

GIS Based Universal Soil Erosion Estimation in District Chakwal Punjab, Pakistan

Mirza Wajid Ali Safi¹, Saima Siddiqui^{2*}, Aqil Tariq³, Syed Waseem Haider⁴

¹GIS-Lab, WWF-Pakistan, Ali Institute Ferozepur Road, Lahore, Pakistan

²Department of Geography, University of the Punjab, Lahore Pakistan

³State Key Laboratory of Information Engineering in Surveying, Mapping and Remote Sensing, Wuhan University, Wuhan (430079), China

⁴National Institute of Oceanography, Karachi, Pakistan

*E-mail: saimagct@gmail.com

Received: 27 April, 2020

Accepted: 07 July, 2020

Abstract: Soil erosion is a serious environmental problem faced by district Chakwal. Unpredictable short term and high intensity rainfall, improper cultivation and deforestation have accelerated the soil erosion in the district. The agricultural productivity of the study area can be enhanced by understanding, estimating and controlling the root causes of soil erosion. This study was undertaken to estimate and spatially represent the rate of average annual soil erosion in Chakwal using GIS/RS techniques. The soil erosion was estimated using Universal Soil Loss Equation (USLE) model. To find out parameters of USLE, ASTER GDEM of 30 m resolution was used to estimate slope length and elevation of the study area. Landsat 8 satellite imagery of year 2019, was used to prepare land use map using supervised classification. Soil map with texture and geomorphology was used to identify soils of study area and rainfall data of last 7 years was also studied. Finally, the soil loss has been computed using raster calculator of ArcGIS 10.2 software. The average annual soil loss was predicted up to 268,619 tons/acre/year, of which maximum soil erosion was occurring near the steep slopes and river channels. It is necessary to adapt sustainable land management practices to reduce the risk of further soil erosion, by adopting rainwater harvesting and choosing right crops for suitable soil types.

Keywords: Chakwal, soil loss, erosion, USLE, ArcGIS.

Introduction

Soil erosion is the removal and movement of top fertile soil particles by the erosive forces of water or wind. In certain conditions soil erosion can be controlled, however it is almost impossible to completely stop this hazard. Soil erosion is considered as most common land degradation issue which affects soil quality and crop productivity (Shaheen et al., 2016). About 1100 million hectares of land in the world is affected by water related soil erosion, out of which 56% is affected by human-induced soil degradation. In Asia 441 million hectares of land (59%) is prone to soil degradation (Oldeman et al., 1991). Over 76% of total land area of Pakistan is affected by soil erosion and approximately one billion tons of fertile soils are eroded annually by wind and water action (Anjum et al., 2010). Soil erosion may be initiated by natural geomorphic causes or anthropogenic activities (Bai et al., 2008). The most common forms of soil erosion caused by water are: gully, rill, inter rill, landslides, riverbank and sheet erosion. However, the most important causative factors are deforestation, unsuitable land uses, overgrazing, mismanaged agricultural activities and rapid urbanization (Reusing et al., 2000). Changes in climatic pattern, steep slopes or basic soil characteristics makes soil at risk to erosion (Gelagay et al., 2016; Pal et al., 2012). High intensity, short duration rainfall and poor watershed management practices lead to uncontrolled soil erosion in Pakistan. The rainfed areas in the country are

severely affected by soil erosion due to uncontrolled livestock grazing, inappropriate land uses, growing unsuitable crops and illegal removal of forest vegetation cover (Khan et al., 2012; Irshad et al., 2007). Potohar region of Pakistan lacks tendency to hold water due to its soil water holding capacity. Therefore, the loss of water is much greater in this region, which is causing loss of fertile top soil and siltation in dams, rivers and water reservoirs. In Potohar region, soil erosion is mostly occurring in areas of high rainfall having steep slopes (Shah and Arshad, 2006). A considerable part of the Potohar region has been gullied and steeply dissected, while pinnacle erosion, piping and slumping are also quite pronounced (Baig et al., 2013; Farooq et al., 2007; Baig et al., 1999). Soil erosion affects food security, as it threatens the agricultural productivity (Sinha and Joshi, 2012). Clearing of natural vegetation, decreased organic matter at terraced slopes and cultivation at steep slopes without terracing, leads to severe erosion issues. Agriculture in Potohar region depends upon rains, so it has less crop yield as compared to irrigated regions of Pakistan. Quantitative soil erosion estimation on the regional scale is essential to identify environmental implications and to develop soil management and conservation plans (Alexakis et al., 2013). The present study was aimed to assess the GIS based Universal Soil Loss Equation (USLE) for determining average annual soil loss in the Chakwal. USLE is the widely used and suitable technique to compute soil loss in smaller areas like hillslopes and fields (Sinha and Joshi, 2012).

Study Area

Chakwal is a rainfed district that lies in the northern part of Punjab. It is neighbored by Jhelum, Mianwali, Attock, Rawalpindi and Khushab districts of Punjab. According to the Provisional Censes Report (2017) the total population of the district is 1,495,982 with an area of 1,652,441 acres (6,609 km²). The summer temperatures range between 15 °C to 40 °C while, winter temperatures range between 4 °C to 25 °C. December is the coldest month and June is the hottest month of the year. The average annual rainfall of the district ranges between 558 mm to 625 mm. However, more than 70% of the annual precipitation falls during monsoon season between the months of June and September (GoP, 2007; Oweis and Ashraf, 2012). It has varying topography comprising of fairly level ground to undulating landscape, with rocks exposed on surface or highly eroded lands with large intricate gullies and cuts. There are many seasonal streams and several mini dams in the district (Ghani et al., 2013). Chakwal area serves as a home to many wildlife species. Moreover, several tourist resorts, magnificent scenery including Kallar Kahar, Uchali, Khabai and Jhallar lakes are also located in Chakwal district. The vegetation of the district is characterized as sparse broadleaved scrub and grasses. The agriculture mainly depends upon rain and is prone to drought in case of insufficient rain. Only 8% of the cultivated land is irrigated through wells, tube wells and canals. Mainly wheat is grown in the district, however maize, groundnut, chickpea, sorghum, millet, canola and guar are also cultivated in patches (Balouch et al., 2016; Akmal et al., 2014; Government of Punjab, 2013; Khan et al., 2002; Aslam et al., 2000). Soils in district Chakwal are predominantly light textured sandy clay loom and sandy loom types. In the alluvial terraces and dissected old loess area, the soils are of silt and silt loam texture with pH level of 7 to 9 (Afzal et al., 2015; Hussain et al., 2009; Latif et al., 2008; Rashid, 1993). About 31% soils are sandy to sandy loam in texture and the remaining are highly eroded (Tager and Bhatti, 2001). Currently the district faces issues of water shortage and soil erosion, causing a big threat to crop yield. Soil erosion adds to loss of soil nutrients, increased water runoff and deficiency of nutrients which cause low crop yields (Moyo et al., 2003).

Materials and Methods

Both primary and secondary data sources were used for present study. The primary data included field visit, where soil samples and GPS points were taken, which were further used for supervised land use classification of the Landsat imagery. Secondary sources include topographic sheets (scale 1:25,000) to draw boundary of the study area, last seven years precipitation data acquired from World climate data website (www.climatedata.eu) and soil texture map (Scale 1:25000) to identify different soil textures in

the study area. ASTER GDEM of 30 m resolution was downloaded from USGS website (www.earthexplorer.org) to calculate length of slope (LS). Landsat imagery of 30 m resolution was downloaded from Global Land Cover Facility (glcf.umd.edu/data/landsat). Extensive literature review was done to get deep insight about the study area problems, containing published and unpublished data such as newspapers, research papers and previous reports. USLE is considered as “universal equation”, because like other soil loss models it does not include restrictions of geography and climate and is also free from generalizations. USLE includes all such possible factors which affect the soil loss process. This soil loss model produced accurate results in most areas of the world including Asian countries such as India, China and Thailand due to its simplicity (Teerawong et al., 2002; Saha et al., 1991; Omakupt, 1989).

Wischmeier and Smith (1978) devised following empirical soil loss model to predict the long-term average annual soil loss in any region.

$$A = R \times K \times LS \times C \times P \quad (\text{Equation 1})$$

Where

A = average annual soil loss in t/a (tons per acre)

R = rainfall erosivity index

K = soil erodibility factor

LS = topographic factor - L is for slope length and S is for slope

C = cropping factor

P = conservation practice factor

Rainfall Erosivity (R)

R factor explains the rainfall impact on runoff and erosion. It also explains the intensities and extents of individual rainfall events throughout a year (Weng and Mokhtar, 2004). The average annual rainfall data (mm) of Chakwal, Islamabad and Jhelum from year 2013-2019 were used to compute R index. Spatial interpolation of rainfall data was conducted using Inverse Distance Weightage (IDW) technique in ArcGIS 10.2 to geographically represent the R factor. The R factor is computed from interpolated map using following formula proposed by Morgan and Davidson (1991).

$$R = P \times 0.05 \quad (\text{Equation 2})$$

where P is average annual rainfall (mm).

Soil Erodibility (K)

K factor represents the susceptibility of different soil types to the erosion and rate of runoff (Renard et al., 1997). K factor cannot be altered, as it tells the binding between soil particles, their cohesiveness or adhesiveness and how the specific soil is prone to erosion on a given slope. Every soil has its own rate

of erosion based upon its physical characteristics such as organic matter and texture type. The values for specific textural classes of soil were obtained from Soil Erodibility Factor K_{fact} table assumed by Stewart et al. (1975). The soil texture map of district Chakwal was prepared from the soil map of Soil Survey of Pakistan. Where K value was selected as 0.27 for sandy loam, 0.48 for silt loam and 0.12 for loamy sand. K value for water bodies was considered as 0 because it has no estimated erosion value (Erdogan et al., 2007).

Length of Slope (LS)

To calculate the length and slope (topographic factor), DEM processing in ArcGIS, serves as an alternative to ground-based models (Van Remortel et al., 2001; Moore and Wilson, 1992). Erosion is directly affected by slope steepness, as steeper slope causes more erosion. The slope (S) was estimated using ASTER GDEM of 30 m spatial resolution. Errors like sink and holes in the DEM were removed, to calculate direction and flow accumulation using Arc hydro tools of ArcGIS. Equation devised by Simms et al. (2003) and Mitsova et al. (1999) was implemented to find out LS factor (Equation. 3).

$$\text{POW} ((\text{Flow accumulation}) * \text{cell size}/22.13, 0.6) * \text{POW} (\sin (\text{slope})) \quad (\text{Equation 3})$$

Crop Factor (C)

Crop management gives the soil losses according to selected vegetation types (Morgan, 2005; Wieschmeier et al., 1978). Land use and land cover (LULC) were identified using supervised classification of Landsat image of study area. The LULC classes include forest, agriculture area, fallow land, built-up areas and water body. Average C-factor values for LULC types in study area were calculated from Wischmeier and Smith (1978) and Morgan (1986). Field surveys were carried out for ground truthing and to validate the LULC classes for accuracy assessment.

Support Factor (P)

Support factor (P) is the management factor for a specific soil type. It reflects the effects of land use practices that will reduce the amount of runoff and thus reduce the rate of erosion. The P-factor shows the ratio of soil loss by a support practice to that of straight row farming up slope and down slope (Wieschmeier et al., 1978). Contour farming, cross slope cultivation, terracing and strip cropping are most commonly used supporting cropland practices (Hyeon et al., 2006). While selecting management practice to reduce soil loss, land use type and slope percentage are kept in view. Shrubs, forested area and crop land were classified into agriculture zone in this study and P-factor values were estimated (Wischmeier and Smith, 1978).

Results and Discussions

Rainfall Erosivity (R)

The values of rainfall erosivity range from 201.97 to 407.78. The R factor map shows high precipitation intensity in the northwest and adjoining areas. High intensity rainfall can lead to high rate of runoff and thus increasing the amount of soil erosion in these areas (Fig. 1).

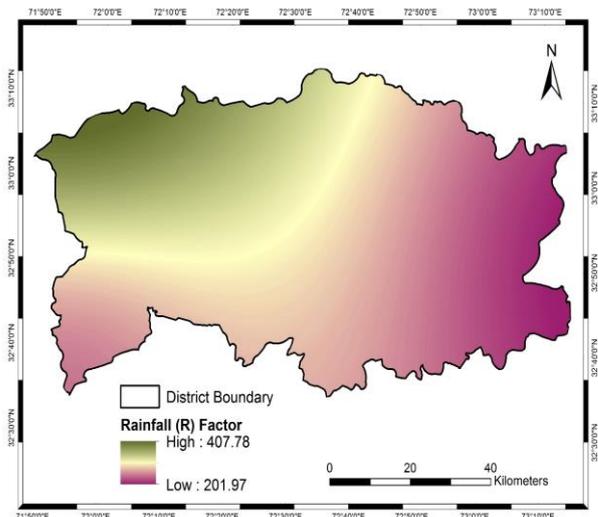


Fig. 1. Rainfall factor (R) estimation in district Chakwal.

Soil Erodibility (K)

The values of K range from 0 to 0.42 (Fig. 2). Sandy loam is the most dominant soil in study area. Silt loam has high erodibility due to weak bonding of particles. The soils in urban areas are considered very poorly erodible because of built-up cover. However, soils affected by salt are highly erodible due to their poor structure and less aggregation. Broken, patchy and gullied soils are included among high K factor soils.

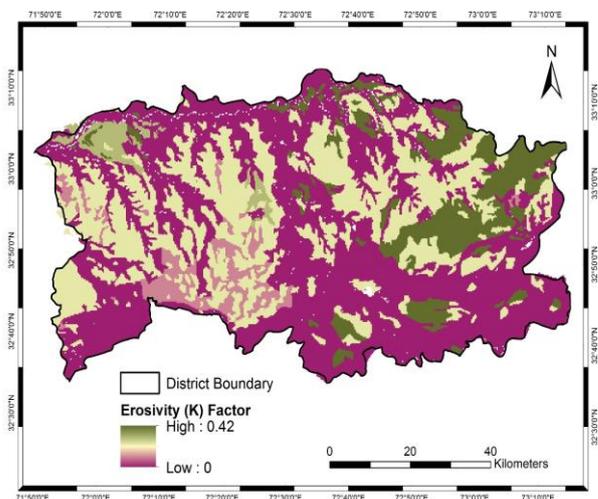


Fig. 2 Erosion factor (K) estimation in district Chakwal.

Length of Slope (LS)

Slope in the study area is not continuous due to varying topography. The south eastern part has high elevation and steep slope. Gradual as well as abrupt slopes can be witnessed in the study area because of hilly terrain. The LS factor value ranges from 0 to 86.32. Steep slopes and complex topography make the study area more vulnerable for soil loss (Fig. 3).

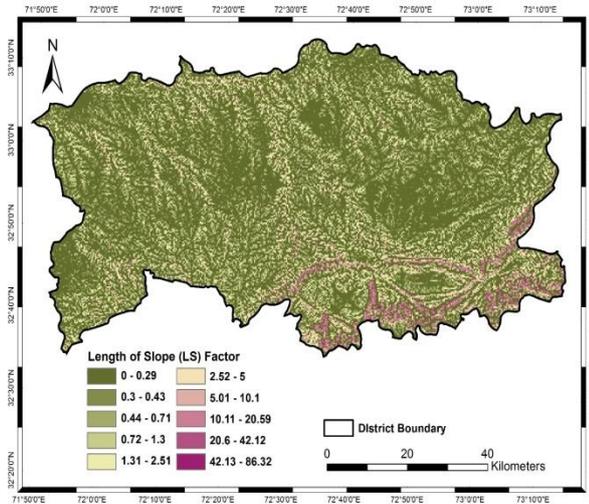


Fig. 3 Length of slope (LS) factor estimation in district Chakwal.

Crop Factor (C)

Major land use classes were identified by applying supervised classification on Landsat image of year 2019. ArcGIS was used for digital image processing. Field observations accompanied with verification of land use classes from Google Earth were also put into use. Values of C factor range from 0 to 6 in the study area. C factor is high at the level surface, especially in the western part of study area, which is rich in cultivation of peanut, sorghum and millet. The forest, shrub and thin forested area were also given significant values (Fig. 4).

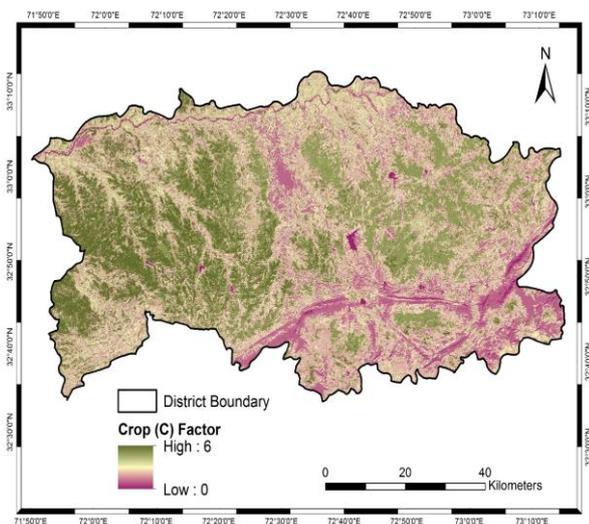


Fig. 4 Crop factor (C) estimation in district Chakwal.

Support Factor (P)

P-factor was estimated based on slope (%) and associated land use. For classes other than agriculture, support value is considered 1 regardless of slope and extent. The agricultural area is spread over vast extent which included level 0 to gently sloping 11% terrain. Slope was estimated in percentage to understand the agricultural extent with respect to slope (Fig. 5).

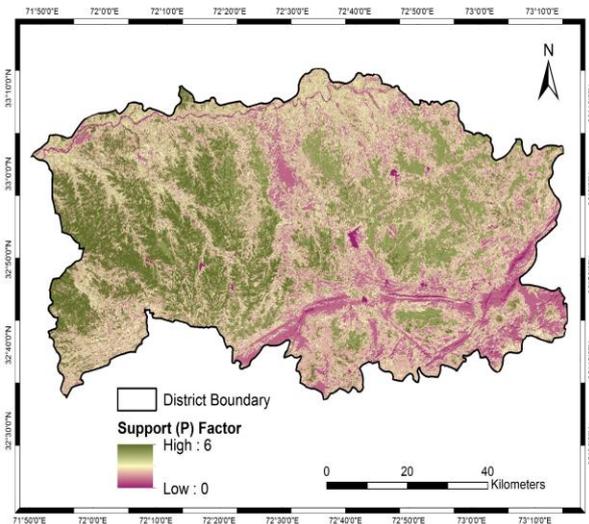


Fig. 5 Support factor (P) estimation in district Chakwal.

Average Annual Soil Loss (A) Estimation

The study area shows varying amount of soil loss due to complex topography and undulating landscape. The average annual soil loss ranges from 0 to 268,619 tons/acre/year (Fig. 6). Present study indicates that the most of the hilly areas and barren lands are prone to severe soil erosion. Extensive deforestation is also causing high rate of soil erosion in the study area.

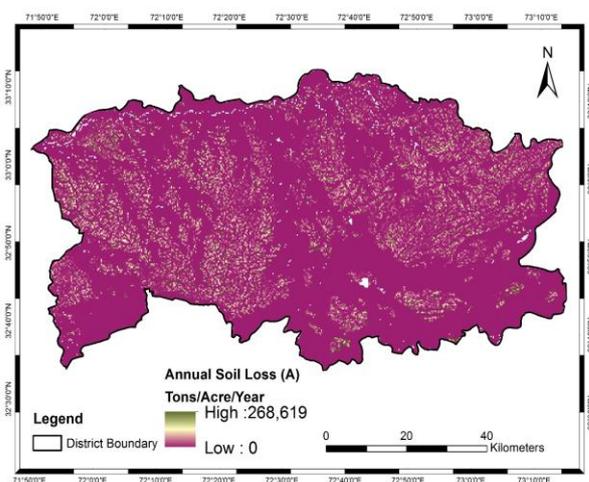


Fig. 6 Average annual soil loss (A) in district Chakwal.

Conclusion

The results indicate that district Chakwal is having moderate to high soil erosion which may lead to soil

degradation and loss of cultivable land. The average annual soil loss was predicted up to 268,619 tons/acre/year, of which maximum soil erosion occurred near the steep slopes and river channels. The study area is much susceptible to erosion because of its undulating landscape and complex drainage system. The alteration of land from forest to cropland is also the cause of soil loss. The infrastructure developments such as factories, housing schemes and amusement parks for public also accelerate the rate of soil erosion especially in Kallar Kahar and Choa-saidan Shah. The ongoing soil erosion can cause siltation in the canals and linked barrages, which cannot only reduce their carrying capacity for water but also can cause flood hazard in the region. To prevent erosion on steep slopes, terraces must be constructed, though it may cause inconvenience in farming practices. Crops selection must be very intelligent. Crops must be selected keeping in view the potential of soil. There must be a "no" intensive agriculture, as it degrades the quality of soil. The tillage method needs to be replaced with zero tillage. Cropping systems that provide maximum conservation for the soil must be adopted. Mulching must be encouraged to conserve moisture during warm season. Cropping pattern must be designed efficiently so that wind has minimum effect on it. Cross slope farming support practices are suggested that can reduce sediment to occur on the surface. The undertaken research will serve for ecosystem conservation and management planning strategies.

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