Soil Loss Prediction and Prioritization Based on Revised Universal Soil Loss Estimation (RUSLE) Model Using Geospatial Technique

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***Abstract*-Watershed prioritization plays a key role in planning and management of sustainable development programmes. The study area, Nun Nadi watershed, is located in Doon Valley which is prone to high erosion. The present study aims to identify the soil loss estimation, to prioritize the micro watersheds on the basis of mean soil loss values and to suggest best conservation measures for the Nun Nadi watershed employing Revised Universal Soil Loss Estimation (RUSLE) model. Approximately 23 km^2 area comprising 7 micro watersheds was classified as very high and high priority risk zones. These micro watersheds demand immediate attention in terms of management and planning perspective. This micro level study provides accurate results in the context of soil loss prediction.**

Keywords-Watershed Management; RUSLE; Soil Loss; Sustainable Development; Prioritization; Conservation and Nun Nadi Watershed

I. INTRODUCTION

Soil erosion is an environmental crisis in the world today that threatens natural environment and also the agriculture. Accelerated soil erosion also adversely impacts economy and environment (Lal, 1998). Evidently, the developing countries suffer more because of the inability of their farming population to replace lost soils and nutrients (Erenstein, 1999). India is a developing country and agriculture is a backbone of the Indian economy. Therefore, sustainable land management practices are urgently required to preserve the production potential. The soil erosion rate in the northern Himalayan region ranged from 2000 to 2500 ton/km^2/yr which is highly erosion prone (Garde and Kothyari, 1987) and according to Singh *et al.*, 1992, the Shiwalik hills, north western Himalayan region, ravines and shifting cultivations are under severe erosion- more than 20 Mg/ha/yr. Catchments and watersheds have been identified as planning units for administrative purpose to conserve the land and water resources (Honore, 1999). The resource development programme can be applied scientifically on watershed basis and thus prioritization is essential for proper planning and management of natural resources for sustainable development. Therefore, the concept of prioritization plays a key role in identifying areas which need more focus or attention (Kanth T.A. and Zahoor ul H, 2010). In this context of watershed management, prioritization has achieved more in terms of natural resource management (Akram, *et al.*, 2009).

There are several empirical models based on the geomorphologic parameters that were developed in the past to quantify the sediment yield. Methods such as sediment yield index (SYI) and universal soil loss equation (USLE) by Wischmeier and Smith, 1978 are extensively used for prioritization of the watersheds. The Revised Universal Soil Loss Estimation (RUSLE) model (Renard *et al.*, 1997) has been used in the present study to achieve the results.

Several studies on the watershed prioritization employed Remote Sensing (RS) and GIS techniques to estimate soil loss estimation. Remote Sensing and GIS are the most advanced tools for watershed development, management and studies on prioritization of micro-watersheds for development (Ratnam *et al.*, 2005). Mani *et al* (2003) and Chakraborti (1991 a) utilized RS and GIS technique to carry out the soil erosion rate in Mujali River Island and for the prioritization of watersheds. For predicting the soil erosion at the field level, its use in a GIS environment has enabled application in large areas and satisfactory results have been reported (Mellerowicz *et al.*, 1994) for delineation of erosion prone areas and prioritization of micro-watersheds for conservation planning purposes. Kiflu Gudeta (2010) has also utilized the watershed management approach and employed RS and GIS as a tool for soil loss estimation, micro watershed prioritization for conservation. The aim of the study is to predict the soil loss, prioritize the micro watersheds on the basis of soil loss and to suggest the conservation measures for the Nun Nadi watershed.

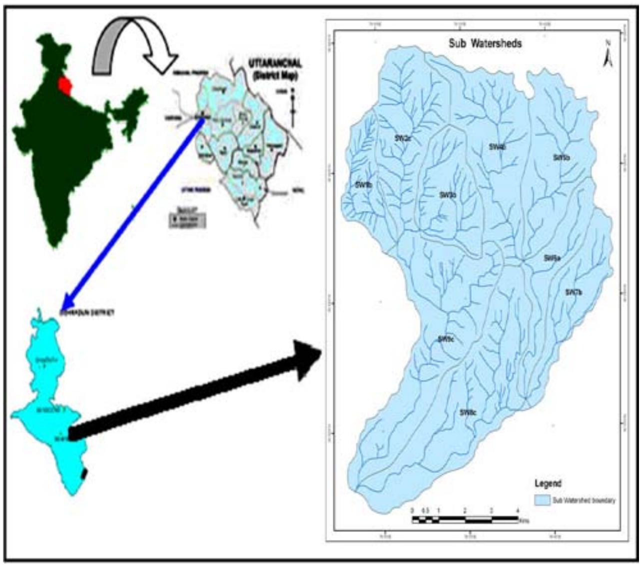

Fig. 1 Nun nadi watershed

II. STUDY AREA

The Nun Nadi Watershed is a part of Yamuna river catchment. It is located in the north eastern part of Doon Valley between 30º 20’ 08” to 30º 28’ 18” N latitude and 77º 58’ 36” to 78º 06’ 21” E longitude in the state of Uttrakhand, India and encompasses a total area of 8697.33 hectares (Fig. 1). The climate is sub tropical with cold winters, warm and crisp springs, hot summers and a strong monsoon. The Shiwalik hills are the part of the study area. The average temperature of the watershed is 20ºC approximately. The average annual rainfall of Dehradun station is 2073.3mm and about 87 percent is received during the months of June to September. July and August are the rainiest months. The complex topography, with elevations ranging from 600 m to 2000m, results in steep gradients of rainfall. The vegetation ranges from subtropical evergreen broadleaved forest to the conifer forest.

III. MATERIAL AND METHODS

Survey of India (SOI) toposheets number 53 F/15, 53 J/2 and LANDSAT-TM image of October 2009 are the main source of data for the present study. Toposheets were 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 same time period obtained from the Indian Meteorological department, Dehradun and other relevant data were procured from published and unpublished records. Fig. 2 explains the methodology.

Fig. 2 Schematic flow chart for conservation planning

A. *Revised Universal Soil Loss Equation (RUSLE) Method*

The Universal Soil Loss Equation (USLE; Wischmeier and Smith 1978), later revised as the RUSLE (Renard *et al*. 1997), is the most widely used model for the prediction of water erosion hazards and planning of soil conservation measures. USLE/RUSLE estimates average annual soil loss rate using a factor-based approach with rainfall, soil, topography, land cover and management practice as inputs. The soil loss (A) due to water erosion per unit area per year (Mg ha-1yr-1) was quantified using RUSLE by the following equation:

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

Where,

A is soil loss in tons/ha/yr,

R is rainfall and runoff erosivity factor in (MJ mm ha-1h-1yr-1),

K is soil erodibility in (Mg h MJ-1mm-1),

LS is slope length and slope steepness,

C is cover management, and

P is support practice.

Since all factors in the USLE/RUSLE have a spatial distribution, a GIS based evaluation of the different factors is possible by overlaying the layers and multiplying them to get the soil loss values. This (USLE/RUSLE) model (fig. 2) only predicts the amount of soil loss that results from sheet or rill erosion and does not account for additional soil losses that might occur from gully, wind or tillage erosion. The prioritization has been done on the basis of this model only.

IV. RESULTS AND DISCUSSION

A. *Soil Loss Estimation Using RUSLE Model*

The layer of all factors has been multiplied in Arc map 9.3 and the values were obtained for the soil loss rate (Fig. 3). The layers of R, K, LS, C and P factors generated through different equations. First of all, the mapping for R factor has been done and interpolated applying Inverse Distance Weighted (IDW) method. As a result the ranges between 1478.25 and 2097.53 were calculated.

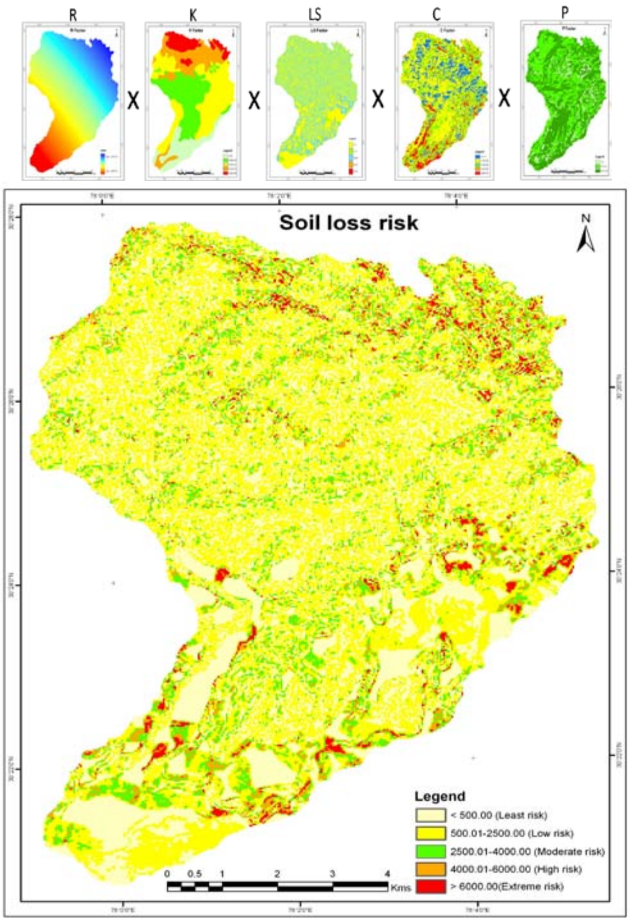

Fig. 3 Estimated soil loss rate

The soil map prepared by Kumar and Sharma (2005) was used for K factor. The area of interest has been subset and the K values were put into the soil texture classes. Ultimately, the values range between 0.36 and 0.48 were derived for K factor. The Digital Elevation Model (DEM) was utilized for LS factor. The classified values show that around 61 percent area falls under the low and nearly low slope category. The combined area under steep and very steep is near about 1.76 percent.

The Landsat TM satellite image was used for preparing the layer of C factor. Various equations were used for this layer and the pure soil and vegetation pixel values were calculated. The cover management factor (C) was then calculated from vegetation coverage data using the equation recommended by Renard et al. (1997). The C value normally ranges between 0 to 1, however the equation result for the study area shows the range from 0 to 0.98. The values close to 1 represent the vegetation health in terms of green cover and values in the vicinity of 0 always shows the pure soil pixel.

The map layer for the factor P was prepared with the help of land use land cover map. The value 1 has been assigned for built up, water bodies, scrub land and bare/barren land by USDA Handbook No. 282 (1981). The values 0.9 and 0.5 were assigned for the fallow land and agricultural cropland respectively. All layers for soil loss prediction were calculated pixel by pixel according to the RUSLE model. Table (I) shows the calculated values of soil loss potential rate.

TABLE I
SOIL LOSS ESTIMATION

S.No.	Erosion Potential Rate	Area in Hectare	Area in Percent (%)
1	< 500 (Least risk)	3083.34	35.45
2	500.01-2500 (Low risk)	4081.53	46.93
3	2500.01-4000 (Moderate risk)	877.51	10.09
4	4000.01-6000 (High risk)	472.33	5.43
5	> 6000 (Extreme risk)	182.62	2.10
	Total	8697.33	100

It found that the major portion (~82 %) of the study area corresponds to that under least and low risk potential zone which occupies 3083.34 and 4081.53 hectare land, respectively. Extreme (182.62) and high (472.33) risk areas constitute approximately 8% of the total land area while, the soil under moderate risk category covers 877.51 hectares of land and contribute 10.09 percent of land under erosion potential rate.

B. Calculated RUSLE Values For Micro Watershed Prioritization

Table II and Fig. 4 give the detailed information about the ranking which is based on mean soil loss values of each micro watershed.

1) Very High Priority: The micro watersheds named SW4a and SW5a are affected with a mean soil loss value of 1948.79 and 2576.80 Mg/ha/yr respectively and needs more attention with very high priority based on RUSLE model. These are situated on the northern part of watershed where the slope played a major role in soil loss.

TABLE III
MICRO WATERSHEDS WITH PRIORITY RANKS BASED ON RUSLE

SW	MWS	Area in km^2	Mean erosion value in Mg/ha/yr	Priority
SW1	SW1a	2.01	1034.82	22
	SW1b	2.48	1244.80	16
SW2	SW2a	2.93	1398.29	10
	SW2b	2.15	1666.98	5
	SW2c	4.84	1090.29	20
SW3	SW3a	3.34	1330.28	14
	SW3b	2.66	1222.52	17
	SW3c	1.47	997.05	23
SW4	SW4a	4.80	1948.79	2
	SW4b	3.70	1301.57	15
	SW4c	3.30	1129.89	19
SW5	SW5a	4.17	2576.80	1
	SW5b	5.58	1428.40	8
SW6	SW6a	3.20	1504.44	7
	SW6b	2.20	1362.23	13
SW7	SW7a	2.75	1403.91	9
	SW7b	3.53	1739.18	3
SW8	SW8a	3.21	1383.36	12
	SW8b	3.77	1384.49	11
	SW8c	5.71	1623.03	4
	SW8d	3.26	846.22	24
SW9	SW9a	4.80	1135.84	18
	SW9b	2.73	1058.17	21
	SW9c	8.38	1570.63	6
		86.97	1419.39	

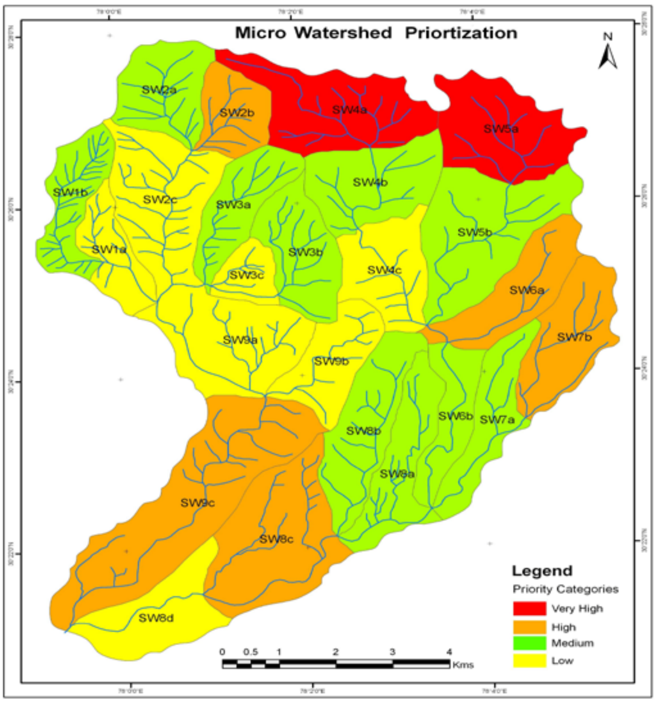

Fig. 4 Micro watershed prioritization through RUSLE

TABLE III
CALCULATED VALUES AND PRIORITY CLASSES OF DIFFERENT MICRO WATERSHEDS

Priority categories	Priority classes	Mean RUSLE Values	Micro Watershed names	Number of Micro Watersheds
Very High	I	> 1800	SW4a and SW5a	2
High	II	1500 – 1800	SW2b, SW6a, SW7b. SW8c and SW9c	5
Medium	III	1200 – 1500	SW1b, SW2a, SW3a, SW3b, SW4b, SW5b, SW6b, SW7a, SW8a and SW8b	10
Low	IV	< 1200	SW1a, SW2c, SW3c, Sw4c, SW8d, Sw9a and SW9b	7

1) High Priority: The mean soil loss value in table II shows that micro watershed named SW2b, SW6a, SW7b, SW8c and SW9c are categorized under high priority areas and immediate attention can minimize the soil loss rate.

2) Medium Priority: The micro watersheds SW1b, SW2a, SW3a, SW3b, SW4b, SW5b, SW6b, SW7a, SW8a and SW8b (Table III) are grouped under this class. These micro watersheds under the medium priority cover a large area among all the priority class. The mean soil loss values of respective micro watersheds are listed in table.

3) Low Priority: The mean soil loss values of micro watershed SW1a, SW2c, SW3c, SW4c, SW8d, SW9a and SW9b are significantly low compared to the others, and are categorized as low priority class on the basis of RUSLE model. The low mean soil loss value of micro watersheds under this class is not immediate area of action plan. Moreover, it might be possible that the low soil loss risk area might be having good quality of soil.

V. CONCLUSION

Soil loss is one of the hazards that reveals the negative impacts and plays an important role as a barrier for sustainable development. In this paper, the soil loss prediction and micro watershed prioritization has been performed on the basis of RUSLE model. The soil loss in Nun Nadi watershed ranged from 0 to 19214 Mg/ha/yr and high risk areas need immediate attention for conservation purpose. In a multi temporal soil loss estimation study (Naqvi et al. unpublished data), it is estimated that the soil loss values in the year 2009 were lower compared to the year 2000. The finding shows the contribution of adopting effective conservation measures in minimizing the soil loss. The other reasons may also be responsible for the decreased soil loss rate, but the problem is still serious in terms of soil loss. Micro watersheds under very high priority (SW4a and SW5a) and high priority (SW2b, SW6a, SW7b. SW8c and SW9c) shows that the estimated soil loss values of these micro watersheds are more than 1500 Mg/ha/yr, which highlights that certain areas are yet prone to this hazard. Mean soil loss value of each micro watershed helps out in determining their priority ranks. During the field survey, it was observed that poor agricultural and conservation practices have been adopted in the study area. Some of the areas were bund by stones and gabion boxes, nonetheless, a large portion of land remains vulnerable to soil erosion. Good conservation practices *i.e.* contour farming, up and down cultivation, channel terraces with contour farming, check dams, channel terraces and plantation of grass that can not be grazed easily but also plays an important role for the protection of top soil layer which can minimize the potential of rain drops, are suggested here which should to be implemented for the soil loss protection. Watershed unit proves helpful for the soil loss based study and its prioritization and management at micro level has good potential for conservation purpose. Although it can not provide an exact or perfect result, nonetheless, using a combinatorial approach our study shows satisfactory results on prioritization of the area. The data can redirect our strategies to protect soil loss. The above discussed conservation techniques for protection of soil (quantity and quality) will definitely show the positive results in terms of sustainable development.

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Hasan, Raja Naqvi. I did my high school and intermediate in 1999 and 2001, respectively, in humanities from Kendriya Vidhyalaya Punjab Line, Meerut Cantt, Uttar Pradesh, India. I have done my graduation and post graduation (2001 to 2006) in Geography from Chaudhary Charan Singh University, Meerut, Uttar Pradesh. Currently, I am pursuing PhD in Geography from Jamia Millia Islamia (A central University), New Delhi, India on research work entitled "watershed management for Soil Conservation: A case study of Nun Nadi watershed". Environmental science with Remote Sensing and GIS tool combination is my major field.

I am also actively involved in a project entitled "solid waste management in Ambedkar Nagar, Uttar Pradesh, India". One of my manuscripts "Mapping and Change Analysis of Land use and Vegetation Cover: A case study of Dehradun District". *Jamia Geographical Society*. **Hasan Raja Naqvi**, Joheb Khan, Laishram Mirana Devi, Lubna Siddiqui and Masood Ahsan Siddiqui. Manak Puplications, 246-255, 2012 is published as a book chapter. Another article related to the research work is under review. Presently, I am working on my research where I have calculated the soil loss in the study area and performed prioritization using RUSLE model and suggested the conservation techniques. Besides, I am also doing some work on flood hazard in Kashmir valley.

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He got the University Merit Scholarship in his masters from the Department of Geography, A.M.U Aligarh from 1980 to 1982 and UGC Research Fellowship (NET/JRF) in Geography from 1984 to 1987.