Sediment Yield Estimation for Developing Soil Conservation Strategies in GIS Environment for the Mountainous Marusudar Catchment, Chenab Basin, J&K, India

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ABSTRACT

Keeping in view the mountainous topography, fragile ecology and high tectonic activity of the Chenab basin in Jammu and Kashmir, India the hydropower infrastructure development has significant environmental costs. Therefore, it is important that the hydropower infrastructure development in the basin is promoted in a way that envisages minimum environmental costs. This article focuses on the soil erosion estimation using the Sediment Yield Index (SYI) model in the Marusudar catchment, one the important catchments in the Chenab basin where a number of hydropower projects are planned to come up soon. Soil erosion was assessed at micro-watershed level in GIS environment and on the basis of the sediment yield potential, watershed prioritization scheme was suggested classifying the micro-watershed into very high, high, moderate and low priority. Out of the 1423 km^2 of the catchment area, ~73 km^2 require soil conservation treatment measures to reduce the sediment yield from the micro-watersheds. On the basis of the prioritization, the catchment area treatment (CAT) plan, requiring a budgetary provision of ~1456 lakhs, was suggested prescribing various structural and non-structural measures for soil and water conservation measures in the catchment. The CAT plan, if implemented in letter and spirit, shall significantly reduce the negative impacts of the hydropower infrastructure development project on land and water resources in the fragile Himalayan ecosystem.

Keywords: *Marusudar catchment, Sediment yield index, Prioritization, CAT plan.*

INTRODUCTION

Soil erosion by water occurs throughout the world, especially more in the mountainous region and has been recognized as the most severe hazard threatening natural environment and agriculture productivity as it reduces soil productivity by removing the most fertile topsoil. The loss of topsoil and terrain deformation due to soil erosion are the consequences of deforestation, removal of natural vegetation, high intensity rainfall and overgrazing in the mountainous regions (Shrestha, 1997; UNEP/ISRIC, 1990). Accelerated soil erosion has adverse economic and environmental impacts (Lal, 1998). It creates on-site and off-site effects on productivity due to decline in land/ soil quality (Lal, 2001). The current rate of agricultural land degradation world-wide by soil erosion and other factors is leading to an irreparable loss in productivity on about 6 million hectares of fertile land a year. Asian rivers contribute about 80% of the total sediments delivered to the world oceans and amongst these Himalayan rivers are the major contributors (Stoddart, 1969). The Himalayan and Tibetan regions although covers only about 5% of the earth's land surface but supply around 25% of the dissolved load to the world oceans (Raymo and Ruddiman, 1992). In India, about 5334 Mt (16.4 ton/hectare) of soil is detached annually, about

29% is carried away by the rivers into the sea and 10% is deposited in reservoirs resulting in the considerable loss of the water storage capacity (Narayan and Babu, 1983). In India, it is estimated that about 38% out of a total reported geographical area, that is about 127 million hectare, is subjected to serious soil erosion (Das, 1985). Jammu and Kashmir Himalaya is highly susceptible to the soil erosion due to the peculiar mountainous landscapes prone to land sliding, denuded and deforested hills, karewas and arid landscapes. However, only a few studies have been conducted on land degradation and soil erosion in Kashmir Himalayas (Meraj *et al.*, 2017; Altaf *et al.,* 2014; Zaz and Romshoo 2012; Rashid *et al.,* 2011). Plio-Pleistocene glacio-fluvio-lacustrine sediments overlain on the Precambrian are vulnerable to soil erosion (Dar *et al.,* 2013). The exposed sections are mainly of sedimentary origin and are highly vulnerable to erosion. About 50% of the land area in the Kashmir valley is highly prone to severe erosion (Zaz and Romshoo, 2012). Rain-induced landslides, more frequent during winters and spring, cause very high soil erosion.

Thus, soil erosion is an important social and economic problem and an essential factor in assessing ecosystem health and function. Estimates of erosion are essential to for developing strategies for land and water management, including sediment transport and storage in lowlands, reservoirs, estuaries, and irrigation and hydropower reservoirs.

STUDY AREA

The area chosen for present study is Marusudar catchment (Fig. 1), where Bursar Hydroelectric Project (longitude 75^0 47´ 06´´ E and Latitude 33^0 30´ 38´´ N), with storage capacity of more than two million acres feet and the power generation capacity of 800 MW is soon coming up near Pakal village on 133-km long Marsudar River (NHPC, 2016), the right bank tributary of river Chenab in Dachhan-Marwah area. Marsudar River originates from Nunkun glacier in Warwan valley from Higher Himalayas and joins Chenab at Bhandarkot. The terrain comprises very steep slopes to escarpments. The catchment is situated within the jurisdiction of Kishtwar district. It receives a large proportion of precipitation in the form of snowfall in the upper catchment while the rainfall is mainly received in the middle and lower parts of the basin. Livelihood of the people in the mountainous Marusudar catchment is mainly dependent on farming system and especially on subsistence agriculture. Therefore, soil and water resources are important to sustain the agriculture productivity in hilly terrain. Different types of erosion that occur in the study area are: sheet erosion; gully erosion and stream bank erosion. In addition to these natural erosion processes, various infrastructure development activities would accentuate the soil erosion process. The landslides in the area are triggered mainly by geological, hydrological and seismic factors. One or combination of all these factors causes the landslides during the rainy season. Recurrent blasting for tunneling, etc. during the construction period does trigger off minor slips/ landslides due to the reduction of shear strength of rock material.

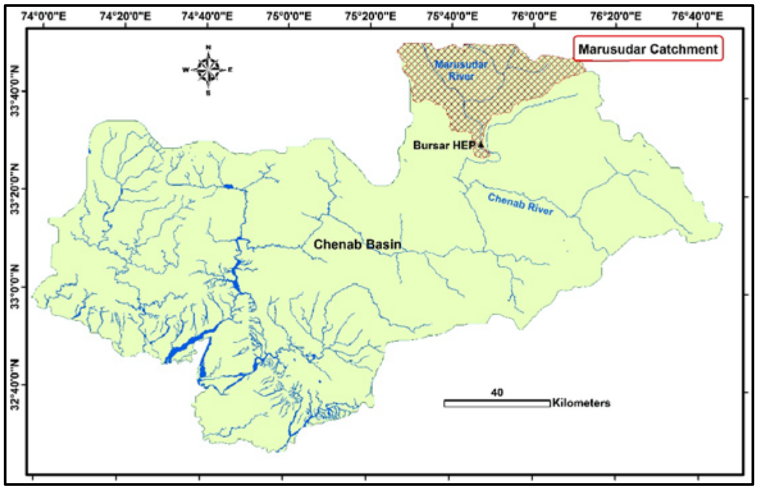


Fig. 1. Showing location of study area (Marusudar catchment)

MATERIALS AND METHODS

Soil Erosion Estimation

In the mountainous catchments of Himalaya like that of the Marusudar Watershed in Chenab basin of Jammu and Kashmir, India, conventional theoretical methods of soil loss estimation are time-consuming and costly. Therefore, Sediment Yield Index (SYI) model was used for the estimation of soil loss using various input parameters in a GIS environment (Naqvi *et al.*, 2015). SYI method is widely used method mainly because of the fact that it is easy to use, has lesser data requirement and can be applied to larger watershed area (Chakraborti, 1991). The SYI model for prioritization of sub-watersheds in the catchment areas involves the evaluation of: Climatic factors comprising total precipitation, its frequency and intensity; Geomorphic factors comprising land forms, physiography, slope and drainage characteristics; Surface cover factors governing the flow hydraulics; and Management factors as discussed in this section. Therefore, simulation models and multi-criteria analysis in GIS environment for prioritization of the micro-watersheds are the most effective for predicting soil erosion processes at watershed level (Mellerowicz *et al.,* 1994; Badar *et al.,* 2013). The efficient and optimum management and conservation of soil, land and water resources is best achieved based on the watershed prioritization scheme (Kanth & Zahoor-ul, 2010). After prioritization, the catchment area treatment plan (CAT plan) for the Marusudar catchment was prepared for checking soil erosion and land degradation by suggesting adequate and effective soil conservation measures in high erosion prone areas; rehabilitation of the degraded forest areas through afforestation and facilitating natural regeneration; and rehabilitation of degraded slopes and landslide prone areas. The CAT plan was formulated to arrest soil erosion in the catchment area up to dam site. The following are the watershed characteristics required for assessing the sediment yield at the catchment level:

Drainage characteristics:

The natural run off of water from an area by streams, rivers etc. is one of the most potent agencies in shaping the landform (Kumar and Verma, 1983). A major stream of water – Marusudar River and its tributaries constitute the drainage system of the Marusudar catchment. The Drainage map was prepared from ASTER DEM in GIS medium. Drainage pattern shows the area is having a dendritic type of drainage pattern as shown in (Fig. 2).

Drainage density is the total length of all the streams and rivers in a drainage basin divided by the total area of the drainage basin (Horton, 1932). The high drainage density of any watershed indicates that it has impermeable subsurface material, lesser vegetation cover and high relief leading to high erosion (Harlin and Wijeyawickrema, 1985; Altaf *et al.*, 2014). Drainage density map of the study area is shown in (Fig.3). It was observed that all the micro-watersheds have slight difference in the values of drainage density with maximum value in micro-watershed (MW) 6 and 7.

The sediment delivery ratio indicates the percentage of eroded material that finally finds entry into reservoir or river/ stream. Delivery ratio is assigned to all erosion intensity units depending upon their distance from the nearest stream (Naqvi *et al.*, 2015). Delivery ratio has been calculated on the basis of nearest stream distance in kilometres. The values of delivery ratio are assigned according to the length of the stream as shown in (Table 1). Most of the streams range between 2-5 km in most of the micro-watersheds and were assigned value a delivery ration of 0.8 as per the drainage density.

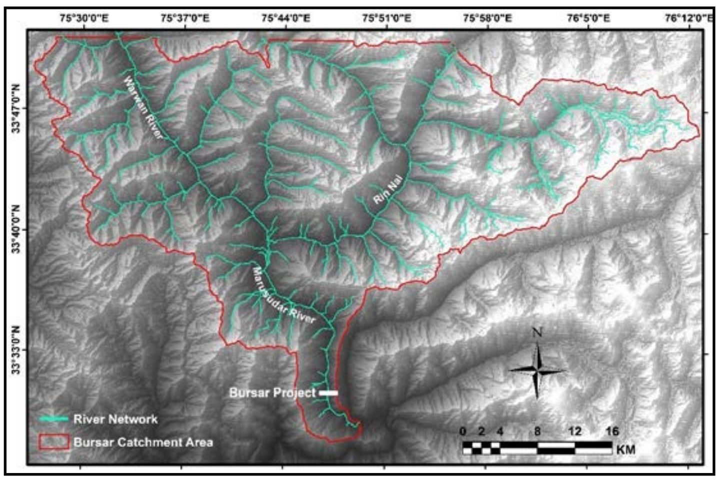


Fig. 2. Drainage map of Marusudar catchment

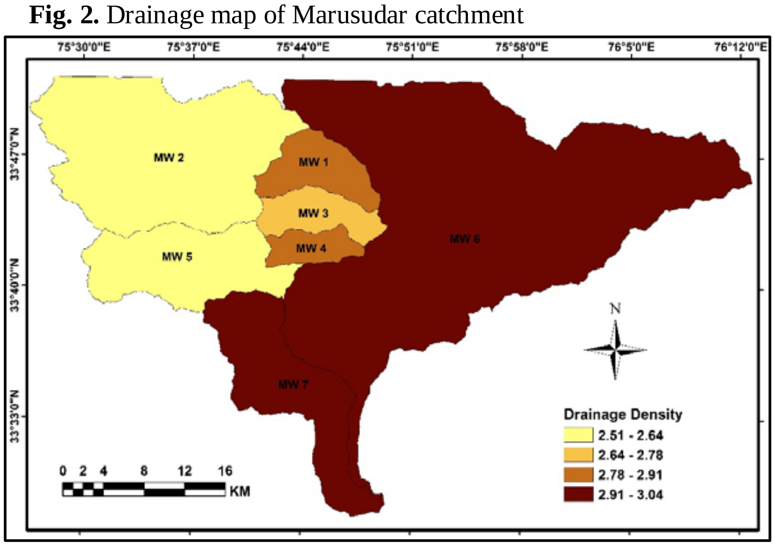


Fig. 3. Drainage density map of Marusudar catchment

Table 1. Values for Delivery ratio used in study

S.No.	Stream Length	Delivery ratio
1	0 - 2.0 km	0.90
2	2.1 - 5.0 km	0.80
3	5.1 - 15.0 km	0.70
4	15.1 - 30.0 km	0.60

Slope characteristics:

Digital Elevation Model (DEM) was analysed in GIS environment to generate the slope map of the study area. As can be seen from the Fig. 4 and Table 2, there are large areas (approx. 60%) in the watershed that are under the slope category 19- 32% and about 20% watershed area has greater than 32% slope indicating that large extent of the watershed area are vulnerable to high degree of water erosion .

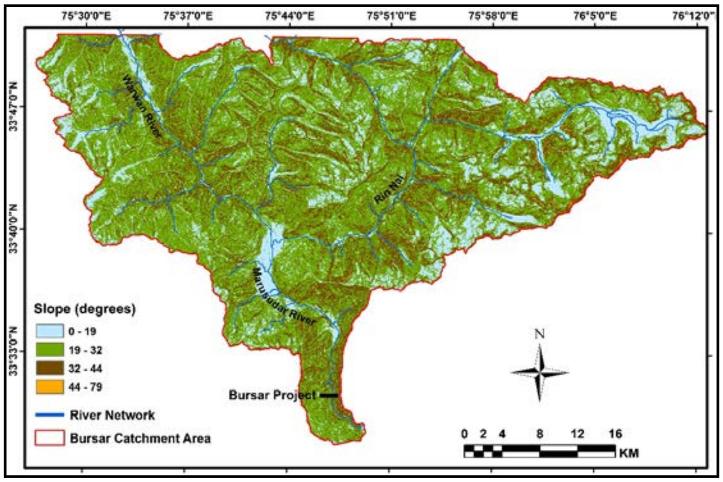


Fig. 4. Slope map of Marusudar catchment

Table 2. LULC area under different classes

S.No.	Slope (degree)	Area (km^2)	Area (%)
1	0 - 19	274.36	19.10
2	19 - 32	854.20	59.46
3	32 - 44	301.34	20.98
4	44 - 79	6.72	0.47

Land use and land cover Characteristics:

Land use/land cover map of the Marusudar catchment was prepared using Landsat 8–OLI OCT 2014 having resolution of 30 m of October. The satellite image was interpreted making use of the interpretation keys. Characteristics of the land surface, including natural and artificial cover were considered to derive information about land use and land cover. The information given in the Table 3 revealed 27.50% of area was under forests. Pasture and agricultural land were clubbed together as the weightage for sediment yield index is same for both the classes as summarized by Morgan *et al.* (1982) and accounts for 20.94 % of total area. Barren land occupied near about 24.92 % area of the catchment. Water is 0.61 % of the total area. A significant area in the upper catchment is always under the snow cover (Fig. 5). The barren lands are vulnerable to soil erosion particularly those on the denuded precipitous slopes.

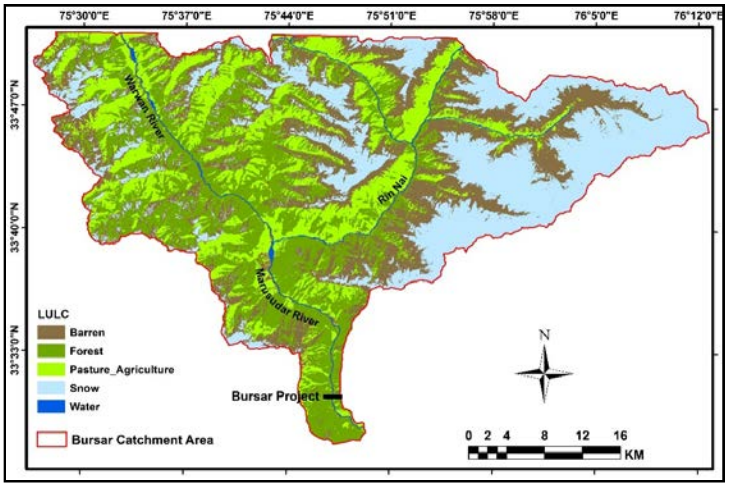


Fig. 5. Different classes of LU/LC map of 2014

Table 3. LULC area under different classes

S.No.	LULC classes	Area (km^2)	Area (%)
1	Forests	391.48	27.50
2	Water	8.71	0.61
3	Pasture & Agriculture	298.08	20.94
4	Barren	354.74	24.92
5	Snow	370.32	26.02

Rainfall pattern:

The average annual rainfall in the catchment as observed in the Kishtwar and Hawal stations is 977 mm; with maximum annual rainfall in the area received during the months from June to September (July and August are the rainiest months). The variation in the rainfall from year to year in the area is appreciable. As suggested by Morgan *et al.* (1984), a typical value for 'rainfall intensity' of erosive rain is 10 mm/h in temperate climate. Fig. 6 shows the annual rainfall pattern in the Marusudar catchment. Rainfall pattern was generated by Krigging interpolation of the observed data at Kishtwar, Hawal, Banihal, Batote, Baderwah, Drabshala, Duldam, Ohli and Palmar stations.

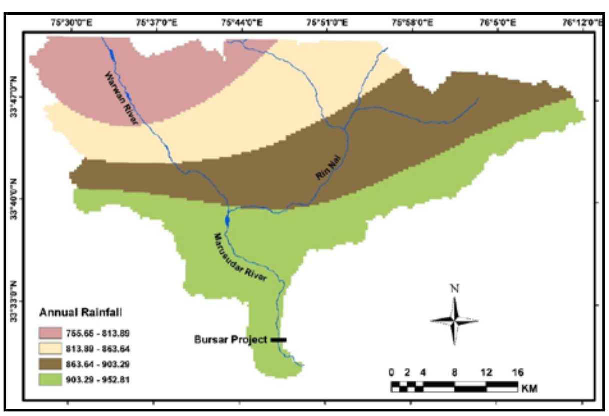


Fig. 6. Annual Rainfall Map of Marusudar catchment

Soils Characteristics:

Soil map provides information regarding soil type and texture and plays very significant role in sediment yield estimation. From the data provided by National Bureau of Soil Survey and Land Use Planning (NBSS & LUP), the soils in the catchment vary from loamy to sandy from different soil texture classes as shown in Fig.7. Marusudar catchment is dominated by loam and sandy loamy, covering 66.4% and 11.22% of the total area respectively (Table 4). pH of the coniferous forest soils in the study area varied in the range of 6.10 and 7.43 (slightly acidic to mildly alkaline). On the whole, the agricultural land are slightly alkaline, while the forest land was acidic in nature.

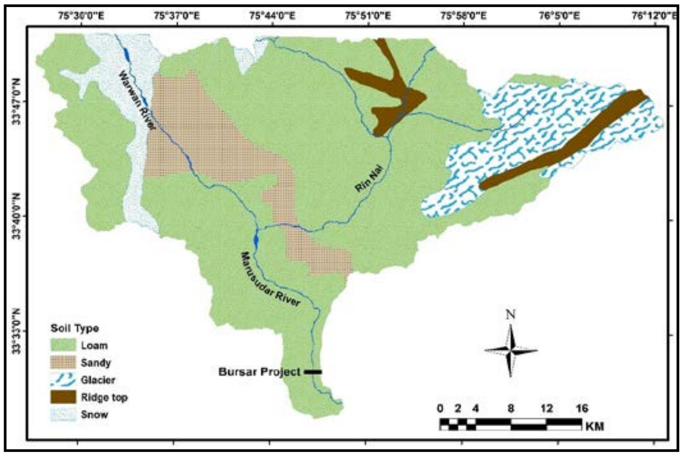


Fig. 7. Soil map of Marusudar catchment

Table 4. Soil area under different classes

S.No.	LULC classes	Area (km^2)	Area (%)
1	Loam	951.9	66.4
2	Sandy	160.9	11.22
3	Glacier	165.58	11.55
4	Ridge top	60.04	4.19
5	Snow	95.14	6.64

RESULTS AND DISCUSSION

Sediment Yield Index (SYI) Model:

Sediment Yield Index (SYI) is defined as the yield per unit area and SYI value for hydrologic unit is obtained by taking the weighted arithmetic mean over the entire area of the hydrologic unit by using suitable empirical equation. SYI considers sedimentation as product of erosivity, morphometry and delivery ratio of a particular sub-watershed and was conceptualized by Soil and Land Use Survey of India (SLUSI) as early as 1969 (Rana *et al.*, 2000) and has been operational since then. In this method, the terrain is subdivided into various sub- or micro-watersheds and the erodibility is determined on relative basis. SYI provides comparative erodibility criteria of catchment (low, moderate, high, etc.) and does not provide the absolute sediment yield. A step-wise approach in GIS environment based on the multi-criteria analysis was adopted using various input parameters like slope, soil type, precipitation, land use/land cover and landscape drainage (Table 5). In case of slope, the spatial queries were undertaken for different slope categories ranging from gently sloping category to escarpments with different soil classes like shallow soils, deep soils, etc. The subsequent analysis was done with resultant outputs using other parameters like land use/ land cover etc.. In all, more than 150 such spatial queries were executed for the purpose of SYI. From the integrated analysis, a thematic map of areas prone to erosion in the entire free-draining catchment area was prepared. Map layers were prepared for each parameter and used for assigning weighted values to calculate the SYI in tons km^{-2} yr^{-1} using the following equation:

Sediment yield index (SYI) = $\sum(Ai * Wi * Di) * 100/Aw$ ------------------------- (i)

where *i*= 1- n; *Ai*= area of ith unit (EIMU); *Wi*= weighted value of ith mapping unit; *Di*= delivery ratio; *Aw*= total area of catchment.

Table 5. Input parameters, sources and the criteria for SYI calculation

S.No.	Parameter	Source	Criteria adopted for weightage values
1	Barren/bare land	Derived from LANDSAT	More the coverage of barren land, higher the weightage value.
2	Dense forest	Derived from LANDSAT	More the dense forest coverage, lower the weightage value has been assigned.
3	Soil texture	Derived from NBSS	Soil texture is a very important parameter in terms of soil loss calculation. High value has been assigned for sandy loam texture.
4	Topography	ASTER DEM	It can vary according to slope steepness and length. Higher the elevation, higher the weightage.
5	Drainage	ASTER DEM	Greater the Drainage Density or number of streams, higher the weightage.
6	Rainfall	Derived from nearby stations	Higher the rainfall, higher the weightage values were assigned.

The rate of soil loss was estimated for each micro-watershed, and then ranked and categorized into four priority ranking classes; very high, high, moderate and low, according to the SYI values. Several map layers were prepared to determine the *Wi* in SYI model. Firstly, the weighted value for every factor was assigned on the basis of its risk level, and then input into the SYI equation. Priority indicators and the composite score for each micro-watershed were assigned according to Table 6. The weighted values were assigned using the weighted overlay tool in ArcMap. There are different ways by which the suitability assessment can be done by employing a "maximization" or "worst case" model (Space Applications Centre, 1999), where the "worst" parameter determines the suitability. Table 6 shows the criteria for adoption, the weighted values, and the total values that were applied for *Wi* in the above equation (I) for SYI calculation. Figure 8 shows the soil erosion intensity map generated using weighted overlay analysis. Low values show the areas which are least prone to erosion while as high values show the areas highly vulnerable to soil erosion. The area under different erosion intensity categories in the Marusudar sub-watersheds is given in Table 7.

Table 6. Assigned weightage values of all factors for SYI calculation

S.No.	Parameters/ factors	Categories/ classes	Assigned weightage values
1	Annual Rainfall	755.65- 813.89	2
		813.89- 863.64	4
		863.64- 903.29	6
		903.29- 952.81	8
2	Slope(in degrees)	0- 19	2
		19- 32	4
		32- 44	6
		44- 79	8
3	Soil texture	Loam	2
		Sand	4
4	LULC	Dense forests	2
		Sparse forests	4
		Pastures, agriculture	6
		Barren	8
5	Drainage Density	2.51- 2.64	2
		2.64- 2.78	4
		2.78- 2.91	6
		2.91- 3.04	8

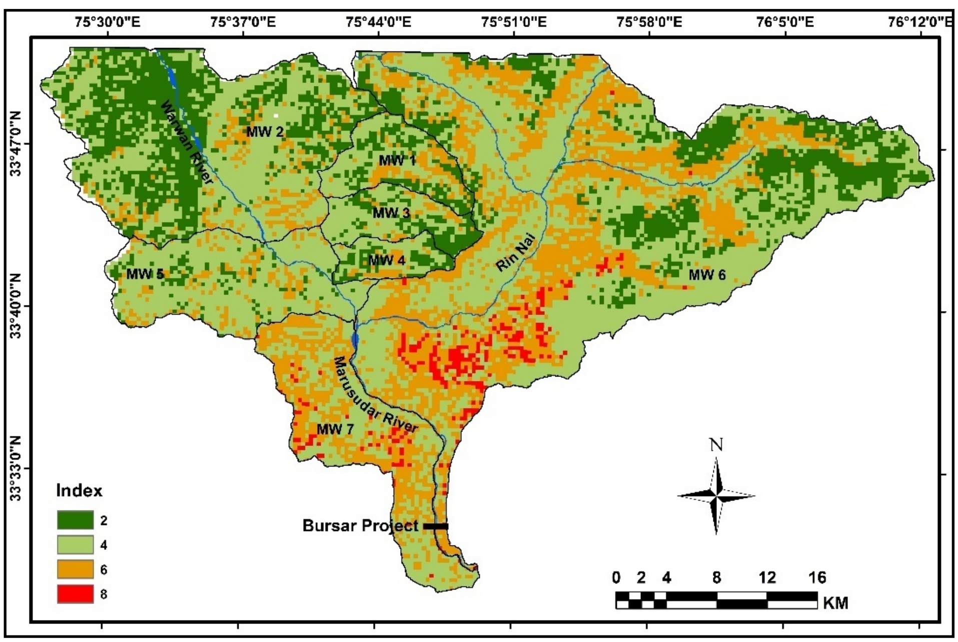


Fig. 8. Soil Erosion Intensity Map of the Marusudar catchment

Table 7. Showing area under different erosion categories in each micro-watershed

S.No.	Watershed code	Area under different erosion intensity category (km^2)				Total
		Slight	Moderate	Severe	Very severe	
1	MW1	16.88	27.05	10.46	0.00	54.39
2	MW2	122.02	147.69	28.28	0.00	297.99
3	MW3	14.40	25.47	4.50	0.00	44.37
4	MW4	9.39	13.52	4.36	0.01	27.28
5	MW5	11.92	96.05	18.61	0.03	126.61
6	MW6	114.37	364.81	232.86	21.50	733.54
7	MW7	0.15	71.29	61.92	5.79	139.15
	Total	**289.13**	**745.88**	**360.99**	**27.33**	**1423.33**

Micro-watershed prioritization using SYI:

After calculation of the soil erosion intensity, the micro-watersheds were classified into various priority zones based on the minimum and maximum SYI values. Table 8 provides detailed information about the input values, prioritization ranking and prioritization categories/ zones of the sediment yield of the different Marusudar micro-watersheds. The micro-watersheds were broadly classified into four priority zones according to their composite scores; classes with very high sediment yield (>2000 t km^{-2} year^{-1}), high sediment yield (1000-2000), medium sediment yield (500-1000 t km^{-2} year^{-1}), and low sediment yield (<500 t km^{-2} year^{-1}) (Table 9). The micro-watershed prioritization map was prepared using these values, as shown in Figure 9. The map identifies the micro-watersheds requiring soil conservation treatment on priority. Micro-watersheds MW6 was assigned the very high priority, with SYI values of 3007.9 t km^{-2} year^{-1}. Most of the lands in these micro-watersheds are covered by forest, built-up and agricultural land. Some areas in the watershed fall under the bare/barren land, imparting high vulnerability to water erosion processes. Micro-watershed MW7 is assigned medium priority. Micro-watershed MW7 is sparsely forested, and is having some agricultural and bare/barren land. The micro-watersheds with the lowest priority ranking are MW1, MW2, MW3, MW4, and MW5, which cover about 38.9% of the Marusudar watershed area. The presence of good coverage of vegetation in these micro-watersheds prevents the soil loss and hence these are assigned the least priority for soil conservation.

Table 8. SYI Values of micro watersheds with priority ranks

S.No.	MWS	Area in sq/km	Weightage value	Weightage product	Delivery ratio	SYI t km^{-2}year^{-1}	Priority rank
1	MW1	54.39	3.59	195.06	0.8	11.0	Low
2	MW2	297.99	8.79	2676.99	0.8	150.5	Low

3	MW3	44.37	2.93	129.82	0.8	7.3	Low
4	MW4	27.28	1.80	49.06	0.8	2.8	Low
5	MW5	126.61	7.40	950.29	0.8	53.4	Low
6	MW6	733.54	72.41	53516.06	0.8	3007.9	V. High
7	MW7	139.15	72.41	10091.06	0.8	567.2	Moderate

Table 9. Micro watersheds under different priority zones

Priority categories	**Priority classes**	**SYI t km^{-2}year^{-1}**	**Micro watersheds**	**Area in (%)**
Very high	I	>2000	MW6	51.4
High	II	1000-2000	-	-
Moderate	III	500-1000	MW7	9.7
Low	IV	<500	MW1, MW2, MW3, MW4, MW5,	38.9

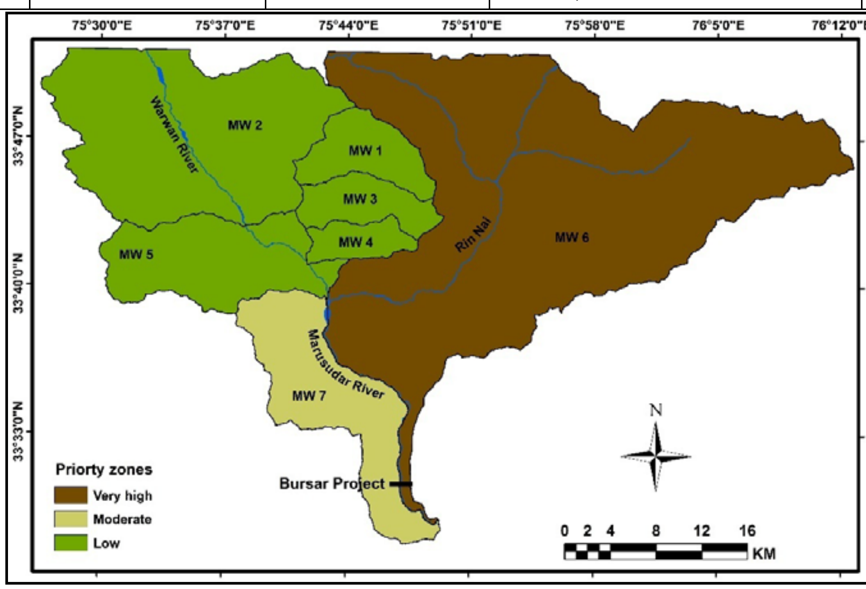
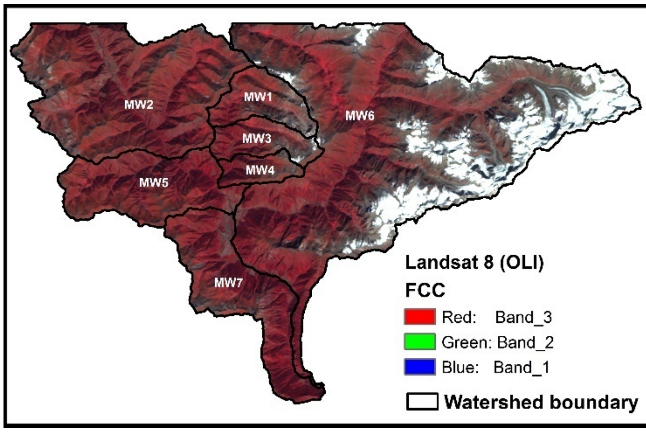


Fig. 9. Micro-watershed prioritization using the SYI model

From the field verification, it was observed that some sites have suffered huge soil loss in the form of landslides, gully erosion, etc. related to the presence of bare and open lands. Several factors are responsible for the estimated and observed soil loss estimated in the catchment, like faulty agricultural practices, human interferences, biotic interferences in forests and lack of awareness about the soil conservation practices resulting in the increased vulnerability to soil erosion. Scientific management of soil and water resources is important to arrest erosion and enhancing the reservoir storage capacity.

Catchment Area Treatment Plan:

From the thematic map of erosion intensity the areas that require treatment measures were extracted with the help of geospatial analysis. Areas which inaccessible i.e. > 45° (50%) slope and above 3,500 m elevation within the natural ecosystems with little human interference were excluded from the CAT plan. 72.54 km^2 spread over all the micro-watersheds in the catchment require various soil and water conservation treatment measures based on varying degree of land degradation (Figure 10; Table 10).



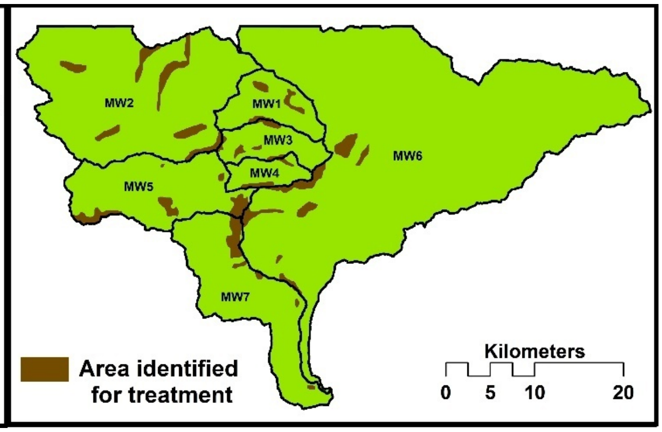


Fig. 10. Showing the False Colour Composite (FCC) and the Degraded land identified for land and water conservation treatment measures in the Marusudar catchment

Table 10. Showing the area identified for every micro-watershed for soil and water conservation treatment

Watershed Code	Micro-watershed details		Area identified for treatment	
	Area (km^2)	% Area	Area (km^2)	% Area
MW1	54.39	3.82	4.67	6.44
MW2	297.99	20.94	21.21	29.24
MW3	44.37	3.12	4.57	6.30
MW4	27.28	1.92	2.59	3.57
MW5	126.61	8.90	11.89	16.39
MW6	733.54	51.54	19.21	26.48
MW7	139.15	9.78	8.40	11.58
Total	1423.33		72.54	

For undertaking soil conservation measures in the Marusudar catchment draining up to the Bursar dam site, various soil and water conservation measures like biological measures and engineering measures are suggested (Table 11). It is always desired to undertake preventive/ biological measures than to mitigate the factors that ultimately lead to soil erosion. Such preventive measures will indirectly help to conserve soil in the long run, keeping in view the importance of integrating eco-restoration strategy with socio-economic needs of the local community wherein both ecology and economics are developed. One of the biological preventive measures that is suggested is afforestation. In the mountainous terrain like the Marusudar catchment, the vegetation cover play an important role in the conservation of soil and ecology. Afforestation should be taken up in the forest areas having large patches of barren grassy slopes generally devoid of trees and are honey-combed by cultivation. Afforestation measure suggested under catchment area treatment plan (CAT) on 1159 ha. In critically degraded areas, plantation of locally useful, diverse and indigenous plant species would be useful. The species for plantations should be selected after considering altitude, aspect, biotic pressures, soil depth, moisture, etc. As there is great pressure due to cattle grazing, non-fodder/ fuelwood species should also be planted in suitable proportion in between the fodder species. The tree species that should be planted under the CAT plan are: *Alnus nitida*, *Albizia odoratissima* (Siris), *Juglans regia*, *Cupressus torulosa*, *Salix* sp., *Robinea pseudoacacia* etc. The plant species which are suitable for fodder/ fuelwood plantations are**:** *Ficus cunia*, *F. hookeri*, *F. nemorabis*, *Thysonalaen*a spp., *Morus alba*, *Bauhinia* spp., *Alnus* sp., *Betula* spp., *Albizia procera* and *Morrus alba*. The important legumes and grasses that should be planted are Cocks foot (*Dactylis glomerata*), Perennial Rye grass (*Lolium perenne*), Tall fescue (*Festuca arundinacea*), Brome grass (*Bromus inermis*) and Timothy grass (*Phleum pratense*) among grasses and White clover (*Trifolium repens*), Red clover (*Trifolium pratense*), Lucerene (*Medicago sativa*), Vetch (*Vicia villosa*), Sainfoin (*Onobrychis viciaefolia*) and Caucasian clover (*Trifolum ambiguum*) among legumes.

Table 11. Watershed-wise details of various activities

S. No.	**Name of watershed**	**Component**								**Total**
		Engineering Measures				**Biological Measures**				
		Gully Control			**Bench terracing**	**Afforestation**	**NTFP Regeneration/ Medicinal Plants Cultivation**	**Assisted Natural Regeneration**	**Pasture improvement**	
		Brushwood Check dams	**DRSM**	**Wire Crates**						
		(Nos.)	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)
1	MW 1	9	37	42	56	75	28	7	5	259
2	MW 2	42	170	191	255	339	127	35	21	1180
3	MW 3	9	37	41	55	73	27	5	5	252
4	MW 4	5	21	23	31	41	16	3	3	143
5	MW 5	24	95	107	143	190	71	11	12	653
6	MW 6	38	154	173	231	307	38	115	48	1104
7	MW 7	17	67	76	101	134	17	50	21	483
	Total	**144**	**581**	**653**	**872**	**1159**	**324**	**226**	**115**	**4074**

Other preventive measures suggested include weeding and mulching to break the capillary action in soil and thus reducing the moisture loss. A strict watch and ward should be maintained for each enclosure to ensure high survival rates of the planted trees. For taking up various conservation activities like afforestation, assisted natural regeneration, promotion of medicinal plants, etc., at least 3 new nurseries need be created besides existing ones. Moreover, shepherds are predominant tribal people the basin. They exert tremendous impact on pasturelands of the division by way of grazing their sheep, goat and cattle. In order to improve the pasturelands and to make them sustainable against grazing pressure, the low elevation pasturelands should be taken up for treatment under silvi-pastoral model. Also, for an efficient management of forest resources, it is essential that field infrastructure of the Forest Department is adequately developed. The terrain being very tough, there is a need to improve the existing forest roads and paths. However, no macadamized road should be constructed in the catchment area as this would lead to deforestation and increase the sediment yield and siltation in the catchment.

The engineering soil and water conservation measures proposed under the CAT Plan for the Marusudar catchment include Gully Erosion Control and Bench Terracing**.** The gullies should be treated with engineering as well as vegetative methods. Check dams should be constructed in some of the areas to promote growth of vegetation that will consequently lead to the stabilization of the slopes and prevent further deepening of gullies and erosion. For controlling the gullies, the erosive velocities are reduced by flattening out the steep gradient of the gully. This is achieved by constructing a series of check dams which transform the longitudinal gradient into a series of steps with low risers and long flat treads. Different types of check dams would be required for different conditions comprising different materials depending upon the site conditions and the easy availability of material at local level. The mostly recommended check dams for this area are: Brushwood check dam; DRSM (Dry Rubble Stone Masonry)- Check dams with stones available at the site; and Combination of DRSM and crate works- For moderate to deep gullies with stones available at the sites. The other engineering method- Bench terracing is one of the most popular mechanical soil conservation practices widely adopted by farmers. It is constructed in the form of step like fields along contours by half cutting and half filling and would result in the conversion of the original slope into levelled fields. Thus, hazards of erosion are eliminated and manure and fertilizers applied are retained in the levelled fields. The sloping fields in the valley need to be bench terraced by cutting and filling with the latter supported by retaining stone wall.

Based on the sediment yield index of the sub-watersheds, the conservation measures suggested to be first taken up in the micro-watersheds with very high priority, high, moderate and low priority watersheds in a phased manner. The total estimated cost of the CAT plan over a period of five years is Rs. 1456.44 lacs. The details of the cost estimates and physical work schedule as well as phasing of expenditure are given as follows in Table 12.

Table 12. Component-wise cost estimate for catchment area treatment works

S. No.	Item of Work		Unit	Qty.	Rate (Rs.)	Amount (Rs. in lacs)
A.	**Engineering Measures**					
1.	Gully Control					
	a)	Brushwood checkdams	Nos.	144	2020/-	2.91
	b)	DRSM checkdams	ha	581	17280/-	100.40
	c)	Crate wires/wiremesh	ha	653	29000/-	189.37
2.	Bench terracing		ha	872	7,500/-	65.40
	Total (1+2)				358.08	
	Add 5% for maintenance of structures					17.90
	Sub-total (A)					**376.70**
B.	**Biological Measures**					
1.	Afforestation					
	i)	**Creation**	**ha**	**1159**	**27,000/-**	**312.93**
	ii)	**Maintenance**				**159.95**
2.	Assisted natural regeneration in existing forests					
	i)	Creation	ha	226	18,810/-	42.51
	ii)	Maintenance				21.52
3.	NTFP Regeneration					
	i)	Creation	ha	324	49,500/-	160.38
	ii)	Maintenance				136.37
4.	Pasture development					
	i)	Creation	ha	115	16780/-	19.30
	ii)	Maintenance				11.72
5.	Nurseries					38.00
	Sub-total (B)					**902.68**
	Sub-Total (A+B)					**1279.38**
C.	**Micro-planning @ 3% of (A+B)**					**38.74**
D.	**Forest Infrastructure**					**38.00**
	Vehicles, machinery & equipment, paths, etc.					
E.	**Administrative charges**					**50.32**
F.	**Monitoring and evaluation**					**50.00**
Grand Total (A to F)						**1456.44**

CONCLUSIONS

After conducting a step-wise approach in GIS environment based on the multi-criteria analysis, sediment yield of each micro-watershed was estimated. Based on the watershed prioritization depending upon the severity of the soil erosion, areas requiring soil conservation measures and treatment in the different sub-watersheds of Marusudar were identified. Deterioration of soil resources in the watershed can be controlled effectively by adopting watershed treatment measures once the spatial distribution of soil erosion is known. The micro-watersheds identified having very high vulnerability and risk to soil erosion, spread over 73 km^{-2}, demand immediate attention for initiating soil and water conservation measures like check dams, Gabion boxes along river sides and stone walls for minimizing the soil loss. A detailed catchment area treatment (CAT) was prescribed detailing the engineering and non-engineering measures that need to be take over the entire Marusudar catchment and envisages a budgetary requirement of about 1456 lakhs over five years. It is hoped that the prescriptions of the CAT, once implanted on the ground, shall ameliorate the negative impacts of the hydropower infrastructure development project in the fragile and sensitive Chenab valley where are a number of hydropower projects are either being construction or in the pipeline.

REFERENCES

Altaf, S., Meraj, G., and Romshoo, S.A. 2014. Morphometry and land cover based multi-criteria analysis for assessing the soil erosion susceptibility of the western Himalayan watershed. *Environ. Monit. and assess.t*, **186** (12): 8391-8412.

Badar, B., Romshoo, S.A., and Khan, M.A. 2013. Integrating biophysical and socioeconomic information for prioritizing watersheds in a Kashmir Himalayan lake: a remote sensing and GIS approach. *Environ. Monit. and assess.*, **185** (8):6419-6445.

Chakraborti, A.K. 1991. Sediment yield prediction and prioritization of watersheds using remote sensing data. In: *Proceedings of the 12th Asian Conference on Remote Sensing, Singapore*, pp. Q-3-1–Q-3-6.

Dar, R.A., Chandra, R., and Romshoo, S.A. 2013. Morphotectonic and lithostratigraphic analysis of intermontane Karewa Basin of Kashmir Himalayas, India. *J. of Mount. Sci.*, **10**(1): 1.

Das, D.C. 1985. Problem of soil erosion and land degradation in India. In *National Seminar on Soil Conserv. and Watershed Manag.* (pp. 17-18).

Meraj, G., Romshoo, S. A., Ayoub, S. and Altaf, S. 2017. Geoinformatics based approach for estimating the sediment yield of the mountainous watersheds in Kashmir Himalaya, India. *Geocarto International, http://dx.doi.org/10. 1080/10106049.2017.1333536*

Harlin, J.M. and Wijeyawickrema, C. 1985. Irrigation and groundwater depletion in Caddo county, Oklahoma. *JAWRA J. of the Amer. Wat. Resour. Asso.* **21**(1): 15-22.

Horton, R.E. 1932. Drainage-basin characteristics. *Eos, transact. Amer. Geophys. union*, **13** (1):350-361.

Kanth, T.A. and Zahoor-ul, H. 2010. Prioritization of watersheds in Wular catchment for sustainable development and management of natural resources. *Rec. Res. in Sci. and Techn.*, **2**(4): 12–16.

Kumar, R. and Verma, Y.K. 1983. Some Geomorphological *Investigations Around Kud, Kashmir Himalaya, Geomorphology, Contributions to Indian Geography (ed.)* K.R. Dikshit. Heritage Publishers, New Delhi. Pp. 72-84.

Lal, R. 1998. Soil erosion impact on agronomic productivity and environment quality. *Crit. Rev. in plant sci.s*, **17** (4):319-464.

Lal, R. 2001. Soil degradation by erosion. *Land Deg. & Develop.*, **12**(6):519-539.

Mellerowicz, K.T., Ress, H.W., Chow, T.L., and Ghanem, I. 1994. Soil conservation planning at the watershed level using the universal soil loss equation with GIS and microcomputer technologies: A case study. *J. of Soil and Water*

Conserv., **49**: 194–200.

Morgan, R.P., Finney, H.J. and Morgan, D.D. 1982. *Stability of agricultural ecosystems: application of a simple model for soil erosion assessment*. 82-50.

Morgan, R.P.C., Morgan, D.D.V. and Finney, H.J. 1984. A predictive model for the assessment of soil erosion risk. *J. of Agri. Eng. Res.*, **30**: 245-253.

Naqvi, H.R., Athick, A.M.A., Ganaie, H.A. and Siddiqui, M.A. 2015. Soil erosion planning using sediment yield index method in the Nun Nadi watershed, India. *Internat. Soil and Water Conserv. Res.*, **3**(2): 86-96.

Narayana, D.V. and Babu, R. 1983. Estimation of soil erosion in India. *J. of Irri. and Drain. Eng.*, **109** (4): 419-434.

NHPC Limited (A Govt. of India Enterprise). 2016. Bursar Project Jammu and Kashmir (800 MW) - Detailed Project Report. Faridabad, Volume I.

Rana, K.P.C., Walia, C.S., Sidhu, G.S., Singh, S.P., Velayutham, M. and Sehgal, J. 2000. Soils of Jammu and Kashmir for optimizing land use. NBSS Publ, 62, 71.

Rashid, M., Lone, M.A. and Romshoo, S.A. 2011. Geospatial tools for assessing land degradation in Budgam district, Kashmir Himalaya, India. *J. of Earth Sys. Sci.*, **120** (3):423-433.

Raymo, M.E. and Ruddiman, W.F. 1992. Tectonic forcing of late Cenozoic climate. *Nature*, **359** (6391):117-122.

Shrestha, D.P. 1997. Assessment of soil erosion in the Nepalese Himalaya: a case study in Likhu Khola Valley, Middle Mountain Region. *Land Husbandry*, **2**(1): 59-80.

Space Applications Centre 1999. Remote sensing and GIS inputs for the preparation of development plan of Pimpri Chinchwad Municipal Corporation Area 2018, Technical Report, Space Applications Centre (ISRO) and Pimpri Chinchwad Municipal Corporation.

Stoddart, D.R. 1969. World erosion and sedimentation in water, in Chorley, R.J. (Ed.) Water, Earth and Man. Methuen, London. pp. 43-64.

UNEP, I. 1990. World map on status of human-induced soil degradation. *Boom-ruygrok, Harllem, the Netherlands*.

Zaz, S.N. and Romshoo, S.A. 2012. Assessing the geoindicators of land degradation in the Kashmir Himalayan region, India. *Nat. haz.*, **64** (2): 1219-1245.