wind sorts aggregates, but not individual soil particles. Both small and large aggregates are usually of similar textural composition. But the deposition of coarser soils of a field which was with fine or medium texture soil is damage of soil texture of the field.

Water and wind erosion are selective. Coarse grains are left near the original locations while the finer ones are transported some distance. The winnowing effect of wind erosion makes the finest soil grains to be carried great distances in suspension. This selective removal makes originally sandy soil sandier.

D. Soil Structure Damage

The beating action of raindrops disintegrates the aggregates and compacts a thin layer into surface crust. This damages the structure of surface soil. Moreover, percolating water carries suspended soil particles and grains into the surface pores that lodge in the pores and reduce permeability.

E. Field Dissection

A farmer can continue to farm a field as a unit in the normal way as long as the channels formed by erosion are small. When the channels become gullies, too large to be crossed with ordinary machinery, the field must be farmed in two or more smaller units, with shorter lands and much more turnings. Therefore, formation of gullies in farm fields is damage to the field.

Gullies may divide the farm in to many valleys and ridges. Fields thus become smaller and more numerous. Crop rows are shortened, movement from field to field is obstructed, and the farm value is decreased. Roads, buildings and fences are often damaged by gully development.

Off-site effect

Off-site problems arise from sedimentation downstream or downwind, which reduces the capacity of rivers and drainage ditches, enhances the risk of flooding, blocks irrigation canals and shortens the design life of reservoirs. Many hydroelectricity and irrigation projects have been ruined as a consequence of erosion. Sediment is also a pollutant in its own right and, through the chemicals adsorbed to it, can increase the levels of nitrogen and phosphorus in water bodies and result in eutrophication. Erosion leads to the breakdown of soil aggregates and clods into their primary particles of clay, silt and sand. Through this process, the carbon that is held within the clays and the soil organic content is released into the atmosphere as CO_2.

A. Loss of Crops

Crop damage particularly at the seedling stage, by runoff water on blowing soil often causes serious concern. Under extreme conditions crops may be completely destroyed. Covering of established crops or pasturage by drifting soil is anther common result in arid and semi-air areas. Grass, trees, shrubs and hedges may be smothered or buried.

B. Silting of Lakes and Reservoirs

Soil erosion from the catchment areas of reservoir results in the deposition of soil, thus reducing their storage capacity and shortening their useful life.

C. Lowering of water table

With the increase in runoff the quantity of water available for entering the soil is decreased. This reduces the supply of water to recharge the ground water in wells, which results yield of the well is reduced.

D. Deposition of sand on productive fields:

In the plains, fertile, lands have been made unproductive by the deposition of coarser material Brought down from the hills streams and rivers.

E. Damage to engineering structures

Erosion causes great damage to buildings and other engineering structures. Foundation is undermined by washing and landslides and soil creeps. Approaches to bridges, footing piles and supports near shore and in midstream are affected by abrasion of soil particles in flowing water, causing structural weakening and actual failure. Erosion in road ditches and culvert sites often causes gullies which cut through or under the road and necessitate its closing.

F. Water and Air Pollution

The muddying of streams and lakes reduces their value for home and industrial uses, for recreation and as habitats for fish and other aquatic life. The greater the sediment load the less suitable the water is for any of these uses. Another problem of more recent concern involves the contaminants that are carried in to the streams and lakes. Fertilizers and pesticides may be dissolved in running water or carried with soil into stream and rivers. In some instances these contaminants affect plants and aquatic animal lives, even land animals and man. Dust from Agricultural activities seldom is the direct cause of fatalities, but it can and does cause accidents and respiratory disorder that sometimes proves fetal. The dust may also carry pathogens that cause skin disease.

Generally soil erosion has the following effects

A. Loss of plant nutrients
B. Soil texture change
C. Soil structure deterioration
D. Disease and public health hazard (water and air pollution)
E. Silting of rivers, Silting of irrigation channels and reservoirs
F. Damage to sea coast and formation of sand dunes.
G. Problems in crop irrigation and consequent need of conserving the water
H. Damages on engineering structures.
I. Field dissection
J. Frequent Floods
K. Water resource depletion
L. Cost of water purification
M. Loss of crops

Chapter 2: Factors Influencing Erosion

2.1. Factors affecting erosion by water

Factors such as rainfall, runoff, wind soil, slope, plant cover and presence or absence of conservation measures are responsible for soil erosion. But mainly three following factors affect the erosion.

A. **Energy:**It include The potential ability of rainfall, runoff and wind to course erosion and other factor which affects the power of erosive agents such as reduction in length of runoff or wind blow through construction of terrace, bunds etc. are for water erosion, and wind breaks or shelter belts in case of wind erosion. ***Erosivity*** is the ability of rain to cause erosion.

• Erosivity of rainfall is the potential ability of rain to cause erosion.

• It is the function of the physical characteristic of rainfall.

• One storm can cause more erosion than another on the same land.

• The relative measure of the power of each storm to cause erosion is the erosivity of the rainfall.

Factors, which affect the erosiveness of rain storm, are given as

❖ **Rainfall intensity**

• It is referred as the rate of fall of rainfall over the land surface in mm/hr

• Soil erosion is a work process in the physical sense that work is the expenditure of energy, and energy is used in all the phases of erosion

– In breaking down soil aggregates,

– In splashing them in the air,

– In causing turbulence/instability in surface runoff,

– In scouring/rubbing and carrying away soil particles.

The factors which are most closely related in soil erosion by rain areamount and intensity of rainfall (**Intensity being critical**)

The **kinetic energy** and **intensity** of rainfall are related; earlier studiesconducted in widely separated countries show some relationship of thekinetic energy and intensity of rainfall.

❖ **Drop size Distribution**

• The average size of a raindrop is 6 millimeters in diameter, about thesize of a housefly.

- **Terminal velocity: the dead or the incurable velocity attained by a falling object**

When a raindrop falls to the surface of the Earth, it is acted on by twomain forces, gravity and drag forces. Usually, air resistance that comes in contact with the water molecules as they fall causes the drag. The combination of these two forces causes a raindrop to reach a terminal velocity when the drag force is approximately equal to the weight of the raindrop. At this point, a raindrop experiences no further acceleration and therefore falls at a constant velocity, i.e. terminal velocity.

Erodibility

The vulnerability or susceptibility of the soil to get erosion is erodibility. It is the function of physical characteristic of soil (texture, structure, organic matter, land use pattern etc.) and land management practices used. Storms with same erosivity may not result equal amount of soil loss from the lands that have different soils. That is, erosion is a function of the erosivity of rainfall and erodibility of the soil. Erodibility is more complex than Erosivity owing to the very far influencing characteristics of soil, management conditions, cropping etc….

 In the widest sense Erodibility can be used to include all the variables which affect erosion except the erosivity of rain.

Relationship between Erosivity and Erodibility

- Erosivity is the function of rainfall properties and to this extent it is dependent on the soil.
- But measurement of erosivity is not possible without erodibility of the soil.
- Similarly, erodibility on the other hand is the function of physical properties of the soil and land management practices; it is independent on the rainfall.
- But the erodibility measurement can not be possible without rainfall. Thus, both terms are not independently quantitative; each may be studied separately, keeping one as constant.
- ✓ THIS IS TO SAY: WITHOUT EROSIVITY THERE IS NO ERODIBILITY and/or WITOUT ERODIBLITY THERE IS NO EROSIVITY.

B. **Resistance:**It is referred to that factors which affect soil erodibility and soil erosion. Mechanical and chemical properties of soil are responsible for infiltration rate of soil which reduces runoff and decreases soil erodibility; ***Erodibility*** is the susceptibility of soil to get eroded. For instance, cultivation decreases the erodibility of clay but increases erodibility of sandy soils.

C. **Protection:** It refers to plant covers which intercept the raindrop falling on ground surface reducing their impact on soil. Plant cover also reduces the runoff and wind velocity, there by soil erosion.

D. Different plant cover offers different protection so suitable cover can be developed to control erosion.

Factors affecting Water Erosion: Water erosion is due to dispersive and transporting power of water.

Factors affecting water erosion are:

1. **Climatic factors:** This includes rainfall characteristics, atmospheric temperature and wind velocity
2. **Soil characteristic:** This affect infiltration rate of soil, Infiltration rate depends upon permeability of soil, surface condition and presence of moisture in it.
3. **Vegetation:** It creates the obstacle for raindrops as well as glowing runoff. A good vegetative cover completely reduces the effect of rainfall on soil erosion.
4. **Topographic effect:** The land slope, length of slope and shape of slope are main factors which influences soil erosion. As slope of land increases from mild to steep, erosion increases

More general: Summary for the factors affecting soil erosion

Table 2Factors affecting soil erosion and the attendant environmental pollution

Table 1.3 Factors affecting soil erosion and the attendant environmental pollution

Land Use	Cultivation	Climate and topography	Social and economic conditions
• Deforestation • Overgrazing • Urbanization • Slashing and burning • Mining • Industrial activities • Road constructions • Forest fires	• Excessive plow tillage • High chemical input • Irrigation • Salinization • Residue removal • Intensive row cropping • Monocropping • Shifting cultivation	• Frequent and intense droughts • Steep slopes (water and tillage erosion) • Rugged topography • Intense rainstorms • Frequent flooding • Intense windstorms • Flat terrains (wind erosion)	• Ineffective conservation policies • Poorly defined land tenure • Lack of incentives and weak institutional support • High population density • Low income • Non-availability of input

The impact of Climate change on Soil erosion

Over the 21st century, the frequency of intense events will increase by about 20 to 60%. Detachment and transport of soil by water depend on the amount and intensity of rainfall. Model results show that rainfall erosivity is projected to increase significantly with the projected climate change.

Even small amounts of rain can cause large amounts of soil loss if rain is in the form of intense storms. An increase of 1% in total rainfall would increase soil erosion rates by 1.7% if rainfall intensity increases correspondingly, whereas it would increase erosion rates by only 0.85% if intensity remains unchanged. Thus, increases in erosive energy of rainfall due to climate change may strongly increase soil erosion rates.

Rainfall exerts both *positive* and *negative effects* on soil's resistance against erosion. It negatively affects soil stability by increasing detachability and transportability of soil particles in runoff, and positively by increasing soil water content and promoting growth of plants and the vegetative cover. The higher biomass production protects the soil from the erosive energy of rainfall and reduces runoff and soil loss.

2.2. Factors Affecting Erosion by Wind

- **Climatic factors**
- **Soil factor**
- **Vegetation covers**

Topography

The major variables affecting soil erosion are climate, soil, vegetation, and topography. Of these, vegetation and, to some extent, soil and topography may be controlled. The climatic factors are beyond the power of human being to control.

I. Climate

However, wind also changes the raindrop velocities and the angle of impact. Humidity and solar radiation are somewhat less directly involved in that they are associated with temperature and the rate of soil water depletion.

The climatic factors that affect wind erosion include ***precipitation, humidity, wind erosive***, and ***temperature.*** Humidity, wind speed and temperature influence evaporation and transpiration of soil moisture, if they are high, they cause high evaporation that lead the soil to be more susceptible to wind erosion. Temperature and wind are the most evident through their effects on evaporation and transpiration.

Wind erosivity refers to the capacity of wind to cause soil erosion. The erosiveness of wind is determined by the wind velocity near the surface, wind turbulence, wind gustiness (rapid velocity increase), and wind direction (change in direction). Generally, wind erosion can only happen when the soil surface is dry or only slightly moist, because surface tension holds the soil particles together when wet.

The climatic factors that influence wind erosion are the characteristics of wind itself in addition to the precipitation, humidity and temperature. The climatic factors influence the soil moisture status which in turn influences the susceptibility of the soil for erosion by wind.

II. Soil

Soil erodibility: Refers to the tendency of the soil to be eroded. This refers to the ability of the surface soil to resist the erosive forces of wind. *Texture, structure, density of particles, soil mass moisture, organic matter and surface roughness* are the important soil factors affecting wind erosion.

Physical properties of soil affect the infiltration capacity and the extent to which particles can be detached and transported.

The resistance of a soil to erosion depends on the nature of the soil:

• **Soil structure:** The less structure-improving matter a soil has on the surface (organic matter, iron and free aluminum, lime), the more fragile it will be, while the presence of sodium or salt often leads to formation of a layer of dust on the surface, which fosters wind erosion.

• **State of the soil surface.** If the soil surface is stony, forming a "pavement", the risks of wind erosion are lower.

A rough surface, left by cloddy tillage or ridges perpendicular to the prevailing wind, slows down the wind at ground level, thus reducing saltation.

• **Vegetation:** Stubble and crop residues in the soil cut wind-speed at ground level.

• **Soil moisture:** increases cohesion of sand and loam, temporarily preventing their erosion by wind.

Texture: particle removal is the order of: clay>silt>fine sand, decreasing with increase in particle size. (Sandy soil is more easily eroded than a hard clay soil. In wind erosion it depends on the cloudiness of the soil. If the soil is cloddy it will be larger enough to reset the forces of the wind. Clods formed during tillage, their firmness and stability depend on soil moisture, compaction, organic matter, clay content, lime and microbial activity. Drier the soil is the more susceptibility for wind erosion.

More clayey soil is much stickier, better-structured, and hence more resistant. Coarse sand and gravelly or rocky soils are also more resistant, since the particles are too heavy to be removed by wind erosion.

In general, soil detachability increases as the size of the soil particles or aggregates increase, and soil transportability increases with a decrease in the particle or aggregate size. That is, clay particles are more difficult to detach than sand, but clay is more easily transported.

Surface roughness: Surface roughness or crust has a retarding influence on the movement of soil by wind. **Smooth soil surface** is generally more erodible by wind than a **rough** one. In general, greater the surface roughness the lower is the wind velocity against the ground and lower is the rate of erosion.

Crusts: Crusts are denser, stable, and resistant to erosion than un-crusted soils. Wind erosion rates decrease exponentially with increase in soil water content owing to the cohesive force of water. Surface crusts when formed have a retarding influence on wind erosion.

III. Vegetation

Type of vegetation, the height of vegetation, density of vegetation and it's seasonal distribution are some of the vegetation factors which influence the soil erosion by wind. Good vegetation cover is the most permanent and effective way to control wind erosion. Living or dead vegetation cover protects the soil surface from wind action by reducing wind speed and by preventing much of the direct wind force from reaching erodible soil particles. Vegetation cover also reduces rate of erosion by trapping soil particles. Protection depend on the quantity, size, height and orientation of the plants in relation to the prevailing wind direction.

Because of the effectiveness of vegetative cover in controlling soil erosion, it is usually the primary choice for long-term erosion control unless there are reasons for doing otherwise.

Vegetation influences wind erosion, directly when the area is under vegetation or indirectly by protecting the adjoining areas.

IV. Topography

Topography refers to the shape, length, inclination and aspect of a slope. The length and inclination are critical factors with longer and steeper slopes producing greater soil erosion.

Chapter 3 - Erosion Hazard Assessment

3.1. Introduction

There are many conditions on a construction site that contribute to the overall hazard and risk of soil erosion and sediment pollution to the environment. Hazard (H) is defined as a description of the magnitude (M) and probability (P) of occurrence within a specified period of time and within a given area of a potentially damaging phenomenon . Hence, H = M × P. it is ―source of potential harm or a situation with a potential to cause loss.

The *Erosion Hazard Assessment* (EHA) determines whether that risk is 'low', 'medium' or 'high' by using a series of questions to assess the risk to the environment. Erosion hazard is a land quality to be considered in land use planning as it influences the productivity of land. It is a special form of land resources evaluation, and defined by the expected degree of damage in the near future.

What is the objective of soil erosion hazard studies?

Erosion hazard assessment aims; to identify those areas of land where the maximum sustained productivity from a given land use is threatened by excessive soil loss or the off-site damage arising from erosion is unacceptable. A distinction is made between potential erosion risk, reflecting the local conditions of soil, climate and slope, and actual erosion risk, which additionally takes account of land cover. It is therefore possible to recognize areas of high potential risk but low actual risk as a result of the protection afforded by vegetation.

Erosion hazard assessment also involves the division of land into land use units, similar in their kind and degree of erosion hazard, as basis for planning soil conservation work.

3.2. Soil Loss Status Based

Usually soil erosion of watershed classified in to four classes:

1) Areas having greater or equal to 200 ton/ha/year as Severe Hazard Zone
2) Areas having 101-200 ton/ha/year as High Hazard Zone
3) Areas having 51-101 ton/ha/year as Moderate Hazard Zone

4) Areas having up to 50 ton/ha/year as Slight Hazard Zone

(1 ton = 10 Quintals = 1000Kg= 1000000 grams (1 Million gram=1Mg)

3.3. Methods of Erosion hazard assessment

There are three types of assessments of erosion hazard

1. Generalized assessment : as national level
2. Semi detailed assessment
3. Detailed surveys

3.3.1. Generalized Assessment

Generalized assessments of erosion risk are made at macro/national level / scale. Considered largely based on analyzing the climatic data or they use measurement of erosion intensity.

1. Factorial Scoring Method

For this method an attempts is made to include factors that influences soil erosion. The soil erosion factors are described for the area under consideration and each of them are rated. Land unit can be rated on scale of 1 to 5 based on factors as of erosivity, erodibility, slope, ground cover and human occupation, the latter taking account of the density of the population and the type of settlement. The five factor scores were summed to give total score, which was then compared with an arbitrarily chosen classification system to categorize areas of low, moderate and high erosion risk. The score ranges from 1(lower risk of erosion) to 5 high risk of erosions.

Table 3 Factorial scouring example

Factors	Land Units / Risk Of Erosion		
	A	B	C
K	4	5	1
R	3	2	1
Ls	2	3	5
C	4	4	5
Total	13	14	12

Which land units are highly severed for erosion? B so we assess first B, next A and the C

Several problems associated with this technique are: First, the classification may be sensitive to different scoring systems. For example, the use of different slope groups may yield different assessments of the degree of erosion risk. Second, each factor is treated independently, whereas there is often interaction between the factors. Third, the factors are combined by addition. There is no reason why this should be a more appropriate method of combining them than multiplication, although multiplication often results in the score for one factor dominating the total score and, for that reason, is difficult to use with zero values in the scoring system. Fourth, each factor is given equal weight.

Despite these difficulties, the technique is easy to use and has the advantage that factors which cannot be easily quantified in any other way can be readily included. When used carefully, factorial scoring can provide a general appreciation of erosion risk and indicate vulnerable areas where more detailed assessments should be made.

- ✓ Each unit of square or sub-watershed is rated on a scale from 1 to 5 in respect of **Erosivity, Erodibility, Slope, Ground cover,** and **Population.**
- ✓ In the scoring '**1**'is associated with **'Low risk**' and'5' is associated with '**high risk**'.
- ✓ The five factor scores are added and the total is used for a classification of low, moderate, and high erosion risk area.

2. Erosivity indices (R):

Erosivity data can be used as an indicator of regional variations in erosion potential. Based on mean annual erosivity values, used to showing that high-risk and low risk areas. Erosivity is low at the beginning of the wet season and increases as the season progresses. Erosivity is highest at the time of minimal vegetation cover.

It expresses the erosive potential or power of the rain. The potential ability of rainfall to cause soil erosion is called erosivity. Therefore rainfall characteristics which influence its erosivity such as amount, duration and intensity, drop size and drop size distribution, terminal velocity and kinetic energy are obtained from measurements carried out with rain gauges. Rainfall intensity is: amount/duration = mm/h. Rainfall intensities exceeding 150 mm h^{-1} are found regularly in the tropics whereas in temperate regions, rainfall intensity hardly exceeds 75 mm h^{-1}. Therefore, rainfall erosivity is considered higher for topical rains than temperate rains.

Drop size and drop size distribution are measured using: drop-stain method. Large drops have higher terminal velocity than small drops. Raindrop size hardly exceeds 5 mm size. Of its Kinetic energy: This is the product of the mass of rain falling per unit time and the square terminal velocity $E = ½mv^2$ this, in units of kg and m /s, also gives a value in Joules. The erosivity index is the product of kinetic energy of the storm (E) its max 30 minute intensity (I 30), R= EI30 = mv2xI30/2, I = intensity of the storm in mm/hr E = expresses in J/m2, R= J mm m-2 h-1

3. **Rainfall aggressiveness**

The most commonly used index of rainfall aggressiveness, shown to be significantly correlated with sediment yields in rivers, sediment production, especially under natural conditions, in a specific area, dependent on annual and seasonal rain. It expressed as degradation coefficient(c) for large catchment > 2000km2 is the ratio p2/P, where p is the highest mean monthly precipitation and P is the mean annual precipitation. To investigate regional variations in erosion risk using correlation between p2/P and drainage texture, defined as the number of first-order streams per unit area. Since drainage texture is analogous to gully density, p2/P may be regarded as an indicator of the risk of gully erosion. In contrast, mean annual erosivity values reflect the risk of erosion by rain splash, overland flow and rills.

By super imposing the maps of p2/P and erosivity, a composite picture of erosion risk is obtained. As expected from the above, there is often a poor relationship between p2/P and mean annual R. The emphasis given in p2/P to the month with the highest rainfall underplays the contribution of the rainfall in the rest of the year to erosion. If the mean annual rainfall increases but the highest monthly total remains the same, the p^2/P actually falls in value whereas the potential for erosion should increase, since a proportion of the additional rain is likely to be erosive. Arnoldus (1980) proposed a way of overcoming this defect by considering the rainfall of all months and developing a modified Fournier Index (MFI).

$$MFI = \sum^{12} \frac{p^2}{P}$$

Where p is the mean monthly precipitation and P is the mean annual rainfall. Based on significant correlations between MFI and mean annual R for different climatic regions, mean annual erosivity maps have been produced for different countries.

3.3.2. Semi Detailed Assessments

Mainly deals with soil erosion risk of a medium scale, it considers land units and farm fields and analysis all factors of soil erosion. Assessing the land erosion hazard in a medium level and we look for the land characteristics.

A. 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.

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. Geomorphological mapping system portrays information on the distribution and type of erosion, erosivity, runoff, slope length, slope steepness, slope curvature in profile and plan, relief, soil type and land use.

In some studies there is no sufficient time or man power to make detailed measurements of erosion depth. The intensity (I) of erosion is estimated by inspection of large areas, and mapped on to aerial photographs. This techniques usually involves the establishment of 3 or 4 categories of erosion intensity (I). Areas of pehaps 5 – 10 ha or individual hill slopes are then classified into one of these categories.

Table 4 Coding system for soil erosion appraisal in the field

Code	Class	Erosion rate ($t\,ha^{-1}$)	Indicators
1	Very slight	<2	No evidence of compaction or crusting of the soil; no wash marks or scour features; no splash pedestals or exposure of tree roots; over 70% plant cover (ground and canopy).
2	Slight	2–5	Some crusting of soil surface; localized wash but no or minor scouring; rills every 50–100 m; small splash pedestals, 1–5 mm depth, where stones or exposed trees protect underlying soil, occupying not more than 10% of the area; soil level slightly higher on upslope or windward sides of plants and boulders; 30–70% plant cover.
3	Moderate	5–10	Wash marks; discontinuous rills spaced every 20–50 m; splash pedestals and exposed tree roots mark level of former surface, soil mounds protected by vegetation, all to depths of 5–10 mm and occupying not more than 10% of the area; slight to moderate surface crusting; 30–70% plant cover; slight risk of pollution problems downstream if slopes discharge straight into water courses.
4	High	10–50	Connected and continuous network of rills every 5–10 m or gullies spaced every 50–100 m; tree root exposure, splash pedestals and soil mounds to depths of 10–50 mm occupying not more than 10% of the area; crusting of the surface over large areas; less than 30% plant cover; danger of pollution and sedimentation problems downstream.
5	Severe	50–100	Continuous network of rills every 2–5 m or gullies every 20 m; tree root exposure, splash pedestals and soil mounds to depths of 50–100 mm covering more than 10% of the area; splays of coarse material; bare soil; siltation of water bodies; damage to roads by erosion and sedimentation.
6	Very severe	100–500	Continuous network of channels with gullies every 5–10 m; surrounding soil heavily crusted; severe siltation, pollution and eutrophication problems; bare soil.
7	Catastrophic	>500	Extensive network of rills and gullies; large gullies (>100 m^2) every 20 m; most of original soil surface removed; severe damage from erosion and sedimentation on-site and downstream.

B. Land Capability Classification

Land capability classification was developed by the United States Natural Resources Conservation Service as a method of assessing the extent to which limitations such as erosion, soil depth, wetness and climate hinder the agricultural use that can be made of the land. The objective of the classification is to divide an area of land into units with similar kinds and degrees of limitation. There are three categories of land capability classification

1. Capability unit: The basic unit is the capability unit. This consists of a group of soil types of sufficiently similar conditions of profile form, slope and degree of erosion to make them suitable for similar crops and warrant the use of similar conservation measures.
2. Sub class: The capability units are combined into sub-classes according to the nature of the limiting factor
3. Class: Consist of sub class combined based on the degree of limitation

The United States system recognizes eight classes arranged from Class I, characterized by no or very slight risk of damage to the land when used for cultivation, to Class VIII, very rough land that can be safely used only for wildlife, limited recreation and watershed conservation. The first four classes are designated as suitable for arable farming. The value of land capability assessment lies in identifying the risks attached to cultivating the land and in indicating the soil conservation measures that are required

Land capability classes (United States system)

Table 4 Land capability class and characteristics

Class	Characteristics and recommended land use
I	Deep, productive soils easily worked, on nearly level land; not subject to overland flow; no or slight risk of damage when cultivated; use of fertilizers and lime, cover crops, crop rotations required to maintain soil fertility and soil structure.
II	Productive soils on gentle slopes; moderate depth; subject to occasional overland flow; may require drainage; moderate risk of damage when cultivated; use of crop rotations, water-control systems or special tillage practices to control erosion.
III	Soils of moderate fertility on moderately steep slopes, subject to more severe erosion; subject to severe risk of damage but can be used for crops provided plant cover is maintained; hay or other sod crops should be grown instead of row crops.
IV	Good soils on steep slopes, subject to severe erosion; very severe risk of damage but may be cultivated if handled with great care; keep in hay or pasture but a grain crop may be grown once in five or six years.
V	Land is too wet or stony for cultivation but of nearly level slope; subject to only slight erosion if properly managed; should be used for pasture or forestry but grazing should be regulated to prevent plant cover being destroyed.
VI	Shallow soils on steep slopes; use for grazing and forestry; grazing should be regulated to preserve plant cover; if plant cover is destroyed, use should be restricted until land cover is re-established.
VII	Steep, rough, eroded land with shallow soils; also includes droughty or swampy land; severe risk of damage even when used for pasture or forestry; strict grazing or forest management must be applied.
VIII	Very rough land; not suitable even for woodland or grazing; reserve for wildlife, recreation or watershed conservation.

Classes I–IV denote soils suitable for cultivation.

Classes V–VIII denote soils unsuitable for cultivation.

In general used to combine data on soil erosion hazard and limitation and also used to select appropriate land use and management plan.

Draw backs of these methods are that it:

- ✓ Gives much emphasis to slope and soil conservation
- ✓ Does not specify the suitability of land for particular crop.
- ✓ Does not give an indication for land value or profitability

C. **Land systems classification**

Land systems analysis is used to compile information on the physical environment for the purpose of resource evaluation. The land is classified into real units, termed land systems, which are made up of smaller units, land facets, arranged in a clearly recurring pattern. Since land facets are defined by their uniformity of landform, especially slope, soils and plant community, land systems comprise an assemblage of landform, soil and vegetation types.

The land systems differed from each other in either their soil erodibility or slope steepness or, in some cases, both. These results demonstrate that land systems represent dynamic erosion-response units that reflect both the extent of erosion at any one time and its evolution over time.

3.3.3. 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. The severity of erosion is rated by a simple scoring system. Taking account of features that are easily visible, such as the exposure of tree roots, crusting of the soil surface, and formation of splash pedestals, the size of rills and gullies and the type and structure of the plant cover.

Observations are made using quadrate sampling over areas of $1m^2$ for ground cover, crusting and depth of ground lowering, $10m^2$ for shrub cover and $100m^2$ for tree cover. In interpreting the results of field surveys, it is important to place the data in their time perspective, particularly with respect to likely seasonal variations in the vegetation cover and soil erodibility.

If detailed field surveys are carried out at a sufficient number of places and the results are shown to be representative of particular soil or landscape conditions, it is possible to extrapolate the data and produce national scale erosion surveys.

Chapter 4 Measurement of Erosion

4.1. Introduction

Data on the amount of soil transported from a field are required to:

- Assess the magnitude or severity of erosion and its effects on soil productivity,
- Develop mathematical models and test their applicability for soil erosion prediction,
- Design and establish erosion control practices,
- Understand and manage sedimentation in depositional areas, and
- Ascertain effects of erosion on water pollution.

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. In general, the ways to measure soil erosion are Estimate how much has been lost from a site and Estimate how much has accumulated elsewhere.

4.2. Indicators of soil erosion

Water erosion leaves many features on the land, which indicates and amount of damage that occurred on the area. Some of the visual indicators are:

- **i.** Lowering of soil surface after the erosion and observation of many rock fragments on the field.
- **ii.** Pedestals and Tree mounds
- **iii.** Observation of rills on the fiend.
- **iv.** Observation of exposed plant root.
- **v.** Occurrence of gullies on the land
- **vi.** Accumulation of eroded sediment behind conservation structures.

Visual indicators for wind erosion

If any one of out to the field and try to observe whether there is wind erosion or not the most important features that should be considered are:

1. Violent and dusty wind

2. Presence of dust on the plants, building...etc
3. Little or no vegetation
4. Deposition of soil in depressions.
5. In area where wind erosion occurred for many years only larger particles like sand and gravels remain on the land.
6. Occurrence of sand dunes on the area could also be one indicator of wind erosion.

Soil Loss Tolerance

By definition, "***Soil loss tolerance for a specific soil is the maximum annual soil loss expressed in ton/ha/year that will permit current production levels to be maintained economically and indefinitely."***

- Soil loss tolerance of different soil types based on their depth is different. But in general, ***2- 11.2 ton/ha/year*** is considered as permissible erosion limit.
- **The assumption of this limit is that**
    1. The rate of soil erosion equals the rate of soil formation
    2. Productivity level of the land will not be disturbed

The rationale behind measuring soil erosion is:

- To see the exact soil loss rate of the given land whether it is below or above the permissible value.
- To decide on how to manage a given land to attain the soil loss rates less or equal to the permissible limit.

Recommended tolerance values of specific soils are used as a guide for soil conservation planning, like the following recommended values for maximum permissible soil loss

Table 1 Recommended values for maximum permissible soil loss

Soil type / Depth	**in ton/ha/yr**
☞ Deep fertile loam soil (1 – 1.5 m)	6 - 11
☞ Thin highly erodible soil	2 - 5
☞ Very deep loam soils (> 1.5 m)	13-15
Soil depth	
☞ 0 – 25 cm	2
☞ 25 – 50 cm	2-5
☞ 50 – 100 cm	5 - 7
☞ 100 – 150 cm	7-9
☞ > 150 cm	11

4.3. Techniques of Soil Erosion Measurement

Measuring Splash Erosion

Splash erosion has been measured in the field by means of **splashboards** or small funnels or bottles. These are inserted in the soil to protrude 1–2mm above the ground surface, thereby eliminating the entry of overland flow, and ***the material splashed into them is collected and weighed.*** An alternative approach is the field splash cup, where a block of soil is isolated by enclosing it in a central cylinder and the material splashed out is collected in a surrounding catching tray. The amounts of splash erosion were collected through the hanging splash erosion board and measured by the oven drying method.

Erosion Pin Method

- A pin made of wood, iron, bamboo, steel; etc. with commonly 300mm length and 5mm diameter will be driven into the soil.
- The pin must not be rot or decay while staying in the soil.
- Length 300mm is an average; it could be less for shallow soils, and more for loose soils.
- Five mm diameter is preferred because thicker pins will interfere the flow of runoff/surface flow/ and cause scour.
- The pins will be driven randomly in rectangular or square grid.

- Surface level change will be monitored after the end of every rain and the length in the pin above the soil surface is measured and recorded continuously.
- Finally, the average of each pin will be found and the final soil loss will be calculated by the following formula;

$$\textbf{Final soil loss} = \frac{\Sigma \text{eroded depths X no.of pins} - \Sigma \text{deposited depth X no.of pins}}{\text{Total no. of pins}}$$

Measuring Sheet and Rill Erosion

Pedestals

• Easily eroded soil if protected by stone, tree or grass root, an isolated pedestal capped by the resistant material are left standing up from the surrounding ground. In this method splash erosion is mainly detected than surface flow.

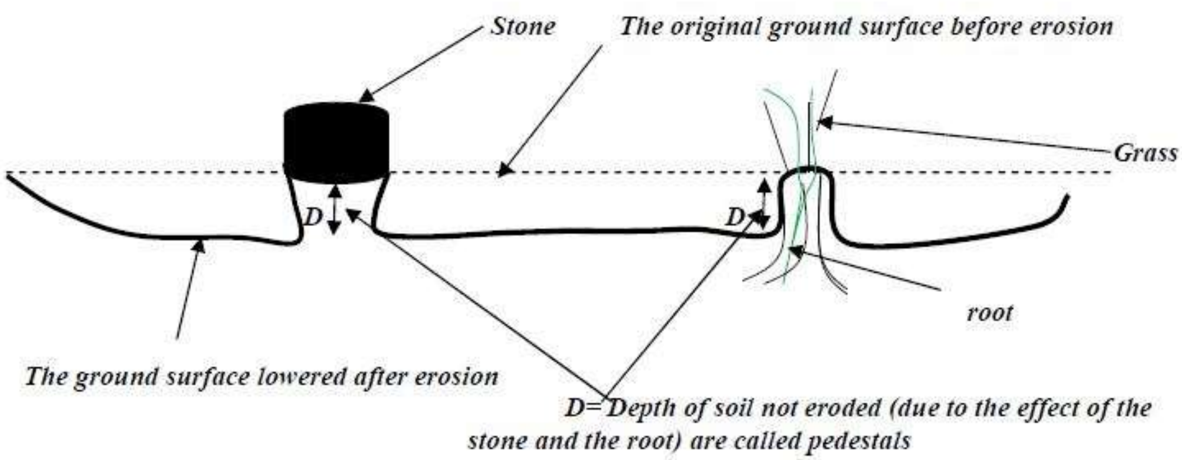

Figure 1 indicators for soil erosion

Therefore, using the lost soil depth D we can estimate the amount of soil lost by averaging.

Rill erosion measurement

- The simplest method of assessing rill erosion is to establish a series of transects, 20–100 m long across the slope
- The cross-sectional area of the rills is determined along two successive transects.
- The average of the two areas multiplied by the distance between the transects gives the volume of material removed.

- Since this method ignores the contribution of inter-rill erosion to the sediment carried in the rills and also depends upon being able to identify distinctly the edge of the rills, it is likely to underestimate rill erosion by 10–30 per cent.

Measuring Gully and Stream Bank Erosion

Catch-pit method

• Eroded and transported soil called sediment can be trapped in its way to rivers by using catch-pits which are dug at the outlet of runoff from a given field and lined by geo-membrane plastics so that the collected sediment and runoff can be hold for measurement. The catch-pits catch unknown amount/ proportion of the sediment to be **used simply for comparative information,** say comparing erosion from terraced area and erosion from un-terraced area.

4.4. Characterization and Simulation of Erosion at Runoff Plot and Micro Watershed Scale

- 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
- Runoff plot is an experimental plot of land used to estimate soil erosion from specified condition of the plot. A plot with known length, width, slope, cover, and supporting conservation practices will be selected and bounded by steel sheet to avoid interference of run-on in to the plot from outside area and to guide the runoff from the plot not to leave elsewhere but only to the prepared sediment and runoff collecting tanker/ storage.

NB. Since slot devisor of 10 partitions is used to let on 1/10 of sediment containing runoff to the collection tank, we require multiplying the final result by 10.

Chapter 5: Erosion Estimation and Modeling

5.1. The Concept of Modeling

Each definition of "model" is insufficient: It covers only a small range of the reach of use. In particular all definitions with the terms 'original, 'reality' and representation' cannot convince.

Modeling soil erosion is the process of mathematically describing soil particle detachment, transport and deposition on land surfaces. It 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: Understanding of the driving processes, Evaluation of on-site and off-site impacts on soil productivity and water and air pollution on large scale, Identification of strategies for erosion control, and Assessment of the performance of soil conservation practices for reducing water and wind erosion.

Three Reasons for modeling erosion: Erosion models can be used

a. As predictive tools for assessing soil loss for conservation planning, project planning, and soil erosion inventories and for regulation.
b. Physically based mathematical model can predict where and when erosion is occurring, thus helping the conservation planner target efforts to reduce erosion.
c. As tools for understanding erosion processes and their interaction and for setting research priorities.

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 (space) and temporal (time) scales. Time and space based model comprises three main components: the rainfall inputs, soil erosion environment and outputs.

Types of models are:

a. Physical: Scaled-down hardware models usually built in the laboratory; need to assume dynamic similitude between model and real world.

b. Analogue: Use of mechanical or electrical systems analogous to system under investigation, e.g. flow of electricity used to simulate flow of water.

c. Digital: they are based on use of digital computers to process vast quantities of data.

Physical based, stochastic and empirical models are classified under the digital models.

a. Physically based models are based on mathematical equations to describe the processes involved in the model, taking account of the laws of conservation of mass and energy.
b. Stochastic models is 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.
c. Empirical model is based on identifying statistically significant relationships between assumed important variables where a reasonable data base exists.

Three types of analysis are recognized:

I. Black-box, where only main inputs and outputs are studied;
II. Grey-box, where some detail of how the system works is known;
III. White-box, where all details of how the system operates are known.

Definition: *Model is a simplified description, especially a mathematical one, of a system or process, to assist calculations and predictions* **especially, for natural systems and processes.**

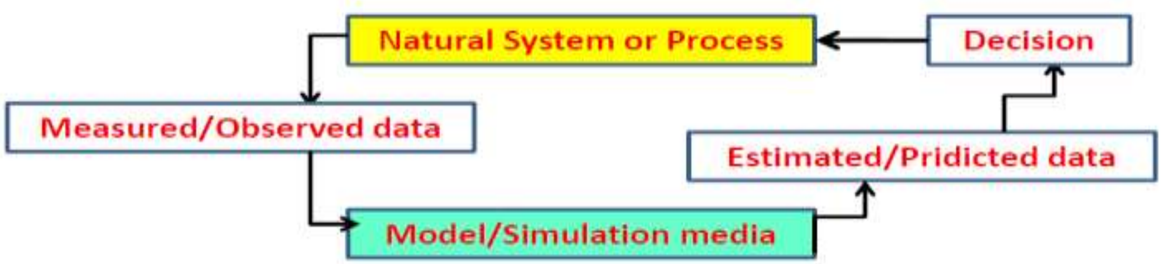

Figure 2 Modeling processes

5.2. Why Model?

- To simulate stream-flow parameters
- To simulate Rf-Rof-Erosion
- Limitations of hydrological measurement techniques
- Not able to measure everything
- Where measurements are not possible
- To assess the likely impact of future hydrological change
- A means of quantitative extrapolation or prediction

Models are of necessity simplifications of reality.

•The model is an interface between data and decision making:

• Data → Model → generate information → Decision

In case of Erosion Models, model attempt to describe additional basic erosion processes

1. Detachment 2. Transportation 3. Deposition

MODEL Classification

Decisions need to be made on whether prediction should be for a year, a day, a storm or short periods within a storm; and whether it should be for a field, a hill slope or a drainage basin. These differences in temporal and spatial perspectives will influence the processes that need to be included in the model, the way they are described and the type of data required for model validation and operation. Good scientific practice should force all modellers to specify the design requirements of their models before they are developed. A user should be able to expect that a model has been tested for the conditions for which it was designed and, from this information, should then be able to select the most appropriate model to meet a specific set of objectives. Any attempt to use a model for conditions outside those specified should be viewed as bad practice and, at best, speculative.

Why classify Model?

Classification gives an idea on:

- How the simulation is accomplished,
- As to the type and level of mathematics involved,
- As to the nature of the model output
- As to the type and amount of input information required
- To see which part of the hydrological system or processes are being simulated
- To select an appropriate model for a particular need
- To obtain an idea of the model’s complexity, Uncertainty, and potential for error

1. Empirical - Conceptual - Physical
2. Linear - Non-linear
3. Lumped - Distributed
4. Deterministic – stochastic
5. Static - dynamic
6. Time-variant - time-invariant
7. Event based - continuous
8. Complete – partial
9. General - special

Type	Description
Physical	Scaled-down hardware models usually built in the laboratory; need to assume dynamic similitude between model and real world.
Analogue	Use of mechanical or electrical systems analogous to system under investigation, e.g. flow of electricity used to simulate flow of water.
Digital	Based on use of digital computers to process vast quantities of data.
(a) 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.
(b) 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.
(c) Empirical	Based on identifying statistically significant relationships between assumed important variables where a reasonable data base exists. Three types of analysis are recognized: (i) black-box, where only main inputs and outputs are studied; (ii) grey-box, where some detail of how the system works is known; (iii) white-box, where all details of how the system operates are known.

Source: after Gregory and Walling (1973).

Model classification by a spatial disaggregation

A. Lumped models

• Represent processes/parameters in a spatially averaged manner,

• Consider catchment/sub catchments as a whole (as a single unit)

• It ignores spatial variations of hydrological processes

Advantages for using lumped models:

• Ease of use

• Easy of obtaining input information

• Scaling up relatively homogeneous sub-catchments to catchments and regional scales

Disadvantage

• Do not allow for descriptions of spatial variability

• They do not indicate where, within a catchment, the source areas of runoff/peak discharge/sediment yield are

• Assuming the entire catchment to respond of identically

• They can be used for simple water resource assessment, quality control of hydrological data, filling missing or incorrect values

• Extension of historical flow records on catchments with non-changing land use

B. Distributed models

• Variable and heterogeneous characteristics of the catchment is conserved

• Each units in the catchment assigned variables and parameters

• More flexible than lumped

• Spatial and temporal variation in climate, land use and vegetation change conserved

Criteria for selection of appropriate model

• ***There is no universal model which is appropriate for solution of all hydrological problems,***

• Selection should not be with availability or strong advocacy,

• The choice of the "best" model depends largely on the nature of the problem and will change as the problem change.

• Characteristics of the model have to be compatible with the requirement of the problem.

• ***The "best" model depends on the criteria used to define "best"***

Therefore "**best**" according to Woolhiser and Brakensiek (1982), Hillel (1986), Tim (1995) and others depends on:

- Desired time resolution,
- Volume or entire hydrograph,
- Use of the model
- Structure and input/output consideration
- Accuracy of prediction--- error statistics are known and uncertainty quantified
- Simplicity of the model--- the fewer parameters the better
- Consistency of parameter estimation--- different model user should obtain consistent values of parameters

- Sensitivity of results to change in parameter value
- Assumption --- minimum Assumptions
- Potential for improvement
- Computing facility
- User friendliness of the model -
- Availability of relevant input data and information
- Scale consideration
- Conceptualization of the major process--- physically correct "ideas"

Problems in model selection

Case 1: Complex Vs Simple Models

• What does complexity imply?

• Complexity of rainfall-runoff models encompasses **three** main aspects:

1. The ***level of detail on processes*** which has been adapted to modeling the various components of the hydrological system
2. The ***level of spatial disaggregation*** allowed in the model structure
3. The ***level of temporal disaggregation*** facilitated by the model structure

• This complexity level is important in light of computer facility, data requirements and model applicability

Problem associated with complex models

1. Complex models have high and/ or complex **input** information demand
2. Over-parameterization and give false impressions of a model's capability
3. More inputs variables is a danger of errors to be made and these errors could be accumulative rather than self correcting
4. needs long computational times
5. Complex models are difficult to calibrate and to verify because of the large number of variables they contain

Advantage in applying simple models

1. Inputs demand are low
2. It is easier to fit simple models with input parameters to estimated data

5.3. USLE (Universal Soil Loss Equation) Erosion Prediction Models

Erosion models are used to describe and understand the behavior of land and water systems under prevailing and projected land use and climate conditions. They are increasingly used to evaluate potential water and air quality.

USLE is a good predictive tool for estimating average annual field soil loss is the universal soil loss equation. It was developed in the 1930 by the US soil conservation service, was improved in 1954 by US agriculture services and was further improved in 1978 by the US department of agriculture. It is much used by consultants and planner worldwide to predict soil loss and to select appropriate agricultural practices and crops. The USLE considers a range of parameters to derive a value for average annual soil loss. The revised version of USLE has been developed for computer applications, allowing more detailed consideration of farming practices and topography for erosion prediction. The equation considers the five parameters as an input and gives an annual average soil loss of the area. The equation uses rainfall erosivity; soil erodibility; slope length and gradient; soil cover; and land management practices.

The mathematical equation of the USLE is given by the formula: $A=R\times K\times LS\times C\times P$

R = Rainfall Erosivity factor

K = Soil Erodibility Factor

S = Slope length and Steepness factor

C = Cover Crop Management Factor

P = Conservative/Management practice Factor

- ❖ The Universal Soil Loss Equation (USLE) predicts the long term average annual rate of erosion on a field slope based on rainfall pattern, soil type, topography, crop system and management practices.
- ❖ USLE only predicts the amount of soil loss that results from sheet or rill erosion on a single slope and does not account for additional soil losses that might occur from gully, wind or tillage erosion.
- ❖ This erosion model was created for use in selected cropping and management systems, but is also applicable to non-agricultural conditions such as construction sites.
- ❖ The USLE can be used to compare soil losses from a particular field with a specific crop and management system to "tolerable soil loss" rates.

Components of USLE

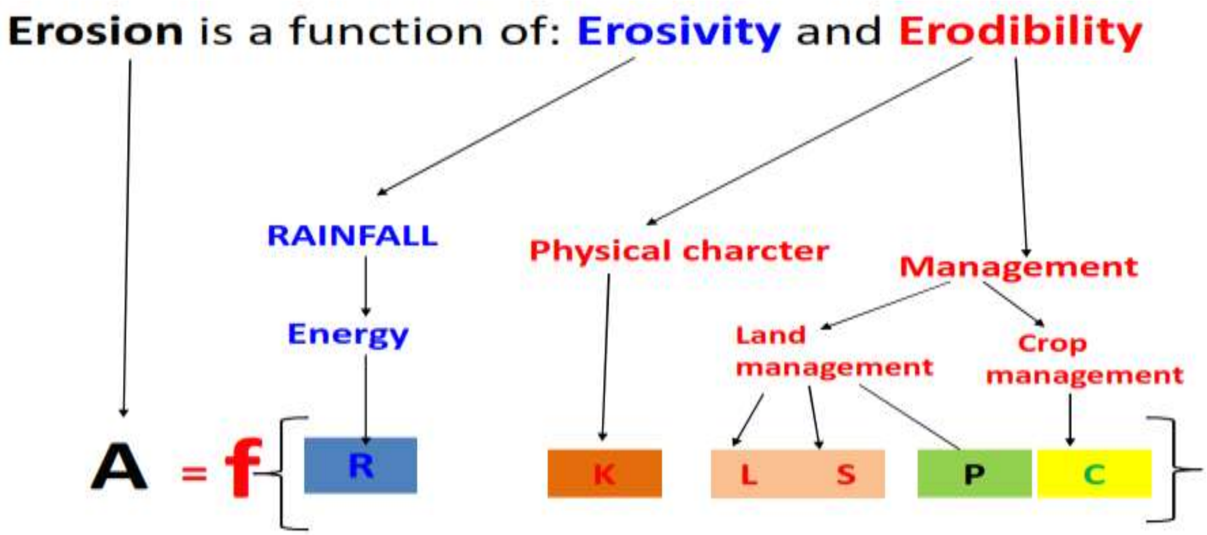

Figure 3 components of universal Soil loss equation

Erosion is a function of (Erosivity, Erodibility)

This formula is developed on standard field conditions like; L=22.1 m; S= 9 %; C = bare fallow; and P= up and down slope farming. Man interference on R and K is almost no. But on L, S, C, and P man can modify positively or negatively.

The USLE represents an erosion model developed for the prediction of soil losses in an average long-term sense. It is based on the knowledge of the physical characteristics of the field area under study, along with the prevailing cropping and management system. USLE has been widely tested in field conditions, and therefore its validity has been established.

USLE consists of the product of six factors, whose numerical values can be specified depending on a particular location. There is a considerable variation in the resulting erosion values, if observations are limited within short periods. However, long-term averages correspond more satisfactorily to predictions.

Table 5 values for different factors used in USLE

Rain fall	R	Soil texture	K	Length (m)	L	Slope %	S	Cover	C	Practice	P
500	300	Sand	0.02	5	-	5	0.4	Cereals, Pulses	0.15	Plowing up & down	1.00
550	330	Loamy Sand	0.04	10	0.67	10	1.0	Teff	0.25	Strip cropping	0.8
600	360	Coarse Sandy Loam	0.07	15	0.81	15	1.6	Sorghum, Maize	0.1	Applying mulch	0.6
650	390	Fine Sand	0.08	20	0.95	20	2.2	Fallow land	0.05	Contour plowing	0.8
700	420	Loamy Fine Sand	0.11	25	1.05	25	2.6	Degraded grass	0.05	Inter cropping	0.8
750	450	Sandy Loam	0.13	30	1.15	30	3.0	Hard badland	0.05	Dense inter cropping	0.7
800	480	Heavy Clay	0.17	35	1.25	35	3.4	Soft badland	0.4		
850	510	Fine Sandy Loam	0.18	40	1.35	40	4.8	Dense forest	0.01		
900	540	Sandy Clay Loam	0.20	45	1.42	45	4.05	Other forest	0.05		
950	570	Clay	0.22	50	1.49	50	4.3				
1000	600	Silty Clay	0.26	55	1.56	55	4.55				
1050	630	Clay Loam	0.30	60	1.63	60	4.8				
1100	660	Loam	0.30	65	1.70						
1150	690	Silty Clay Loam	0.32	70	1.73						
1200	720	Very Fine Sandy Loam	0.35	75	1.76						
1250	750	Silt Loam	0.38	80	1.90						
1300	780	Loamy Very Fine Sand	0.39	85	1.95						
		Very Fine Sand	0.43		2.00						

Table 6 For Ethiopian highlands, Soil Conservation Research Project of Hurni (1985)

Rainfall Erosivity (R) factor	
Annual RF in mm	**Annual R factor**
100	48
200	104
400	217
800	441
1200	666
1600	890
2000	1115
2400	1340

Soil Erodibility (k) factor	
Soil Color	K -factor
Black	0.15
Brown	0.2
Red	0.25
Yellow	0.30

Slope gradient (S) factor	
Slope in %	**S- factor**
5	0.4
10	1
15	1.6
20	2.2
30	3
40	3.8
50	4.3
60	4.8

Slope length (L) factor	
Length in m	**L- factor**
5	0.5
10	0.7
20	1.0
40	1.4
80	1.9
160	2.7
240	3.2
320	3.8

Land Cover	C- factor
Dense forest	0.001
Other forests	0.01
Dense grass	0.01
Bad land hard	0.15
Bad land soft	0.4
Sorghum	0.1
Cereals, pulses	0.15
Continuous fallow	1.0
Fallow ploughed	0.05

Conservation	P- factor
Ploughing up and down slope	1.0
Strip cropping	0.8
Applying mulch	0.6
Stone cover (40 %)	0.8
Terracing and bunding	0.5
Ploughing on contour	0.9
Inter cropping	0.8
Dense inter cropping	0.7
Contour cultivation	0.6

Limitations of USLE

a) It is empirical **b)** It predicts average annual soil loss (computes less value than the measured) **c)** It does not compute gully erosion **d)** It does not compute sediment deposition

Revised Universal Soil Loss Equation

- The Revised Universal Soil Loss Equation (RUSLE) is an upgrade of USLE that is land use independent. It can be used on cropland, disturbed forestland, rangeland, construction sites, mined land, reclaimed land, military training grounds, landfills, waste disposal sites, and other lands where rainfall and its associated overland flow cause soil erosion. RUSLE was first introduced in the USDA Soil and Water Conservation Service in 1993. RUSLE maintains the same empirically based equation as USLE to compute sheet and rill erosion as follows: A=RKLSCP where A is computed soil loss, R is the rainfall-runoff erosivity factor, K is a soil erodibility factor, L is the slope length factor, S is the slope steepness factor, C is a cover management factor, and P is a supporting practices factor.
- The major changes compared to USLE are in the values given for erosion as modified by vegetative cover and better calculations of the slope (LS) factors, as well as more advanced computerization. RUSLE gives more credit to the ability of surface residues to reduce erosion, as well as residues incorporated in the soil near the soil surface. Where USLE assumed that runoff was uniform over the catchment, RUSLE takes better into account that some runoff is channeled into rills and gullies. RUSLE also captures better than USLE that long rains can saturate the soil, leading to reduced intake and greater erosional runoff. In contrast with USLE, RUSLE can handle converging and diverging terrain and considers areas with net sedimentation.
- An additional change incorporated in the RUSLE is to account for rock fragments on and in the soil. Rock fragments on the soil surface are treated like mulch in the C-factor, while K is adjusted for rock in the soil profile to account for rock effects on permeability and, in turn, runoff.

There are many changes for estimating revised erosion universal by water soil loss equation in RUSLE, the changes include the following:

- Computerizing the algorithms to assist with the calculations.

- New rainfall-runoff erosivity term values (R) in the western United States, based on more than **1,200** gauge locations.
- Some revisions and additions for the eastern United States, including corrections for high R-factor areas with flat slopes to adjust for splash erosion associated with raindrops falling on ponded water.
- Development of a seasonally variable soil erodibility term (K).
- A sub factor approach for calculating the cover-management term (C), with the sub factors representing considerations of prior land use, crop canopy, surface cover, and surface roughness.
- New slope length and steepness (LS) algorithms reflecting rill to inter-rill erosion ratios..,..
- The capacity to calculate LS products for slopes of varying shape.
- New conservation practice values (P) for rangelands, strip-crop rotations, contour factor values, and subsurface drainage

Chapter 6: Sediment Measurement and Yield Prediction.

6.1. Introduction to Sedimentation

Sedimentation is the deposition of soil particles previously held in suspension by flowing water. The phenomenon of sedimentation takes place at those locations experiencing a reduction in the velocity of flow. Initially the larger particles settle out. As the flow velocity reduces further, the smaller particles settle, eventually, leaving only the clay sized particles, being the smallest, as the last to be deposited. Sedimentation can also occur in slower-moving, quiescent water bodies, or in treatment facilities such as storm water ponds.

Suspended material, particularly fine organic material such as organic silt, can have low total suspended solids (TSS) test values but high turbidity measurements. TSS is the mass of suspended solids per volume of water whereas turbidity is an indication of the ability of light to pass through the water. Both TSS and turbidity can have detrimental effects on an aquatic environment.

Clay particles will only settle out after extended periods of time due to their fine particle size and, the potentially, elevated pH of the water. As a result, settling by gravity alone is often ineffective for clay size particles.

6.2. Sediment Load Measurement

Usually the sediment transport is represented as the summation of the bed load and suspended load transport. Both stream flow and sediment concentration are continually changing. Stream flow is measured by making a discharge measurement. Suspended sediment, the kind of sediment that is moved in the water itself, is measured by collecting bottles of water and sending them to a lab to determine the concentration.

To measure the bed load transport, two measuring methods are available: simple mechanical trap-type samplers (collecting the sediment particles transported close to the bed) and the recording of the bed profile as a function of time (bed form tracking).

To measure the suspended load transport, a wide range of instruments is available from simple mechanical samplers to sophisticated optical and acoustical (electronic) sensors. Most instruments are used as point-integrating instruments which means the measurement of the relevant parameters in a specific point above the bed as a function of time. Some instruments are used as depth-integrating samplers, which means continuous sampling over the water depth by lowering and raising the instrument at a constant transit rate.

All instruments are described in terms of their measuring principle, practical operation, inaccuracy and technical specifications. To get a better understanding of the accuracy of the various instruments, special attention is given to comparative measurements.

Selection of sediment transport samplers

Guidelines for selection of sediment transport samplers

Guidelines for the selection of the most appropriate sampling technique for a certain environment are given, based on the following criteria:

- ✓ Type of process/parameters to be measured,
- ✓ Type of sampling environment,
- ✓ Type of sampling,
- ✓ Type of project and required accuracy,
- ✓ Available instruments and available budget.

The basic principle of mechanical trap-type bed-load samplers is the interception of the sediment particles which are in transport close to the bed over a small incremental width of the channel bed. Most of the particles close to the bed are transported as bed load but the sampler will inherently collect a small part of the suspended load (related to vertical size of intake mouth).

Popular instruments to sample bed load transport are bed load transport meter.

Sediment samplers

The basic principle of all mechanical bottle and trap samplers is the collection of a water-sediment sample to determine the local sediment concentration, transport and/or particle size by physical laboratory analysis.

6.3. Sediment Yield Prediction

Estimating soil loss from measurements of sediment movement in streams and rivers faces several problems. Taking the measurements is time consuming and expensive; the accuracy of the measurements is likely to be poor; and even if there are good data on the movement in a stream it is not known where the soil came from and when. However, it may be useful to be able to make comparisons of the movement in different streams, or at different times of year, or from watersheds under different land uses.

Sediment movement in streams and rivers takes two forms. Suspended sediment is the finer particles which are held in suspension by the eddy currents in the flowing stream, and which only settle out when the stream velocity decreases, such as when the streambed becomes flatter, or the stream discharges into a pond or lake. Larger solid particles are rolled along the streambed and called the bedload. There is an intermediate type of movement where particles move downstream in a series of bounces or jumps, sometimes touching the bed and sometimes carried along in suspension until they fall back to the bed. This is called movement in saltation, and is a very important part of the process of transport by wind, but in liquid flow the height of the bounces is so low that they are not readily distinguished from rolling bedload.

The relative quantities moved in suspension and as bedload vary greatly. At one extreme, where the sediment is coming from a fine-grained soil such as a wind-deposited loess, or an alluvial clay, the sediment may be almost entirely in suspension. On the other hand, a fast-flowing clear mountain stream may have negligible amounts of suspended matter and almost all the movement by rolling gravel, pebbles and stones on the streambed.

There are several sources of error associated with trying to correlate the amount of sediment measured in streams with the extent of erosion within the watershed.

Firstly, there may be significant amounts of erosion taking place which do not contribute to sediment in the stream because the eroded material is deposited before it reaches the stream. The proportion of sediment which does reach the stream compared with the gross sediment movement within the watershed is called the delivery ratio. It could be as low as 1% if there are depressions or heavily vegetated areas where most of soil would be deposited.

A second possible source of error is the time factor. In a larger watershed sediment may be eroded and deposited, then eroded again and redeposited, and this process could be repeated a number of times before the sediment reaches the stream. A sample of sediment could include material which had been originally eroded several years previously.

The third difficulty is that the sediment in the stream includes material which has come from several different sources with widely different delivery ratios. Sediment caused by the collapse of gully sides or river banks passes immediately into the streamflow, whereas soil lost from a small cultivated area within a dominantly forested watershed might have high local rates of erosion but contribute little to the total sediment load.

Estimating Suspended Load

Grab samples

The simplest way of taking a sample of suspended sediment is to dip a bucket or other container into the stream, preferably at a point where it will be well mixed, such as downstream from a weir or rock bar. The sediment contained in a measured volume of water is filtered, dried and weighed. This gives a measure of the concentration of sediment

Computer programs are now available for calculating the storage volume from the relationship of surface area to depth of water (called the stage/area curve), and the total weight of sediment can be calculated from the sediment volume and density.

Chapter7: Wind Erosion Prediction

7.1. Introduction

Wind erosion is the process of detachment, transportation, and deposition of soil material by the action of wind. It occurs almost in all parts of the world and is a cause of serious soil deterioration. Of course, there are conditions that favor the occurrence of wind erosion. These are:-

1. Loose (weak soil cohesive force)& finely divided dry soil;
2. with dry dispersible sand dominant soil;
3. Steady and strong prevailing wind at all levels, from the upper air to the ground level
4. Smooth and bare soil surface, with lowered surface roughness

The vulnerable regions for wind erosion are those with low mean annual rainfall, particularly less than about 250 to 300 mm (Arid and semiarid regions).

Table 7 Factors affecting wind erosion

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 • $CaCO_3$ concentration	• Residue 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

7.2. Mechanics of Wind Erosion

The occurrence of wind erosion could be described under following three different phases. These are

1. Initiation of soil movement
2. Transportation of soil particles and
3. Deposition/ settlement of the transported soil particles

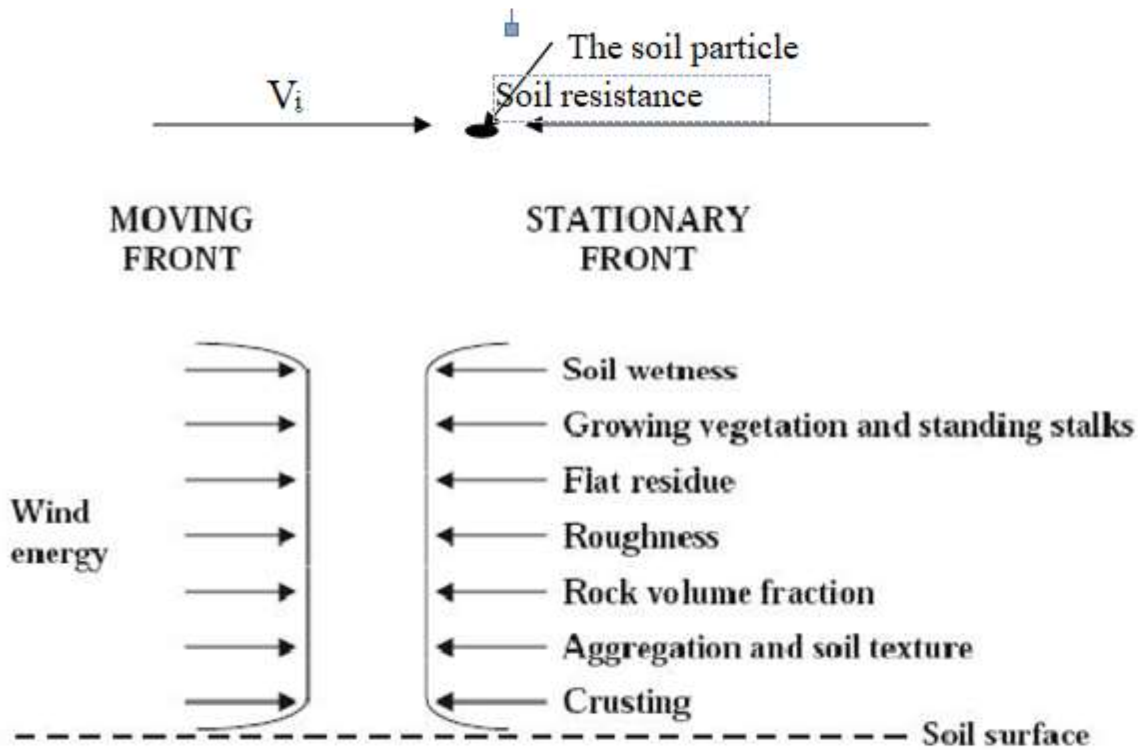

Figure 4 factors affecting wind erosion

Soil loss estimation due to Wind erosion

• Soil erosion by wind is initiated when wind speed exceeds the saltation threshold velocity for a given land surface condition, which is dependent on the erodible material and surface roughness. The duration and severity of an erosion event depends on the wind speed distribution and changes in the surface condition

Fluid threshold velocity:- is the minimum wind velocity required to initiate soil particle movement (detachment).

Impact threshold velocity:- is the minimum wind velocity required to move the soil particles

7.3. Factors that affect wind erosion

Climatic factors

The climatic factors that affect wind erosion include precipitation, humidity, wind erosivity, and temperature. Humidity, wind speed and temperature influence evaporation and transpiration of soil moisture, if they are high, they cause high evaporation that lead the soil to be more susceptible to wind erosion. The erosiveness of wind is determined by the wind velocity near the surface, wind turbulence, wind gustiness (rapid velocity increase), and wind direction (change in direction).

Soil factor

Texture, structure, density of particles, soil mass moisture, organic matter and surface roughness are the important soil factors affecting wind erosion. Surface roughness or crust has a retarding influence on the movement of soil by wind. Drier the soil more is the susceptibility for wind erosion.

Vegetation covers

Type of vegetation, the height of vegetation, density of vegetation and its seasonal distribution are some of the vegetation factors which influence the soil erosion by wind. The availability of wind breaks and shelter belts;

Mismanagement of land resources:- intensive farming, over grazing, deforestation, etc

The three types of particles movement/ Forms of wind Erosion:

A. Suspension, B. Saltation, and C. surface creep

Suspension: is the movement in which the finer particles (< 0.1 mm in dia.) are dislodged (removed) and remain aloft (up) for an extended period in the air stream.

Saltation: is the process where fine particles (0.05 to 0.5 mm) are lifted from the surface and follow some distinct trajectories under the influence of air resistance and gravity. When the Particles return to the surface, they may rebound or become embedded. Impacting the surface, but in either case, they initiate movement of other particles to create an avalanching effect of additional soil movement. Most saltation occurs with in 0.3 m of the surface.

Surface Creeping: is the movement of soil particles in which sand– sized particles or aggregates (0.5 - 2 mm), dislodged by the impact of saltating particles & wind force, rolls or creeps over the surface.

Wind Velocity distribution with height

Wind erosion is mainly a surface phenomenon and is influenced directly by wind velocity in various strata near the ground through which soil particles rise in saltation. Therefore, a brief discussion about wind structure near the ground would be necessary for understanding the mechanics of soil movement by wind. The surface wind is always turbulence.

Air movement of the free atmosphere is retarded near the surface of the ground. In immediate contact with the soil surface, the air is nearly at rest because of the drag force between the air and the ground surface.

7.4. Equations for Prediction of wind erosion

The wind erosion equation is not a simple product of erodibility parameters, but is a set of complex relationships among these parameters that affect erosion.

The present wind erosion prediction equation is:

$$E = f(I, K, C, L, V)$$

Where E = the estimated average annual soil loss (Mg/ha – year), weight of annual soil loss I = the soil erodibility index (Mg/ha –yr),

K = the ridge roughness factor,

C = Climate factor,

L = Unsheltered length of eroding field in meters, equivalent field length along the prevailing wind direction

V = Vegetation cover factor

This is the most widely used method for assessing average annual soil loss by wind from agricultural fields in the US and probably some other countries.