Catena 164 (2018) 71–78

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Prioritization and field validation of erosion risk areas for combating land degradation in North Western Himalayas

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ARTICLE INFO

Keywords:
Soil erosion
Targeted erosion rates
Priority areas
Field verification
Soil conservation strategies

ABSTRACT

Appropriate soil conservation practices are essentially required in Indian Himalayan region to prevent degradation of natural resources. Thus erosion priority risk areas need to be identified to efficiently plan and execute conservation programmes. This study envisages to develop a strategy based upon the concept of partial area treatment by classifying erosion risk areas and prioritizing them upon the basis of existing erosion rates with targeted soil loss limits (T-value). The hypothesis is that highest priority for conservation action should go to such areas where the difference between potential erosion rate and the targeted limit is maximum so that available financial resources are efficiently utilized. The analysis indicated that about 25% of the total land area (TLA) in the north-western Himalayan region falls under severe or very severe erosion risk categories, especially where steeply sloping lands are under cultivation or overgrazed for decades. Only about 13% of TLA has T-value of > 10 Mg ha^{-1} yr^{-1} while about 30% area of the area is less prone to soil erosion. Within the region, Uttarakhand state has highest erosion risk area (58%) followed by Himachal Pradesh (48.5%). The concept of prioritization of erosion risk areas and their treatment with appropriate conservation measures was validated with the field data collected from two representative watersheds in the Himalayan region. The present approach can be easily extrapolated to other agro-climatic regions of the country to develop conservation master plans for efficient utilization of limited financial resources on sustainable basis.

1. Introduction

Soil erosion is one of the most serious environmental threats affecting all natural and human-managed ecosystems (Pimentel, 2006; Kalibová et al., 2016; Galdino et al., 2016). Although soil erosion occurs throughout the world since long past, its intensity has steadily increased in recent times due to burgeoning population pressures coupled with diversified and inappropriate land use practices (Mandal and Sharda, 2013; Sharda et al., 2013a, 2013b; Nearing et al., 2005; Leh et al., 2013). The risk of soil erosion in some parts of Indian Himalayas is so serious that the land can no longer be restored for productive utilization thus leading to its abandonment (Mandal, 2014). Intensive or inappropriate land use practices very often lead to serious land degradation problems (Mandal et al., 2010). Almost all the soil threats are caused and aggravated due to anthropogenic activities. It is thus our primary responsibility to plan our activities in such a way that minimizes their impact on soil erosion, especially in mountain areas (Hu et al., 2013; Stanchi et al., 2015). Increasing tourist pressure, changing climate and intensive crop husbandry activities have further aggravated soil erosion problems in hilly regions. The irreversible degradation due to breakdown of soil aggregates, depletion of nutrients, reduction in soil water availability, and enhanced risk of flooding and landslides are the processes closely associated with soil erosion in the region.

The Agro-climatic Zone 1 (ACZ 1) of India represents North-Western Himalayan region comprising of Uttarakhand, Himachal Pradesh and Jammu and Kashmir states, where water erosion is a major factor leading to environmental degradation (Harden, 2001; Angima et al., 2003; Sharma, 2004). As per harmonized database on land degradation, water erosion alone contributes about 68% to the total land degradation problems in India (Maji, 2007; NAAS, 2010). Excessive soil erosion adversely affects soil productivity besides several off-site effects such as damages in terms of rapid siltation of multipurpose reservoirs and lakes (Sharda and Ojasvi, 2016). According to an estimates given by Sharda et al. (2010) the production loss of rainfed agricultural crops due to water erosion in the north western Himalayan states was highest in Uttarakhand (20%) followed by Himachal Pradesh (13%) and least in J &K (10%).

Soil erosion risk assessment is of paramount importance for sustainable land use systems (Zhang et al., 2010; Kheir et al., 2006; Strohmeier et al., 2016). Soil erosion is of great concern if it exceeds a

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https://doi.org/10.1016/j.catena.2017.12.037
Received 4 September 2017; Received in revised form 21 December 2017; Accepted 27 December 2017

certain threshold value at a given location. However, no methodology is available to identify and prioritize the erosion risk areas following a targeted approach (Biswas et al., 2015). Hence, it is necessary to devise a procedure for delineating erosion risk categories based upon potential erosion rates and targeted value or T-value in a given region. For erosion risk assessment and delineation of priority areas, the spatial information has been used as an effective tool to display the product in an easily understandable form (Wu et al., 2013). Establishing zone wise priority classes would help in proper environmental planning and management of natural resources in each zone as per existing conditions with regard to resistance and vulnerability (Le Bissonnais et al., 2001).

In this paper, erosion risk has been assessed in the agro-climatic zone I (ACZ—I) of India to identify the areas where intensive and moderate conservation measures are urgently required. The main objective of this study is to assess and analyse the erosion risks in ACZ-1 of India by integrating potential soil erosion rates with it respective targeted values of soil loss. Delineation of priority classes of erosion risk areas would help in identifying the most critical areas so that limited public funds are judiciously utilized to achieve the desired objectives. The practical applicability of identifying critical areas was further validated considering long term time series data of two representative watersheds.

2. Materials and methods

2.1. Study area

The study area covers a larger agro-geological unit called Agro-climatic Zone 1 covering states of Uttarakhand, Himachal Pradesh and Jammu & Kashmir. This region occupies an area of 33.14 m ha which is about 10.07% of the country (329 m ha). As per classification, climate in this region varies from humid temperate to humid tropical and cold alpine in the northern and eastern high mountains. During summer season, Jammu city is very hot and the temperature may reach up to 40 °C. The average annual rainfall varies from 350 mm to 3000 mm in different parts of the region, except in Leh where it is extremely low (92.6 mm) with rainy season falling between June to September and relatively dry season during winter. The area is characterized by steep topography with very high slopes. Blessed with diverse physiographic and climatic conditions, the region has unique soil, water and biotic resources. Most of the northern parts of the region are part of Greater Himalayan ranges, covered by high peaks and glaciers. The topography is by and large rugged except for *Bhabar, Tarai* and Valley regions. Soils on the hills and steep slopes have a relatively shallow depth compared to soils in the valley region. Entisols were observed to be dominant type of soils covering around 47.3% area followed by Inceptisols (18.5%), Mollisols (0.6%) and Alfisols (0.4%) (Sharda and Mandal, 2011). Highest range of organic carbon was observed in soils of greater Himalayas and Shiwalik regions. The higher organic matter content in high altitudinal regions is due to thick forest vegetation. Soil reaction varies from slightly acidic to moderately alkaline with pH ranging between 5.5 and 8.4 and soil depth varying from 25 to 100 cm. Western aspects of Ladakh region and high altitude areas of Jammu, Uttarakhand and Shiwalik parts of the region suffer from serious erosion problems. A major constraint in the region is the prevalence of shallow, sandy and gravelly/bouldery soils in some parts which causes moisture and nutrient imbalance for normal crop production.

2.2. Determination of erosion risk

Threat of soil erosion is a function of two major contributing factors i.e. rainfall erosivity and soil erodibility. If either of these two components is favourable, there is no erosion threat. However, the combination of individual external factors (soil management, precipitation) in most cases may provide an effect strong enough to cause erosion. For determining the risk of soil erosion by water, we used the well-known Universal Soil Loss Equation (USLE) and the corresponding T-value of a given soil. The USLE was used to compute the potential soil loss as:

$$E_{water} = RKLSCP \quad (1)$$

where, E_{water} is the potential average annual soil loss (Mg ha^{-1} yr^{-1}), R is the rainfall erosivity factor (MJ mm ha^{-1} h^{-1} yr^{-1}) considering the intensity, the duration and the frequency of rain storms, K is the soil erodibility factor (Mg h MJ^{-1} mm^{-1}), LS is the slope length-gradient factor (dimensionless), C is the crop/vegetation cover and management factor (dimensionless), and P is the conservation practice factor (dimensionless). Targeted soil loss or T-value was computed following the procedure given by Mandal et al. (2006) and Mandal and Sharda (2011). Each factor defined by USLE and T-value was developed in ARC GIS environment. In the present study, potential soil erosion rates for different states of the region were estimated for various soil mapping units by collecting data on various parameters of USLE in Microsoft Excel package. It was then coupled with ARC-GIS (version 9.3) software to prepare composite potential soil erosion rate map of the region. Depending upon the intensity of erosion, the potential erosion rates were organised into five classes, namely, very low (< 5 Mg ha^{-1} yr^{-1}), low (5–10 Mg ha^{-1} yr^{-1}), moderate (10–20 Mg ha^{-1} yr^{-1}1), severe (20–40 Mg ha^{-1} yr^{-1}) and very severe (> 40 Mg ha^{-1} yr^{-1}). Similarly, T- values were computed for each soil mapping unit. A general guide developed at the Iowa State University Statistical Laboratory (USDA NRCS, 1999) was used to arrive at the soil loss tolerance values for each soil unit based on the soil group and the soil depth. Soil groups were determined based on the weighted additive model as described by Mandal et al. (2006) and Mandal et al. (2010). The maps of potential and tolerable erosion rates were superimposed on a common scale on the basis of initial polygons of soil mapping units (SMUs) (Sharda et al., 2013a, 2013b; Mandal and Sharda, 2013). The digital maps or spatial layers of potential erosion rates and T-values were then integrated to assess erosion risks in a geospatial format (ARC-GIS 9.3). The digital intersection of the potential erosion rates and the T-values provide the information about the spatial variability of the actual erosion risks.

2.3. Determination of priority classes

The criteria used for identifying priority classes in the study area are described as follows:

Step 1: Assessment of potential soil erosion rate (factors used R, K, L, S, C and P) (E_{water})

Step 2: Soil vulnerability assessment by fixing permissible erosion rates or targeted soil loss values (T-values).

Step 3: Identify the areas of critical concern (difference between E_{water} and T-values of a given soil).

If E_{water} is > T-value, then decide the priority class as given in Table 1.

If E_{water} ≤ T-value, then the area is relatively safe from erosion point of view and requires no treatment.

Table 1
Priority classes of erosion risks.

Priority class	(E_{water} - T-value) (Mg ha^{-1} yr^{-1})	Remarks
1	> 35	Needs special soil and water conservation measures
2	25–35	High priority for soil conservation
3	15–25	Medium priority for soil conservation
4	5–15	Less priority for soil conservation
5	0–5	Very less priority for soil conservation
6	< 0	Requires no treatment
7	Non-soil area	Rock outcrops, glaciers and sand dunes etc.