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Full Length Research Paper

Prioritization of micro watersheds on the basis of soil erosion hazard using remote sensing and geographic information system

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Degradation of agricultural land by soil erosion is world wide phenomenon leading to loss of nutrient-rich surface soil, increased run off from more impermeable subsoil and decreased water availability to plant. Thus estimation of soil loss and identification of critical area for implementation of best management practice is central to success of soil conservation programme. In this study universal soil loss equation (USLE) interactively with raster-based geographic information system (GIS) has been applied to calculate potential soil loss at micro watershed level in the Konar basin of upper Damodar Valley Catchment of India. The main advantage of the GIS methodology is in providing quick information on the estimated value of soil loss for any part of the investigated area. The rainfall erosivity R-factor of USLE was found as 293.96 and the soil erodibility K-factor varies from 0.325 - 0.476. Slopes in the catchment varied between 0 and 83% having LS factor values ranging from 0 - 6.7. The C-factor values were computed from existing cropping patterns in the catchment and support practice P-factors were assigned by studying land slope. Average annual soil erosion at micro watershed level in Konar basin having 961.4 km^2 areas was estimated as 1.68 t/ha/yr. Further, micro watershed priorities have been fixed on the basis of soil erosion risk to implement management practices in micro watersheds which will reduce soil erosion in Konar basin.

Key words: Remote sensing, soil erosion, geographic information system, universal soil loss equation, priority.

INTRODUCTION

Land and water are the two basic natural resources for the survival of living systems. These two resources have been interacting with each other in various phases of there respective cycles. The future of the nation depends largely on the effective utilization, management and development of these resources in an integrated and comprehensive manner. Soil erosion in catchment areas and the subsequent deposition in rivers, lakes and reservoirs are of great concern for two reasons. Firstly, rich fertile soil is eroded from the catchment areas. Secondly, there is a reduction in reservoir capacity as well as degradation of downstream water quality. Sediment particles originating from the continuous process of erosion in the catchment area propagated along the river flow. When this flow accumulates into the reservoir the sediment that has been carried with the stream gets settled into the reservoir and reduces its capacity. Reduction of storage capacity of a reservoir beyond a certain limit hampers the purpose of the reservoir for which it was designed. Estimation of sediment deposition in a reservoir using conventional techniques like hydrographic survey is a cumbersome procedure. It involves huge time, manpower and even it is not cost effective.

Several empirical models based on the geomorphological parameters were developed in the past to quantify the sediment yield. Several other methods such as sediment yield index (SYI) method proposed by Bali and Karale (1977) and universal soil loss equation (USLE) by Wischmeier and Smith (1978) are extensively used for prioritization of the watersheds. The USLE has been widely applied at a watershed scale on the basis of lumped approach to catchment scale (Jain et al., 2001).

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In several other studies, watershed has been sub-divided either into cells or of regular grid or into units where a unique run off direction exists (Onyando et al., 2005; Wu et al., 2005). Renschler et al. (1997) used USLE and RUSLE to predict the magnitude and spatial distribution of erosion within a GIS environment using ILWIS software in catchment of 211 km2 at grid resolution ranging from 200 to 250 m to be more reasonable. Dabral et al. (2008) divided Dikrong river basin into 200 × 200 m grid cells. He found the average annual soil loss of the Dikrong river basin is 51 t/ha/yr. About 25.61% of the watershed area is found out to be under slight erosion class. The USLE model applications in the grid environment with GIS would allow us to analyze soil erosion in much more detail. It is more reasonable to use the USLE on physical basis than to apply it to an entire watershed as a lumped model. Although, GIS permits more effective and accurate application of the USLE model for small watershed, most GIS-model applications are subject to data limitations (Fistikoglu and Harmancioglu, 2002).

An W (2008) used GIS-Based hydrological model for highway environmental assessment study. He developed highway watershed model (HWM) using the watershed modeling system (WMS) to simulate the hydrology and hydraulic behavior along the stream system draining selected watersheds near I-99 highway construction site. With 15% deviation as accepted criterion, the modeling results of WMS show all total run off volumes are satisfactory. The technology of remote sensing and GIS is gaining importance as a powerful tool in the management of information in agriculture, natural resources assessment, environmental protection and conservation (Javed et al., 2009). Pandey et al. (2007) divided Karso watershed of Hazaribagh, Jharkhand State, India into 200 × 200 m grid cells and average annual sediment yields were estimated for each cell of the watershed to identify the critically prone areas of watershed. Recent studies (Pandey et al., 2007; Yoshino and Ishioka, 2005; Chowdary et al., 2004; Sharma et al., 2001; Khan et al., 2001; Sidhu et al., 1998) revealed that RS and GIS techniques are of great use in characterization and prioritization of watershed areas.

DESCRIPTION OF THE STUDY AREA

Damodar Valley Catchment lies between 23°34' to 24°9' N latitude and 85°00' to 87°00' E Longitude. The total valley area covered by DVC is approximately 24,235 sq. km. Mean annual rainfall in the basin is of the order of 1,300 mm and about 80% of rain precipitates during the monsoon (June to September). The lower valley known as Damodar catchment (Drainage area - 10966.10 km^2) has three reservoirs, namely, Tenughat, Konar and Panchet comprising of drainage area of 4395.15, 997.15 and 5573.8 km^2 respectively, which lies between 23°34' to 24°9' N latitude and 84°42' to 86°46' E longitude. Konar basin having drainage area 997 .15 km^2 and 39 micro watersheds is taken for this study.

MATERIALS AND METHODS

Data used

The rainfall, run off and sediment yield data were collected from the soil conservation department of DVC, India. Daily rainfall data for the period from 1993 to 2001 in the study area was used to compute rainfall erosivity - R factor. The soil maps of the study area in the scale of 1:250,000 were traced, scanned and exported to Erdas imagine 8.5.

The scanned maps were loaded in ERDAS and georeferenced. Boundaries of different soil textures were digitized and the polygons representing various soil categories were assigned with different colours for identification. Required data like soil texture, bulk density etc. were extracted for each micro-watershed of Konar basin. Toposheet of study area was taken from DVC. SRTM Digital elevation model (DEM) was used to prepare LS factor map. The LANDSAT ETM images for the study area were downloaded from http://glcf.umiacs.umd.edu. These images were used to prepare land use/ land cover map. The micro-watershed treatment map and boundary map of 1": 4 miles scale for the upper Damodar valley were also collected from DVC Hazaribagh.

Soil erosion model- universal soil loss equation

The universal soil loss equation was used to determine the average annual soil loss and its spatial distribution on the watershed. The USLE predicts soil loss for a given site as a product of six major erosion factors (Equation 1), whose values at a particular location can be expressed numerically. The limitation of this model is that it does not estimate deposition, sediment yield, channel erosion, or gulley erosion. Thus, the USLE is suitable for predicting long-term averages and the soil erosion is estimated as follows:

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

Where; A is average annual soil loss rate (t/ha/yr), R is rainfall erosivity factor (MJ-mm/ha/h/yr), K is soil erodibility factor (t-ha-h/ha/MJ/mm), LS is topographic factor, C is crop management factor and P is conservation supporting practice factor. The data used for calculating these USLE factors is shown in Table 1.

Development of model database for universal soil loss equation

Rainfall erosivity factor (R)

The rainfall erosivity factor (R) map is prepared using daily rainfall data from Nagwan station located in the Konar basin. This map is based on 9 year-average rainfall data which is used to calculate annual average R factor values. All the storms do not produce run off and hence storms more than 12.5 mm were only used in computation as suggested by Wischmeier (1959).

Panigrahi et al. (1996) developed a model for estimation of R factor (Equation 2) from daily rainfall amount (P) for 31 years for Bhubaneshwar. They reported 12.2 average percentage deviations between the observed and calculated R factor and concluded that their model given below could be well used for computation of R factor using the daily rainfall amount.

$$R = P^2 (0.00364 \log_{10} P - 0.000062) \qquad (2)$$

Table 1. Universal soil loss equation factor – data used.

USLE factor	Data
R	Daily rainfall data
K	Soil sample analysis data
LS	SOI topographic maps
C	Digital land use/land cover map
P	Field survey data

Table 2. Soil structure code.

Code	Structure	Size, mm
1	Very fine granular	<1
2	fine granular	1 - 2
3	Medium or coarse granular	2 -10
4	Blocky, platy or massive	>10

Table 3. Soil permeability code.

Code	Description	Rate, mm/h
1	Rapid	> 130
2	Moderate to rapid	60 - 130
3	Moderate	20 - 60
4	Slow to moderate	5 - 20
5	Slow	1 - 5
6	Very slow	< 1

Soil erodibility factor (K)

The soil erodibility factor (K) was computed using field and laboratory estimated physical-chemical properties of the surface soils. The laboratory soil analysis was carried out to determine soil texture, structure, permeability and organic matter content for various soil group of the area. Wischmeier et al. (1971) developed the procedure for determination of soil erodibility factor by developing an equation based on five soil parameters, which is used in the present study.

$$100K = 2.1M^{1.14} (10^{-4}) (12 - a) + 3.25 (b -2) + 2.5 (c-3) \quad (3)$$

Where, K = soil erodibility factor, M = percentage silt, very fine sand and sand > 0.10 mm, a = organic matter content, b = structure of the soil, c = permeability of the soil.

Soil structure code was assigned on the basis of particle size of soil using values given in Table 2. Permeability code for soil type was assigned on the basis of permeability rate using values given in Table 3. Soil erodibility factor (K) is a measure of the total effect of a particular combination of soil properties. Some of these properties influence the soil's capacity to infiltrate rain and therefore, help to determine the amount of rate of run off; some influence its capacity to resist detachment by the erosive forces of falling raindrops and flowing water and thereby determine soil content of the run off. The inter-relation of these variables is highly complex.

Topographic factor (LS)

Derivations of topographic factors (L and S) were performed by computing slope length and gradient respectively, using SOI topographical maps at a scale of 1:25,000. Combined (LS) factor for all the micro-watersheds was computed using the slope map generated from the DEM of study area. LS is the expected ratio of soil loss per unit area from a field slope to that from a 22.13 m length of uniform 9 percent slope under otherwise identical conditions. Although, L and S factors can be determined separately, the procedure has been further simplified by combining the L and S factors together and considering the two as a single topographic factor (LS) (Wischmeier and Smith, 1965). Combined LS factor layer was generated as:

(I) For slopes up till 21%, the equation modified by Wischmeier and Smith (1978) was used which is:

$$LS1 = (L / 22.1) \times (65.41 \sin^2\theta + 4.56 \sin \theta + 0.065) \quad (4)$$

Where LS1 is the slope length and gradient factor and θ is angle of the slope.

(II) For slope steepness of 21% or more, the Gaudasasmita equation was used which is:

$$LS2 = (L / 22.1)^{0.7} \times (6.432 \times \sin (\theta^{0.79}) \times \cos (\theta)) \quad (5)$$

Where LS2 is the slope length and gradient factor and θ is angle of the slope.

$$L = 0.4 \times Sp + 40 \quad (6)$$

Where L is slope length in meters and Sp is slope steepness in percentage.

Crop management factor (C) and conservation practice factor (P)

The crop management (C) factor reflects the combined effect of cover, crop sequence, productivity level, length of growing season, tillage practices, residue management and the expected time distribution of erosive rainstorm with respect to seeding and harvesting date in the locality. Actual loss from the cropped field is usually much less than the amount of soil loss for a field kept continuously in fallow conditions. This reduction in soil loss depends on the particular combination of cover, crop sequence and management practices. Crop management factor is the expected ratio of soil loss from a cropped land under specific condition to soil loss from clean tilled fallow on identical soil and slope under the same rainfall conditions. In this study, the land use/land cover map was derived from the satellite images and served as a guiding tool in the allocation of C and P factors for different land use classes. The study area has been classified into seven land use classes. Crop management factor was assigned to each land use class by using available C factor values in literature for that class in same agro climatic conditions. In this study, P factor values have been assigned on the basis of percent slope of the micro watershed.

RESULTS AND DISCUSSION

Development of thematic map of universal soil loss equation factors

Rainfall erosivity (R) factor

The catchment sediment yield is more sensitive to rainfall

Table 4. Rainfall erosivity factor.

Year	Average annual rainfall (mm)	Annual R factor
1993	890	135.1
1994	1693	415.0
1995	1425	426.0
1996	1265	393.0
1997	1380	285.8
1998	1263	195.9
1999	1580	414.3
2000	1047	211.3
2001	1195	169.3
Average	1304.2	293.96

amount than to either EI_{30} or the R-factor. The daily rainfall is better indicator of variation in sediment yield with the added advantage that it can be used to characterize the seasonal distribution of sediment yield. While the advantages of using annual rainfall include its ready availability, ease of computation and greater regional consistency of the exponent. Therefore, in the present analysis R factor using daily rainfall amount suggested by Wischmeier (1959) and validated by Panigrahi et al. (1996) for Indian conditions was used. The average annual precipitation in the Upper DVC is 1300 mm with a standard deviation of 161.13 mm. Using daily rainfall data from year 1993 to 2001 and Equation 2, R factor value for Konar basin was estimated and was found as 293.96 (Table 4). Using R factor value, R factor map was prepared in ArcView3.1 and shown in Figure 1(c).

Soil erodibility (K) factor

The factors like texture, structure, organic matter content and permeability are very significant in determining soil erodibility. Soil erodibility is regulated by a complex set of physical and chemical properties and is usually determined empirically. Soil analysis data was available for all soil types found in Konar basin. K factor values for each soil type were calculated using Equation 3. K factor values are assigned to respective soil types in soil map. Using K factor values, K factor map was prepared in ArcView3.1, and shown in Figure 1(d). The value of K-factor was found to be ranging between 0.325 and 0.476.

Topographic factor (LS)

DEM generated slope length are based on the assumption that each slope plane consists of a homogenous form of slope and vegetation cover, which in practice may not be the case. While deriving topographic factors, GIS techniques tend to predict very long slope lengths on flat to very gentle slopes, which can lead to overestimation of soil loss. As a result, the LS factor fails to fully account for the hydrological processes that affect run off and erosion, its importance as a measure of the sediment transport capacity of run off from the landscape not withstanding. SRTM DEM shown in Figure 1(b) was used to derive slope map in percent and degree. Using slope map and Equations 4 and 5, LS factor map was prepared using ArcView3.1 and shown in Figure 1(e). The elevation of the study area is ranging between 140 to 844 m and the value of LS factor for study area was ranging from 0 to 6.7.

Crop management factor (C) and conservation practice factor (P)

Information on land use permits a better understanding of the land utilization aspects on cropping pattern, fallow land, forest and wasteland and surface water bodies, which are vital for development planning/erosion studies. Remote sensing and GIS technique has a potential to generate a thematic layer LU/LC of a region. The study area has been classified into seven land use classes shown in Figure 1(a). Crop management factor was assigned to different land use patterns using values given in Table 5. Using LU/LC map and C factor values, C factor map was prepared in ArcView3.1 and is shown in Figure 1(f) Crop management factor was found to be in the range of 0.002 to 1.00. Conservation practice factor for micro watersheds of Konar basin was assigned on the basis of percent slope. Soil and Water assessment Tool (SWAT) given criteria for P factor was used for this purpose. Conservation practice factor was assigned for different slope range using values given in Table 6. Using P factor values, P map was prepared in ArcView3.1 and is shown in Figure 1(g).

Average annual soil loss of Konar Basin

The annual soil loss for micro watersheds was calculated by using annual average R (based on daily rainfall data of 1993 - 2001), K, LS, C and P factors. All the layers viz. R, K, LS, C and P were generated in GIS and over layed to obtained the product, which gives annual soil erosion map (Figure 2) for the Konar basin. This soil loss map is over layed with micro watershed map of Konar basin which contains 39 micro-watersheds to get micro watershed wise soil loss. The soil erosion rate (t/ha/yr) of a micro watershed was estimated as total soil loss of ith micro watersheds (t/yr) / total geographical area of ith micro watersheds (ha). The classification of erosion rate has given rise to five categories of soil loss intensity (Figure 2). The observed sediment yield of Nagwan catchment having 92.46 km^2 area was 2.79t/ha. The

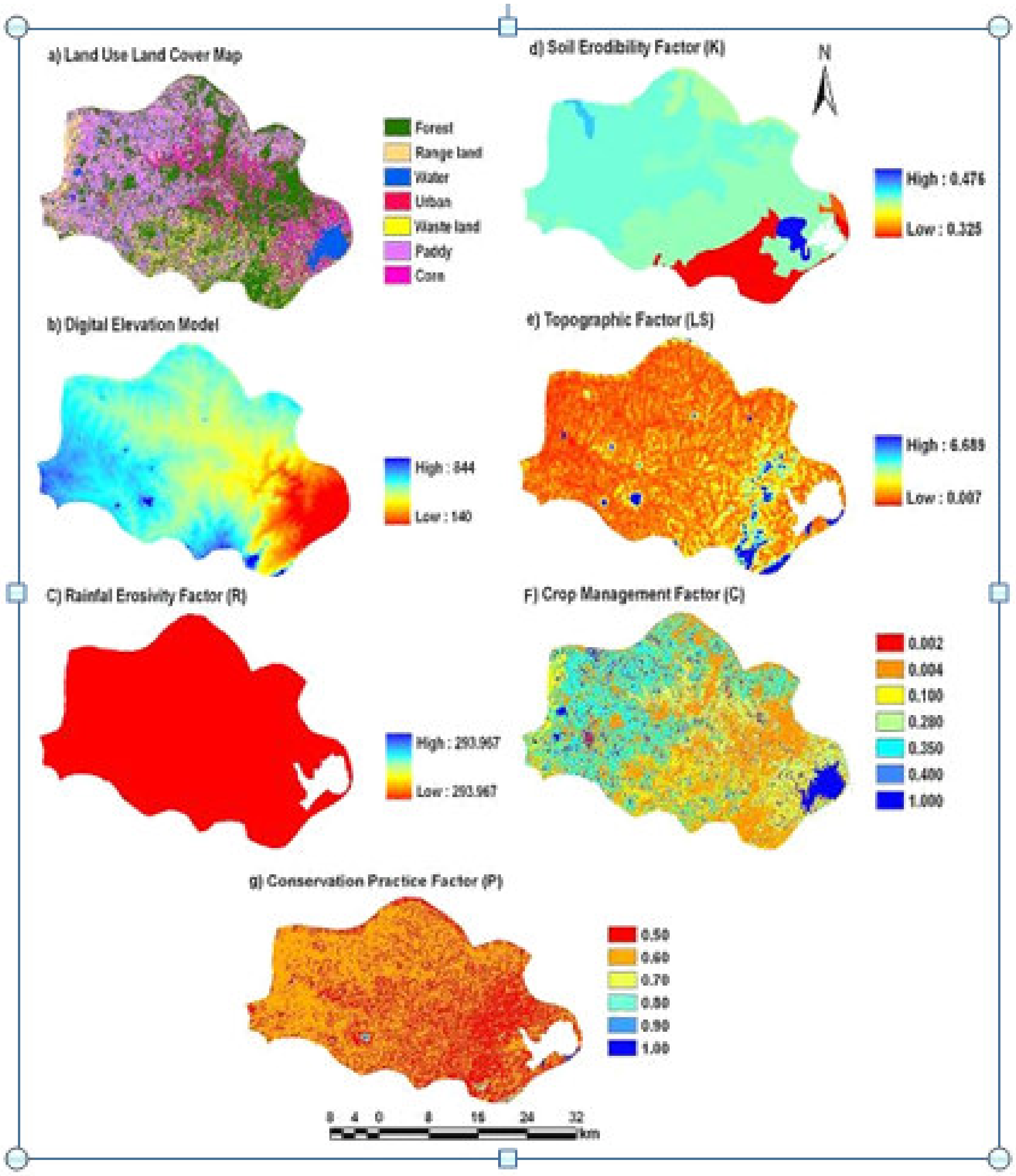

Figure 1. Thematic layers of USLE factors.

Table 5. Crop management factor values.

Land use/land cover	C value
Forest	0.004
Range	0.1
Water body	1
Urban	0.002
Wetland	0.4
Corn	0.35
Paddy	0.28

Table 6. Conservation practice factor values.

Slope, %	P value
0 - 2	0.6
2.1 - 5	0.5
5.1 - 8	0.5
8.1 - 12	0.6
12.1 - 16	0.7
16.1 - 20	0.8
20.1 - 25	0.9

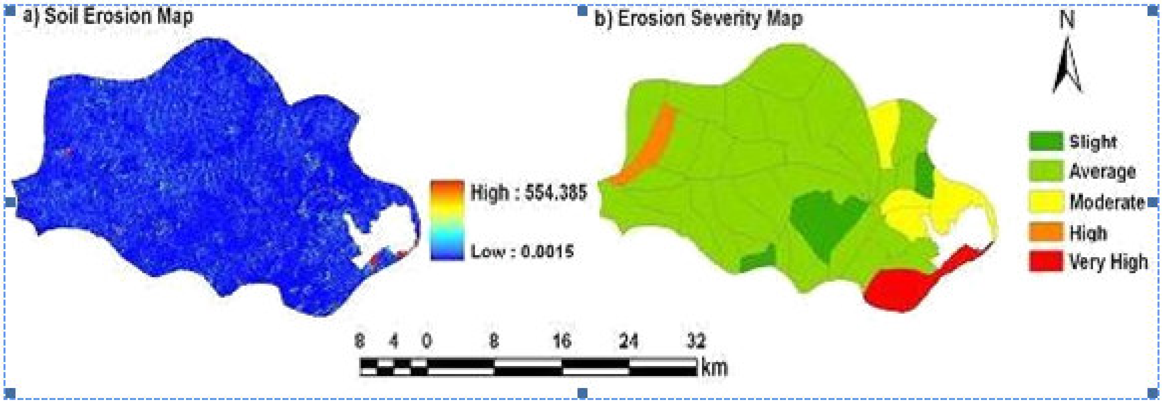

Figure 2. Soil erosion map and micro watershed wise severity map.

calculated soil loss for micro watershed having code kd1f of Konar basin which falls under Nagwan Catchment having area of 50.59 km^2 was 1.31t/ha as compared to that of 1.527t/ha as observed value. The slight difference in observed sediment yield value and calculated erosion value was due to the deposition of soil particles during erosion process, as USLE does not consider deposition of soil particles. Prioritization of micro watersheds within the basin based on soil erosion risk has been made.

Prioritization of micro-watersheds

Considering the massive investment in the watershed development programme, it is important to plan the activities on priority basis for achieving fruitful results, which also facilitate addressing the problematic areas to arrive at suitable solutions. The resources-based approach is found to be realistic for watershed prioritization since it involves an integrated approach. Prioritization of micro-watersheds was done on the basis of average annual soil loss. All the 39 micro watersheds in the study area have been prioritized by considering the results of various thematic maps derived from satellite imagery as well as rainfall and soil data. Table 7 indicates distribution of the 39 micro watersheds of Konar basin according to soil erosion intensity.

SUMMARY AND CONCLUSION

A quantitative assessment of average annual soil loss on micro-watershed basis was made using USLE with a view to know the spatial distribution in the Konar basin. The use of GIS and remote sensing data enabled the determination of the spatial distribution of the USLE parameters. Micro-watershed wise soil loss was estimated and prioritization of micro-watersheds was done on the basis of annual average erosion obtained

Table 7. MW wise average annual soil loss and priority.

MW Code	Area (km^2)	Erosion (t/ha/yr)	Priority
ka1b	44.51	10.058	1
Ka1c	18.95	1.7484	9
Ka1d	14.64	1.5926	13
Ka1f	19.6	1.067	32
Ka1g	16.51	2.1963	5
ka1h	11.42	2.3546	3
Ka1j	23.78	1.28	26
Kb1a	30.71	2.2699	4
Kb1b	11.24	0.4746	39
Kb1c	8.88	1.0978	30
Kb1d	8.35	1.6008	11
Kb1f	27.31	1.3516	22
Kb1g	21.77	2.1521	6
Kc1a	20.3	0.8972	36
Kc1b	19.4	0.9213	35
Kc1c	9.76	0.6384	38
Kc1d	25.32	1.0685	31
Kc1f	30.73	1.4888	16
Kc1g	31.62	1.5909	14
Kc1h	34.96	1.3923	20
Kc1j	8.35	1.0296	34
Kc1k	8.74	1.2296	28
Kc1m	8.6	0.8272	37
Kc2a	28.99	1.2905	25
Kc2b	37.3	1.6672	10
Kc2c	14.98	1.3338	23
Kc2d	31.22	1.5289	15
Kd1a	27.72	1.0413	33
Kd1b	39.13	1.392	21
kd1c	44	1.2667	27
Kd1f	50.59	1.3102	24
kd1g	29.47	1.4265	17
Kd1h	31.21	1.7776	8
Kd1j	28.7	1.424	19
Kd2a	26.61	1.4246	18
Kd2b	27.65	1.5949	12
Kd2c	25.19	3.9731	2
Kd2d	33.44	1.1036	29
Kd2f	29.77	1.7987	7

from 9 years daily rainfall data. Annual average soil erosion for Konar basin was 1.68 t/ha/yr at micro-watershed level. Particularly R and K are least influencing as rainfall decreases and clay proportion in soils increases downstream. The micro watershed priority-zation indicated that the micro watersheds falling under high and very high priority class requires immediate attention for soil conservation treatment. The prioritization map prepared using remote sensing and GIS technology for the present study satisfactorily matched (65%) with the priority map prepared through field based sediment yield index method of AISLUS. Hence, remote sensing and GIS technology can be used as an alternative to conventional method of soil loss estimation and subse-quent prioritization of micro watershed for implementing soil conservation practices. The best management practices proposed for micro watersheds of Konar basin are; afforestation, trenching, bunding, stone wall fencing, brushwood check dams, earthen check dams, gabian structures and masonry structures.

REFERENCES

An W (2008). GIS-Based Hydrological Model - Study in Highway Environmental Assessment, ISBN-10: 3639098382, VDM Publishing House, Germany. ISBN.13: 978-3639098389,

Bali YP, Karale RL (1977). A sediment yield index for choosing priority basins. IAHS-AISH Publ. 222: 180.

Dabral PP, Baithuri N, Pandey A (2008). Soil Erosion Assessment in a Hilly Catchment of North Eastern India Using USLE, GIS and Remote Sensing, Water. Resour. Manage., 22: 1783–1798.

Deore SJ (2005), Tripathi MP (1999). Prioritization of Micro-watersheds of Upper Bhama Basin on the Basis of Soil Erosion Risk Using Remote

Sensing and GIS Technology. Ph. D. thesis, submitted to Department of Geography, University of Pune, India.

Fistikoglu O, Harmancioglu NB (2002). Integration of GIS with USLE in assessment of soil erosion, J. Water. Resour. Manag., 16: 447-467.

Jain SK, Kumar S, Varghese J (2001). Estimation of soil erosion for a Himalayan watershed using GIS technique, J. Water. Resour. Manag., 15: 41–54.

Javed A, Khanday MY, Ahmed R (2009). Prioritization of Sub-watersheds based on Morphometric and Land Use Analysis using Remote Sensing and GIS Technique,. J. Indian. Soc. Remote. Sensing. 37: 261-274.

Khan MA, Gupta VP, Moharanam PC (2001). Watershed prioritization using remote sensing and geographical information system: a case study from Guhiya, India. J Arid. Environ., 49: 465-475.

Kothyari UC, Jain SK (1997). Sediment yield estimation using GIS. Hydrol. Sci. J., 42 (6): 833–843

Onyando JO, Kisoyan P, Chemelil MC (2005). Estimation of potential soil erosion for river perkerra catchment in Kenya, J. Water. Resour. Manag., 19: 133–143.

Pandey A, Chowdary VM, Mal BC (2007). Identification of critical erosion prone areas in the small agricultural watershed using USLE, GIS and remote sensing, J. Water. Resour. Manag., 21: 729-746.

Panigrahi B, Senapati PC, Behera BP (1996). Development of erosion index model from daily rainfall data, J. Appl. Hydro.,. 9 (1,2): 17-22.

Renschler C, Diekkruger B, Mannaerts C (1997). Regionalization in surface runoff and soil erosion risk evaluation, in regionalization of hydrology. IAHS-AISH. Publ., 254: 233-241.

Sharma JC, Prasad J, Saha SK, Pande LM (2001). Watershed prioritization based on sediment yield index in eastern part of Don valley using RS and GIS, Indian. J. Soil. Conserv., 29 (1): 7-13.

Sidhu GS, Das TH, Singh RS, Sharma RK, Ravishankar T (1998). Remote sensing and GIS techniques for prioritization of watershed: a case study in upper Mackkund watershed, Andhra Pradesh, Indian. J. Soil. Conserv., 2 (3): 71-75.

Wischmeier WH, Smith DD (1978). Predicting rainfall erosion losses- a guide to conservation planning, Agricultural Handbook USDA.p. 537.

Wu SLiJ, Huang G (2005). An evaluation of grid size uncertainty in empirical soil loss modelling with digital elevation models, Environ. Monit. Assess., 10: 33-42.

Yoshino K, Ishioka Y (2005). Guidelines for soil conservation towards integrated basin management for sustainable development: a new approach based on the assessment of soil loss risk using remote sensing and GIS, Paddy. Water. Environ., 3: 235-247.