Soil and Water Conservation

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Chapter 12

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Abstract

Conservation of soil and water resources is important for sustainability of agriculture and environment. Soil and water resources are under immense pressure due to ever increasing population thereby ensuing growing demand for food, fiber and shelter. Soil and water resources are being deteriorated due to different anthropogenic and natural factors. Soil erosion is one of the several major deteriorative processes which results in deterioration of the soil. Soil erosion is removal of soil due to movement of water and/or air. Soil erosion may lead to the significant loss of soil productivity and thus may lead to the desertification under sever conditions. Water and wind are the major agencies which are responsible of soil erosion. Deforestation, over-grazing, mismanagement of cultivated soils, intensive cultivation and intensive urbanization are major factors triggering the soil erosion. For sustainable agriculture and environment, it is pertinent for the protection of soil resources against erosion. Different control measures should be adopted to protect the soil resources against erosion. The concept of soil conservation cannot be materialized without conserving and efficient use of water resources. It is therefore pre-requisite that soil conservation practices should be adopted. Soil conservation practice include soil management, crop management, engineering, range management and forestry operation.

Keywords: Soil, Water, Erosion, Conservation, Management

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12.1. Introduction

Soil is the most fundamental resource to fulfill basic requirements of food, fiber and shelter of human race. The basis of all terrestrial life is soil although it is perceived as something of insignificant value and it is considered as dirt but humans cannot survive without soil. Soil provides a wide range of ecosystem services which are summarized in Table 12.1. Soil erosion is detachment and dislocation of soil due to the action of water or wind. Soil loss due to erosion has great consequences because it leads to loss of its productivity. Soil erosion occurs though out the world but it is a very common feature and more serious problem in dry areas. Soil erosion disturbs agricultural, environmental and ecological functions performed by the soil. Soil erosion results in depletion of soil fertility, decreased moisture storage capacity and consequently in decreased crop productivity. In addition to loss of soil fertility and crop yields, soil erosion also increases environmental pollution, increasing the sediment load in streams and rivers, thereby disturbing the aquatic life, particularly fish. In the long run, soil erosion affects socio-economic conditions of the society by causing floods, silting up of water reservoirs and disruption of communication systems. The soil covering the Earth surface has taken millions of years to develop. The rate of soil formation is very slow (during every 100 to 400 years, only 1 cm soil is formed) and the enough soil depth is formed in 3000 to 12000 years to have a productive land. Thus, when soil, a non-renewable natural resource is ruined then it will be lost entirely (Pimentel et al. 1995; Lal 2001). Globally, out of 22% of the land suitable for sustaining agricultural productivity, around 5 to 7 Mha are being lost annually due to land degradation, consequently, threatening food security of the world. Soil and water resources conservation and management is important for the welfare of the people.

Table 12.1 Ecosystem services provided by soils

Food security, biodiversity and urbanization	**Water quality control**	**Climate change mitigation**	**Energy resource**
Fiber Food Housing Recreation Infrastructure Disposal of waste Diversity of microbes Flora and fauna Conservation	Pollutants filtration Purification of water Retention of sediments and chemicals Chemicals buffering and transformation	CH_4 and CO_2 sinks Sequestration of Carbon in soil and biota Nitrification inhibitors Deposition and burial of carbon enriched sediments	Bioenergy crops (warm season grasses and short rotation woody crops Prairie grasses)

Source: Blanco and Lal (2008)

The demands of growing world population force the wise use and management of resources to meet the high demands of food production. If we will not realize the importance then there will be a time when we will not have enough soil left to support life on this planet, as the soil is an essential resource to support plants for producing food, and to provide shelter to insects and animals. Thus, it is important to consider soil as a living object. Soil and water conservation and sustainable use of these resources are not only crucially important to farmers but to the entire mankind for their sustenance. Sustainable agriculture, therefore, is dependent on conservation of water and soil resources through a variety of methods.

12.2. Soil Erosion

In agriculture, soil erosion refers to the removal of topsoil by the natural physical forces of water and wind at a greater rate than it is formed or through forces associated with farming activities such as tillage. Erosion removes the topsoil first and once this nutrient-rich layer is lost, the potential of soil to sustain plants is reduced. Without soil and plants the land becomes desert like and unable to support life. Soil erosion is a naturally occurring process that affects all landforms.

Soil erosion can be classified into two major types, i.e., accelerated and geological erosion. The normal process of weathering is geological erosion that usually happens as a part of natural soil-forming mechanisms at low rates in all soils. It is not affected by human activities as well as it happens at the period of long geological time. The processes influenced by the slow but constant geological erosion are the development and disintegration of rocks. On the contrary, in accelerated erosion, soil erosion becomes a main anxiety and a specific threshold level is exceeded by the erosion rate and soil loss through erosion exceeds the soil formation through pedogenic processes. Anthropogenic activities such as slash-and burn agriculture, intensive and uncontrolled grazing, deforestation and burning of biomass and intensive plowing are main factors which trigger accelerated soil erosion. The soil becomes less productive after the loss of fertile topsoil even by applying the same farm inputs. So, the control and management of soil erosion are essential. Although soil erosion cannot be eliminated but there are ways to minimize excessive erosion and its adverse effects on agricultural production. The extent and the effects of soil erosion on yield depend on soil profile development, terrain, soil management and climatic conditions.

When we consider the scenario of soil erosion in Pakistan (Table 12.2), the soil in the territory of Indus River are comparatively young and under the process of development and mountains in the region have sharp and long slopes in the world. Heavy rainfalls in the summer and snow melting in hilly areas aid to the soil erosion hazards. The major factors linked to soil and water erosion are management practices, vegetation type, soil type and soil structure. The northern hilly areas having steep slopes are less prone to water erosion due to presence of forests with permanently closed canopy but arable crops sown in steep slopes are more vulnerable to erosion. In Pakistan, water erosion affect the total area about 11 million hectares. Because of soil erosion in the upstream, land and water use efficiency decreases by the sedimentation in canal irrigation system in the plains. It is estimated that about 40 million tonnes of soil is brought into the Indus basin every year because of accelerated soil erosion in mountainous and sloppy areas and thus life span of major water reservoirs and their efficiency have been shortened. The productivity of area has been declined due to removal of top soil and destruction of upstream riverside infrastructure. In downstream, efficiencies of irrigation system and hydropower generation system have been reduced due to sedimentation.

Considering wind erosion in Pakistan, the sandy deserts of Tharparkar, Cholistan, Thal and sandy areas along Maekran coastal areas in Baluchistan are commonly degraded by the wind erosion. The areas near populated areas and watering points with free access to livestock are more vulnerable to wind erosion. The major factor of degradation in these areas is the over exploitation of rangelands by deforestation and livestock grazing. The worldwide effect of wind erosion is more dominant in the areas where sand dunes are leveled off for crop irrigation. Movements of sand dunes at a height of 0.5-4 meters are known to occur which possess threat to infrastructure and cultivated land. Wind erosion affected about the 3-5 million hectares of land. Only wind contributed the 28% of total soil loss in this area. Deposition of thick sand layers on roads, severe movement of sand dunes, croplands, railway tracks resulted by the fast moving wind storms that ultimately threaten the rural life as well as the communication systems. Detailed description of wind and water erosion is given below.

12.2.1. Water erosion

On global level, most severe type of soil erosion is water erosion. Detachment of soil particles from its original place due to movement of water is called water erosion. Water from runoff, rain, irrigation and snowmelt may contribute to soil erosion but rainwater is the major factor which causes the movement and detachment of soil particles. The transportation of soil organic and inorganic particles with the water flowing along the slope is subsequently deposited in surface water bodies and at lower landscape positions in water erosion. The new soil reservoirs, streams or simply fill lakes are formed from these transported materials. In humid and sub-humid areas of world which are characterized by repeated rainstorms, the dominant form of erosion is wind erosion. The same problem is noticed in the soil that is bare and have no vegetation like in the arid and semiarid regions that have limited precipitation in the form of intense storms (torrential rain). There are many types of water erosion: inter rill, splash, rill, gully, stream bank, and tunnel erosion. Inter rill erosion is also known as sheet and splash erosion, but these two differ in the underlying fluvial processes (Blanco and Lal 2008).

12.2.1.1. Raindrop or splash erosion

Raindrops strike the soil surface, scatter and then splash the soil by displacing particles from their original location. Splash erosion is initiated by hitting of the soil surface by the falling raindrops (Fig.12.1). Soil particles displace from their original position after the striking of raindrops that scatter and splash the soil. Falling drops initiate the splash erosion by hitting the soil surface. Splash of soil particles, depression formation, raindrop impacts are included in the process of splash erosion. (Ghadiri 2004). A raindrop-soil particle momentum is formed after the hitting of raindrops to the soil surface before discharging their energy in the form of splash. These raindrops form holes or cavities after hitting the soil like small bombs of different shapes and sizes. A function of raindrop size, shape and velocity is penetration and the depth of raindrop energy is equal to the holes depth (Blanco and Lal 2008).

Table 12.2 Area Affected by Wind and Water Erosion (000' ha)

Degree and Type of Erosion	Punjab	Sindh	KPK + FATA	Baluchistan	Gilgit-Baltistan	Pakistan
Wind erosion						
Slight	2251.4	295.0	13.1	36.0		2595.5
Moderate	279.1	70.2	3.8	143.6		496.7
Severe to very severe	1274.0	273.8	19.6	100.9		1668.3
Total	3804.5	639.0	36.5	280.5		4760.5
Water erosion						
Slight Sheet or rill erosion	61.2		156.3		180.5	398.0
Moderate Sheet or rill erosion	896.8		853.8	1805.0	25.8	3581.4
Severe Rill, Gully and/or stream bank erosion	588.1	58.9	1765.1	829.6	504.2	3754.9
Very severe Gully, Pipe and Pinnacle erosion	357.9		1517.0		1571.6	3446.5
Total	1904.0	58.9	4292.2	2634.6	2282.1	11171.8

Source: Ahmad et al. (1998)

12.2.1.2. Sheet/ inter-rill erosion

Immediately after the sheet/inter-rill erosion starts, runoff quickly forms small rills and part of the runoff flowing in between these rills is called sheet or inter-rill erosion. Shallow flow of water is the main reason of such type of erosion. Some soil particles in form of a thin sheet are moved away with the runoff and some settle in these small rills. The most common type of soil erosion is the sheet or inter rill erosion. About 70% of total soil is contributed by splash and inter-rill erosion and occur simultaneously with the splash erosion dominating during the initial process.

A function of rainfall intensity, field slope and particle detachment is inter-rill erosion. The gradual removal of entire field surface in more or less uniform way starts the sheet erosion. It is a gradual process and it is not immediately obvious that the soil is being lost.

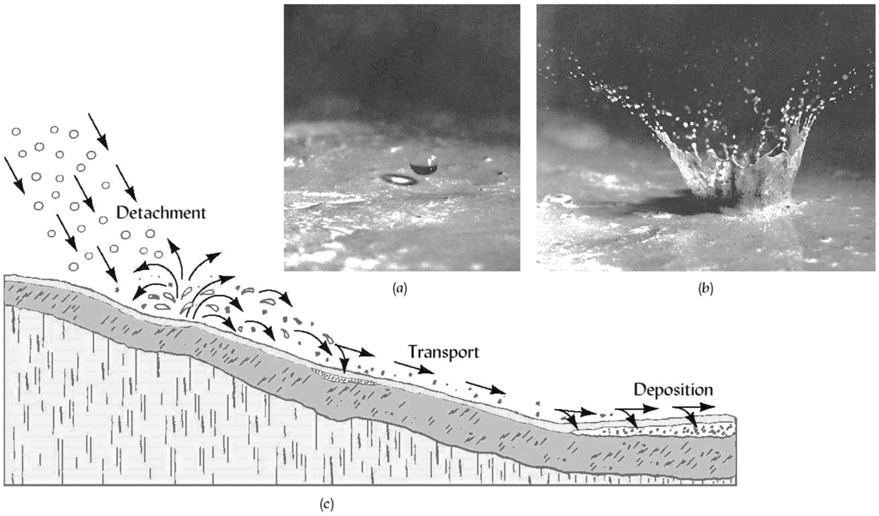

Fig.12.1 (a) Raindrop falling on the surface (b) Splash impact of raindrop (c) Process of water erosion (modified from Stitcher 2010)

12.2.1.3. Rill erosion (channel erosion)

The erosion occurs in small channels or rills is rill erosion (Fig. 12.2). It is due to rigorous rather than shallow flow. The soil is eroded more quickly in small channels by the runoff water than inter-rill erosion. The soil particles creeping and flow velocity along the rill bed widen the rills. The second most common form of soil erosion is rill erosion. The tillage operations can easily manage these rills but large soil erosion might be caused especially under heavy rains. In Pakistan, erosion found in the regions of Pothwar Plateau and western hilly areas is visible rill erosion.

12.2.1.4. Gully erosion

Formation of V- or U-shaped channels takes place in gully erosion (Fig. 12.3). These gullies are formed in form of small channels with 0.3 m depth and 0.3 m width. The concentrated runoff which is joined in lower slopes is the primary mechanism of formation of these gullies in the field. Concentrated flow erosion is a term that is used to describe the erosion occurring in these channels. When the water moves down the slopes in small channels, the uneven fields demonstrate the concentrated runoff in natural swales. The entire soil profile can also be removed in confined segments by continuous gully. Increase in gully growth increases sediment transport. Gully erosion can be permanent and ephemeral. The normal tillage practices can easily remove the ephemeral gullies that contain shallow channels. On the other hand, permanent gullies require expensive means of reclamation and control as these are too large to be corrected by regular tillage. The most common locations for gully erosion in Pakistan is Pothwar Plateau especially on loess soil.

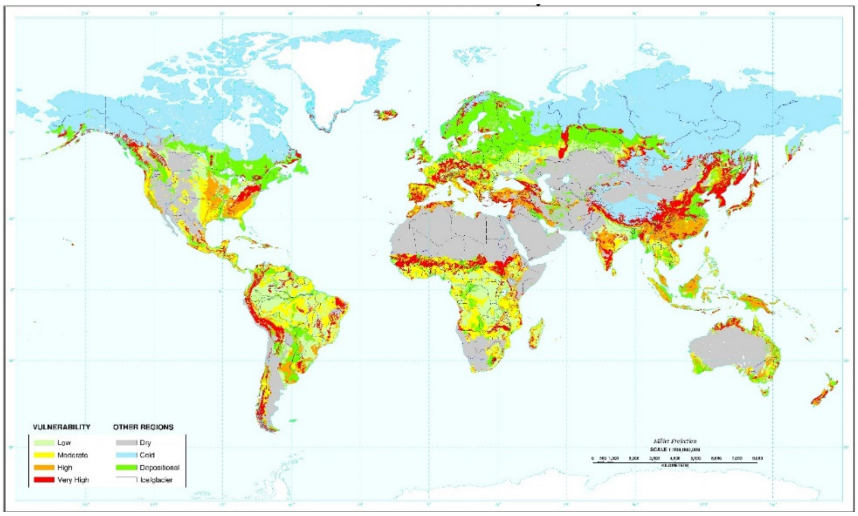

Fig.12.2 Global Water erosion vulnerability (USDA-NRCS 2003)

12.2.1.5. Tunnel erosion

The lands in arid and semiarid areas are highly erodible and sodic B horizon but have a stable A horizon and it is also known as pipe erosion. Tunnel erosion is initiated by the runoff in natural cracks and channels produced due to the movement of burrowing animals in subsoil layers. Due to tunnel erosion, geo-morphological and hydrological characteristics of the area are affected. These tunnels can be cured by deep ripping, repacking of soil surface, contouring, reduction of runoff ponding and diversion of heavy runoff. This type of erosion is also reduced by the revegetation that include tree and deep rooted grass species.

12.2.1.6. Stream bank erosion

In this type of erosion, breakdown of banks along streams, creeks, and rivers occurs due to the erosive power of runoff from uplands fields. Pedestals formation with fresh vertical cuts along streams is the reason of stream bank erosion. Exhaustive cultivation, grazing and traffic along streams, and presence of bare land accelerate stream bank erosion. This type of erosion can be reduced by planting grasses and trees, establishing engineering structures, mulching stream borders with rocks and woody materials, geo-textile fencing, and diverting runoff (Blanco and Lal 2008).

12.2.2. Wind erosion

Wind erosion occurs mainly in dry areas where soil surface is left bare. In dry regions, because of low rainfall, soil is too dry and flat to allow the wind to carry the soil away over several consecutive days. Mostly the material carried by winds contains silt-sized particles.

Accumulation of this material is named as “loess”. Normally, the areas where loess deposits are converted into soils are very fertile with deep soils. The thickness of recorded loess deposits ranges between 20 and 30 m, but it can be as thick as 335 m. Animals also play major role to cause erosion i.e. the upper part of soil is disturbed by the hooves of animals and as well as plant protective cover is removed when animals graze in land. The bare arable lands are also major problem leading to erosion.

Soil mismanagement is the key factor which results in excessive wind erosion and resulted in barren land in many arid regions. Anthropogenic activities such as deforestation and excessive tillage also lead to severe wind erosion. In arid and semiarid regions, the major factors of wind erosion are fast moving winds, low rainfall (≤ 300 mm annually), high evapo-transpiration, low vegetation and undeveloped soils. Rates of wind erosion in arid to humid areas of the world are in the order of: arid > semiarid > dry sub-humid areas > humid areas. Contrasting water, wind has the capability to transport soil particles up- and down-slope and can contaminate both air and water (Blanco and Lal 2008). Wind erosion is not only disturbing the properties and the processes of eroding soils but also is severely affecting the neighboring soils and landscapes where the deposition occurs. One of the dominant sign of wind erosion is the formation of sand dunes and some time these can be as high as 200 meters in deserts. Wind erosion can be classified into different types based on movement of soil particles.

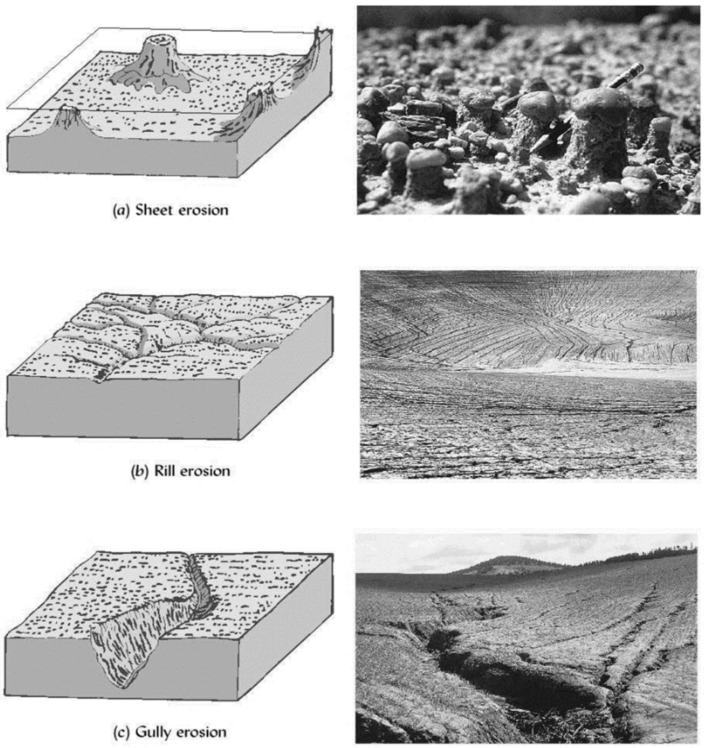

Fig. 12.3 Types of water erosion (a) Sheet erosion (b) Rill erosion (c) gully erosion Modified from Kilders (2015)

12.2.2.1. Suspension

The fine particles that are pushed upward into the atmosphere by strong wind and moved parallel to the soil surface have size of 0.1mm. This is exceptional erosion process because of which the fine soil particles can be conveyed high into the atmosphere and settle down again when the wind speed diminishes or brought around precipitation. The suspended fine particles can move to the hundreds of miles by wind.

12.2.2.2. Saltation

Soil particles dislodged with every impact and these moves along the surface of the ground by a series of short bounces. Some bouncing particles remain within 30 cm of ground surface mostly have the size of 0.1-0.5 mm. the 50 to 90% of the total soil movement by wind is accounted for this process that depend on the wind movement.

12.2.2.3. Soil creep

The soil particles along the surface of ground roll and slide. The bouncing effect of saltating particles is responsible for the movement of these particles. The total soil movement by wind is accounted 5 to 25% and soil creep having size of 0.5 to 1 mm in diameter can move comparatively large particles.

12.3. Causes of Soil Erosion

Soil erosion is influenced by political, economic, social conditions, climate, land use and management and topography. Poverty level directly relates with soil erosion in developing countries. There is no way to measure conservation practices for poor farmers that have limited or lacked resources. The risk of soil erosion is decreased by the elimination of implementing conservation practices and for year after year food production on small agriculture farms (0.5-2 ha) compels farmers to use over exploiting practices by Subsistence farming.

12.3.1. Deforestation

Energy fluxes, erosion control, moderation of climate and ecosystem stabilization are the essential ecosystem services provided by forest. Medications, wood, numerous other wood-based items and sustenance is also provided by wood. The major causes of denudation are urbanization, unnecessary logging and clear-cutting, construction of roads and highways, frequent fires and expansion of farming to marginal lands. As the human population continues to increase, there is a clear need for more food. In addition, the increases demand of agricultural products has created incentives to convert forests to farmland and pastures. Once a forest is converted to agriculture, usually gone forever, along with many of the plants and animals that once lived there. The land availability for agriculture or other uses is done by deforestation that causes the permanent destruction of forests. The land is swept into river by erosion without vegetative cover. So, the cycle of soil loss continues by the movement of farmers in the forest, clearing more forest as well as soil fertility is also lost.

12.3.2. Intensive cultivation

Industrial agriculture that is also termed by the intensive farming or cultivation is attributed by maximum use of inputs such as low fallow ratio, labor and capital per unit land. Higher yields are produced with the use of less land and less labor that capable the farmer by more intensive agriculture. But, blessing is not unmixed for the agriculture intensification. Human health and farm productivity is affected by increased environmental impacts by the potential degradation of water and soil resources. Even when there is not excessive soil erosion, soil quality can also be reduced by depletion in organic matter and natural supplies of trace elements as the result of intensive cropping. Wide range of plant and animal species maintain the fertility of soil with the diverse contributions and recycling of nutrients in natural ecosystem. When no fertilizers are used than some trace elements are depleted as a result of no diversity and rotation is replaced year after year by a single species grown. The organic content of the soil also decreased if there is no replacement of consumed nutrient over time when no crop residues or organic matter is added.

12.3.3. Overgrazing

In many livestock farms, the same piece of land for a long time is mostly concentrated by the herds of cattle and sheep. Soil displacement during traffic, repeated crushing or trampling and overgrazing is resulted by this confinement. Soil erosion on steeps slope or hillsides is increased when the protective cover is reduced by removing or thinning of grasses. Acceleration of water and wind erosion, degradation of soil structure and reduction in organic matter content of soil is resulted by overgrazing. Reduction in root proliferation and growth, soil compaction, drainage and water infiltration rate decreases by cattle trampling. Soil erosion in heavily grazing areas increase runoff by increasing stocking rate. Soil erosion is increased in wet and clayey soils by surface runoff and compaction on overgrazing lands. Siltation and sediment-related pollution of downstream water bodies also increase the soil erosion of pasture lands. Wind erosion is susceptible to increase soil erosion in surface soils that disintegrate the particles by animal traffic in dry regions. Flowing water and wind preferentially removed the detached fine particles of surface sand. Loss of topsoil and nutrients by the conversion of natural ecosystem that caused higher rates of erosion by increasing continuous grazing that initially damage the land. Wind and rain enabling erosion, ground cover and compaction of soil by overgrazing.so, water penetration and plant growth is reduced that is harmful to soil microbes and lead to soil erosion.

12.3.4. Cultivation of steep slopes

Raindrop is absorbed into soil pore spaces as it falls on the soil. When all the pore spaces are filled with water soil becomes saturated and extra water will either stand on surface or flow down as runoff. The moving water will flow soil particles away and starts the process of erosion. As the intensity of rain increases, the runoff increases and the force exerted on soil particles also increases. As the slope steepness increases, the velocity of runoff and force on soil particles also increases. The soils which have less or no vegetation on the surface are more vulnerable to erosion caused by flowing water. Amount of rainfall, slope steepness, vegetation and soil type are the major factors causing slope erosion. Terracing on the slopes decreases the erosion by decreasing speed of runoff and crops which require heavy irrigation i.e. rice can be grown on these terraces.

12.3.5. Soil mismanagement

The common cause of soil erosion is the expansion of agriculture on poor quality water irrigation, indiscriminate chemical input, and no vegetation degrade soils. Crop residues are removed for fodder and biofuel and industrial uses, this practice leaves the soil bared from protective cover below a critical level and soil becomes vulnerable to erosion. Runoff is increased by intensive cultivation causing soil erosion, and ultimately transporting nutrients and pesticides off-site and water and soil quality is reduced. When a eroded soil is left fallow to recover and new land is brought into cultivation, the erosion problem is worsened as during fallow period amount of dense vegetative cover is reduced.

12.3.6. Urbanization

There is significant effect of urbanization because most of the productive agricultural land near cities has been converted into residential and commercial area. As a result, agricultural area is decreasing which ultimately affects the farmer's income as the natural resources are also decreased. Despite decrease in agricultural land, the limited land is used intensively for cultivation which results in decreased soil fertility over the time.

12.4. Factors Determining Soil Erosion

Shear stress of runoff water and the critical shear stress of soil are the two major factors affecting gully erosion. Soil materials from the base and sides of channels by the shear stress of runoff are removed and transported to the small channels. Some of the important factors affecting soil erodibility are:

12.4.1. Slope

Slope is the major factor to control soil erosion. Length and steepness of slope are the main factors that affect soil erosion. As the steepness increases the erosion increases similarly, as the length of slope increases the eroded effect of running water increases. The water conservation practices such as terraces and buffer strips reduce the intensity of flowing water by reducing the slope. Runoff velocity of water and discharge is more from channels that have relatively more smooth surfaces. On the other hand, construction of water catchments and minimizing the soil slope reduces water runoff and thus decrease the erosion.

12.4.2. Soil structure

The arrangement or aggregation of soil particles is termed as soil structure. Intensive cultivation and large compaction results in deterioration of soil structure and particles binding and thus make them susceptible to erosion. Soil structure results from of symmetrical arrangements of soil particles, which keep pore spaces, micro and macro-organisms, and different sized aggregates, shapes and stability within a limit. The resilience of soil to erosion is largely depends upon its structure. The soils with poor structure more are weekly aggregated, easily compacted and have high runoff with low infiltration. The quantitative measurement of soil structure is difficult therefore water infiltration, air permeability, and soil organic matter dynamics are usually related to soil structure development. Measurement of properties of aggregate is also a helpful way if soil structural stability at the aggregate level determines the macroscale structural attributes of the whole soil to withstand erosion. There are numerous techniques for characterization and modeling of soil structure. Advanced techniques for soil structure modeling aim to capture the heterogeneity of soil structure and correlate these quantifications with various processes such as erosion. The focus on soil-based techniques, coupled with the characterization of aggregates, can provide additional insight into soil structure dynamics. Current technologies include tomography, neural networks and fractals. Tomography allows the investigation of soil interior architectural design and allows for three-dimensional visualization of soil structures. By using this method, the geometry and distribution of macro pores and microporous networks in the soil can be examined, which facilitates the flow of air and water. The use of neural networks is another way to observe the structural properties of the soil to conserve water, store organic matter and resist erosion. Soil debris and its sensitivity to soil erosion are controlled by fractal theory in the process of cultivation. This theory involves the study of the complexity of soil particle arrangement, tortuosity and soil pore abundance, which is the key to explain the process of water flow through the soil. These relatively new technologies can help quantify the structural properties of the soil.

12.4.3. Organic matter

The cementing agent that binds the soil particles together is the organic matter. Organic matter plays important role in soil erosion prevention. The fundamental source of energy for soil organisms is organic matter. It is both of animal and plant origin. Soil protection from compaction and erosion, improvement in soil structure, water and nutrient holding capacity increases and healthy communities of soil organisms are supported with the frequent addition of organic matter. Crop rotations that contains high plants residues, leaving crop residues in the field growing cover crops, using low or no tillage systems, mulching, growing perennial forage crops, using optimum nutrient and water management strategies for healthy plants production with large number of residues and roots, growing cover crops and applying compost or manure are the practices that increase organic matter addition in soils.

12.4.4. Vegetation cover

Loss of protective vegetation through fire makes, ploughing and overgrazing makes soil susceptible to being wash away by water and wind and to reduce erosion losses, the vegetative cover provides natural measure. The water is slowed down by the plants as it flows over the land and ground is soaked by allowing much of the rain to do this. Soil is prevented from being swept or blown away by the plant roots that hold the soil in place. Soil's ability to erode is reduced by plants that protect the soil from the abrasive effect of raindrops. The flow of water is slowed down by the plants in wetland and on the banks of river and the roots prevent erosion by binding the soil.

12.4.5. Land use

The best soil protector against soil erosion is grass due to its highly dense cover. The considerable obstruction to surface wash is small grains such as wheat. During the early stages of growth, little cover is provided by the row crops such as potatoes, maize that also encourage erosion. The areas that are most subjected to erosion are fallowed areas where entire residue has been incorporated into the soil and no crop is grown.

12.5. Soil Erosion Prediction

Soil losses from cultivated fields by sheet and rill erosion are predicting by Universal soil loss equation (USLE) developed by Wischmeir and Smith (1978). USLE considers all the variables as the soil erosion is influenced by several factors. Soil management by erosion losses reduce to permissible limits is done by information of USLE equation variables. In Europe and USA, this equation was successfully applied and validated in various fields. The equation is as follows

$$A=R\times K\times LS\times C\times P$$

Where

A = soil loss in metric tonnes per hectare (t ha^{-1})

R = rainfall and runoff factor or rainfall erosivity (j ha^{-1})

LS = slope length and steepness factor (compared to reference values of 22.6 m and 9%), dimensionless.

C = crop management factor – a ratio which compares soil loss from an experimental field with that from a field with standard treatment, dimensionless.

The soil loss in t ha-1 is obtained by multiplying all the variables

12.6. Soil Conservation Measures

Soil erosion is prevented by several agronomic and biological properties. Crop rotations, agro-forestry and soil synthetic conditioners, reduced tillage, riparian buffers, cover crops, vegetative filter strips, residue, canopy cover management and no-till are important among these. This Chapter discusses the importance of (1) soil amendments (e.g. manures) (2) soil conditioners (e.g., polymers) (3) crop residues (4) cover crops for soil erosion reduction. There are differences among these biological practices in relation to their mechanisms of erosion control. Biological measures such as buffers or thin films (e.g., conditioners), conditioner application in direct contact with the soil surface, crop residues using manure protect the soil from erosion. The raindrop is intercepted above the soil surface by the protective effect of canopy cover and standing vegetation reduces soil erosion. Growing vegetation produce the mulching effect.

12.6.1. Agricultural conservation measures

Contour cultivation, manuring, mulching and mixed cropping are included in these practices.

12.6.1.1. Crop management

Soil fertility is improved and wind and water reduce soil erosion by good crop management practices. Keep soil covered is fundamental principle of conservation agriculture. Soil protection from erosion by leaving crop residues on soil surface after harvesting is also helpful approach.

12.6.1.2. Crop selection

If the gap is too long between harvesting one crop and sowing of the next crop than the additional cover crops may be required. The stability of the conservation agriculture system is increased by cover crops and erosion impacts are reducing by the improvement of soil properties and this biodiversity in the agro-ecosystem are promoted for their capacity. The more effective crops in soil erosion are perennials than annual crops. The most effective are sugar cane, fodder grasses, sweet potatoes and tea.

12.6.1.3. Early planting

The protection of the ground against raindrop impact is ensured by the crop shoots from the ground within one or two weeks after the onset of the rains.

12.6.1.4. Crop rotation

The practice of growing a series of dissimilar types of crops in the same space in sequential seasons is crop sequencing or crop rotation for benefits such as such as avoiding pathogen and pest buildup that occurs when one species is continuously cropped. Soil nutrient depletion is avoided by the crop rotation that balance the nutrient demand of various crops. The replenishment of nitrogen with the use of green manure and legumes in sequence with cereals and other crops is a traditional component of crop rotation. Soil structure and fertility by alternating shallow-rooted and deep-rooted plants can also be improved by crop rotation. The multi-species cover crops between commercial crops is also another technique. The advantages of intensive farming with polyculture and continuous cover are combined by these techniques. So, soil fertility, reduction of diseases and pests, addition of humus and control of erosion is ensured by crop rotation.

12.6.1.5. Inter-cropping

The impact of raindrops is reduced with the soil cover by the fast-growing legumes such as cowpeas and beans early in the season before a canopy is developed by cotton or maize to shield the soil.

12.6.1.6. Cover cropping

The practice of growing crops to cover the soil surface to reduce wind and water erosion is called cover cropping. This practice creates a favorable habitat for microorganisms by regulating the soil heat and temperature. These also sources of organic matter in soil as the fallen are decomposed.

12.6.1.7. Strip cropping

This is the practice of growing different crops in alternate strips in the same field. It helps minimizing wind and water erosion. Crop rotation and minimum tillage in addition to contour strip cropping has proven to be best method to conserve soil and water.

12.6.2. Soil management

Soil conditions are often changed by the inappropriate land use practices which ultimately result in soil erosion. Optimum soil management aims to provide favorable conditions for plant growth through improved soil nutrient availability and aggregation. Optimum soil management practices improve infiltration of water and improve soil capacity to hold water and in result reduce runoff and erosion.

12.6.2.1. Use appropriate tillage practices

Optimum soil physical conditions for better crop production are the main objectives of tillage. It also ensures timely seedbed preparation, planting and weed control.

Tillage practices should be adopted by keeping in mind that;

- Soil is neither too fine nor powdery; and
- It breaks up the hardpan if necessary.

The main tillage methods are slash and burn, hand hoeing, ploughing and harrowing, conservation or minimum tillage, deep tillage.

12.6.2.2. Applying organic manures and mineral fertilizers

Application of manure and fertilizers provide essential plant nutrients in the soil for better crop growth. The crops with fast growth cover the soil quickly and give higher yields. Essential plant nutrients such as nitrogen, phosphorus, potassium, and sometimes Sulphur required by plants are provided by inorganic fertilizers. There is no substitute of inorganic fertilizers therefore integrated use of organic and inorganic fertilizers should be adopted. Farmyard manure, green manure and composts etc. are the main sources of organic fertilizers.

12.6.2.3. Mulching and the use of crop residues

Spreading on the bare soil surface or placement of plant materials such as dry grass, straw, dry leaves, banana leaves, sugar cane trash, and other crop residues around the stem of the plants is helpful in controlling soil erosion and moisture conservation.

12.6.3. Agro-forestry

Planting of trees or shrubs or protecting the naturally sustaining trees is called agroforestry. Trees decrease the magnitude of splash erosion by reducing the raindrops impacts on the soil. They regulate soil temperature by shading the soil thus reducing the water evaporation. They also minimize the wind erosion by acting as wind breaks. They also play important role in nutrient recycling in the deep soil; leguminous trees fix nitrogen that benefits food crops.

12.6.4. Contour farming practices

Cultivation across the slope rather than up and down is called contour farming. Soil loss as much as 50% has been reported to be reduced by contour farming on gentle. The main objective of contour ridges in semi-arid areas is water harvesting and in humid areas potato cultivation. Plant residues are placed in lines along the contour for construction of trash-lines. These trash-lines slow down the runoff and trap the eroded soil. Grass barrier strips of Napier or other fodder grasses are planted along the contour.

12.6.5. Physical soil conservation measures

Physical soil conservation structures are permanent features made of Earth, stones or masonry, designed to protect the soil from uncontrolled runoff and erosion and retain water where needed.

- Selection and design of structures depend on:
- Climate and the need to retain or discharge the runoff
- Farm sizes
- Soil characteristics (texture, drainage, and depth)
- Availability of an outlet or waterway
- Labour availability and cost
- Adequacy of existing agronomic or vegetative conservation measures.

Below are some of the physical conservation measures:

12.6.5.1. Cut-off drains

Cut-off drains are made across a slope for intercepting the surface runoff and carrying it safely to an outlet such as a canal or stream. Their main purpose is the protection of cultivated land, compounds, and roads from uncontrolled runoff, and to divert water from gully heads.

12.6.5.2. Retention ditches

These are made along the contours to capture and retain incoming runoff water and hold it until it seeps into the ground. They are alternate to cut-off drains when there is no channel to discharge the water nearby. Sometimes these are for water harvesting in semiarid areas.

12.6.5.3. Infiltration ditches

The structure used to harvest water from roads or other sources of runoff is infiltration ditches. They comprise dug along the contour, upslope from a crop field and a ditch of 0.7-1.5m deep. Water is blocked at the other end when it is diverted from the roadside into ditch and seep into soil after it is being trapped.

12.6.5.4. Water-retaining pits

Water-retaining pits allow runoff water to seep into soil after by trapping the water. The runoff normally occurs into a series of pits which are dug into ground. Banks around the pits are made by the soil from the pit. Excessive water carry from one pit to next by furrows. The amount of runoff determines the size of pit and its typical size is 2 m square and 1 m deep.

12.6.5.5. Broad beds and furrows

The runoff water is diverted into field furrows (30 cm wide and 30 cm deep) in a broad bed and furrow system. The lower end of field furrows is blocked. The water backs up into the head furrow after the filling of one furrow and flows into the next field furrow. Crops are grown on the broad bed furrows of about 170 cm wide between the fields.

12.7. Water Loss

Water loss to the atmosphere by two natural processes that are evaporation and transpiration. Water loss from soil surface by evaporation and from leaf surface by transpiration. Evaporation is the combination of evaporation and transpiration.

Physical characteristics of soil and water affect the evapotranspiration as well as density, type and rate of plant growth in the field. Some other factors like wind speed, solar radiation, rooting depth, season of year, availability of soil moisture and land surface characteristics. Evapotranspiration is mainly dependent on the solar energy that is utilized to vaporize the water when the water is available.

12.8. Water Conservation

12.8.1. Plant wind breaks

Wind velocity is reduced by windbreaks. Reduced wind velocity reduces the evapotranspiration rate in the area that is directly downstream of the barrier. 50 % porosity should present in wind breaks to slowed down the wind that passes through windbreaks as well as it is not deflected over the wind break. The direction of predominant wind is necessary to plant the wind breaks. A diversity of adapted species decreases the soil erosion by stabilizing the slope, decreases the risk of pest and disease problems and it provide shade for livestock. So, these provide better results. Minimized competition for water around the surrounding crops and irrigation would not be needed as much by drought tolerant species.

12.8.2. Keeping plant residues on the field

Wind speed over the soil surface is reduced by crop residues that also decreases evapotranspiration; soil temperature and moisture is also reduced as it provides shades by conserving soil moisture. So, crop residues act as wind breaks over the soil surface. The residues that are not break down or decompose readily are best. Crop residues should be partially removed for fodder or fuel use and if possible, it should be left standing in the field after harvest. To retain much of the plant residues in the field, the stubbles should be cut at high point in the plant during harvesting time. The soil loss and impact of raindrop also reduces by keeping crop residues in the field.

12.8.3. Choosing water conserving species

Too much high water utilizing crops like alfalfa cannot conserve water in the landscape. Generally, low biomass producing annual legumes like chickpeas and lentils are the crops that transpire the least amount of water.

12.9. Environmental and Agricultural Consequences of Soil Erosion

The valuable top soil is the most productive part of soil profile for agricultural purposes is removed by soil erosion. Production cost will be high and yield will decrease resulted by the loss of this top soil. Gullies and rills make the cultivation of paddocks impossible and these are produced by the erosion when the top soil is removed.

The long-term impacts of erosion on cropping lands include:

- Top soil that is rich in organic matter and nutrients is removed
- The depth of soil that is available for water storage for crop growth and for rooting is reduced.
- Increase runoff by reducing the infiltration of water into soil.

Short-term loss and increased costs can result from:

- Seedlings, fertilizers and pesticides, need to repeat field operations and loss of seeds.
- Erosion of soil from the roots
- Wind erosion blasted the young plants with sand
- Extra cultivations are needed to level out the eroded surfaces

Damage to the off-farm environment includes:

- Sediment deposition onto roads, in roadside drains and on neighbouring properties.
- Excess inputs of phosphorus, pesticides and nitrogen damage the quality of lakes, coastal water and watercourses.

- Spawning grounds of fish damage by sediments in rivers.
- Greater flood hazard downstream is caused by the deposition of sediment and increased runoff.

12.10. Recent Developments in Soil and Water Conservation

Substantial development has been made in emerging conservation techniques against erosion. A better understanding of factors, processes of soil erosion, causes and the related process are being investigated by the middle of 20th century. The magnitude of soil erosion risk is determined by the better understanding of the factors that establish more effective control practices in many regions of the world. The extent of soil erosion remains high in spite of these technological advances. The on- and off-site severe effects of soil erosion are stressed by conservation policies from 1980's. Soil erosion is reduced by the conservation practices as well as by adopting no-till farming. No-till farming is a practice of growing crops without turning soil. Better soil management are due to these efforts. The major problem is a water pollution with chemicals and sediments. USA and other developed countries have achieved significant improvements in soil and water conservation and these efforts are not reflected in those parts of the world where erosion possesses a great threat to food security. The integrated economic, political, social and agronomic approach are base to counteract the soil erosion by the more difficult measures of soil conservation. Soil erosion is a potential threat to environmental and agriculture sustainability and economically feasible, environmentally sound practices of soil conservation are the base of farming system. Soil management, type, climatic characteristics and ecoregion varies with the rate and magnitude of soil erosion. Soil erosion data is highly limited in less developed regions and estimates are particularly crude in degraded and erosion-prone areas. That's why some people think that soil erosion issue is exaggerated while according to others views soil erosion is a severe problem and possesses great threat to the stability of agricultural production. Implications of erosion are either under- or over-estimated when credible data on the rate of erosion and its impact are non-existent or limited (Blanco and Lal 2008).

12.11. Soil and Water conservation practices in Pakistan

Water conservation and reduction in water logging is managed by the by the consumptive use of water (CWU) for 19 crops in agro-ecological zones of Pakistan. Water scarce areas like DG Khan, Bahawalpur, Kohat, Balochistan and Attock had trickle irrigation systems. Rainfed ecologies were introduced with drip and sprinkler irrigation.

Increased use of ground water decreases the water logging and it also helps in lowering the groundwater table, much of the salts are leached down below the root zone as well as increased evapotranspiration. Crop yields and income increased with the installation of diesel and tube-well engine for the use of ground water by the farmers that were the drivers of this revolution. On-Farm Water Management Programme (OFWM) is to promote the efficiency in the distribution and use of water to some extent that have been operating in Pakistan from 1976. There are 86,000 watercourses remain to be attended and 21,000 have been brought under OFWM. The work through Water Users' Associations (WUAs) is the major achievement of OFWM. Farming community is totally involved in the renovation, post improvement maintenance of water courses as well as in their constructions. Trained and untrained labor with technical help is provided by the members of WUAs from the OFWM staff. Some of the costs involved is also borne by them. Sprinkler irrigation, lifting devices, mountainous regions and hydra dams are the water storage tanks that are constructed intimately for water management. The siltation decreases from 30 to 7 tonnes per acre foot of run-off in the Kanshi basin by the plantation of 5% of watershed with long rooted trees and grasses, construction of 350,000 mansonry check dams and 2,500 silt traps by Mangla Watershed Management Project that is under the Water and Power Development Authority (WAPDA). The life of Mangla Dam prolonged to 70 years by this project. Developed by PARC in collaboration with the International Center for Integrated Mountain Development (ICIMOD), the Sloping Agricultural Land Technology (SALT) for the Himalayan foothills of Pakistan was developed. Preservation of the soil fertility was the aim of this technology. Pakistan Agricultural Research Council (PARC) set up a model in the Pothowar Plateau of northern Punjab at Mungial (near Fatehjang) to develop the integrated land and water conservation approach.

According to the land capability for pasture, fruit trees, crops and other tree planting, the land area was used. The land was used to produce pastures, grasses forest trees and crops while its 4% of total area had grassed waterways of ponds and gullies. Without removing or disturbing the soil, the minimum required land-development operations were carried out. Erosion has been fully removed as well as gully have been completely reclaimed after 10 years. An appreciable wood is a source of handsome return that is produced by the harvesting of forest trees. The continuous source of income is fruit trees. Other farmers of the area inspired and got confidence from this model. The farmers can raise their income reasonably as well as make best use of degraded land by adopting this model.

The bed planting technologies for the major cotton wheat and rice wheat system of the country as well as zero tillage was developed by the Pakistan Agricultural Research Council (PARC) in collaboration with provincial research and extension system. Water resource conservations, crop stand establishment, fertilizer use efficiency enhance and germinating issues resolve by these technologies that significantly contributed in improving crop productivity.

The technologies related to sustainable high value crop production, increasing cropping intensity and moisture conservation were identified by the development of an integrated land use for Barani areas. The better crop production in rain-fed Pothwar by soil moisture conservation and land protection from water erosion is obtained from the low-cost water conservation structure technologies that was developed by the Soil and Water Conservation Research Institute. Other watershed management related projects presently under implementation in rain-fed areas consider these technologies in the up-scaling phase.

Water distribution structures for combating effects of cyclical droughts, for flood water diversions and also for increasing moisture availability were developed for rod-Kohi system agriculture (2 million ha). Reseeding of grasses like Symbo and Chryso species in Punjab and Balochistan provinces, V-shape plants rehabilitations structures, as ridge formation for shrubs establishments, the plantation of drought tolerant shrubs for winter grazing by the development of fodder reserves (Atriplex and Acacia species) are the micro-catchment water harvesting technologies that is included in the rangeland development technologies. The spread of these rangeland development technologies requires planned participatory efforts through social mobilization and community involvements and these are also still limited.

12.12. Conclusions

The growth of agriculture sector and rural livelihood depends on important natural resources like soil and water. High productivity goals and intergenerational food security is achieved critically by the conserving these vital natural resources. Overall improvement in ecological environment and sustained availability of the basic human needs for shelter, food and fiber is ensured by the optimal use of these resources. The basic factors causing soil erosion-induced degradation are wind and water erosion. Acidification, compaction and salinization are some other causes of soil degradation. The main causes of enhanced soil erosion are intensive cultivation, urbanization, overgrazing, poor management of arable soils and deforestation. Soil deserves more attention as it is being eroded faster than its formation. Agricultural productivity and environmental quality is sustained by managing and alleviating the off-site and on-site impacts of accelerated soil erosion. The livelihood of all inhabitants particularly in poor regions of the world is affected by the high cost of erosion. The global climate is affected by soil and soil maintains water resources clean as well as providing food security. Soil erosion is a major issue but the medium to store carbon globally and buffers water pollutant is soil. The regions where farmers are poor and the soil erosion is the major risk, the proper conservation policies implementation and the technologies must be done. Soil erosion is reduced and effectively stabilized in developed countries by the implementation of adequate conservation policies and programs but there is needed much more to be done. The poor farmers that do not have adequate resources to implement erosion control practices and mitigate the threat of soil erosion in developing countries require greater needs.

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