Estimation of soil erosion risk in upper catchment of Wular Lake, Jammu & Kashmir using RUSLE model

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ABSTRACT

Wular lake, one of the largest freshwater lake in Asia is at the verge of extinction as the lake is losing its water holding capacity day by day due to the increased level of soil erosion in the catchments and consequential sedimentation. The soil erosion risk was estimated in the upper catchment of Wular lake on the spatio-temporal basis in order to quantify and detect the areas prone to the soil erosion and its impact on lake ecosystem. The annual soil loss has been assessed by the Revised Universal Soil Loss Equation (RUSLE) model in the Geographic Information System (GIS) environment for the period of 10 years (2004-2013). The anticipated amount of soil erosion has increased in the past 10 years (2004-2013), with mean annual rate of 140.31 t ha^{-1} year^{-1} in the year 2004 to 942.52 t ha^{-1} year^{-1} in the year 2013. It has been perceived that the area under the moderate to extreme risk of soil erosion augmented a tremendous increase from the 1.72% to 14.82 % in the last 10 years due to the increased anthropogenic activities like unplanned urbanization and deforestation, hence consequent sedimentation of Wular lake.

Keywords: Erin watershed, LULC, Madhumati watershed, RUSLE, Wular Lake.

I. INTRODUCTION

Soil erosion, one of the major land and water deterioration problems [1] is globally worsened by increased man made activities such as ploughing, land clearance, deforestation, overgrazing, and urbanization. Soil erosion by water, one of the most important environmental problems results in both direct and indirect consequences [2] influencing agricultural productivity and environmental quality [3]. The exposure of the top fertile soil not only creates problems in agriculture, but also results in the sedimentation and siltation of aquatic ecosystems, therefore reducing the reservoir capacity [4]. In addition, it contributes to the water pollution and also leads to the eutrophication due to the presence of harmful fertilizers and chemicals present in agricultural land [5-6].

Kashmir valley which holds a unique position in the Himalayas is afflicted by accelerated erosion due to cultivation on steep slopes, intensive deforestation [7]. It has been revealed that more than 48.27 % of the area in the valley is under very high erosion risk [8]. The study under investigation is the upper catchments of Wular lake comprising two watersheds, namely Madhumati and Erin. The watersheds are situated on the Northern side of Wular, and comprise 52% of catchment area i.e. 32% of Madhumati and 20% of Erin. The rapid degradation of forest and excessive grazing in the catchment results in erosion and subsequent sedimentation, hence

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decreasing water holding potential of Wular lake [9]. It is important to monitor the changes in the catchment areas of Wular lake (Wetlands of International Importance under the Ramsar Convention of 1975) due to its vital role in the Kashmir's hydrography. The lake not only acts as a vast absorption basin for floodwater but also support the hydropower generation, agricultural activities and accounts for 60% of the fish production in Jammu and Kashmir. In order to reduce the problem of soil erosion in the catchment and sedimentation of lake, it is therefore important to detect the areas prone to erosion.

The present study aims to assess the soil loss for the year 2004 and 2013 and to identify soil erosion risk zones in the catchment of Wular lake using RUSLE approach. The RUSLE model was selected for the present study due to its usefulness in the areas which lack adequate input data [10-12].

II. STUDY AREA

The area stretches approximately from 34°18'-34°34'N latitude to 74°30'-74°55'E longitude with a total area of 712 Km^2 (Fig.1). Madhumati also known as Bod Kol originates from the northern slopes of Harmukh glacier. Adjacent to the Madhumati catchment on the northern side is Erin catchment. The river is formed from the outflow of various streams which finally joins together at Isrur tar to form Erin. The rivers fall under the jurisdiction of Bandipora district and finally drain into the Wular Lake. The altitudinal range of the study is from 1578 to 5056 m a.m.s.l with varying slope from 0 to 66.41 degrees (Fig.2).

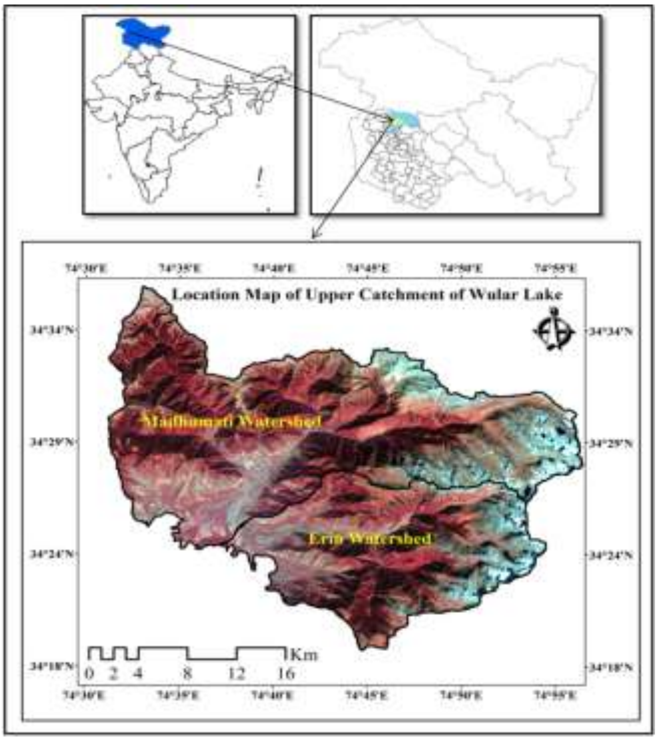

Fig.1 Location map of the upper catchment of Wular lake

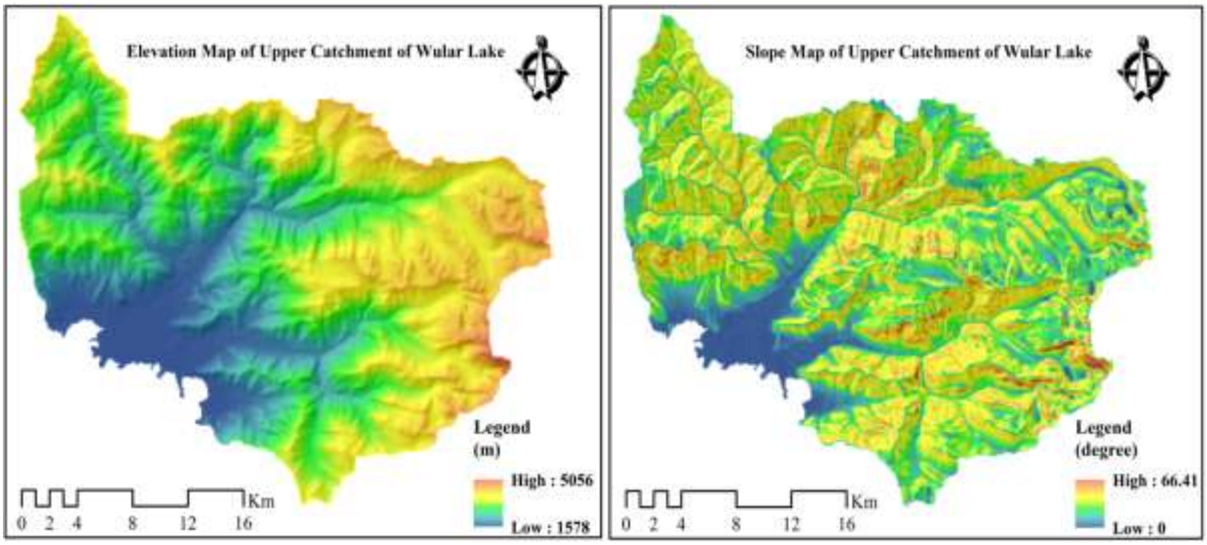

Fig.2 Elevation and slope map of upper catchment of Wular lake

III. MATERIALS AND METHODS

3.1 Datasets Used

The daily precipitation data was acquired from Climate Forecast System Reanalysis (CFSR) for the estimation of rainfall erosivity factor. The satellite image of IRS LISS III of 2004 and Landsat 8 OLI of 2013 were obtained from NRSC Bhuvan and USGS respectively for the delineation of LULC classes in order to prepare final C and P factor maps. Survey of India toposheet and soil map of National Bureau of Soil Survey and Land Use Planning was used for the delineation of watershed boundary and various soil groups. Samples of soil pertaining to different soil groups were sampled and analyzed for textural properties and organic matter. Digital elevation model (DEM) from Shuttle Radar Topography Mission (SRTM) was employed to prepare the slope map and spatial topographic factor map.

3.2 Calculation of soil loss

The Revised universal soil loss equation (RUSLE) [10], based on the product of factors i.e. climate, soil types, topography, and types of land use/ land cover (Fig.3) was used for the estimation of average annual soil loss given by the following equation;

$$A = RKLSCP \qquad \textbf{(1)}$$

where, A= average soil loss (t ha^{-1} $year^{-1}$), R = Rainfall erosivity factor (MJ mm ha^{-1} h^{-1} $year^{-1}$), K = Soil erodibility factor (t ha h MJ^{-1} ha^{-1} mm^{-1}), LS = Topographic factor (non-dimensional), C & P = Cover management and conservation support practice factor (non-dimensional)

3.2.1 R-factor estimation

It is computed by overall rainfall erosivity of single erosive storms as the outcome of overall storm energy and its maximum 30-min intensity [13]. However, due to the non-availability of intensity data, the annual rainfall

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erosivity for the year 2004 and 2013 were calculated employing the linear equation given by [14-15]. The equation used is given below;

$$R_{factor} = 79 - 0.363R \qquad \textbf{(2)}$$

where, R_{factor} is rainfall erosivity factor in MJ mm ha^{-1} h^{-1} year^{-1}. R is annual average rainfall in mm. Finally, the rainfall erosivity map for the year 2004 and 2013 were prepared by the interpolation of R- factor values using inverse distance weighted (IDW) interpolation technique of ArcGIS.

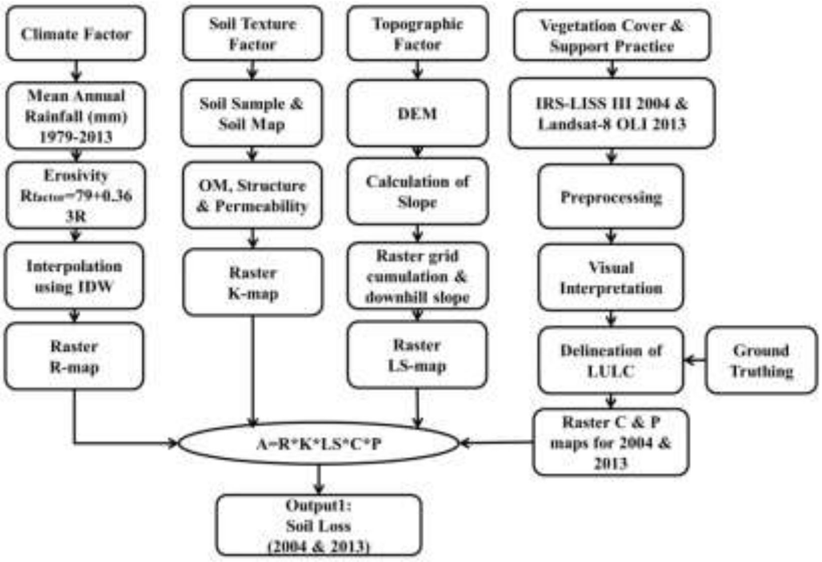

Fig.3 Integration of factors for assessing erosion

3.2.2 K-factor estimation

The soil erodibility factor (K) represents the overall effect of combinations of inherent properties of soil [16]. The soil boundaries were digitized over geo-referenced soil map in ArcGIS environment and soil attributes were added to the digitized map. The soil from different soil group were sampled and analyzed for sand, silt, clay, and organic matter content of each sample. The K-factor values were estimated using the soil erodibility nomograph method [13,10] which is also based on the expression given below;

$$K = 2.1 * 10^{-4} M^{1.14}(12 - OM) + 3.25(S - 2) + 2.5(P - 3)/100 * 0.1317 \qquad \textbf{(3)}$$

where, OM = Percent of organic matter, S & P = Soil structure and permeability class [16], M = (% silt + % very fine sand)* (100- % clay)

Finally, K factor map was generated in the ArcGIS environment using the feature to raster conversion tool of spatial analyst in order to covert the K factor map to a raster of desired cell size same as that of the DEM.

3.2.3 LS-factor estimation

The slope length and steepness factor (LS) represents the effect of slope length and gradient on erosion

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respectively [11]. LS-factor was estimated using the raster grid cumulation and maximum downhill slope method established by [17-18]. The program of Arc Macro Language (AML) was obtained from Van Remortel's website (www.onlinegeographer.com/slope/slope.html) and the SRTM DEM along with the watershed boundary was used as two inputs into the program to produce the LS factor map.

3.2.4 C-factor estimation

This factor reveals the effect of vegetation canopy and ground covers in forest regions and cropping management practices in agricultural fields [19]. The values of C factor on the higher side point towards the negligible cover effect and hence, high proportion of erosion [20]. The lower values nearly zero depict the well protected land with greater cover effect, hence reduced amount of soil loss [21]. The LISS III image of 2004 and Landsat 8 OLI image of 2013 were used after processing for onscreen visual interpretation to map various LULC classes. Eight LULC classes have been categorized (Fig.4) and values of C factor was obtained from the literature as suggested by [22-23].

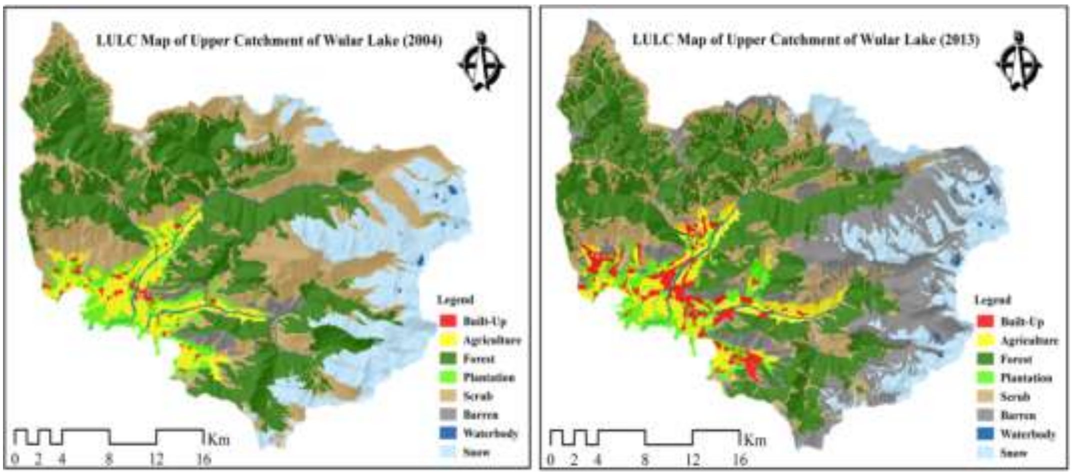

Fig.4 LULC maps for the year 2004 and 2013

3.2.5 P-factor estimation

The slope of the terrain and the method of cultivation prevalent in the area are used to determine the value of P-factor [24]. The values of P factor varies from 0 to 1, the high values are assigned to the areas where no conservation practice is prevalent. In the present study, the only conservation practices followed is the contour-farmed terraced plots in agricultural fields. The values are obtained from the literature as suggested by [13] and adopted by [15]. The value of 0.7 was assigned to agricultural fields at slope nearly 15%.

3.3 Assessment of soil loss and prospect zones

The spatio-temporal annual soil loss was obtained by multiplying all the thematic maps (R, K, LS, C, and P) in the ArcGIS environment. The calculated soil loss values were finally categorized into five erosion classes on the basis of classification used in Himalayan region due to the similar type of terrain conditions. The classification was used because categorization of the soil erosion zones is extremely reliant on the obtained erosion rate value

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and the local terrain condition [25-26]. Annual soil risk map was superimposed with the LULC map in the ArcGIS environment in order to find out the risk zone areas.

IV. RESULT AND DISCUSSION

4.1 RUSLE factors

The analytical details of RUSLE parameters are described as follows:

4.1.1 R-factor

The annual R factor was calculated for two different years i.e. 1992 and 2013 (Fig.5). The annual R factor for 1992 ranged from 352.9 to 448.3 MJ mm ha^{-1} h^{-1} $year^{-1}$ with the mean of 378 MJ mm ha^{-1} h^{-1} $year^{-1}$. In the year 2013, the annual R-Factor ranged from 328.9 to 411.1 MJ mm ha^{-1} h^{-1} $year^{-1}$ with the mean of 351.38 10.99 MJ mm ha^{-1} h^{-1} $year^{-1}$. The highest value of rainfall erosivity was observed at higher elevations along the northwest, and northeast of the watershed. The decreasing value of the R-factor had the strong relationship with decreasing elevation of the watershed.

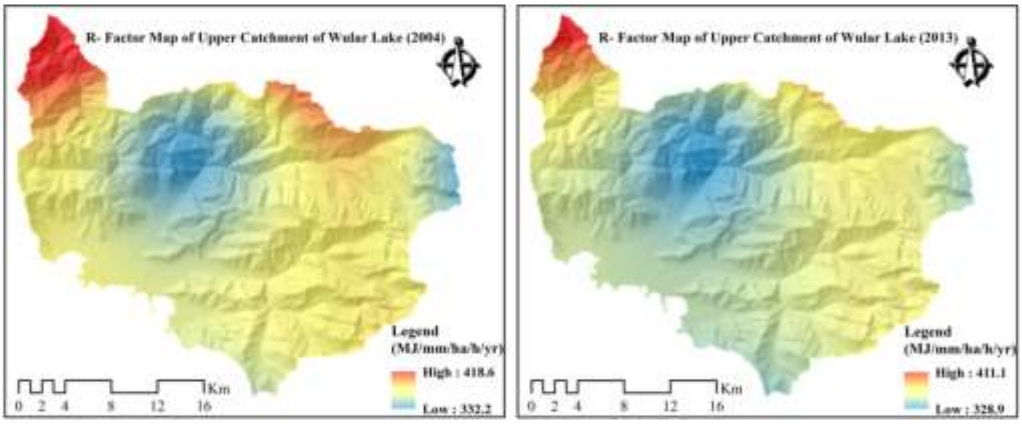

Fig.5 R-factor maps for the year 2004 and 2013

4.1.2 K-factor

The average value of K estimated for the textural groups varied from 0.32 to 0.48 t ha h MJ^{-1} ha^{-1} mm^{-1} (Fig.6) with the mean of 0.41 t ha h MJ^{-1} ha^{-1} mm^{-1}. The study area has four types of soil textures such as loam, loamy sand, sandy loam, and loamy sandy loam. The highest K value was witnessed in the northeast portion of the catchment depicting higher susceptibility of soil erosion.

4.1.3 LS-factor

The elevation in the Erin & Madhumati watersheds increases from south to north. It was observed that the eastern and western side of watersheds has high values of LS factor with high variation in altitude. It can be discerned from (Fig.7) that the range of topographic factor is ranged from 0 to 184 with mean of 23.3.

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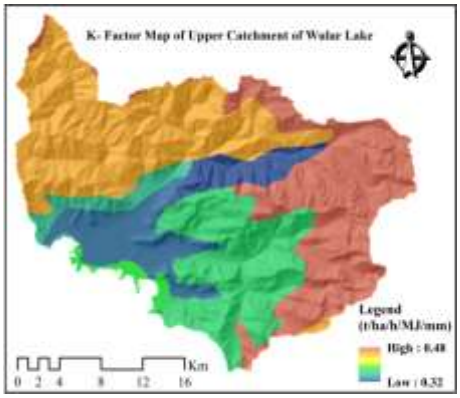

Fig.6 K-factor map

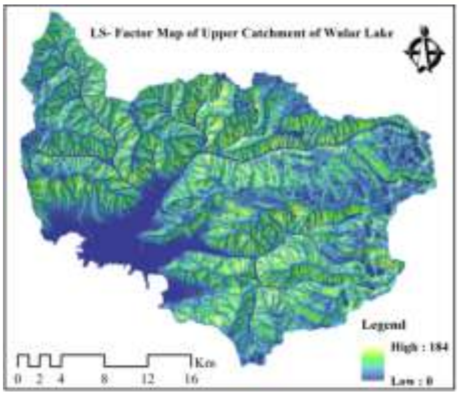

Fig.7 LS-factor map

4.1.4 C& P factor

The study area comprises built-up, agriculture, forest, plantation, scrub, barren, waterbody, and snow. It has been observed that significant changes have taken place in various land use/ land cover classes for the period from 2004 to 2013 (Table 1). The built-up, barren and plantation class recorded an increase while as agriculture, forest, scrub, and snow decreased which was reflected in the C factor map. The values of C & P factor ranged from 0 to 1 and 0.7 to 1 respectively (Fig.8 & Fig.9).

Table 1 LULC statistics in the upper catchment of Wular lake (2004-2013)

Year	2004	2013	Total Change	
Area	(Km²)	(Km²)	(Km²)	(%)
Built-up	5	22	19.00	633.33
Agriculture	39	36	-1.00	-2.70
Forest	266	242	-72.00	-22.93
Plantation	29	31	3.00	10.71
Scrub	222	124	-72.00	-36.73
Barren	11	161	158.00	5266.67
Waterbody	5	5	0.00	0.00
Snow	135	91	-35.00	-27.78

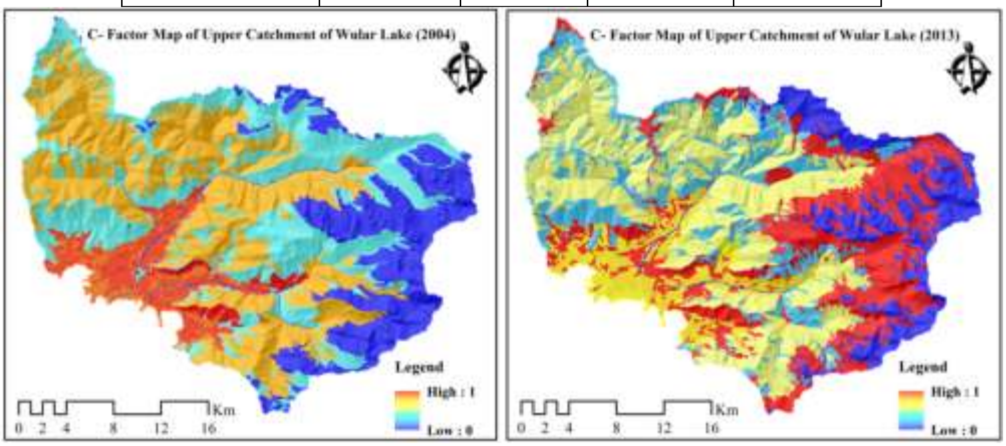

Fig.8 C-factor maps for the year 2004 and 2013

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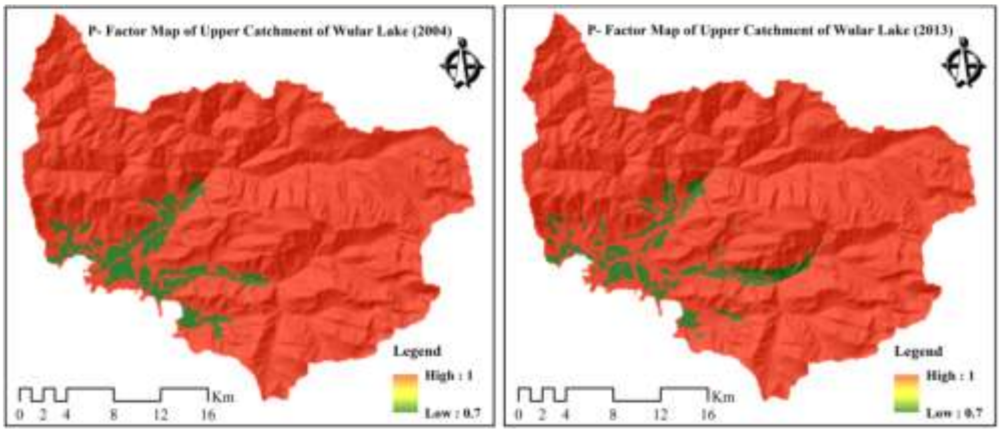

Fig.9 P-factor maps for the year 2004 and 2013

4.2 Spatial pattern of predicted soil loss

In order to delineate the erosion severity zones the actual soil erosion map was classified into five classes on the basis of the classification scheme given in literature for Himalayan region (Table 2). The anticipated proportion of annual soil loss in the year 2004 ranges from 0 to 14200.22 t ha^{-1} $year^{-1}$. The mean annual rate of soil loss was estimated to be 140.31 t ha^{-1} $year^{-1}$. The standard deviation of 496.44 t ha^{-1} $year^{-1}$ was observed in the year 2004 (Fig.10).

Table 2 Areal extent of various erosion classes in Wular catchment

Soil Loss (t ha^{-1} $year^{-1}$)	2004 (Area)		2013 (Area)	
	ha	%	ha	%
< 500 (Least Risk)	68102	95.65	52347	73.52
500-2500 (Low Risk)	1881	2.64	8281	11.63
2500-4000 (Moderate Risk)	495	0.70	3719	5.22
4000-6000 (High Risk)	476	0.67	3736	5.25
>6000 (Extreme Risk)	246	0.35	3117	4.38

In the year 2013, the amount of soil erosion increased and it varied from 0 to 18078.18 t ha^{-1} $year^{-1}$ with the mean and standard deviation of 942.52 t ha^{-1} $year^{-1}$ and 1923.23 t ha^{-1} $year^{-1}$ respectively (Fig.11). A very small number of pixels exhibited extremely high range of soil loss mainly confined towards the eastern part of the watershed. In addition, as regard to spatial variation, it can be observed that Erin watershed has more erosion as compared to Madhumati watershed. The reason for the soil loss in that portion of the watershed has a close relationship with land use, elevation, and soil type.

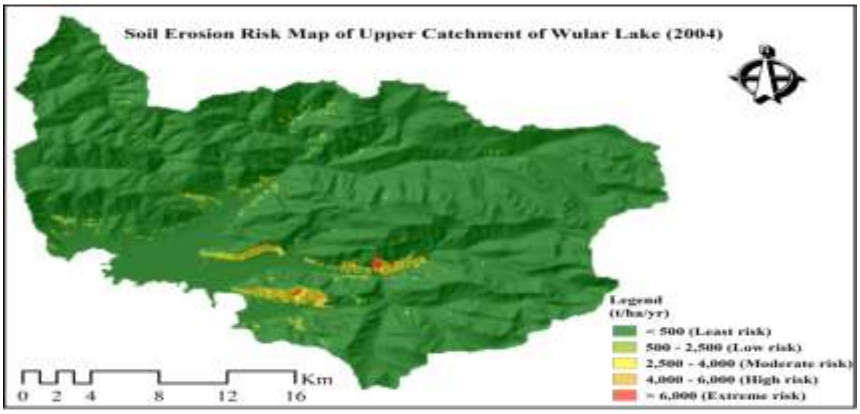

Fig.10 Soil erosion risk map for the year 2004

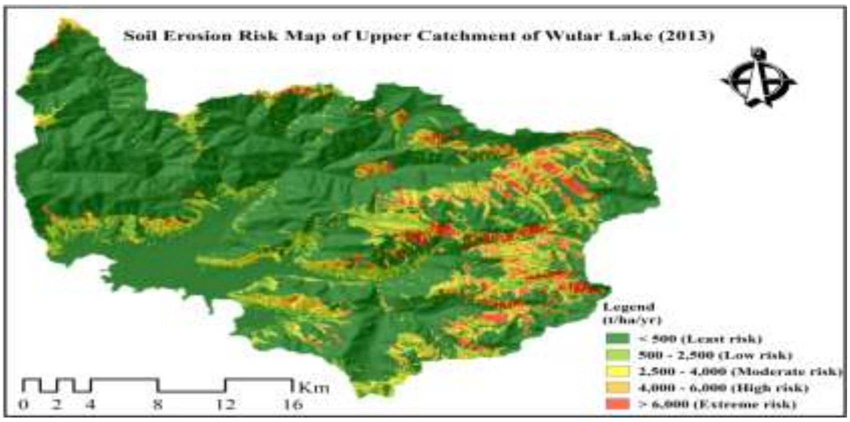

Fig.11 Soil erosion risk map for the year 2013

4.3 Assessment of soil erosion prospect zone

The results of anticipated soil loss were classified into five classes for further analysis as shown in Table 2. The result of the study indicates that in the year 2004, the area under least risk reported covered the maximum area in the year 2004 (68102 ha) covering 95.65% of the study area. In addition, it was observed that very less area was covered under the extreme risk in the year 2004 covering only 0.35% of the study area.The area under moderate and high risk covered total area of 1.37 % in the year 2004.

The situation in 2013 degraded considerably as the area under moderate, high, and extreme risk increased and under least risk of erosion deceased. The area under extreme risk increased from 0.35 % in 2004 to 4.38 % (3117 ha) in 2013. Similarly, the area under high risk increased from 0.67 % in 2004 to 5.25 % (3736 ha) in 2013. About an increase of 5.22 % (3719 ha) from 0.70 % in 2004 was observed in the moderate risk erosion zone. On the other hand, the least risk erosion zone decreased from 95.65% in 2004 to 73.52 % (52347 ha) in 2013, with an increase in low risk erosion from 2.64 % to 11.63 % (8281 ha). The results revealed that the areas confined towards the eastern part of the watershed recorded very high risk of erosion.

The impact of different land use types to erosion were analyzed by overlaying soil risk map with LULC (Table 3). It was observed that the forest and scrub land are the chief contributors in the year 2004. In the year 2004, the forest covers 37.2 % under least to low risk of erosion and scrub covers 30.9 % under least risk of soil erosion. In the year 2013, in addition to the forest and scrub, barren land also contributes maximum percentage of soil loss. The barren land constitutes 23.2 % of the entire area of watershed under soil erosion risk zones. The barren land covers 14.6 % of the area under moderate to extreme risk of soil erosion. It was noticed that although forest and scrub land constitute largest area susceptible to soil erosion, but the severity of erosion are less as compared to barren class. The reason being these are covered by vegetation that prevents soil erosion. The areas such as barren land are more susceptible to soil erosion. The reasons for the higher values of erosion are due to changes in LULC, and bare soils. Although the barren land is more affected in terms of soil erosion, but it can be observed that entire watershed contributes to soil erosion. The severe soil loss in the catchment is leading to the sedimentation and siltation, thus affecting the overall water holding capacity of the Wular lake.

Table 3 Percent area of erosion risk classes on land use types

LULC	2004					2013				
	Least	Low	Moderate	High	Extreme	Least	Low	Moderate	High	Extreme
Built-up	0.53	0.10	0.00	0.00	0.00	2.04	0.91	0.14	0.06	0.02
Agriculture	4.81	0.59	0.01	0.00	0.00	3.65	1.40	0.04	0.00	0.00
Forest	36.36	0.81	0.00	0.00	0.00	32.72	0.68	0.00	0.00	0.00
Plantation	3.48	0.55	0.00	0.00	0.00	3.35	0.98	0.02	0.00	0.00
Scrub	30.88	0.00	0.00	0.00	0.00	17.51	0.00	0.00	0.00	0.00
Barren	0.02	0.59	0.68	0.67	0.35	0.98	7.67	5.02	5.19	4.36
Waterbody	0.71	0.00	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.00
Snow	18.85	0.00	0.00	0.00	0.00	12.68	0.00	0.00	0.00	0.00

V. CONCLUSION

This study is an attempt to estimate soil erosion, in the upper catchment of Wular lake using existing conceptual methods and Geospatial techniques. The results clearly reveal that soil erosion have been intensified in the Madhumati and Erin watershed from the period 2004 to 2013 due to the increased human activities like unplanned urbanization and deforestation. The rapid intensification of the land use in the catchment area leads to the increased erosional activities therefore, leading to the sedimentation of the Wular lake. During the period from 2004 to 2013, the amount of soil loss increased with the changes in the land use patterns with the highest loss observed in the year 2013 mainly due to the increase in barren (5266.67%) and built-up (633.33%) class. It was observed that 14.82 % of the area of the watershed is under moderate to extreme risk of erosion in the year 2013. The study also indicated that the entire watershed contributes large amount of soil erosion leading to the sedimentation and siltation, thus affecting the overall water holding capacity of the Wular lake. The highest erosion risk zones are identified in the Erin watershed, where soil conservation measures are urgently needed in order to reduce the sedimentation of Wular lake. This study can be used for the identification of erosion prone areas and could be taken as baseline information from the environmental perspective of soil erosion and can be applied in the formulation of policies and soil conservation programs. Soil erosion control in the upper catchment of Wular lake is a serious environmental issue that needs to be addressed in order to save the world famous lake from more deterioration.

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