CHAPTER 12

CLIMATE CHANGE AND SOIL EROSION

Jaivir Tyagi

12.0 Soil Erosion

Soil erosion by water is a serious threat to soil resource. Soil erosion causes reduction in the depth of soil and soil organic matter which consequently leads to low agricultural productivity. Further, it becomes a matter of great concern to water resources engineers when eroded sediments are transported through river channels and cause sedimentation in rivers and reservoirs and reduce their carrying capacity and gives rise to the floods (Greig et al., 2005). The other potential ill-effects of soil erosion include diffuse pollution and degradation of aquatic ecosystem in rivers and water bodies. The soil erosion problem may also lead to the channel instability due to imbalance in sediment supply and sediment transport capacity of the channel (Rakovan and Renwick 2011).

The rate of soil erosion and sediment transport is governed by a complex interaction of climatic, soil, topographic, and land cover characteristics. Therefore, any changes in these characteristics will also lead to changes in soil erosion rates. Since future climate change is expected to alter many of these characteristics, an understanding of the climate change impacts on the future soil erosion rates is crucial for planning a framework of options of protection measures and management practices to meet the future challenges of adverse impacts of climate change.

12.1 Climate Change

There is a broad consensus among the researchers that both temperature and rainfall patterns are changing due to global warming. While it is perceived beyond doubt that temperature would continue to increase in future, there is less agreement as regards the changes in precipitation (Segura et. al., 2014). Concentrations of greenhouse gases in the atmosphere are increasing globally due to anthropogenic activities (Trenberth et al., 2007). Significant progress has been made by the scientific community to understand the climate change phenomena through analysis of numerous long term datasets and improved data analysis techniques. The results of several studies indicate widespread changes in precipitation and weather pattern including occurrence of intense rains, droughts and intensity of tropical cyclones at continental, regional and basin scales. However, such changes at regional or basin scale are expected to be different from global average depending on factors like atmosphere-ocean interactions and orography etc. (Trenberth et al., 2007).

Numerous studies have shown that climate change is occurring in Indian sub-continent too. The results of the studies carried out in India indicate that annual surface temperatures are rising in general (Rupa Kumar et al., 1994; Pant et al., 1999; Singh and Sontakke, 2002; Subash and Sikka, 2014),while a mixed trend of decreasing/increasing rainfall is observed at different regional and local scales (Srivastava et al., 1998; Kumar et al., 2010; Adarsh and Janga Reddy, 2015).In an analysis of monthly rainfall observations carried out for 36 climatological regions in India for the period1901-2003, Guhathakurta and Rajeevan (2008) reported significant decreases in monsoon rainfall for Jharkhand, Chhattisgarh and Kerala, while significant increases in rainfall were reported in 8 regions.

The Indian Institute of Tropical Meteorology (IITM) conducted a daily precipitation analysis using the daily rainfall data of 1901-1995 from nearly 1,000 stations located across the country. Based on the regional climate model HadRM2, the impacts of climate change on water resources were summarised as:

(i) More intense hydrological cycle will result in increased annual average rainfall and increased droughts.
(ii) Increased extreme rainfall amounts with higher rainfall intensity are projected towards the end of the 21st century in all three major river basins (the Krishna, the Ganga and the Godavari). The highest precipitation is predicted in the Godavari basin as compared with other two basins.
(iii) Increased intensity of daily rainfall is also predicted.
(iv) A decrease in the number of rainy days is predicted in the Western Ganga basin, while most parts of the Godavari and Krishna basins are likely to experience increased number of rainy days.

Goswami et al. (2006) carried out rainfall analysis over central India. Significant increasing trend was observed in the frequency and intensity of heavy and very heavy rain events, while low and moderate rainfall events exhibited significant decreasing trend. In an analysis of the summer monsoon rainfall, Singh and Sontakke (2002) found a west ward shift in rainfall activities over the Indo Gangetic Plain Region (IGPR). The rainfall showed a significant increasing trend from 1900 over western IGPR, insignificant decreasing trend from 1939 over central IGPR, insignificant decreasing trend during 1900-1984 but insignificant increasing trend during 1984-1999 over eastern IGPR.

12.2 Physical Basis of Climate Change Impact on Soil Erosion and Sediment Transport

It is perceived that soil erosion rates will change in future with the changes in climate for a variety of reasons, the most direct being a more intense hydrological cycle associated with higher amount of precipitation and high intensity rainfall events of increased frequency (Nearing et al., 2004). The soil erosion that involves the detachment of soil particles and the transport of the eroded particles (Wischmeier & Smith, 1978) is directly proportional to the rainfall erosivity (R factor as used in Universal Soil Loss Equation) which is a function of rainfall amount and maximum 30 minute rainfall intensity. The rainfall events of short duration but of high intensity result in most severe erosion on a catchment. Nearing (2001) and Pruski and Nearing (2002) observed that the change in erosive nature of rainfall would be one of the most direct factors affecting the soil erosion rates due to more intense rains in the coming decades as predicted by IPCC (2007). The climate change may cause a shift from snowfall to rainfall that will translate into increased soil erosion. The intensity, duration, and amount of rainfall and type of precipitation also affect surface runoff leading to changes in erosive power and sediment transport capacity of the surface runoff.

An indirect impact of climate change on soil erosion rates is through changes in vegetation biomass, rising temperature and increased atmospheric carbon dioxide (Zhiying and Haiyan, 2016). More precipitation may result in increased vegetation production. Rosenzweig and Hillel (1998) observed that increased concentration of carbon dioxide in the atmosphere will lead to increased plant production and thereby the increased evapotranspiration rate. The increased plant canopy / vegetation cover provides a protection to soil surface and reduces detachment of soil particles by intercepting the raindrops and dissipating their energy. Temperature changes will also cause decrease or increase in biomass production levels and rates depending on the temperature stress and the altered growing season of the crops. The change in temperature and rainfall pattern may also lead to change in land-use pattern in order to adapt to a new climatic regime (Williams et al., 1996). The type of land use and vegetation cover influences the overland flow in terms of the roughness. The vegetation and the crop residuals on the ground surface act as dams and reduce the velocity and the sediment transport capacity of the flow.

The resistance of soil against the erosive forces of water depends on the soil texture, structure, permeability, and organic matter content. In general, the soils which have higher permeability, higher organic matter content and improved soil structure are less susceptible to erosion. An increase in moisture level, soil and air temperature due to climate change may cause residue decomposition at a faster rate due to increased microbial activities. Carbon compounds added to soil through soil organic matter affects both the chemical and physical properties of the soil including enhancing the infiltration rate, improving the soil moisture holding capacity, improving and stabilising the soil structure, developing strength of soil aggregates which reduces soil erodibility and provide important benefits in the prevention of erosion and desertification and for the enhancement of bio-diversity. Soil aggregate stability is positively correlated with clay content but negatively correlated with silt and very fine sand content. Higher soil erosion rates under intense hydrological cycle will modify soil properties. The erosion causes loss of organic matter and effects changes in soil texture, porosity, and soil water holding capacity (Heckrath et al., 2005). Erosion specifically detaches finer-sized soil particles (mainly silt) which have higher chances of transport by surface flow than coarser particles. With increasing degree of soil erosion, silt fractions of eroded soil horizons will decrease while sand and clay fractions will usually increase. The eroded fine particles clog soil pores, causing surface crusting, reduction in the soil's infiltration rate, and an increase in runoff. Increased velocity and depth of surface runoff due to intense rainfall events under climate change scenario will further increase its transport capacity and aggravate the sediment transport process in the river catchments. Thus, the rate of soil erosion and sediment transport which are non-linearly related with climatic and catchment characteristics are bound to change in future due to climate change.

12.3 Observed Impacts of Climate Change on Soil Erosion and Sediment Transport

Impacts of climate change on soil erosion are being experienced in various parts of the world (Zhiying and Haiyan, 2016). While there is no dearth of the available studies in the literature on climate change and its impact on water resources, the studies related to its impact on soil erosion and sediment transport are, however, very limited (IPCC, 2007). The available studies have attempted to analyse the impact of various direct and indirect factors related to climate change on future soil erosion rates (Yang et al., 2003; Zhang and Nearing, 2005; Zhang, 2007; Nunes et al., 2009; Maeda et al., 2010; Nunes and Nearing, 2011; Nunes et al., 2013; Mondal et al., 2015; and Khare et al., 2017).

Mathematical modelling has been a common and essential approach in projecting future impacts of climate change (Zhiying and Haiyan, 2016). The approach utilizes General Circulation Models (GCMs) and a suitable hydrological/soil erosion model. The GCMs provide projected climatic characteristics under downscaling for different climate scenarios which serve as input data to the hydrological/soil erosion model to get the soil erosion under changed climate. USE, RUSLE, EPIC, WEPP, SWAT and Erosion 3D are some of the commonly used models for climate change studies. Two downscaling techniques namely, the dynamic downscaling and the statistical downscaling are employed to produce a local scale climate series from global scale series generated by the GCMs.

Based on the above approach, expected impacts of climate change on soil erosion have been estimated by various researchers. The results indicate high variability in future soil erosion rates and sediment yield across the world due to difference in climatic features and the complex interactions that undergo in a catchment under altered climate to produce soil erosion. Although, both increasing and decreasing soil erosion rates have been reported under climate change depending on geographical location, precipitation characteristics, climate scenarios, topographical conditions, and land use/management practices, yet, most studies conclude an increase in the future soil erosion rates under climate change.

Rainfall being a major factor inducing soil erosion, a number of authors have analysed the impact of change in rainfall on the erosion. Pruski and Nearing (2002) reported a change of 1.7% in soil erosion and 2% in runoff for every 1% change in precipitation amount. Zhang (2007) found that an increase of 4-18% in precipitation would increase the runoff and soil loss by 49-112% and 31-167% respectively. In analyzing the change in soil erosion for 11 regions from five US States for the period of 2040-2059, O'Neal et al. (2005) found that a 10-20% increase in annual precipitation resulted in an approximate 300% change in runoff and soil loss. These results indicate that keeping other factors unchanged, the higher amount of precipitation would lead to higher runoff and higher soil erosion.

Since rainfall intensity is known to affect the soil erosion rates greatly, Routschek et al. (2014) studied the impact of rainfall intensities in a catchment in Germany for the period 2031 to 2050 and found that the expected increase of 23% in rainfall intensity during June to August at Chemnitz climate station would result in an increased soil loss (+ 64%) by the year 2050.Despite predicted decline of precipitation, increased soil loss has also been reported due to increased frequency of intense rainfall events in the US(Zhang, 2012),Germany (Michael et al., 2005), Portugal (Nunes et al., 2009), Thailand (Plangoen et al., 2013), Iran (Azari et al., 2016) and Morocco (Simonneaux et al., 2015). The rainfall intensity is reported to have greater impacts on soil erosion than the storm frequency i.e. the number of rainy days (Pruski and Nearing, 2002). Nearing et al.(2005) observed that the combined effect of changes in precipitation amount and precipitation intensity would be more severe than the change in any single factor. Yang et al. (2003) predicted the global average soil erosion to increase by 9% by the year 2090. The increased soil loss is attributed to the increased erosive power of rainfall due to changes both in intensity and amount of rainfall.

The rise in temperature has an influence on the soil erosion as higher temperature may shift the snowmelt timing and would also increase the proportion of precipitation that would be received in the form of rainfall instead of snowfall. Mukundan et al. (2013) reported an increase in soil erosion and sediment yield during winter and early spring as a result of increased precipitation occurring as rainfall; and increased evapotranspiration and decreased runoff in summer due to higher temperature.

Soil erosion, however, may not always increase with increased amount and intensities of rainfall because of increased vegetation cover under increased CO_2 concentration due to climate change. For El Reno watershed in US, Zhang and Nearing (2005) reported that runoff and soil erosion will decrease due to better crop growth, and higher evapotranspiration and evaporation because of increased temperature. On the other hand, a 13% increase in sediment yield was computed in the Pearl River basin of Southern China despite a 3°C increase in annual temperature (Li et al., 2011). One of the possible reasons for higher sediment yield could be the higher evapotranspiration demand under extreme temperature that induced the decreased vegetation growth. It is reported that the susceptibility of soil erosion to climate change is more in agricultural land use as compared to that in natural land uses viz., forests which effectively maintained the erosion level at less than 1 tonne/ha/year even under climate change scenario (Nunes et al., 2013; Serpa et al., 2015).

Comparatively, a very few studies on impacts of climate change on soil erosion are available for Indian catchments. The effects of climate change on change in rainfall erosivity for past and future rainfall (1961-2100) were studied by Mondal et al. (2016) in a part of the Narmada river basin in the central India. Nine rainfall locations were selected in the study area and surrounding. A decreasing trend with statistically less than 0.05% significance level was observed in the past rainfall. The future rainfall was predicted using GCMs data from HadCM3 (A2 and B2 scenario) and CGCM3 (A1B and A2 scenario). The projected rainfall for the basin was generated using Statistical Down Scaling Model (SDSM).The predicted rainfall was found to increase gradually in 2020s, 2050s and 2080s. All the stations showed a significant increasing trend (at 0.05% significance level) in the projected rainfall in all the GCMs scenarios with a minimum increase in the A1B scenario of CGCM3 and maximum increase in the A2 scenario of HadCM3.As a result, the increase in rainfall erosivity in 2080s was found to vary from 20.95% in A1B scenario of CGCM3 to 202.40% in A2 scenario HadCM3.The rainfall erosivity during 2020s and 2050s of all nine stations was found to vary from -32.91% to 24.12% and -18.82 to 75.48% respectively. The increase in rainfall erosivity for the projected rainfall is indicative of their higher erosive potential in future.

Mondal et al. (2015) estimated the future soil erosion because of climate change in Narmada River Basin in Madhya Pradesh, India. The future precipitation was generated by downscaling GCM data of HADCM3 for A2 scenario using least-square support vector machine (LS-SVM) and SDSM. The soil erosion in the basin was evaluated using the Universal Soil Loss Equation. The projected precipitation averaged for 30 years during 2011-2040 (denoted by 2020s), 2041-2070 (denoted by 2050s) and 2071-2099 (denoted by 2080s) showed an increase at all the stations. The soil erosion was found to increase by 18.09% in 2050s and 58.9% in 2080s using LS-SVM downscaled data, and 15.52% and 105.80% in respective years using SDSM data. However, a decrease in soil erosion by 5.47% and 8.51% was indicated in 2020s by LS-SVM and SDSM data respectively.

Khare et al. (2017) assessed the impact of climate change on soil erosion in Mandakini river basin, a hilly catchment in Uttarakhand, India using the downscaled GCM data and the USLE. The projected mean rainfall for the study area was computed as 1077, 1350, 1595 and 1978 mm and the rainfall erosivity factor (R) was estimated at 459, 558, 646, and 784 metric tonnes ha^{-1} cm h^{-1} 100^{-1} for 1961–2001, 2020s (2011-2040),2050s 2041-2070), and 2080s (2070-2099) respectively. The sediment yield computed for respective years as 586337, 711328, 824050, and 999746tonnes/year show a remarkable increase in sediment yield from base period of 1961-2001 to 2080s

From the foregoing discussion and available researches, it is clear that the climate change can impact the soil erosion rates directly and indirectly by altering climatic and other catchment characteristics. The expected higher intensity and higher amount of rainfall in future are the key direct factors that will have the greatest impact on soil erosion rates. The catchment condition, specially the change in vegetation and soil characteristics due to climate change can also affect the soil erosion, runoff generation and sediment transport considerably. The soil erosion under climate change is therefore a very complex process but its estimation is highly required to assess the future possible environmental and agricultural problems.

12.4 Concluding Remarks

The climate change has the potential to increase the soil erosion rates and its associated adverse environmental impacts. Therefore, it is crucial to model the future erosion rates using integrated modelling approach in order to assess the potential future agricultural and environmental problems that may arise due to higher soil erosion. The modelling framework that would ideally consist of hydrological, erosion, climate, climate-induced land use/cover change, and crop management practices models is required to achieve more realistic assessments of impacts of climate change on hydrology and associated soil erosion/ sediment transport. The model would help achieve a broad range of results for different crops, crop rotations, shift in cropping season (planting and harvesting dates) for planning the adaptive control measures under future climate change.

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