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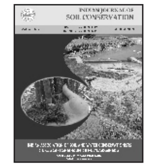

Assessment of erosion prone areas at hillslope level using WEPP model – A case study in Patiala-ki-Rao watershed of Shivalik foot-hills, India

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ABSTRACT

Soil erosion is the main reason for land degradation in any watershed, which affects the agricultural productivity to a great extent. Identification of erosion prone areas is important to implement management strategies for conserving natural resources in a watershed. In the present study, critical erosion prone areas have been assessed in Patiala-ki-Rao watershed located in Shivalik foot-hills, using geographic information system (GIS) and water erosion prediction project (WEPP) model. The simulated sediment yield from WEPP model seems to be moderate (16.80 t ha^{-1}) at the watershed outlet, although the sediment yields at foot of the hillslopes is quite high ranging between 0.03 and 165.53 t ha^{-1}. Detailed distribution of the seriously eroded areas within the watershed was obtained in the form of different erosion classes by analyzing hillslope level sediment yield information in GIS environment. The results showed that about 35.96% area of Patiala-ki-Rao watershed is under critical erosion zone. Further, assessment about effect of land-use, slope and soil characteristics on sediment yields of different erosion classes showed that built-up, agriculture and fallow lands with high slopes and sand content are more prone to soil erosion. Simulating the sediment yield at hillslope level provided an idea about the critical erosion prone areas within watershed, and thus appropriate management strategies can be planned for sustainable livelihood of the inhabitants in the watershed.

1. INTRODUCTION

Soil and water resources are necessary for living organisms. Sustainable development of an area largely depends on the management, development and effective utilization of these resources (Shinde *et al.*, 2010). These resources are well interacted with each other in various phases of hydrologic cycle. Soil is a non-renewable resource which takes 200 to 400 years for formation and above 3000 years for soil fertility development (Richter and Markewitz, 2001). The world's growing human population changed many ecosystems rapidly and extensively by actively depleting the soil resource over decades (Lafond *et al.*, 2006). Soil erosion due to the wind and water forces is also a main reason for the degradation of soil. Soil erosion deteriorates the soil characteristics and fertility level and makes the land unsuitable for cultivation. These eroded soil particles reach water bodies and settle down, causing sedimentation. Sedimentation affects the water ecosystem by degrading the quality of water, modifying the dissolved oxygen levels, and enhancing emperature in water bodies (Feng *et al.,* 2012; Jena *et al.,* 2018).

In world, 0.3 to 0.8% of land area per year is becom uncultivable due to soil erosion (Biggelaar *et al.*, 2004; Lafond *et al.*, 2006). In India, erosion scenario has became worst by affecting 145×10^6 ha out of total geographical area (329×10^6 ha) and causing a soil loss of 5.3×10^6 Mg yr^{-1} (Sehgal and Abrol, 1994). The Shivalik foot-hills are located in north-western part of India, extending from Jammu to Himachal Pradesh, and some parts of Punjab and Haryana. This area is facing severe problems of land degradation, soil erosion and sedimentation. Around 5.38×10^5 ha area of Punjab state comes under Shivalik foot-hills which is the eighth most delicate and degraded agro-ecosystem of the country (Bhardwaj and Rana, 2008; Bhardwaj and Kaushal, 2009). In this area, a large portion of rainfall (35-40%) goes as runoff during monsoon season (Bhardwaj and Rana, 2008) causing severe soil erosion (>80 Mg ha^{-1}) in many watersheds while flowing down the slopes (Sehgal and Abrol, 1994). The Patiala-ki-Rao watershed which is located in Shivalik foot-hills of Punjab, India is facing similar problems. The watershed land-use is greatly altered by urbanization of major cities like Mohali and Chandigarh, which are located adjoining to the watershed (Sushanth *et al.,* 2018).

Soil erosion and sedimentation processes are complex in nature, and these processes are analyzed by using hydrological models (Haan *et al.,* 1994; Morgan, 1986; Rose, 1993). Globally, there are many hydrological models developed to simulate runoff, soil loss, and sediment yield (Brazier, 2004; Gao, 2008). Among all the models, WEPP model is best suited for simulating runoff and sediment yield in small watersheds. WEPP model is a process based model developed by USDA-ARS and their cooperators in 1985. WEPP model was developed on the basics of plant science, hydrology, hydraulics, and erosion mechanics. The notable advantages of the developed model include effective estimation of runoff and sediment yield spatially and temporally. WEPP model also simulates runoff and sediment yield daily, monthly, or annually for entire watershed or each hillslope (Flanagan and Nearing, 1995; Lane *et al.,* 1997). It has the provision to divide the watershed in different hillslopes. Runoff and sediments from hillslopes are linked with channels, and impoundments and are routed through the outlet. WEPP model has been tested for simulating runoff and sediment yield successfully all over the world (Yu and Rosewell, 2001; Amore *et al.,* 2004; Baigorria and Romero, 2007; Pieri *et al.*, 2007; Shen *et al.,* 2009; Shen *et al*., 2010; Saghafian *et al*., 2015), including India (Pandey *et al.,* 2008; Singh *et al.,* 2011; Yousuf *et al.,* 2015; Sharma and Bhardwaj, 2017). Conventional methods are not adequate to collect and monitor the data required by the WEPP model due to high cost and time involved in it. In this context, GIS provides convenient platform for data update and analysis in less time with low cost and greater accuracy (Kachhwala, 1985; Cihlar, 2000).

Soil erosion was observed at many places of Patiala-ki-Rao watershed while ground-truthing. Therefore, it necessitates the assessment of critical erosion prone areas in the watershed. But, assessment of sediment yields at the outlet of the watershed will not give a clear picture of sediment distribution and eroded areas in the watershed. Identifying the specific areas of erosion at hillslope level gives the detailed distribution of erosion to plan soil conservation practices in the watershed. Several scholars have identified and prioritized soil erosion prone areas in a watershed/basin by using SWAT and USLE (Shinde *et al.,* 2010; Kumar and Mishra, 2015; Ahmed *et al.,* 2017; Chaudhary and Kumar, 2018). But limited literature is available on assessment of erosion prone areas using WEPP model at hillslopes level. Hence, there is a need to analyze the critical erosion prone areas in Patiala-ki-Rao watershed using WEPP model at hillslope level for better soil conservation planning in the watershed.

2. MATERIALS AND METHODS

Description of Study Watershed

The Patiala-ki-Rao watershed in Shivalik foot-hills of Punjab is situated between the coordinates of 30º45'27. 53"N, 76º44'44.03"E and 30º49'54.40"N, 76º52' 24.86"E as shown in Fig. 1. The watershed has an area of 5140 ha with major land-uses of forest, agriculture, built-up, fallow land and grass land (Sushanth *et al.,* 2018). The watershed is located in sub-humid climate where monsoon season is the main contributor to rainfall. The average annual rainfall of

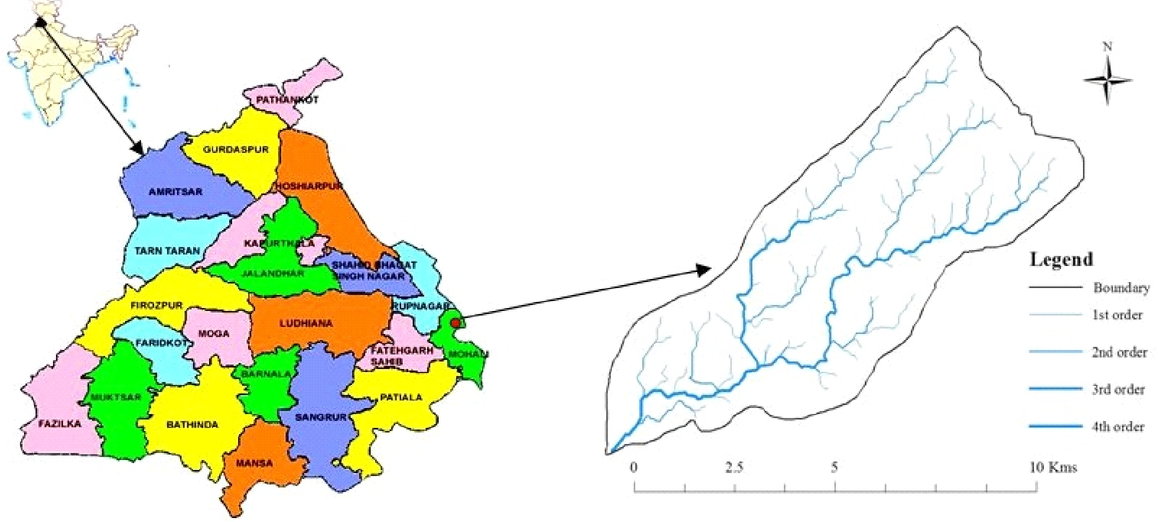

Fig. 1. Location map of study watershed at Patiala-ki-Rao in Punjab

study area is 910 mm (Yadav *et al.,* 2005). Topography of watershed is hilly and undulating having mean slope of 1.95%. Erosion and deposition in the study area is mainly done by fluvial action of seasonal streams, locally known as *Choes* (Bazgeer *et al.,* 2007).

Data Used

Climate data for the year 2016 was collected from the ICAR-IISWC, Research Centre, Chandigarh, which is situated 5 km away from the watershed. The elevation data for each individual hillslope of watershed was drawn from derived digital elevation model (DEM) of the watershed. Soil samples were collected from each individual hillslope and further analyzed in laboratory for soil characteristics. Digitized watershed and land-use information of the watershed for the year 2016 were collected from Sushanth *et al.* (2018). Cropping patterns, management practices and other information was collected from local farmers.

Hydrologic Modeling: WEPP Model

Runoff and sediment yield in the study watershed were simulated and quantified using WEPP model. The procedure followed in WEPP model application is explained in the subsequent sections.

Sub division of watershed into hillslopes

Stream network of the watershed was delineated from the DEM in GIS environment using following steps. First step was to fill the sinks which are formed due to the surrounding high elevation cells by using Fill function. Next step is to compute the direction of flow and flow accumulation grids using Flow Direction and Flow Accumulation functions, respectively. Final step is to define the streams by assigning threshold value of watershed flow accumulation using Raster Calculator tool. The delineated stream network map is shown in Fig. 1. The delineated stream network with watershed boundary added into WEPP model as background. Channel segments were delineated in WEPP model from most remote point to the outlet with reference to added stream network. The watershed was divided into number of hillslopes by overlaying the slope, soil and land-use characteristics in context to channel segments, so that each hillslope represents uniform slope, soil and land-use characteristics (Pandey *et al*., 2008). Divided 167 hillslopes (H1-H167) with 119 channel segments (C1-C119) are shown in Fig. 2. These hillslopes require input data of slope, soil, and land-use parameters, which can be provided in the form of input files through hillslope profile.

Preparation of input files

WEPP model requires certain input files like of climate, slope, soil, land-use/management, and channel files. Climate input file was generated using CLIGEN Program

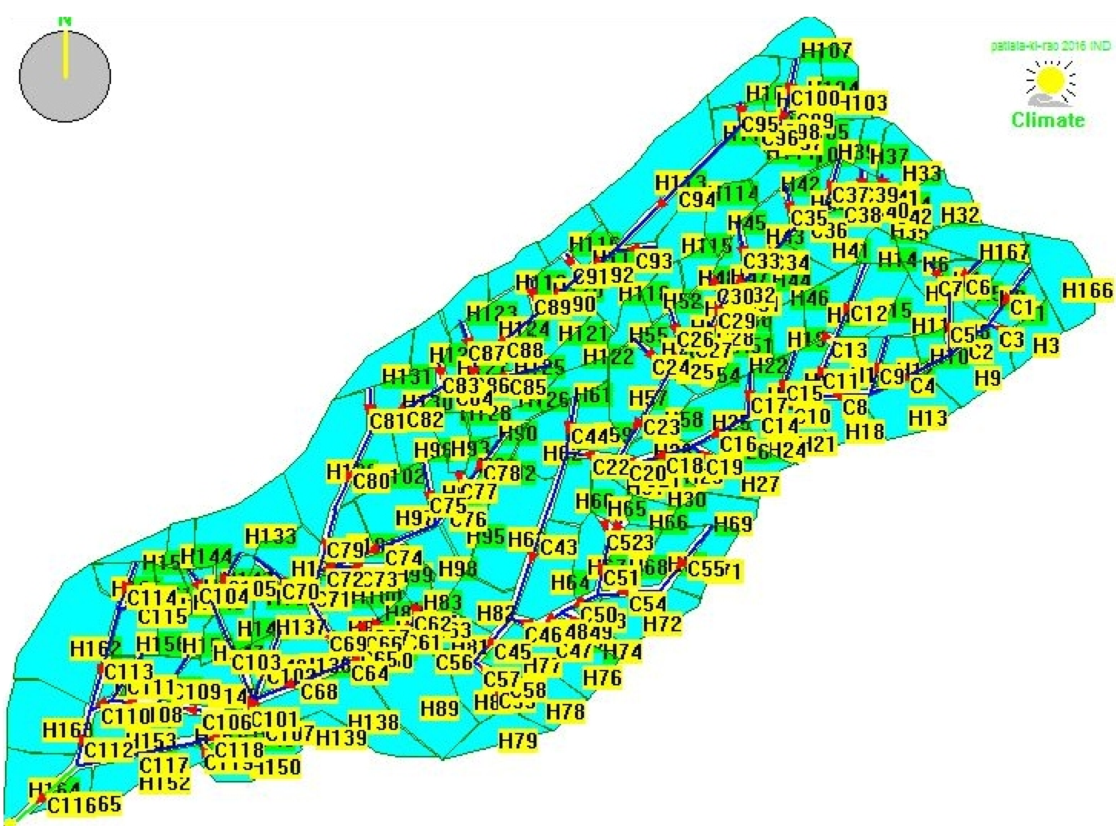

Fig. 2. Map of study watershed showing all hillslopes and channels

(Yousuf *et al.,* 2015). Soil texture and its characteristics (hydraulic conductivity, thickness, bulk density, organic matter percentage, soil albedo and initial saturation, etc.) of each hillslope were taken from laboratory analysis and literature. Soil input files were prepared for each type of soil texture by providing its soil characteristics. Topographic map was prepared by using DEM of the watershed in GIS and classified into five elevation sections. The slope input file was prepared by generating segment-wise distance-elevation data for each hillslope calculated from topographic map in GIS. The plot between elevation and distance gives the slope profile. It is assumed that slope remains constant along the length of hillslope and channel. The land-use/management input file was prepared by providing land-use, plant parameters, and management practices information necessary for WEPP model. This information was collected from land-use map, local farmers and ground truthing. Channel input file was prepared by providing information of channel cross section, soil characteristics, hydraulic properties, etc.

Application of WEPP watershed model

The WEPP watershed model was used to simulate runoff and sediment yield from study watershed for the year 2016. CLIGEN generated climate file for the year 2016 is provided in the model. All remaining input files were provided for each individual hillslope and channel profiles. Model was set to run for each hillslope and runoff and sediment yield were calculated at the foot of each hillslope. These runoff and sediment yield quantities were routed through the channel segments and calculated at the outlet of the watershed.

Identification and Assessment of Erosion Prone Areas in Watershed

The model gave the output values of runoff and soil loss for each individual hillslope as well as whole watershed. The soil loss from the watershed was further analyzed annually and event-wise to know the relation between soil loss and rainfall. Exact distribution of severely eroded areas within the watershed was obtained by analyzing hillslope level soil loss information in GIS environment (Kumar and Mishra, 2015). Identification of critical areas was done on the basis of different erosion classes *i.e.* 0-10 t $ha^{-1}yr^{-1}$ for slight, 10-20 t $ha^{-1}yr^{-1}$ for moderate, 20-40 t $ha^{-1}yr^{-1}$ for high, 40-80 t $ha^{-1}yr^{-1}$ for very high, and 80-166 t $ha^{-1}yr^{-1}$ for severe erosion. The judgment on different soil erosion classes was based on the authors' expertise and literature survey. The sediment yield details of each hillslope calculated by WEPP model were provided in GIS. The hillslopes were classified on the basis of above classes and represented in a map. This map gave a clear picture of erosion prone areas in the watershed. The hillslopes of each class were analyzed to know the variation in sediment yields. Details of soil type, slope, and land-use for each erosion class were calculated from individual hillslope data. Then, impact of soil type, slope, and land-use on the soil loss of different classes were analyzed. This information is useful for planning the best suited management practices for soil conservation in the watershed.

3. RESULTS AND DISCUSSION

Model Evaluation

Yousuf *et al.* (2017) calibrated and validated the WEPP model for a micro watershed of the study watershed. The model performed well in simulating sediment yield. The model was calibrated from the year 1982 to 1991 and validated from the year 1993 to 2004 on daily basis. The total measured and simulated values of sediment yield for the calibration period were 14.91 t ha^{-1} and 13.08 t ha^{-1}, respectively and the corresponding values for the validation period were 26.94 t ha^{-1} and 26.90 t ha^{-1}, respectively. The model simulated sediment yield with percent error of 5.01 and 4.96, RMSE of 0.41 and 0.66 mm, and model efficiency of 86.56% and 82.78%, respectively for the calibration and the validation periods.

Watershed Sediment Yield

The annual precipitation during 2016 in the watershed was 1104 mm, which caused annual runoff of 81.90 mm at the watershed outlet with a runoff coefficient of 0.074. Sediment delivery ratio and annual sediment yield of watershed were 0.303 t ha^{-1} and 16.80 t ha^{-1}, respectively. Total 69 rainfall events were observed during 2016. Thirteen events (18.8%) out of 69 events produced significant sediment yield (greater than 1 ton). The cumulative and event-wise sediment yield values in the year 2016 at the watershed outlet are shown in Fig. 3. It is evident from Fig. 3, magnitude and duration of the event affects the sediment yield. When event duration is large, then the sediment yield values are more noticeable. The highest sediment yield occurred on 11-08-2016 where rainfall magnitude was 102 mm. The sediment yield at the watershed outlet seems to be moderate, although annual sediment yields at foot of the hillslopes was quite high ranging between 0.03 t ha^{-1} and 165.53 t ha^{-1}. Therefore,

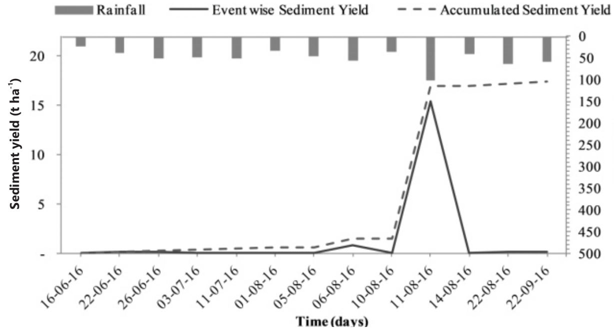

Fig. 3. Event-wise sediment yield distribution

erosion prone areas at hillslope level need to be identified for a better land management in the watershed.

Identified Erosion Prone Areas in Watershed at Hillslope Level

Annual sediment yield values of hillslopes obtained from the model output were used to identify the erosion prone areas. Spatial distribution of erosion classes of the watershed are displayed in Fig. 4. The hillslopes details of each erosion class are listed in Table 1. From delineated 167 hillslopes, 26 hillslopes are under severe erosion class, which occupy 17.30% of area with average sediment yield of 137.49 t $ha^{-1}yr^{-1}$. The remaining hillslopes under very high, high, moderate, and slight erosion classes occupied 11.30%, 7.36%, 9.01% and 55.03%, respectively. From the analysis of hillslope level information, it was noticed that slight and moderate erosion was observed in 112 hillslopes out of 167 hillslopes, which account 64.04% of total watershed area. This is may be due to the high dense forest cover with marginal slopes in upper part of the watershed. High and above erosion rates were observed in 55 hillslopes occupying about 35.96% area of watershed. This is may be due to the increased agriculture area and urbanization by deforestation. The analysis suggested that the identification of critical erosion prone areas should be done at hillslopes level, which will help in making proper strategies in erosion prone areas for land and water management in the watershed. The sediment yield details of high, very high and severe erosion class hillslopes were shown in Fig. 5. From the Fig. 5, it is concluded that the sediment yield values from hill slopes of each erosion class were randomly distributed. But, the hillslopes with same characteristics in each erosion class were producing same amount of sediment yields. This information necessitates the study on relation of soil erosion class with different land-use, slope and soil types.

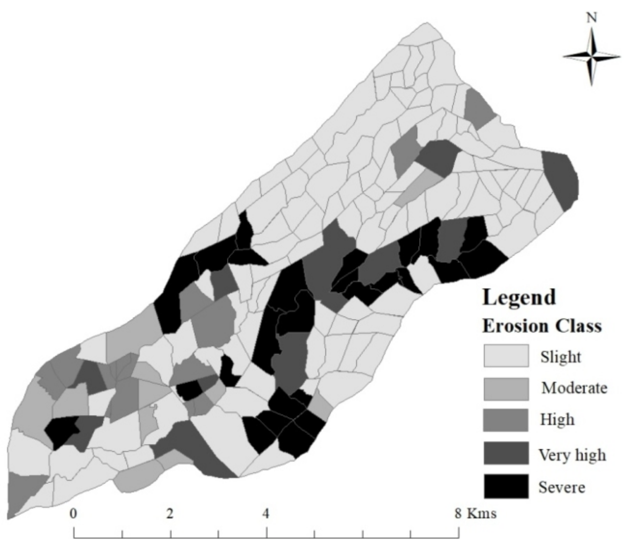

Fig. 4. Spatial distribution of erosion classes

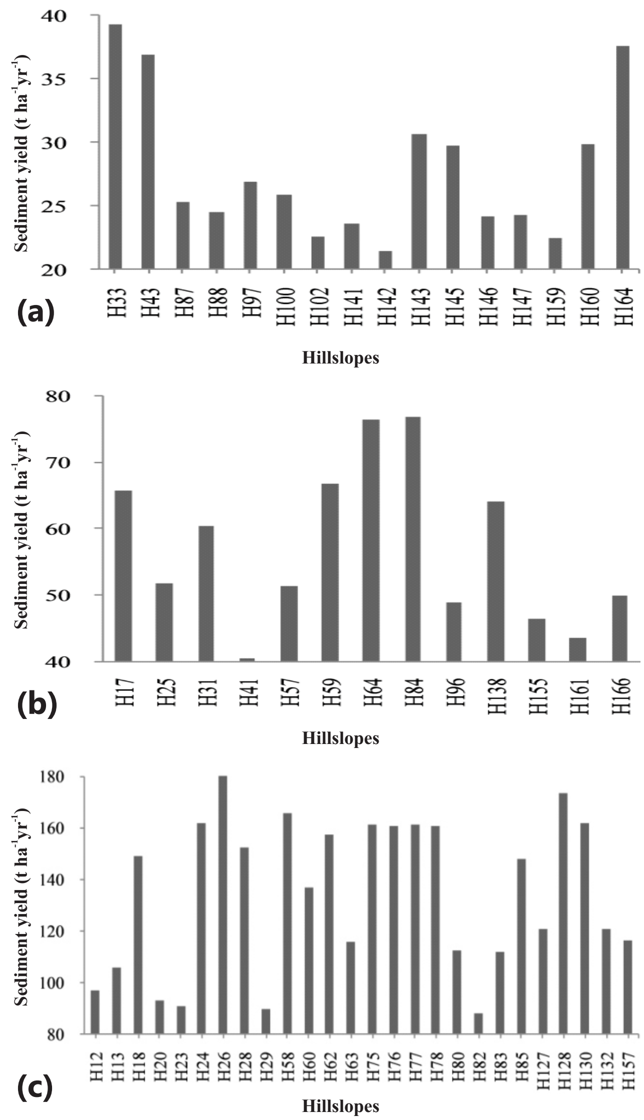

Fig. 5. Sediment yield details of hillslopes under (a) high, (b) very high, and (c) severe erosion classes

Table: 1
Hillslopes details under each erosion class of study watershed

Class	Soil loss range (t ha^{-1})	No. of hillslopes	Area (ha)	Percentage area (%)	Average soil loss (t ha^{-1})
Slight	<10	101	2759.01	55.03	3.16
Moderate	10-20	11	451.94	9.01	15.81
High	20-40	16	369.28	7.36	27.85
Very High	40-80	13	566.49	11.30	57.13
Severe	80-166	26	867.28	17.30	137.49

Soil Erosion Relation with Different Land-use, Slope and Soil Types

Hillslopes consist of land-use, slope and soil type layers, which are necessary for determination of sediment yield from that hillslope. The effect of land-use, slope and soil type on sediment yield was analyzed was better understanding of variation of sediment yield among the hillslopes.

Effect of land-use

Areas under different land-uses in Patiala-ki-Rao watershed are shown in Fig. 6, during the year 2016 forest was the main land-use in the watershed followed by agriculture. It covered 32.67 km^2 (63.57%) of the watershed area. The area under agriculture, built-up, grassland, streams, fallow land and water bodies was 8.42 km^2 (16.39%), 7.04 km^2 (13.71%), 1.42 km^2 (2.75%), 0.95 km^2 (1.85%), 0.59 km^2 (1.17%) and 0.29 km^2 (0.57%), respectively (Sushanth *et al.,* 2018). The areas of different soil erosion classes with respect to land-use in catchment are shown in Fig. 7 and it indicates that high agriculture and built-up areas are more prone to erosion, whereas, high forest areas are less prone to erosion. The figure also indicated that built-up area is major contributor to soil erosion in the catchment. The built-up area comprises of 13.71% area of the watershed out which 84.78% comes under high and above erosion classes. The area under agriculture and fallow land are 16.39% and 1.17%, out of which 80.19% and 71.54% area comes under high and above erosion classes, respectively. This may be because of urbanization of Chandigarh and Mohali cities, which are located adjoining to the watershed. Proper urban planning and management should be done in these areas to control soil erosion for the best use of catchment in the future.

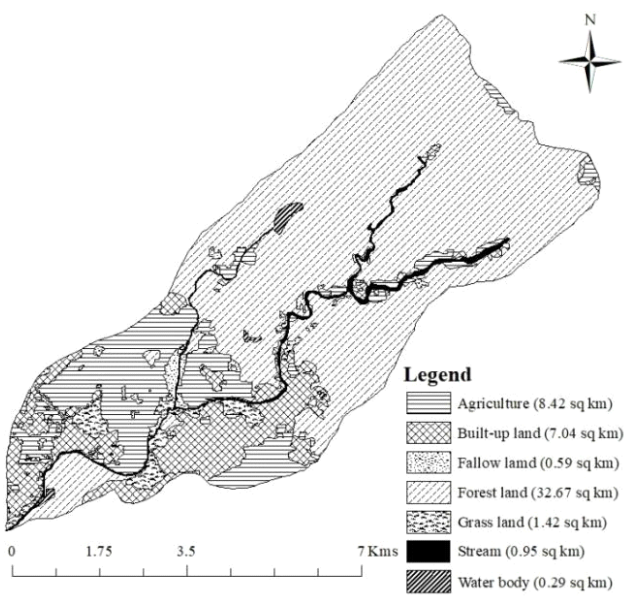

Fig. 6. Land-use map of Patiala-ki-Rao watershed for the year 2016

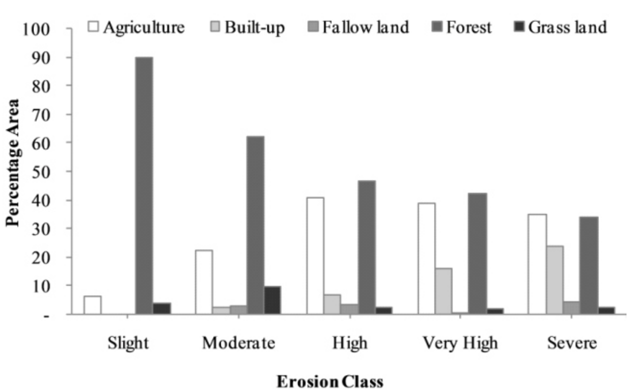

Fig. 7. Percentage area of different soil erosion class with respect to land-use

Effect of slope

The topographic characteristics (Fig. 8) clearly divide the study watershed into two distinct areas with almost same areal extent *i.e.* the lower reaches near to the outlet of the watershed which are relatively flat/plain (slope < 10%), and the upper reaches which are steeply sloped (slope >10%). The slope within the watershed varies from 0.3% to 24.7%. The area of different soil erosion classes with respect to different slope classes of hillslopes in catchment is shown in Fig. 9. It is observed from the figure that slight erosion class has more area (36.09%) under 0-5% slope range and less area under remaining classes. Whereas severe erosion class has less area under 0-5% slope range and more area under remaining classes. From this, it is concluded that high slope areas greater than 5% are more prone to soil erosion. So, it is recommended to construct bunds and terraces to check the erosive velocity of runoff in high and above erosion classes for better soil conservation in the watershed.

Effect of soil type

The watershed has four types of soils: clay loam, loam, sandy loam and sandy clay loam. The major area of the

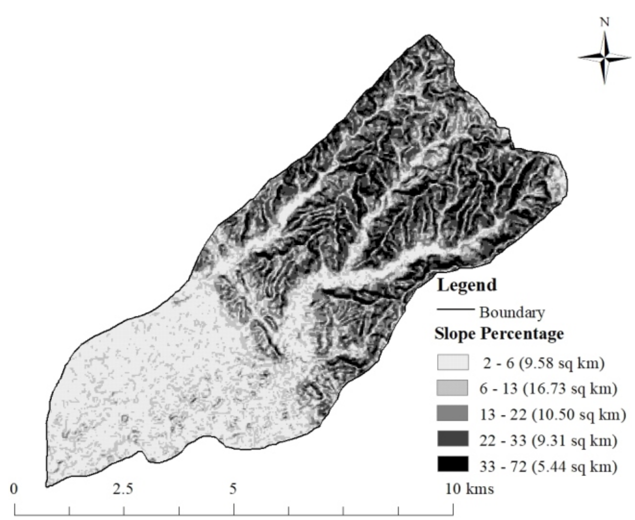

Fig. 8. Topographic map of Patiala-ki-Rao watershed

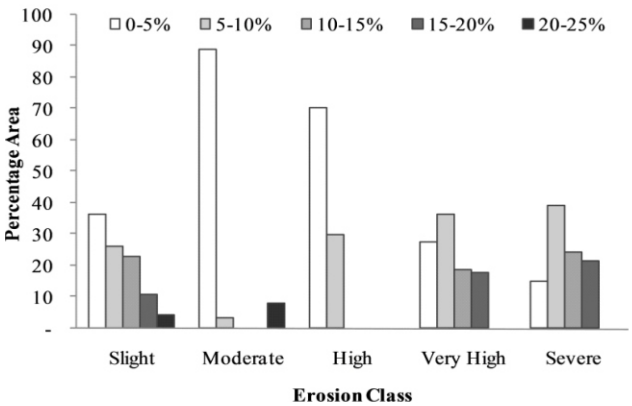

Fig. 9. Percentage area of different soil erosion classes with respect to slope classes

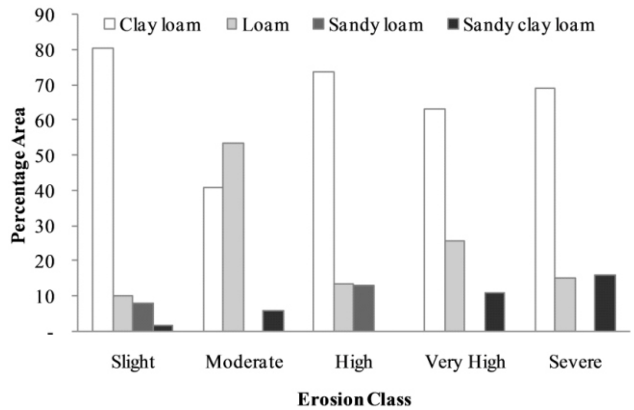

Fig. 10. Percentage area of different soil erosion classes with respect to soil types

watershed is covered with clay loam (72.40%). The area under loam, sandy loam and sandy clay loam are 16.80%, 5.3% and 5.5%, respectively. The area of different soil erosion classes with respect to soil type in catchment is shown in Fig. 10. It was observed from the figure that slight erosion class has more area (80.03%) under clay loam and less area under remaining classes. In severe erosion class, area under clay loam is lesser and area under remaining classes is higher. From this, it is concluded that high clay content soils are less to prone to erosion whereas slight increase in sand content has more effect on soil erosion. This may be due the high content of sand in the soil, which is easily erodible. So, it is recommended to use suitable soil conservation techniques in sandy soils of hillslopes to reduce the erosion.

From the analysis it has been found that some parts of the watershed are under high threat of soil erosion due to its slope, soil properties and land-uses. It might create problems of soil degradation and reduction of water storage capacity of the reservoirs. Specially urbanization of Chandigarh and Mohali cities has altered the land-use of hillslopes. So, better urban planning and land-use management practices should be adopted in hillslopes for reducing the soil erosion. In case of slopes, areas greater than 5% slope are more prone to erosion. This can be restricted by construction of bunds and terraces in the affected hillslopes. Light textured soils have more effect on soil erosion and it can be limited by suitable soil conservation techniques. The combined effect of land-use, slope, and soil type on soil erosion in critical erosion areas can be minimized by adopting the above mentioned techniques.

4. CONCLUSIONS

Soil erosion is the most significant threat to land and water resources in a watershed. Identification of erosion prone areas is the best way to conserve the land and water resources by implementing appropriate strategies. Sediment yield is the main factor for deciding the soil erosion prone areas in a watershed. In the present study, erosion prone areas were identified and assessed using WEPP model and GIS. The simulated sediment yield at the watershed outlet was 16.80 t ha^{-1} which seems to be moderate, although the sediment yields at foot of the hillslopes was quite high ranging between 0.03 t ha^{-1} and 165.53 t ha^{-1}. Simulating the sediment yield at hillslope level showed that about 35.96% area of Patiala-ki-Rao watershed is under critical erosion zone. Further, the effect of land-use, slope and soil characteristics on sediment yields of different erosion classes was analyzed. The analysis showed that built-up, agriculture and fallow lands with high slopes and sand content are more responsible for high soil loss. Finally, the study concludes that identification of erosion prone areas at hillslope level deserve priority attention within watershed for soil and water conservation to improve soil fertility and storage capacity of the reservoirs.

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