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MICRO-WATERSHED PRIORITIZATION USING RUSLE, REMOTE SENSING AND GIS

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ABSTRACT

Micro-watershed prioritization plays a key role in planning conservation programmes for environmental rehabilitation under limited available financial resources. In this study, micro-watersheds of Takarla-Ballowal watershed located in Shivalik foot-hills of Punjab, India have been prioritized based on estimated average annual soil loss using RUSLE. The average annual soil loss in the watershed ranged from 5.73 tons ha^{-1} yr^{-1} in MWS-8 to 63.46 tons ha^{-1} yr^{-1} in MWS-1. Three micro-watersheds MWS-1, MWS-4 and MWS-7 were having soil loss greater than 50 tons ha^{-1} yr^{-1} and fall under very high priority category. Micro-watersheds MWS-3 and MWS-5 have been given high priority as their rates of erosion were 35.30 and 30.34 tons ha^{-1} yr^{-1}, respectively. Soil loss in MWS-2 and MWS-6 was found to be 23.52 and 20.12 tons ha^{-1} yr^{-1}, respectively thereby were given moderate priority. Micro-watersheds MWS-9 and MWS-8 were given low priority as estimated soil loss was 18.31 and 5.73 tons ha^{-1} yr^{-1} respectively and there is no serious soil erosion problem in these micro-watersheds due to their gentle slope. The order of priority ranking of the micro-watersheds for conservation treatments is MWS-1 > MWS-4 > MWS-7 > MWS-3 > MWS-5 > MWS-2 > MWS-6 > MWS-9 > MWS-8.

KEY WORDS
Prioritization
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Remote sensing
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INTRODUCTION

Soil is the most precious natural resource and conservation of fertile top soil of earth surface is vital to meet the growing demand of food, fibre, fuel and fodder (Ram Partap *et al*., 2015 and Bhomika *et al*., 2016). Soil erosion adversely impacts both the economy and ecology of a region (Lal, 1998). Evidently, the developing countries suffer more because of the inability of their farming population to replace lost soils and nutrients (Erenstein, 1999). Soil erosion is a major problem in the Shivalik foot-hills located in north-western Himalayan region of India, where average annual soil loss is around 80 Mg ha^{-1} yr^{-1} (Singh *et al*., 1992) and ecology is fragile. It is one of the eight most ecologically degraded regions of the country that require urgent rehabilitation measures. Watershed is the most acceptable unit for the purpose of planning for conservation and rehabilitation measures and also for most hydrological studies (Verma *et al*., 1995; Sharma *et al*., 2003; Mulligan, 2004). However, prioritization of the micro-watersheds of a large watershed is an essential step in this direction and to achieve sustainable development of the region under limited financial resource availability.

The Revised Universal Soil Loss Equation (RUSLE) model is applied worldwide for soil loss prediction. Although it is an empirical model, it not only predicts erosion rates of ungagged watersheds using knowledge of the watershed characteristics and local hydro-climatic conditions but also presents the spatial heterogeneity of soil erosion that is too feasible with reasonable costs and better accuracy in larger areas (Angima *et al*., 2003). It has been extensively used to estimate soil erosion loss to assess soil erosion risk, and to guide development and conservation plans in order to control erosion under different land-cover conditions, such as crop lands, rangelands, and disturbed forest lands (Millward and Mersey, 1999; Boggs *et al*., 2001). Remote Sensing and GIS have become important tools to study and understand landscape changes and management of natural resources at watershed scale including prioritization of micro-watersheds for conservation planning and development (Ratnam *et al*., 2005; Sunitha *et al*., 2011). Various studies have been conducted in the past on prioritization of watersheds using RUSLE model, to suggest best conservation measures (Lu *et al*., 2004; Kim and Julien, 2006; Naqvi *et al*., 2012; Kartic *et al*., 2014). Hence, in the present study RUSLE in combination with RS and GIS techniques will be used to prioritize the micro-watersheds on the basis of average annual soil loss to plan various conservation / rehabilitation measures for Takarla-Ballowal watershed in Shivalik foot-hills.

Geographical setting of the study watershed

The Takarla-Ballowal watershed which has been selected as the study watershed (Fig. 1) is a part of Himalayan mountain chain with an area of 2401.82 ha. It is bounded by latitude 31°8′ 28" N to 31°4′ 11" N and longitude 76°21′ 52" E to 76°25′ 17" E, in Shaheed Baghat Singh Nagar district of Punjab state, India. Himalayan mountain chain locally known as *Kandi* area, continuously runs from Jammu and Kashmir, Himachal Pradesh, Punjab, Haryana and finally end up at

Bhabbar tracts of Garhwal and Kumaon in Uttarakhand. The climate of the area is semi-arid sub-tropical with hot summers and cold winters. The watershed experiences precipitation with an annual average of 898 mm. The mean maximum temperature varies from 20.6ºC in January to 38.6ºC in May while the mean minimum temperature varies from 5.2ºC in January to 25.4ºC in June.

MATERIALS AND METHODS

Survey of India (SOI) toposheet number 53 A/8 on 1:50,000 scale of the Takarla-Ballowal watershed (Source: Survey of India), Satellite images of LISS 4 (2010) with spatial resolution of 5.8 m (Source: PRSC Ludhiana) and ASTER (Advanced Space borne Thermal Emission and Reflection Radiometer) with spatial resolution of 30m are the main source of data for the present study. Toposheet was used not only to delineate the watershed and micro-watersheds, but also for the preparation of the base map containing information about drainage, contours etc. The satellite images have been used to prepare a land use/land cover map. The rainfall data for the period 2005 to 2012 was collected from PAU, Regional Station, Ballowal Saunkhri, and other relevant data were procured from published and unpublished records. The methodology adopted for prioritization of micro-watersheds has been given in Fig. 2.

The average soil loss from Takarla-Ballowal watershed is estimated using RUSLE model, outlined by Wischmeier and Smith (1978) and improved and modified by Renard *et al.*, (1997). The RUSLE is a combination of five factors which are represented as follows:

$$A = R \times K \times LS \times C \times P \qquad (1)$$

Where, A is the average annual soil loss (tons ha^{-1} yr^{-1}), R is the rainfall-runoff erosivity factor (MJ mm ha^{-1} h^{-1} yr^{-1}), K is the soil erodibility factor (tons ha h ha^{-1} MJ^{-1} mm^{-1}), LS is the slope length and steepness factor (Dimensionless), C is the cover and management factor (Dimensionless) and P is the support practice factor (Dimensionless).

The rainfall-runoff erosivity factor (R) has been determined based on annual and monthly rainfall data for the year 2005-2012 using the following relationship given by Wischmeier and Smith, (1978):

$$R = \sum_{i=1}^{12} 1.735 \times 10^{\left[1.5\log_{10}\left[1.5\log_{10}\left\{\frac{Pi^2}{P}\right\} - 0.08188\right]\right.} \qquad (2)$$

Where, R is rainfall-runoff erosivity factor (MJ mm ha^{-1} h^{-1} yr^{-1}), P_i is the monthly rainfall in mm and P is the annual rainfall in mm. The annual summation of P_i^2/P is called the fournier equation.

The soil erodibility factor (K) was calculated for each soil sampling points identified in Takarla-Ballowal watershed. The computation was done based on the formula given by Wischmeier and Smith, (1978) as:

$$K = \frac{\{2.1 \times 10^{-4}(12 - OM) \times M^{1.14}\} + \{3.25 \times (S - 2)\} + \{2.5 \times (P - 3)]}{100} \qquad (3)$$

where, K is soil erodibility factor (tons ha h ha^{-1} MJ^{-1} mm^{-1}), OM is percentage of organic matter, M is particles size parameter (% silt + % very fine sand) × (100 - % clay), S is soil structure code and P is profile permeability class. Soil structure code and permeability class code have been given in Table 1 and Table 2, respectively.

In this study the slope length and steepness factor (LS) is computed using the raster calculator in ArcMap to build an expression for estimating LS, based on flow accumulation and slope steepness (Anamika *et al.,* 2013).

$$LS = \{\text{Flow accumulation} \times \left(\frac{\text{cell size}}{23.13}\right)\}^{0.4} \times \left\{\frac{\text{Sin (Slope of DEM} \times 0.01745)}{0.09}\right\}^{1.3} \times 1.6 \qquad (4)$$

The cover and management factor (C) represents cover conditions that can be managed most easily to reduce erosion. In this study, for Takarla-Ballowal watershed the C-factor was derived from the land use/land cover map, which was prepared from the IRS LISS 4 (2010) data.

The support practice factor (P) is the ratio of soil loss with a specific support practice to the corresponding loss with up slope and down slope cultivation (Anamika *et al.,* 2013). In the present study the values were assigned for cover and management factor (C) and support practice factor (P) to each corresponding land use/land cover classes within Takarla-Ballowal watersheds as per Table 3 and Table 4 respectively (Rao, 1981).

RESULTS AND DISCUSSION

Rainfall-runoff erosivity factor (R)

Monthly erosivity factors were computed for years 2005-2012 and these values were summed up to obtain annual rainfall-runoff erosivity factor R which comes out to be 2459.46 MJ mm ha^{-1} h^{-1} yr^{-1}. As the watershed is small, uniform R value is considered for the preparation of rainfall-runoff erosivity map of the watershed. The rainfall-runoff erosivity factor (R) during the years 2005-2012 *i.e.* for eight years was found to be in the range of 1062.41 to 4692.5 MJ mm ha^{-1} h^{-1} yr^{-1}. The average R-factor was estimated to be 2459.46 MJ mm ha^{-1} h^{-1} yr^{-1}. The variation of rainfall-runoff erosivity factor over different years (2005-2012) in Takarla-Ballowal watershed is shown in Fig. 3.

Soil erodibility factor (K)

The soil erodibility (K) factor for Takarla-Ballowal watershed

Table 1: Soil structure code

S. No.	Type of soil structure	Size(mm)	Code
1	Very fine granular	<1	1
2	Fine granular	1-2	2
3	Medium coarse granular	2-5	3
4	Blocky, platy or massive	5-10	4

Table 2: Permeability class code

S. No.	Profile permeability class	Code
1	Rapid to very rapid	1
2	Moderate to rapid	2
3	Moderate	3
4	Slow + moderate	4
5	Slow	5
6	Very slow	6

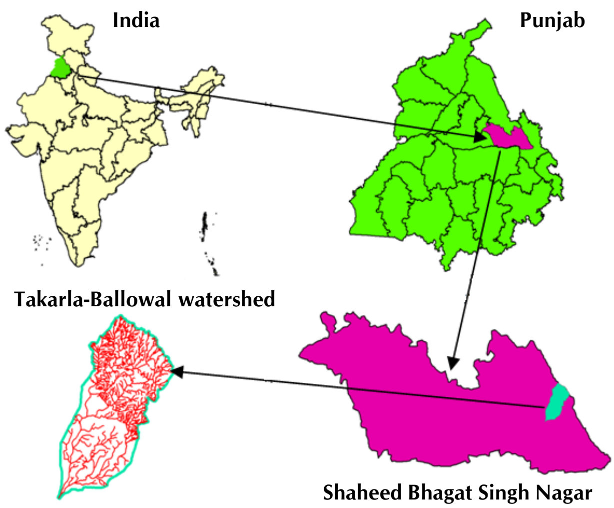

Figure 1: Location map of the Takarla-Ballowal watershed

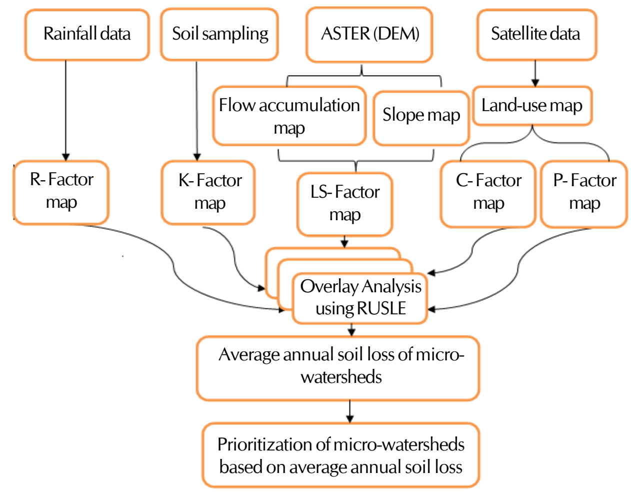

Figure 2: Flow chart of the methodology adopted for prioritization of micro-watersheds

Table 3: Cover and management factor (C) for different land use/ land cover classes

S. No.	Land use classes	C-factor
1	Settlement	1.0
2	Vacant land	1.0
3	Quarry / Brick kilns	1.0
4	Crop land	0.28
5	Fallow land	1.0
6	Plantations	0.28
7	Dense forest	0.004
8	Open forest	0.008
9	Degraded forest	0.008
10	Land with scrub	0.7
11	Land without scrub	0.18
12	Marshy	0
13	Water bodies	0

Table 4: Support practice factor (P) for different land use/land cover classes

S. No.	Land use classes	P-factor
1	Settlement	1.0
2	Vacant land	1.0
3	Quarry / Brick kilns	1.0
4	Crop land	0.28
5	Fallow land	0.28
6	Plantations	0.28
7	Dense forest	1.0
8	Open forest	1.0
9	Degraded forest	1.0
10	Land with scrub	1.0
11	Land without scrub	1.0
12	Marshy	1.0
13	Water bodies	1.0

Table 5: Area-weighted mean soil loss and priority class for micro-watersheds of Takarla-Ballowal watershed

Micro watershed	Area (ha)	Estimated average soil loss (tons ha^{-1} yr^{-1})	Priority class	Percentage area of watershed
MWS-1	285.81	63.46	1	11.9
MWS-2	222.39	23.52	6	9.26
MWS-3	219.26	35.30	4	9.13
MWS-4	88.03	60.39	2	3.66
MWS-5	211.92	30.34	5	8.82
MWS-6	310.98	20.12	7	12.94
MWS-7	376.72	54.03	3	15.68
MWS-8	320.72	5.73	9	13.35
MWS-9	365.98	18.31	8	15.24

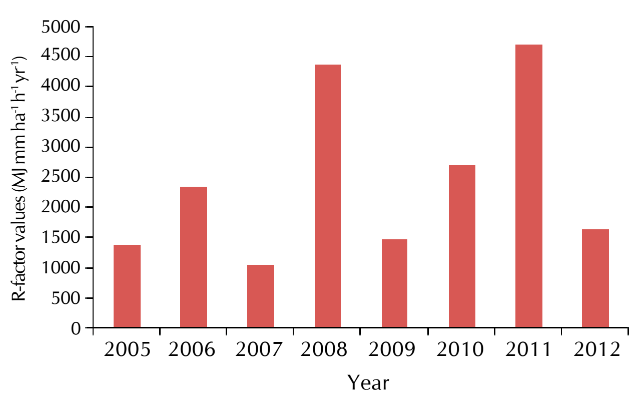

Figure 3: Variation of rainfall-runoff erosivity factor (R) during the year (2005-12) in Takarla-Ballowal watershed

was calculated based on the nine soil sampling points identified in various micro-watersheds using the Eq. 3 given by Wischmeier and Smith, (1978). The sand, silt, clay and organic matter percentage for each soil mapping point were determined. It was observed that soils with higher clay content experience high cohesion as a result of which it is less vulnerable to erosion whereas soils with low clay percentage have higher infiltration rate resulting in smaller K values. High K values are obtained for forest areas of the watershed. The soil erodibility map of the watershed is given in Fig. 4. The K-value is maximum for MWS-1 (0.371) followed by MWS-3 (0.321) and is minimum for MWS-8 (0.072).

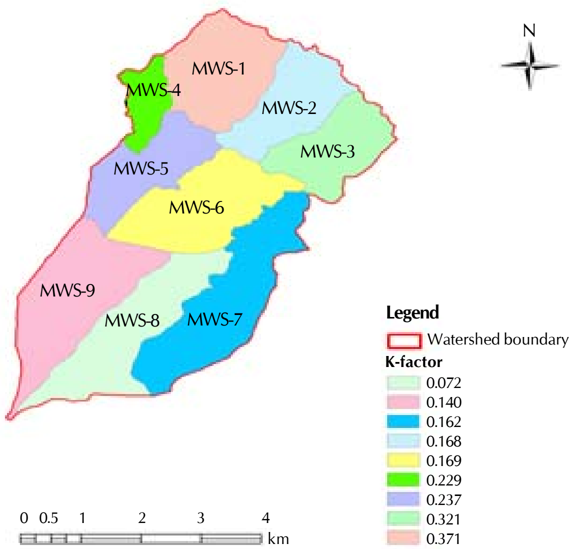

Figure 4: Variation of soil erodibility factor (K) in Takarla-Ballowal watershed

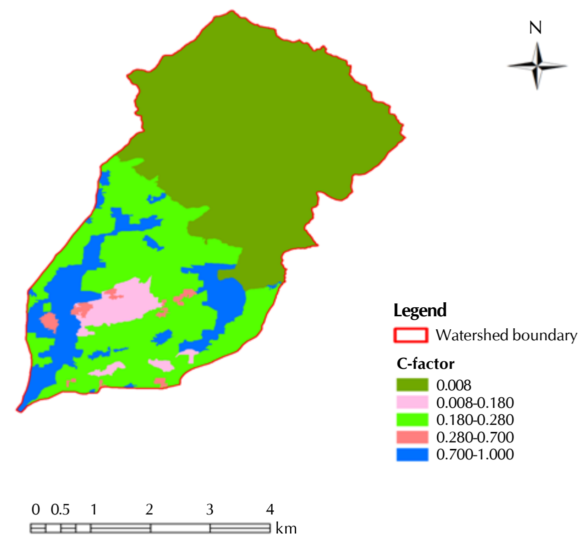

Figure 6: Variation of cover and management factor (C) in Takarla-Ballowal watershed

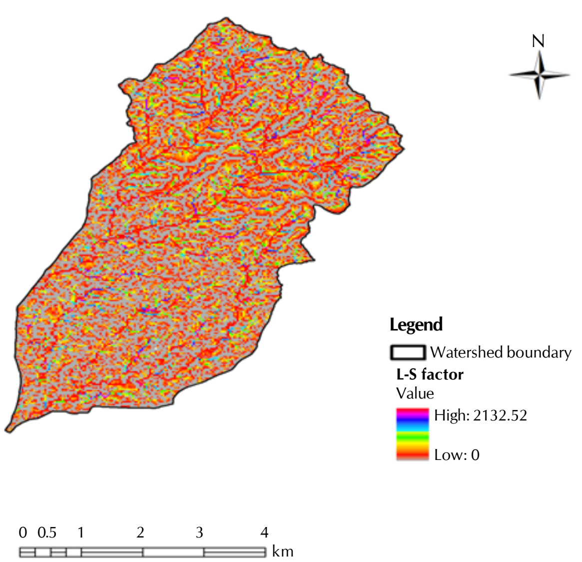

Figure 5:Variation of slope length and steepness factor (LS) in Takarla-Ballowal watershed

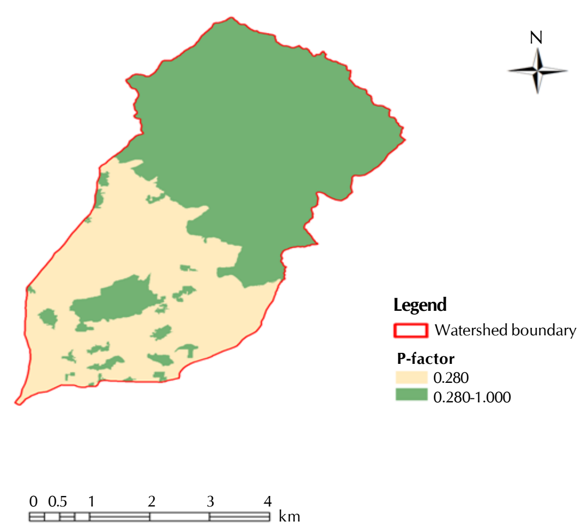

Figure 7:Variation of support practice factor (P) in Takarla-Ballowal watershed

Slope length and steepness factor (LS)

The LS-factor map was created for Takarla-Ballowal watershed and is shown in Fig. 5. The LS factor values range from 0 to 2132.52. Small LS values were obtained for cultivated plain areas of micro-watersheds MWS-7, MWS-8, MWS-9 and for some terraced agricultural lands located in the middle of Takarla-Ballowal watershed. On other hand, high LS values were obtained for forest micro-watersheds MWS-1, MWS-2, MWS-3 and MWS-4. This is because slope steepness (S) is higher in these micro-watersheds which is responsible for high LS values. The slope length of these micro-watersheds were found to be larger which account for increased erosion due to greater accumulation of runoff.

Cover and management factor (C)

Soil erosion potential is increased if the soil has no or very little vegetative cover of plants and/or crop residues. The effectiveness of this cover to reduce erosion depends on the type, extent and quantity of cover. Fallow lands have higher values of C (1.0), which shows that they contribute more to soil erosion as they are mostly devoid of vegetation cover that protect the soil from raindrop impact and splash, and slow down the movement of surface runoff. Plantation and agricultural lands have C value of 0.28, while forest, land with scrubs, land without scrubs are having C values of 0.008, 0.7 and 0.18, respectively. The result of reclassification of the map shows that agricultural and fallow lands have larger

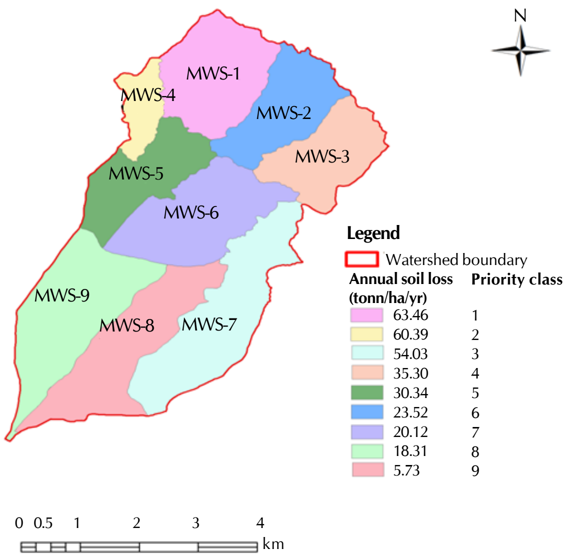

Figure 8: Prioritization of micro-watersheds based on soil loss in Takarla-Ballowal watershed

C-value as a result of which these contribute higher soil loss as compared to forest land that has good cover condition and hence show lower C value (Fig.6)

Support practice factor (P)

In this study, P values were assigned as per Rao, (1981) by considering the existing control-practice and the slope range of each land unit and the variation within Takarla-Ballowal watershed is shown in Fig. 7. High P values are found to be associated with high slope. Even the dense forest areas are associated with high values of P-factor. However, because the other factors of RUSLE such as C factor are low, the erosion is not so severe in forest areas.

The down reach of Takarla-Ballowal watershed shows lowest P value due to its flat slope even though no major conservation measures are practiced. This area is rather a point of deposition of sand debris washed from hilly parts of the watershed.

Soil erosion intensity and prioritization of micro-watersheds

All the factor maps for R, K, LS, C and P were integrated to generate a composite map of soil erosion intensity of Takarla-Ballowal watershed and its micro-watersheds. An integration of the five RUSLE factor layers has resulted in a new layer. A direct multiplication of the five factor values in the database of the resultant layer using ArcMap calculation module has given the corresponding erosion intensity value in tons ha^{-1} yr^{-1} for each of the micro-watershed. The new layer was reclassified in to seven erosion intensity classes *viz.* <1, 1-5, 6-10, 11-25, 26-50, 51-100 and >100 tons ha^{-1} yr^{-1} based on the newly created erosion intensity field comparable to Kartic *et al.*(2014) . The area-weighted mean soil loss was then determined and priority class of each micro-watershed within Takarla-Ballowal watershed is given as shown in Table 5. Rank was assigned based on the amount of average annual soil loss in which the first rank is given to the micro-watershed with maximum soil loss. Other ranks were assigned in decreasing order of soil loss intensity where the last rank goes to the micro-watershed with the least soil loss (Table 5).

The micro-watersheds MWS-1, MWS-4, MWS-7, MWS-3 and MWS-5 have been ranked as 1, 2, 3, 4 and 5 on the priority list and hence require immediate treatments. Prioritization map was then prepared based on erosion hazard as shown in Fig. 8. Micro-watershed priority has been classified into four categories namely; Very high when soil loss is greater than 50 tons ha^{-1} yr^{-1}; high for soil loss between 30-50 tons ha^{-1} yr^{-1}; moderate when it is between 20 and 30 tons ha^{-1} yr^{-1} and low when soil loss is less than 20 tons ha^{-1} yr^{-1}. Keeping in view this criteria, micro-watersheds MSW-1, MSW-4 and MSW-7 falls under very high priority; micro-watersheds MSW-3 and MWS-5 under high priority; micro-watersheds MSW-2 and MWS-6 under moderate priority; and micro-watersheds MWS-8 and MWS-9 under low priority. According to this classifications 31.26%, 17.95%, 22.20%, and 28.59% of the area of the Takarla-Ballowal watershed fall under the categories of very high, high, moderate, and low priorities to execute conservation treatments.

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