In the Name of God

Unit 3: Water Erosion

Importance of Soil

In any ecosystem, whether your backyard, a farm, a forest, or a regional **watershed**, soils have five key roles to play. *First,* soil supports the growth of higher plants, mainly by providing a **medium for plant roots** and supplying nutrient elements that are essential to the entire plant. Properties of the soil often determine the nature of the **vegetation** present and, indirectly, the number and types of animals (including people) that the vegetation can support. *Second,* soil properties are the principal factor controlling the **fate of water in the hydrologic system**. **Water loss, utilization, contamination, and purification** are all affected by the soil. *Third,* the **soil functions** as nature's recycling system. Within the soil, **waste products** and dead bodies of plants, animals, and people are assimilated, and their basic elements are made available for reuse by the next generation of life. *Fourth,* soils provide **habitats** for a myriad of living organisms, from **small mammals** and **reptiles** to **tiny insects** to **microscopic cells** of unimaginable numbers and diversity. *Finally,* in **human-built ecosystems**, soil plays an important role as an **engineering medium**. Soil is not only an important building material in the form of **earth fill** and **bricks** (baked soil material), but provides the foundation for virtually every road, airport, and house we build. For these reasons, we need to protect our soils against human and natural agents. Figure 1 illustrates these five roles of soils.

Soil Erosion

Soil erosion is a gradual process that occurs when the impact of water or wind **detaches** and removes soil particles, causing the soil to **deteriorate**. Soil deterioration and low water quality due to erosion and **surface runoff** have become severe problems worldwide. The problem may become so severe that the land can no longer be **cultivated** and must be **abandoned**. Many **agricultural civilizations** have declined due to **land and natural resource mismanagement**, and the history of such civilizations is a good reminder to protect our natural resources.

Erosion is a serious problem for productive agricultural land and for **water quality concerns**. Controlling the **sediment** must be an integral part of any **soil management system** to improve water and soil quality. **Eroded topsoil** can be transported by wind or water into streams and other **waterways**. Sediment is a product of land erosion and derives largely from **sheet and rill erosion from upland areas**, and to a lesser degree, from cyclic erosion activity in **gullies** and **drainageways.**

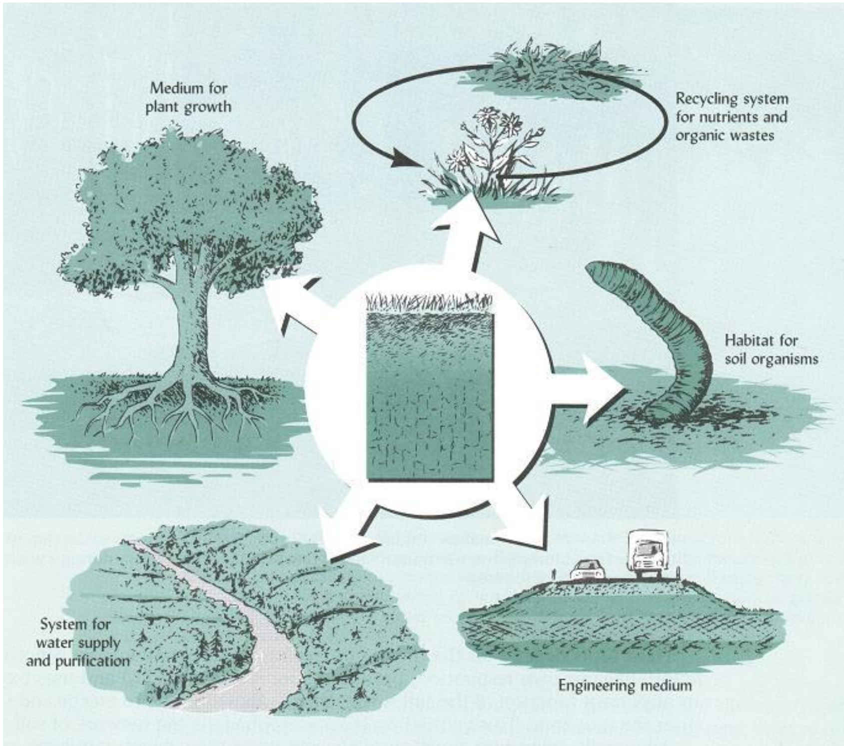

Fig. 1: Roles of soil in ecosystems

The impact of soil erosion on water quality becomes significant, particularly as soil surface runoff. Sediment production and soil erosion are closely related. Therefore, the most effective way to minimize sediment production is the **stabilization of the sediment source** by controlling erosion. Several conservation practices can be used to control erosion but first you need to understand the factors affecting soil erosion. Soil erosion is the detachment and movement of soil particles from the point of origination through the action of water or wind. Thus, minimizing the impact of water or wind forces is the main objective for erosion control. Water erosion is the most pertinent erosion problem in Iowa.

Mechanism of Soil Erosion

Soil erosion is a two-phase process consisting of 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 to transport the particles, a third phase, **deposition**, occurs (Fig. 2).

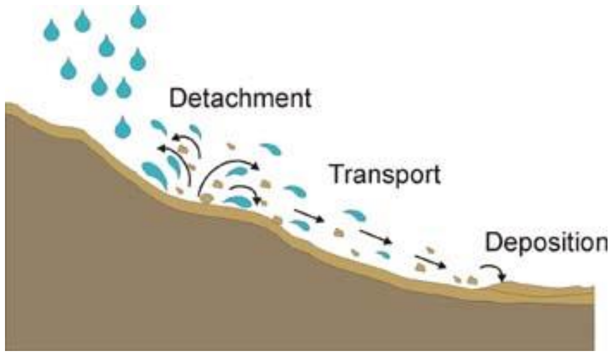

Fig. 2: Three phases of soil erosion by water

Rainsplash is the most important detaching agent. As a result of raindrops striking a bare soil surface, soil particles may be thrown through the air over distances of several centimetres. Continuous exposure to intense **rainstorms** considerably weakens the soil. The soil is also broken up by **weathering processes**, both mechanical, by alternate **wetting and drying**, **freezing and thawing** and **frost action**, and **biochemical**. Soil is disturbed by **tillage operations** and by the **trampling of people and livestock**. Running water and wind are further contributors to the detachment of soil particles. All these processes loosen the soil so that it is easily removed by the agents of transport.

The transporting agents comprise those that act areally and contribute to the removal of a relatively uniform thickness of soil, and those that concentrate their action in **channels**. The first group consists of rainsplash, surface runoff in the form of shallow flows of infinite width, sometimes termed sheet flow but more correctly called **overland flow**, and wind. The second group covers water in small channels, known as **rills**, which can be obliterated by weathering and **ploughing**, or in the larger more permanent features of **gullies** and **rivers**. A distinction is commonly made for water erosion between rill erosion and erosion on the land between the rills by the combined action of raindrop impact and overland flow. This is termed **interrill erosion**. To these agents that act externally, picking up material from and carrying it over the ground surface, should be added transport by **mass movements** such as **soil flows**, **slides** and **creep**, in which water affects the soil internally, altering its **strength**.

Types of Soil Erosion

Soil erosion can be broadly categorized into 1) **geologic erosion, normal erosion, or natural erosion** and 2) **accelerated erosion**. Geologic erosion is a natural process that wears down **topographic highs** (**hills and mountains**) and fills in **topographic lows** (**valleys, lakes, and bays**) through the deposition of eroded sediments. Geologic erosion occurs at a rate equal to the rate of **pedogenesis**. Accelerated erosion happens when this rate is much greater than the rate of soil forming, mostly due to **human activities**. Accelerated erosion can be further subdivided into several types as follows:

1- **Water erosion:** The main agent of eroding soil is the power of water.
2- **Wind erosion:** Wind plays the dominant role in transporting soil particles.
3- **Gravity erosion:** The earth materials are transported mainly by the force of gravity.
4- **Glacial erosion:** Glaciers erode soil and move it from a place to another place.

Water Erosion

Soil erosion by water occurs when bare-sloped soil surface is exposed to rainfall, and the rainfall intensity exceeds the rate of soil intake, or infiltration rate, leading to soil-surface runoff. Soil erosion can occur in two stages: 1) detachment of soil particles by raindrop impact, **splash**, or flowing water; and 2) transport of detached particles by splash or flowing water. Therefore, soil erosion is a physical process requiring energy, and its control requires certain measures to dissipate this energy. The hydrologic processes of rainfall and runoff play an essential role in water erosion. The amount and rate of surface runoff can affect erosion and sediment transport. Water erosion can be seen in different types. These are:

1- Raindrop erosion: **Splash erosion** is the detachment and airborne movement of small soil particles caused by the impact of raindrops on soil. The raindrop dislodges soil particles, making them more susceptible to movement by overland water flow. The loosened particles that are not **washed away** can form a muddy slick that clogs pores in the ground surface. The **sealed surface** further reduces infiltration and increase runoff. The magnitude of soil loss resulting from rain splash can best be seen on a **gravelly or stony soil**. Figure 3 shows how a raindrop impacts the surface of a soil and detaches aggregates and throw them away.

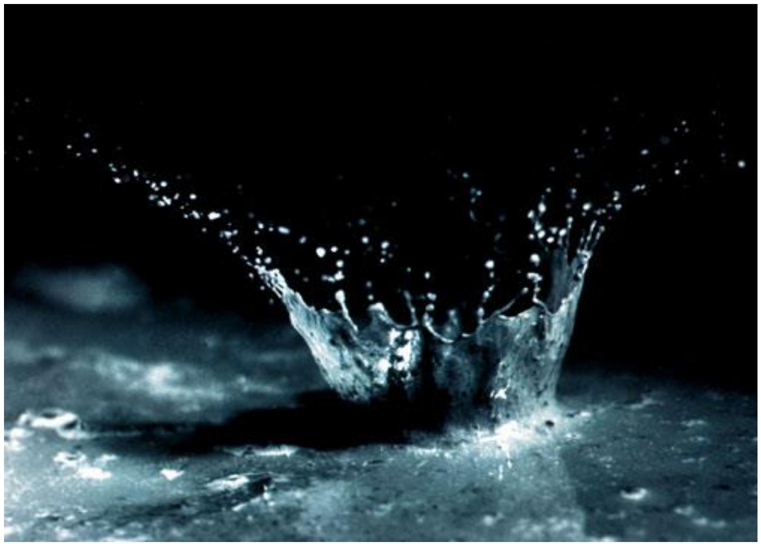

Fig. 3: Raindrop erosion

2- **Sheet erosion: Sheet erosion** is the detachment of soil particles by raindrop impact and their removal downslope by water flowing overland as a sheet instead of in definite channels or rills. The impact of the raindrop breaks apart the soil aggregate. Particles of clay, silt and sand fill the soil pores and reduce infiltration. After the surface pores are filled with sand, silt or clay, overland surface flow of water begins due to the lowering of infiltration rates. Once the rate of falling rain is faster than infiltration, runoff takes place. There are two stages of sheet erosion. The first is rain splash, in which soil particles are knocked into the air by raindrop impact. In the second stage, the loose particles are moved downslope by broad sheets of rapidly flowing water filled with sediment known as **sheetfloods**. This stage of sheet erosion is generally produced by **cloudbursts**, sheetfloods commonly travel short distances and last only for a short time. Figure 4 shows the symptoms of sheet erosion on slopes.

3- **Rill erosion: Rill erosion** refers to the development of small, **ephemeral concentrated flow paths**, which function as both sediment source and **sediment delivery systems** for erosion on **hillslopes**. Generally, where water erosion rates on disturbed **upland areas** are greatest, rills are active. Flow depths in rills are typically on the order of a few centimeters or less and slopes may be quite **steep**. These conditions constitute a very different hydraulic environment than typically found in channels of streams and rivers. Eroding rills evolve morphologically in time and space. The rill bed surface changes as soil erodes, which in turn alters the hydraulics of the flow. The hydraulics is the driving mechanism for the erosion process, and therefore dynamically changing **hydraulic patterns** cause continually changing **erosional patterns** in the rill. Thus, the process of rill evolution involves a feedback loop between flow detachment, hydraulics, and **bed form**. **Flow velocity**, depth, width, **hydraulic roughness**, local bed slope, **friction slope**, and detachment rate are time and space variable functions of the rill evolutionary process. Superimposed on these interactive processes, the **sediment load**, or amount of sediment in the flow, has a large influence on soil detachment rates in rills. As sediment load increases, the ability of the flowing water to detach more sediment decreases. Figure 5 shows rill erosion.

Fig. 4: Sheet erosion

Fig. 5: Rill erosion

4- **Gully erosion:** A gully is sufficiently deep that it would not be routinely destroyed by tillage operations, whereas rill erosion is smoothed by ordinary farm tillage. The narrow channels, or gullies, may be of considerable depth, ranging from 1 to 2 feet (0.61 m) to as much as 75 to 100 feet (30 m). Figure 6 illustrates gully erosion.

Fig. 6: Gully erosion

5- **Badland:** A **badlands** (also **badland**) is a type of dry terrain where softer **sedimentary rocks** and **clay-rich soils** have been extensively eroded by wind and water. It can resemble malpaís, a **terrain** of **volcanic rock**. **Canyons, ravines, gullies, hoodoos** and other such geological forms are common in badlands. They are often difficult to navigate by foot. Badlands often have a spectacular color display that alternates from dark black/blue coal stria to bright clays to red scoria. Figure 7 demonstrates a badland area.

Fig. 7: A badland area

Factors Affecting Water Erosion

The rate and magnitude of soil erosion by water is controlled by the following factors:

1- **Rainfall Intensity and Runoff:** Both rainfall and runoff factors must be considered in assessing a water erosion problem. The impact of raindrops on the soil surface can break down soil aggregates and disperse the aggregate material. Lighter aggregate materials such as very fine sand, silt, clay and organic matter can be easily removed by the raindrop splash and runoff water; greater raindrop energy or runoff amounts might be required to move the larger sand and gravel particles.

Soil movement by rainfall (raindrop splash) is usually greatest and most noticeable during short-duration, high-intensity **thunderstorms**. Although the erosion caused by long-lasting and less-intense storms is not as spectacular or noticeable as that produced during thunderstorms, the amount of soil loss can be significant, especially when compounded over time. Runoff can occur whenever there is excess water on a slope that cannot be absorbed into the soil or trapped on the surface. The amount of runoff can be increased if infiltration is reduced due to soil compaction, **crusting** or freezing. Runoff from the agricultural land may be greatest during spring months when the soils are usually **saturated**, snow is **melting** and **vegetative cover** is minimal.

2- **Soil Erodibility:** Soil erodibility is an estimate of the ability of soils to resist erosion, based on the physical characteristics of each soil. Generally, soils with faster infiltration rates, higher levels of organic matter and improved soil structure have a greater resistance to erosion. Sand, sandy loam and loam textured soils tend to be less erodible than silt, very fine sand, and certain clay textured soils.

Tillage and cropping practices which lower soil organic matter levels, cause poor soil structure, and result of compacted contribute to increases in soil erodibility. Decreased infiltration and increased runoff can be a result of compacted subsurface soil layers. A decrease in infiltration can also be caused by a formation of a soil crust, which tends to "seal" the surface. On some sites, a soil crust might decrease the amount of soil loss from sheet or rain splash erosion, however, a corresponding increase in the amount of runoff water can contribute to greater rill erosion problems.

Past erosion has an effect on a soils' erodibility for a number of reasons. Many exposed subsurface soils on eroded sites tend to be more erodible than the original soils were, because of their poorer structure and lower organic matter. The lower nutrient levels often associated with subsoils contribute to lower crop yields and generally poorer crop cover, which in turn provides less crop protection for the soil.

3- **Slope Gradient and Length:** Naturally, the steeper the slope of a field, the greater the amount of soil loss from erosion by water is. Soil erosion by water also increases as the slope length increases due to the greater accumulation of runoff. **Consolidation** of small fields into larger ones often results in longer slope lengths with increased erosion potential, due to increased **velocity of water** which permits a greater degree of **scouring** (**carrying capacity for sediment**).

4- **Vegetation:** Soil erosion potential is increased if the soil has no or very little vegetative cover of plants and/or **crop residues**. Plant and residue cover protects the soil from raindrop impact and splash, tends to slow down the movement of surface runoff and allows excess surface water to infiltrate.

The erosion-reducing effectiveness of plant and/or residue covers depends on the type, extent and quantity of cover. Vegetation and residue combinations that completely cover the soil, and which intercept all falling raindrops at and close to the surface and the most efficient in controlling soil (e.g. forests, permanent grasses). Partially incorporated residues and residual roots are also important as these provide channels that allow surface water to move into the soil.

The effectiveness of any crop, **management system** or protective cover also depends on how much protection is available at various periods during the year, relative to the amount of erosive rainfall that falls during these periods. In this respect, crops which provide a food, protective cover for a major portion of the year (for example, **alfalfa** or winter cover crops) can reduce erosion much more than crops which leave the soil bare for a longer period of time (e.g. **row crops**) and particularly during periods of high erosive rainfall (spring and summer). However, most of the erosion on annual row crop land can be reduced by leaving a residue cover greater than 30% after harvest and over the winter months, or by **inter-seeding** a **forage crop** (e.g. **red clover**).

Soil erosion potential is affected by **tillage operations**, depending on the depth, direction and timing of **plowing**, the type of tillage equipment and the number of passes. Generally, the less the disturbance of vegetation or residue cover at or near the surface, the more effective the tillage practice in reducing erosion will be.

5- **Conservation Measures***:* Certain conservation measures can reduce soil erosion by both water and wind. **Tillage and cropping practices**, as well as **land management practices**, directly affect the overall soil erosion problem and solutions on a farm. When crop rotations or changing tillage practices are not enough to control erosion on a field, a combination of approaches or more extreme measures might be necessary. For example, **contour plowing**, **strip cropping**, or **terracing** may be considered.

Erosion Rate

Although gullies can remove vast quantities of soil, gully densities are not usually greater than 10 $kmkm^{-2}$ and the surface area covered by gullies is rarely more than 15 percent of the total area. This results in a considerable contrast between the erosion rate for an individual gully and its contribution to the overall soil loss of an area. Rates of **headwall extension** can be very rapid for relatively short periods of time. Measurements on the Mbothoma Gully system, Swaziland, showed very rapid retreats of between 2.5 and 6.3 myr^{-1} from 1947 to 1961, followed by a slowing down to 0.13–0.51myr^{-1} for the period 1961–1980. A new gully opposite Mbothoma developed in the 1960s and up to 1990 eroded headwards at a rate of 14 myr^{-1}; the rate then decreased to 5 myr^{-1} between 1990 and 1998. Erosion from a gully developed on arable land near Cromer, Norfolk, England in 1975 was estimated at 195 t ha^{-1} and erosion from a winter runoff event in southern Norway in January 1990 exceeded 100 t ha^{-1} in many gullies. In gullies near Bathurst, New South Wales, soil loss from the side walls alone amounted to 1100 t ha^{-1} over a three-year period beginning April 1984. These figures contrast with annual rates for whole catchments for which typical figures include 3–5 t ha^{-1} for the gullied **watersheds** at Treynor, Iowa, 3–16 t ha^{-1} for the *lavakas* in Madagascar and 6.4 t ha^{-1} for a watershed near Gilgranda, New South Wales, of which 60 per cent came from gully heads. In a review of worldwide data, Poesen et al. (2003) showed that gully erosion can contribute between 10 and 94 percent of overall soil loss from an area, with values between 30 and 75 percent being typical. The contribution of gullies to total erosion is therefore not easily predictable. It depends on the characteristics of the storm, the topography of the catchment and the land cover at the time the storm occurs. In the 94-hectare Blosseville **catchment**, Normandy, France, a rain storm of 60 mm on 26 December 1999 with a maximum six-minute intensity of 55 mmh^{-1} caused erosion of 10 tha^{-1}. Some 93 per cent of the catchment had less than 20 per cent vegetation cover. Ephemeral gullies contributed 24 percent of the erosion. A 60 mm storm with a maximum six minute intensity of 105 mmh^{-1} in the same catchment on 9 May 2000 produced a much lower erosion of 1 t ha^{-1} because some 73 percent of the catchment had a **vegetation cover** greater than 60 per cent. However, 83 percent of the erosion occurred in ephemeral gullies.

Soil Erosion Consequences

Soil erosion costs the US economy between US$30 billion (Uri & Lewis 1998) and US$44 billion (Pimental et al. 1993) annually. The annual cost in the UK is estimated at £90 million (Environment Agency 2002). In Indonesia, the cost is US$400 million per year in Java alone (Magrath & Arens 1989). These costs result from the effects of erosion both on- and off-site.

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. If fertilizers were used to compensate for loss of fertility arising from erosion in Zimbabwe, the cost would be equivalent to US$1500 million per year, a substantial hidden cost to that country's economy. 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**.

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. Lal (1995) has estimated that global soil erosion releases 1.14 PgC annually to the atmosphere, of which some 15 TgC is derived from the USA. Erosion is therefore a contributor to **climatic change**, since increasing the **carbon dioxide** content of the atmosphere enhances the **greenhouse effect**.

The Prevention of Soil Erosion

The **prevention of soil erosion**, which means reducing the rate of soil loss to approximately that which would occur under natural conditions, relies on selecting **appropriate strategies** for **soil conservation**, and this, in turn, requires a thorough understanding of the processes of erosion. The factors that influence the rate of erosion may be considered under three headings: energy, resistance and protection. The energy group includes the potential ability of rainfall, runoff and wind to cause erosion. This ability is termed **erosivity**. Also included are those factors that directly affect the power of the erosive agents, such as the reduction in the length of runoff or wind blow through the construction of **terraces** and **wind breaks** respectively. Fundamental to the resistance group is the **erodibility of the soil**, which depends upon its mechanical and chemical properties. Factors that encourage the infiltration of water into the soil and thereby reduce runoff decrease erodibility, while any activity that pulverizes the soil increases it. Thus cultivation may decrease the erodibility of clay soils but increase that of sandy soils. The protection group focuses on factors relating to the **plant cover**. By **intercepting rainfall** and reducing the **velocity of runoff and wind**, plant cover can protect the soil from erosion. Different plant cover affords different degrees of protection, so that human influence, by determining land use, can control the rate of erosion to a considerable degree.

Top 10 Scientific Journals Publishing Articles Related to Water Erosion

1- *Journal of Hydraulic Engineering*
2- *Journal of Hydrologic Engineering*
3- *Hydrology Research*
4- *Journal of Environmental Quality*
5- *Catena*
6- *Agricultural Water Management*
7- *Journal of Soils and Sediments*
8- *Water Quality and Ecosystems Modeling*
9- *Water Resources*
10- *International Journal of Sediment Research*