Soil Erosion: Causes, Extent and Management in India

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Abstract: Soil is a dynamic complex of minerals and organic matter supporting plants or having capacity to support plant growth. Soil formation is slow process and it is result of interaction of parent material, climate, biotic, slope and time factors. Soil is the most significant resource and provides base for life on earth. Soil erosion, on the other hand, is a very fast process. Soil erosion results into depletion and degradation of fertile productive base. Soil conservation and management is required to achieve the goal of sustainable development. The objectives of the present paper are: (i) to identify and describe the causes of soil erosion in India; (ii) to highlight the extent of soil erosion in India (iii) to mention the consequences of soil erosion; and (iv) to describe the measures to tackle the problem of soil erosion in India.

Key Words: Erosion, Ravines, Depletion, Extent, Conservation.

Soil Erosion: Definition and Causes

Soil erosion is a natural process associated with geomorphic processes or agents such as running water, winds, coastal waves and glaciers. Therefore it is occurring since time immemorial. But it has become a serious problem due to increased anthropogenic interferences over the period of time. Soil erosion represents the process of detachment and transportation of soil particles by geomorphic agents. Detachment is the dislodging of soil particles from the soil mass and transportation is movement of detached soil particles (sediment) from their original site.

Soil erosion in India is widespread and a serious threat to survival and well-being. It occurs in forest lands, arid and semi arid lands, agricultural lands, construction sites, roadways, disturbed lands, surface mines, glaciated and coastal areas and in areas where natural or geologic disturbances take place. In extreme case, it may lead to total loss of soil and exposure of the bed rock. Since soil formation is an extremely slow process, once removed completely, soil will take thousands or millions of years to form again and in the meantime land will be unproductive.

Among two main agents of erosion namely water and winds in India about 90 per cent role is played by water. In the case of erosion by water, soil particles are either detached by impacting raindrops or run-off water moving over soil surface. The high striking velocities (up to 9 m/sec) and large number of drops generate intense hydro-dynamic force to detach huge amount of soil particles. Overland flow detaches soil particles by erosive hydro-dynamic forces. The detachment by raindrops is widespread and by run-off generally confined to small definable channels. The rate of detachment varies due to variations in rainfall, run-off, soil characteristics, topography, and cover conditions. Therefore, climate, hydrology, structure, topography, soil surface conditions and interactions of all these major factors together determine the rates of erosion.

Water during heavy rains removes a lot of top soil. When rain drops strike the surface, sands and silts are detached from the soil body and it is called *splash erosion*. As rainfall continues, a large amount of water flows in the form of surface run-off which removes the top soil from a large area. This process is called *sheet erosion*. Due to higher velocity of the run off along areas of higher gradient and soft parent material, numerous finger-shaped grooves may develop all over the area. Such grooves or channels are formed on the surface where water flows rapidly, for example the water flowing down the edges of roads and embankments. This form of erosion is called *rill erosion*. These rills may deepen and enlarge into gullies if the erosion continues further. Extensive areas may be affected by gully formation and the whole area is turned into *badlands*. Gully erosion is result of lateral and vertical erosion of rills. Sandy soils are more prone to formation of gullies. Ravines of Yamuna and Chambal have been formed in this manner. Rate of soil erosion by running water depends on intensity of rainfall or in coastal areas waves, velocity and volume of water, gradient, sediment load, nature of rocks and extent of vegetative cover. The water erosion occurs through the processes of – solution or corrosion, abrasion, attrition and hydrolic pressure. In the coastal areas sea waves, tidal waves and tsunamis dash along the coast and cause heavy damage to soil. This is called *littoral erosion* and it is most intense along the Kerala coast. In the high altitude areas of the Himalayan region, glacial action causes soil erosion on a large scale.

Wind erosion is active in arid and semi-arid areas which are devoid of vegetative cover. Removal of soil particles by winds is called wind erosion. The wind erosion occurs through the processes of deflation and attrition. The rate of wind erosion is a function of wind velocity, dryness of soil, extent of vegetative cover and the particles size of surface soil. Higher the wind velocity, higher will be the rate of removal of soil. Dry soils and soils having no plant cover are also more prone to soil erosion. Also the finer textured soils are more prone to erosion than coarser materials. Soil erosion by wind erosion is common in Rajasthan and the adjoining areas of Haryana, Punjab and Gujarat.

In addition to action of water, winds and glaciers, human and animal interferences also lead to soil erosion in a variety of ways. Deforestation, overgrazing and faulty methods of agriculture contribute significantly to soil erosion. Trees and plants protect soil from erosion by binding the structure directly and by constantly adding moisture to it. Vegetation and litter from trees also acts as a cushion against splash erosion during rains. Therefore, deforestation invariably leads to soil erosion and floods. The large scale rill and gully erosion in the Siwalik foothills in Punjab leading for formation of *chos* and the ravines in Madhya Pradesh, Rajasthan and Uttar Pradesh formed through gully erosion are largely the result of reckless deforestation.

To estimate long-term soil loss based on considerable research data, Wischmeier and Smith (1978) developed the Universal Soil Loss Equation (USLE). The USLE is an empirical erosion model to predict long-term average annual losses of soil per unit area from sheet and rill erosion, under a specified cropping and management system.

The Universal Soil Loss Equation (USLE) is: $E = R \times K \times SL \times C \times P$ -------------------(1)

where, E = the soil loss in tonnes per hectare per year; R = the rainfall erosivity factor; K = the soil erodibility factor; S = the slope steepness factor; L = the slope length factor; C = the cover and management factor; and P = the support practice factor. In the following section all these factors are described with reference to India in terms of broad generalization about the factors associated with soil erosion.

Rainfall Erosivity Factor (R)

There is close relationship between erosion and rainfall intensity. The rainfall erosivity is expressed in terms of kinetic energy of rain. It is a function of its intensity and duration, and of the mass, diameter and velocity of the raindrops. Ram Babu et el. (1978) calculated the rainfall Erosivity Indices (EI), or R factor value of USLE, for different zones of India and prepared an iso-erodent map of the country based on data from 45 stations and computed values of 180 stations. The annual average EI values varied from 120 at Bhuj in Gujarat to 1457 in Mangalore at coastal Karnataka. The factors responsible for erosion are numerous and soil erosion is combined effect of all those factors. The generalizations on the basis of a single factor may not have the validity. For instance, the arid and semi-arid regions which receive low rainfall have poor vegetative cover and result into more soil loss per hectare than the humid or wet regions with highly erosive rains but well protected vegetative cover. Anthropogenic interventions also upset the natural interactions and management practices of the land also play a dominant role in determining the soil erosion rates.

Soil Erodibility Factor (K)

Soils differ in their susceptibility to erosion. Some soils are more prone to erosion whereas some are less prone to erosion. Soil texture, soil structure, organic matter, iron and aluminium oxide minerals and initial moisture content influence soil erodibility. Gurmel et el. (1981) computed the soil erodibility factor (K) for different sites in India. Red, laterite and black soils are relatively more prone to erosion. Recent deposits and soils with higher thermal ranges are more prone to erosion. Over the period of time depending on positive or negative anthropogenic interventions soil erodibility may decrease or increase. For instance, continued intense tillage practice reduces humus content and also breaks down soil structure and this is reflected in increased erodibility.

Topography: Slope Steepness (S) and Length of Slope (L)

Topography also plays a significant role in determining soil erosion. It is expressed in terms of slope steepness, slope length and shape. Generally, soil erosion is more on steep (S), long (L) and convex slopes. Topographic characteristics and geological structure play significant role in determining drainage network and sediment yields of watersheds.

Soil Surface Cover (C)

Soil surface cover includes plant canopy and crop residues like mulches. A good canopy or mulch cover significantly reduces soil erosion. The vegetative cover in contact with soil surface, such as grass, is most effective in checking soil erosion not only of raindrops but also of run-off. Erosion from a field is greatly influenced by type of crop cover, density and root system, water-use of plants and amount of prior crop residues in the tillage zone. These conditions vary within the life cycle of a crop in a particular field and are reflected in varying soil erosion rates.

Support Conservation Practice Factor (P)

Soil erosion also depends upon level, extent and types of the traditional and modern practices used to check soil erosion. The slope management practices such as contour bunding, check dams, contour tillage, strip cropping, shelter belts and terrace farming significantly reduce soil losses. Likewise the practice of spreading crop residue or mulching and managing waterways are also effective in soil and water conservation. The differences in erosion rates from terrace farms of Nepal and Sikkim and shifting cultivation slopes of North Eastern States is well documented. Therefore, anthropogenic interventions play a significant role in soil erosion.

Deforestation

Deforestation is considered as the most potent factor leading to soil erosion over extensive areas. Vegetation protects soil from erosion in a number of ways. First of all the plant cover interferes with rain drops falling from the sky and reduces their velocity thus reducing their physical impact on the soil. In addition the vegetative cover has cushion effect against the rain drops. Vegetation also retards surface runoff and enhances the rate of percolation, thus leaving lesser amount of water to flow as surface runoff. A close plant cover on the ground reduces the velocity of runoff thereby reducing its erosive capacity. The roots of the plants keep soil particles bound together making them less susceptible to erosion. Finally as the velocity of runoff is checked by plants, the soil particles being carried with water are deposited against the plants. Removal of natural plant cover implies loss of all these benefits and the rate of erosion is thus enhanced. Soils in many parts of India have suffered erosion due to deforestation. Large tracts of Himalayas and Central India have become prone to erosion due to loss of forest cover.

According to the Ministry of Environment and Forest report (1999) in the decade of 1980s the rate of deforestation was about 0.34 million hectare per year. The depletion and degradation of the natural woody cover of trees and shrubs is main cause for wind and water erosion. Population explosion, expansion of agriculture and settlements, expansion of transport network especially in mountain areas, mining and quarrying, timber, firewood and fodder extraction have resulted into impoverishment of forests. The actual extraction of timber far exceeds the permissible sustainable limits. Frequent forest fires, natural as well as anthropogenic, also result into forest and land degradation and are followed by increased soil erosion rates. Intense forest fires change the physical, chemical and biological characteristics of surface soils and result into depletion of soil by increasing soil erosion along with quality constraints in the form of reduced soil fertility.

Overgrazing

Overgrazing is also an important factor leading to soil erosion. Continuous grazing by animals on the same patch of land without sufficient recovery periods, leads to the removal of plant cover on a large scale. This makes it easy for the wind and running water to erode the soil. Overgrazing especially in arid and semi-arid regions over a period of time leads to soil erosion. Excessive grazing depletes the area not only of grasses but also of bushes and trees as the new plants are also grazed or uprooted by animals. The grazing animals also pulverize the soil by the hoofs and teeth, especially sheep and goats, and the soil thus loosened is easily washed away when heavy showers take place. Erosion due to overgrazing is very common over the hilly areas of Madhya Pradesh, Himachal Pradesh, Uttarakhand, Jammu and Kashmir and in arid and semi-arid areas of Rajasthan, Maharashtra, Karnataka and Andhra Pradesh. Due to livestock population pressure and inadequate grazing lands, overgrazing and over extraction of green fodder the physical deterioration of forest cover increases soil erodiblity.

Faulty Practices of farming

Much of soil erosion in India is caused by faulty practices of farming. The most outstanding among these are faulty ploughing, lack of mulching and above all the practice of shifting cultivation. One example of such practices is seen in the form of fields ploughed along the slope and not along the contours. This method of tilling the land provides readymade rills at the time of rain and the flow of water concentrates in the furrows made through ploughing. It increases the velocity of runoff thereby facilitating quick removal of soil. Contour ploughing, in contrast, provides a sequence of ridges and furrows to the water flowing over the surface and the velocity of runoff is thus retarded and lesser amount of soils is likely to be removed in such a situation.

Bringing land under steep slopes under cultivation is another major problem that leads to excessive soil erosion. It is primarily a result of increasing pressure of population on land and consequent increased demand for cultivable land. All types of areas are not suitable for cultivation. Generally the slopes with a gradient of more than 15 degrees should not be brought under cultivation and if at all cultivation is to be extended to such areas it should be done with suitable precautions like making of terraces. Very steep slopes cannot be cultivated even with terraces without harming soil. Increasing demand for agro-products has induced people to extend cultivation to such areas and it has led to severe soil erosion in such areas. Cultivation on steep slopes often leads to complete removal of soil and exposure of bedrock in hilly and mountainous regions. Soils in many parts of Himalayas and the hilly areas of Peninsular Plateau have been severely eroded due to faulty land use practices.

Under ideal conditions the agricultural residue should be left in the cultivated areas. Maintaining such a layer of plant residue is called *mulching*. Mulch, provides a cushion against splash erosion, retards the velocity of runoff and helps keep the soil bound and moist for longer duration by reducing rate of evapotranspiration. It also provides a cover over soil against wind erosion. Mulching is not practiced in most parts of India due to various reasons including using the agricultural residue as fuel, fodder and packaging material. As decomposition of mulch material is time taking process it is not popular among farmers because they have to use the field for next season crop. Crop residue burning is also commonly practiced though it is illegal. Hence the soils are more exposed to erosion by running water as well as wind.

Shifting Cultivation

Shifting cultivation is responsible for soil erosion in many tropical forest areas occupied mainly by tribal communities. It is also known as *slash and burn* cultivation. Under this practice, a piece of forest land is cleared by slashing and burning of trees and plants to cultivate crops without use of manure or fertilizers. The soil becomes sterile after a few years and weeds also start overtaking this land. The farmers then move to another area and clear a new patch off forest to repeat the practice. After a gap of 10-15 years they may return to these fields in a cyclic manner. Since land is cleared in a reckless manner by burning the vegetation and no steps are taken to protect the soil, intensive erosion often sets in as these regions receive copious rainfall. Due to increase in population pressure the areas and frequency of shifting cycle has increased and it is reflected in increased soil erosion rates and reduction in biodiversity. This practice has been common in the northeastern states of Arunachal Pradesh, Nagaland, Meghalaya, Manipur, Mizoram, Assam and Tripura where it is called *jhoom*. This mode of cultivation is a serious menace in the hilly and tribal areas of Madhya Pradesh, Chhattisgarh, Odisha, Andhra Pradesh and Kerala. Efforts are now being made to wean people away from this type of cultivation.

Extent of Soil Erosion in India

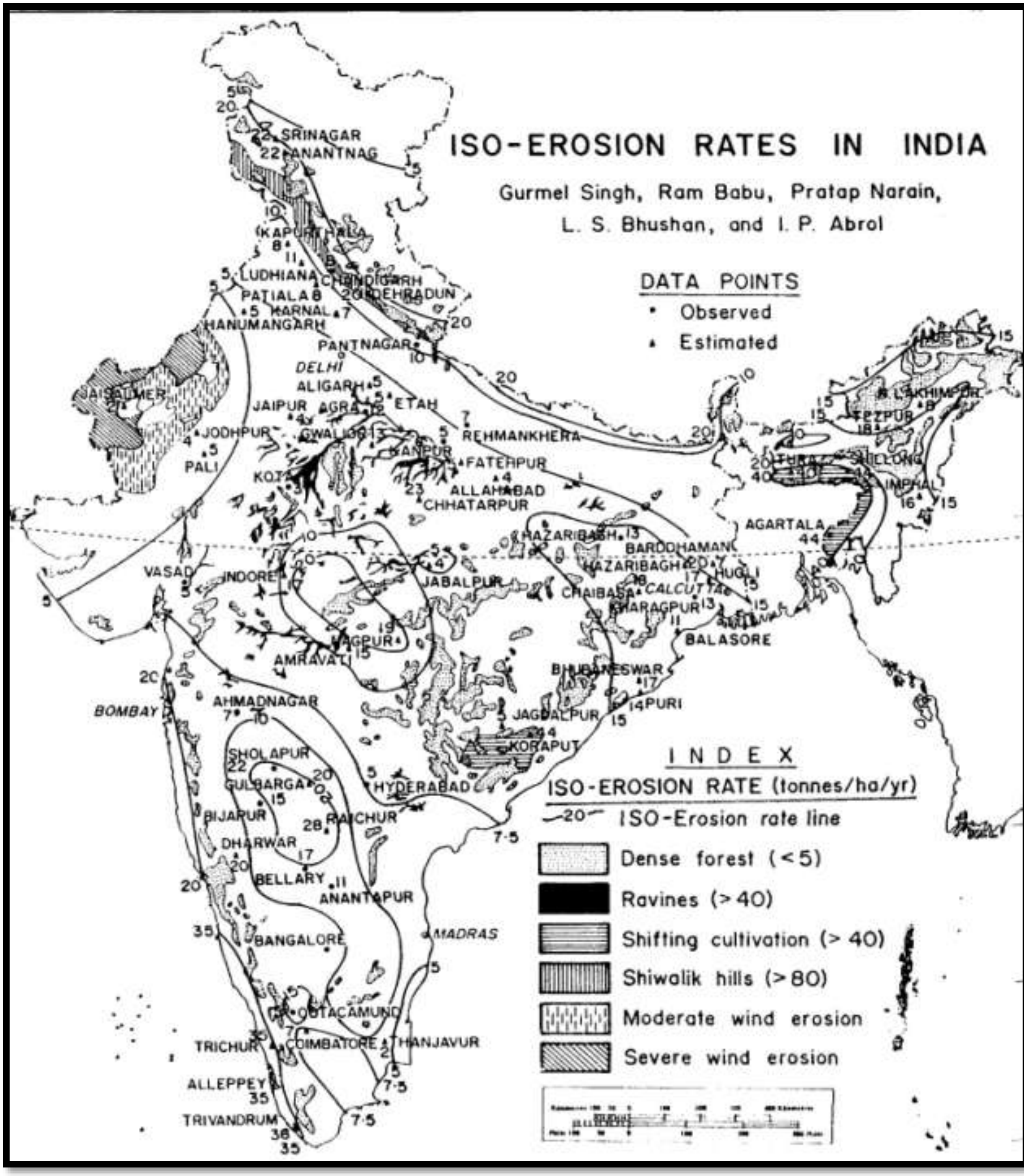
A lot of research work has been conducted on the extent of soil erosion in India but the final figures vary from study to study (Table 1). On the basis of analysis of existing data on soil loss, as a first approximation, Narayana and Ram Babu (1983) concluded that in India soil is eroded at an average annual rate of 16.35 tonnes per hectare which means 5334 million tonnes per year for the country as a whole. Out of this, about 29 per cent is permanently lost to the sea, nearly 10 per cent is deposited in reservoirs (which mean the storage capacity is reduced by 1-2 per cent annually) and the remaining 61 per cent of the eroded soil is merely shifted from one site to another.

Table 1: Estimates of Extent of Soil Erosion in India

Studies	Area (million hectares)
National Commission on Agriculture (1976)	150.0
Sehgal and Abrol (1994)	162.4
Sehgal and Abrol (1997)	167.0
The National Bureau of Soil Survey & Land Use Planning (NBSS & LUP, 2005)	119.19

Gurmel Singh, Ram Babu, Narain and others (1990) estimated that the average annual soil loss is about 15.2 tonnes per hectare and at national level it amounts to about 4978 million tonnes annually. The annual erosion rates vary from region to region. In dense forests covers, snow-clad cold deserts and arid regions of western Rajasthan the annual erosion rates are less than 5 tonnes per hectare. On the other hand, about 64 per cent of the total soil is contributed by highly to very severely eroded areas, such as the Shiwalik hills (annual rate is more than 80 tonnes per hectare), the Western Ghats, black and red soil regions, ravines and other gully eroded areas and the northeastern region. On the basis of iso-erosion lines i.e. line joining the place of same erosion rates map of soil erosion in India was prepared by these scholars for the first time (Figure 1). The soil erosion data was tabulated according to level of soil erosion (Table 2).

Figure: 1. Soil Erosion in India



Source: http://www.ciesin.columbia.edu/docs/002-413/fig1.gif

Table: 2. Levels of Severity of Soil Erosion in India

Severity of Erosion	Annual Soil Loss Range (tonnes per hectare)	The Share of Total Affected Area (%)	Annual Loss of Soil (million tonnes)
Slight	≤ 5	24	401
Moderate	5-10	43	1406
High	10-20	24	1610
Very High	20-40	5	640
Severe	40-80	3	666
Very Severe	≥ 80	1	255
Total			4978

Source: Singh, G (1990).

Sehgal and Abrol (1994 and 1997) estimated that water and wind erosion in India extends over about 162.4 (1994) and 167.0 (1997) million hectare area and out of this about 91 per cent is water eroded area. Deforestation, overgrazing, extension of agriculture to marginal areas, road construction, land use changes and unscientific cultivation practices were identified as major factors for accelerated water and wind erosion. Sandy soils with limited organic matter and moisture are vulnerable to strong winds in arid and semi-arid regions of India. Wind erosion dominates in arid and semi arid regions of hot desert of India and its peripheral parts, cold deserts regions of Leh and in coastal areas. Nearly 13.5 million hectare area is affected by wind erosion. The National Bureau of Soil Survey & Land Use Planning (NBSS & LUP, 2005) reported about 119.2 million hectare area suffering from soil erosion in India. The latest study by NRSA (2014) reflects that pattern of soil erosion in India based on interpretation of satellite imageries has great similarity with studies conducted by scholars in past without using satellite imageries. The water eroded areas are most widely distributed. The severe wind eroded area lies in the extreme western sectors of the country.

Consequences of Soil Erosion

Soil erosion is a serious menace. It has direct adverse affect on primary sector and indirectly affects the whole economy. The consequences of soil erosion are severe on the site as well as off the site. The loss of top layer is not only quantitative loss but also qualitative loss of productive base. It results into depletion and degradation of soil resource. Loss of soil quantity and fertility results into fall in agricultural production and productivity. According to Prof. S.P. Chatterjee, "Soil erosion is the greatest single evil to Indian agriculture and animal husbandry." Excessive erosion transforms fertile soils into wastelands. In addition the nutritional loss is also a huge economic burden. This way directly or indirectly the whole economy suffers.

Different crops vary in their response to soil erosion due to variations in their rooting patterns and soil layer thickness. For instance, the loss of productivity is maximum in case of groundnut and minimum in cotton crop and shallow soils suffer more than deep soils. The productivity of crops is reduced in the range of 5 to 50 per cent by soil erosion depending on the severity level of soil erosion. According to Sehgal and Abrol (1994) water induced soil erosion reduces soil productivity in the range of 12 per cent in deep soil to 73 per cent in shallow soils and loss is more in red and black soils as compared to alluvial soils. The annual loss in output of main crops in India because of soil erosion has been estimated to be 7.2 million tonnes by UNDP, FAO and UNEP (1993) and 13.5 million tonnes or 3.1 per cent of total production of major crops by Bansil (1990) and 4 to 6.3 per cent of annual agricultural production in a World Bank study by Brandon, Hommann, and Kishor (1995). Even these estimates are undervalued because productivity losses are not confined to one agricultural year but are cumulative losses over long period of time. Reddy (2003) on the basis of analysis of various data estimated that the range of loss in terms of replacement cost range from 1 to 1.7 per cent of GDP.

Soil erosion also results into loss of nutrients and/or organic matter. About 3.7 million hectare land suffer from nutrient loss and/ or depletion of humus or organic matter (Sehgal and Abrol, 1994). At country level, according to CSWCRTI, ICAR the loss due to soil erosion is estimated to be of nearly 74 million tonnes of major nutrients per year. As about 61 per cent of the eroded soil is merely shifted from one place to another, the effective soil loss is only 39 per cent. Therefore, there is loss of 0.8 million tonnes of nitrogen, 1.8 million tonnes of phosphorus and 26.3 million tonnes of potassium every year. Soil erosion is thus a menace which adversely affects agricultural production and productivity and creates not only food insecurity but insecurity for the whole economy.

Siltation is a major off site consequence of soil erosion. Siltation in rivers, canals, tanks and reservoirs reduces their water holding capacity. All studies have reported much higher rates of siltation in reservoirs than estimated at the time of designing of river valley projects. This has drastically reduced the life span of these long term projects to medium term and associated reductions in cost-benefit analysis. For instance, the rate of siltation in the Mayurakshi reservoir is 20.09 tonnes/ha/year against the pre-project estimates of 3.61 tonnes/ha/year (Bali, 1994).

Siltation reduces the water holding capacities of rivers, canals, tanks and reservoirs. It reduces the power and irrigation potential of reservoirs. Soil erosion results into decrease in soil moisture and decline in ground water table. Further, soil erosion increases the frequency and intensity of landslides, floods and droughts. The siltation in river beds results into formation of braided streams such as in the middle and lower courses of the Brahmaputra, Ganga and Kosi rivers. The deposition of silt in river beds and formation of sand barriers or river islands within river bed not only reduces the water holding capacity of rivers but also obstructs free flow of water and result is over flow or breaking down of banks or embankments and resultant flooding.

Management of Soil Erosion

Soil is most precious asset of nature as it is essential for all life on earth. Only a productive soil base can ensure prosperous agriculture which in turn forms the basis of economic advancement and a higher standard of living in a society. Conservation and management of soils, therefore, is necessary to make economic development a sustainable process. Soil conservation includes all such measures that help in protecting the soil from erosion and exhaustion. There are numerous methods that can be adopted for conservation of this vital resource. Since the causes of soil erosion differ from one area to the other, different measures need to be adopted to combat the problem in different areas. Some of the important methods include contour tillage, contour bunding, construction of check dams, terrace farming, checking the extension of gullies, strip cropping and shelter belts, afforestation, ban on shifting cultivation, controlled grazing, mixed cropping, mixed farming, rotation of crops and mulching.

Contour tillage is the practice of ploughing the fields along the contours and not along the hill slope. It leads to formation of ridges and furrows against the direction of flow and reduces the velocity of water. It also increases the infiltration of water into the soil and more absorption by plants. Thus the total amount of runoff is also reduced. Contour bunding also works in a similar manner. Check dams help not only in reducing the velocity but also the overall amount of water lost as runoff. It thus contributes to not only soil conservation but also to water conservation.

Strip cropping implies growing of crops in strips parallel to one another. While some strips may be allowed to remain fallow at a time, others might be under a crop. Some of the strips may be used for raising tree crops too. The trees or tall crop strips act as wind breaks or shelter belts. As different crops are harvested at different times, only a limited area is left bare or exposed to soil erosion at a time. Adjoining strips to such areas are at that time under a crop or tree cover thus providing protection to even the bare strip from erosion.

Efforts should also be made to reclaim lands where soil erosion has been severe and the soil depth has been reduced. Such areas should be planted with suitable species of plants that can help in ecological recovery of the degraded areas. This measure can also help in stabilizing gullies and at least a part of the area under badlands can thus be recovered.

The Government of India realized the significance of soil and water conservation with the beginning of planned development era. During the First and Second Five Year Plans, a chain of Soil Conservation, Research, Demonstration and Training Centres was established. These centres were later on transferred to ICAR in 1967 and ICAR combined these Research Centres and established the Central Soil and Water Conservation Research and Training Institute (CSWCRTI) with the headquarter at Dehradun, in 1974.

Majority soil erosion control and prevention in India is focused on watershed management approach. In 1962 Soil Conservation in the Catchments of River Valley Projects (RVP) was started. The scheme aims at controlling the premature siltation of reservoirs, enhancing productivity of catchment areas, through integrated planning of watersheds by appropriate measures such as vegetative hedges, contour/graded bunding, agro-forestry, horticulture plantation, silvi-pastoral development, pasture development, afforestation etc. only very high and high categories of watersheds identified by All India Soil and Land Use Survey Organization (AISLUSO) are taken for treatment under the scheme.

The scheme 'Integrated Watershed Management in the Catchments of Flood Prone Rivers' (FPR) was launched in 1982-83 and is, currently, the scheme is being implemented in 291 watersheds of 8 catchments located in 8 States. The motive is to reduce floods frequency and extent by controlling soil erosion in the catchments of flood prone rivers. In the Fifth Drought Prone Area Programme (DPAP) and Desert Development Programme (DDP) were also implemented on the basis of watershed approach with focus on soil and water conservation. In 1990-91, the National Watershed Development Programme for Rainfed Areas (NWDPRAs) and the Integrated Wasteland Development Project (IWDP, 1995) focused on sustainable utilization of soil and other resources.

The National Bureau of Soil Survey & Land Use Planning and the Central Soil and Water Conservation Research and Training Institute, the ICAR, the All-India Soil and Land Use Survey and NRSA are engaged in preparing soil erosion maps at watershed level, state level and country level to address properly the issue of soil erosion and its management.

Conclusion

Soil erosion in India is result of interplay of physical and anthropogenic factors. Climate, hydrology, structure, topography, soil surface conditions, land use and land cover changes and interactions of all these major factors together determine the rates of erosion. Water erosion is widespread over all regions but wind erosion dominates mainly in the western part of the country. The average annual soil loss is about 16 tonnes per hectare or about 5 billion tonnes annually. Soil erosion has serious on site and off site impacts for the whole economy. Soil erosion results into siltation in reservoirs, tanks and rivers. The depletion and degradation of soil base due to erosion is reflected in reduced agricultural production and productivity. To assess the extent of soil erosion over time and space more frequent and standard data base is required. The watershed management approach is most common practice to control and prevent soil erosion in India. To achieve the goal of sustainable development soil conservation and management is pre requisite.

References

1. Bansil, P.C. (1990) Agricultural Statistical Compendium, Vol.1, Techno-economic Research Institute, New Delhi.

2. Bali, J.S. (1994) 'Soil and land use policy', in D.L.Deb (ed.) Natural Resource Management for Sustainable Agriculture and Environment, Angkor Publishers Ltd, New Delhi.

3. Das, D.C. (1977) 'Soil conservation practices and erosion control in India – a case study', FAO Soils Bulletin 33: 11–50.

4. Gurmel Singh; Ram Babu; Narain, P.; Bhusan, L.S.; Abrol, I.P. (1990) 'Soil erosion rates in India', Journal of Soil and Water Conservation. 47(1): 97–99.

5. MoAC (1992) Indian Agriculture in Brief, 24th ed., New Delhi: Ministry of Agriculture and Cooperation, Ministry of Agriculture, 328 pp.

6. MoEF (1999) National Forestry Action Programme, Ministry of Environment and Forests, Govt. of India, New Delhi, Vol. I, 79 pp.

7. Mythili G and Goedecke J. (2016) Economics of land degradation in India, In: Nkonya E., Mirzabaev A., von Braun J. (eds) Economics of Land Degradation and Improvement – A Global Assessment for Sustainable Development. Springer, Cham.

8. Narayan, V.V.D. (1993) Soil and Water Conservation Research in India, ICAR Publication, New Delhi.

9. Narayana, V.V.D and Babu, Ram. (1983) 'Estimation of soil erosion in India'. Journal of Irrigation and Drainage Engineering, 109(4), 419–434.

10. Pachauri, R.K and Sridharan, P.V. (1998) Looking Back to Think Ahead: Growth with Resource Enhancement of Environment and Nature, Tata Energy Research Institute, New Delhi.

11. Reddy, V. R. (2003). Land degradation in India: Extent, costs and determinants. Economic and Political Weekly, 38(44), 4700–4713.

12. Sehgal, J. and Abrol, I.P. (1994) Soil degradation in India: status and impact, Oxford and IBH, New Delhi.
13. Singh, S. and Saroha, J. (2014): Geography of India, Access Publishing, New Delhi.

14. Wischmeier, W.H. and Smith, D.D. 1978. Predicting Rainfall- Erosion Losses. A Guide to Conservation Planning. U.S. Dep. Agric. Handb. No. 537. Washington, DC.

Web Links

http://www.ciesin.columbia.edu/docs/002-413/fig1.gif