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ESTIMATION OF SOIL LOSS USING GIS AND USLE METHOD IN DWARKA RIVER BASIN, EASTERN INDIA

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Abstract: Universal Soil Loss Equation (USLE) was developed in the U.S., based on soil erosion data collected beginning in the 1930s by the U.S. Department of Agriculture (USDA) Soil Conservation Service. It is designed as a method to predict average annual soil loss. It can estimate long term annual soil loss and guide conservationists on proper cropping, management, and conservation practices. For the present work Dwarka River basin has been selected. As it covers different physiographic divisions, various topsoil regions, different climatic set up etc there is possibility of spatial variation in soil loss in the river basin. The prime objective of the current study is to estimate average annual soil loss based on USLE method for better watershed management planning. Individual layers of USLE parameter have been prepared based on relevant secondary data and these overlay analysis of all the layers have been done under GIS environment. Finally, soil erosion zones have been demarcated through the said overlay analysis and some management strategies have been put forwarded.

Key words: USLE, USDA, GIS, Soil Erosion Zone, Watershed Management

1. Introduction

According to Ellison (1944), "Erosion is a process of detachment and transport of soil particles by erosive agents." Water erosion is currently one of the main environmental problems for degrading soil and water resources. In addition, it poses a risk to food safety and represents a serious barrier to sustainable development (Telles et al., 2011). Studies on soil use and management in watersheds, especially predictive models, are fundamental to reduce erosive processes (Daniel et al., 2014). Erosion often results in a decrease of the soil supply functions by three ways: The removal of organic matter, the change in depth to a possible root-barrier and the loss of structure and increased compaction (Bakker et al., 2004; Wang and Cui, 2005; Rabia, 2012; Ranya et al., 2015). Various models have been developed to estimate soil loss of a particular region. Universal Soil Loss Equation (USLE) model is one of the empirical models of soil loss estimations. Dwarka River basin covers different physiographic divisions; hence, there is possibility of spatial variation in soil loss.

2. Objective

The prime objective of the current study is to estimate average annual soil loss based on USLE method for better watershed management planning.

3. Study Area

3.1 Location: For the present research purpose Dwarka River Basin (DRB) has been selected. Latitudinal extension of the basin is 23º57′43.905″ North to 24º29′27.685″ North and longitudinal extension is 87º17′39.515″East to 88º10′36.061″ East. The administrative status of the basin area is shown in the following table.

Name of States	Name of Districts	Name of C. D. Blocks
Jharkhand	Pakur	Maheshpur, Pakuria, Amrapara
	Godda	Sundarpahari
	Dumka	Gopikandar, Kathikund, Ramgarh, Dumka, Shikaripara, Ranishwar
West Bengal	Birbhum	Murarai II, Nalhati I, Nalhati II, Rampurhat I, Rampurhat II, Mayureshwar I, Md. Bazar

	Murshidabad	Raghunathganj I, Sagardighi, Nabagram, Khargram, Kandi

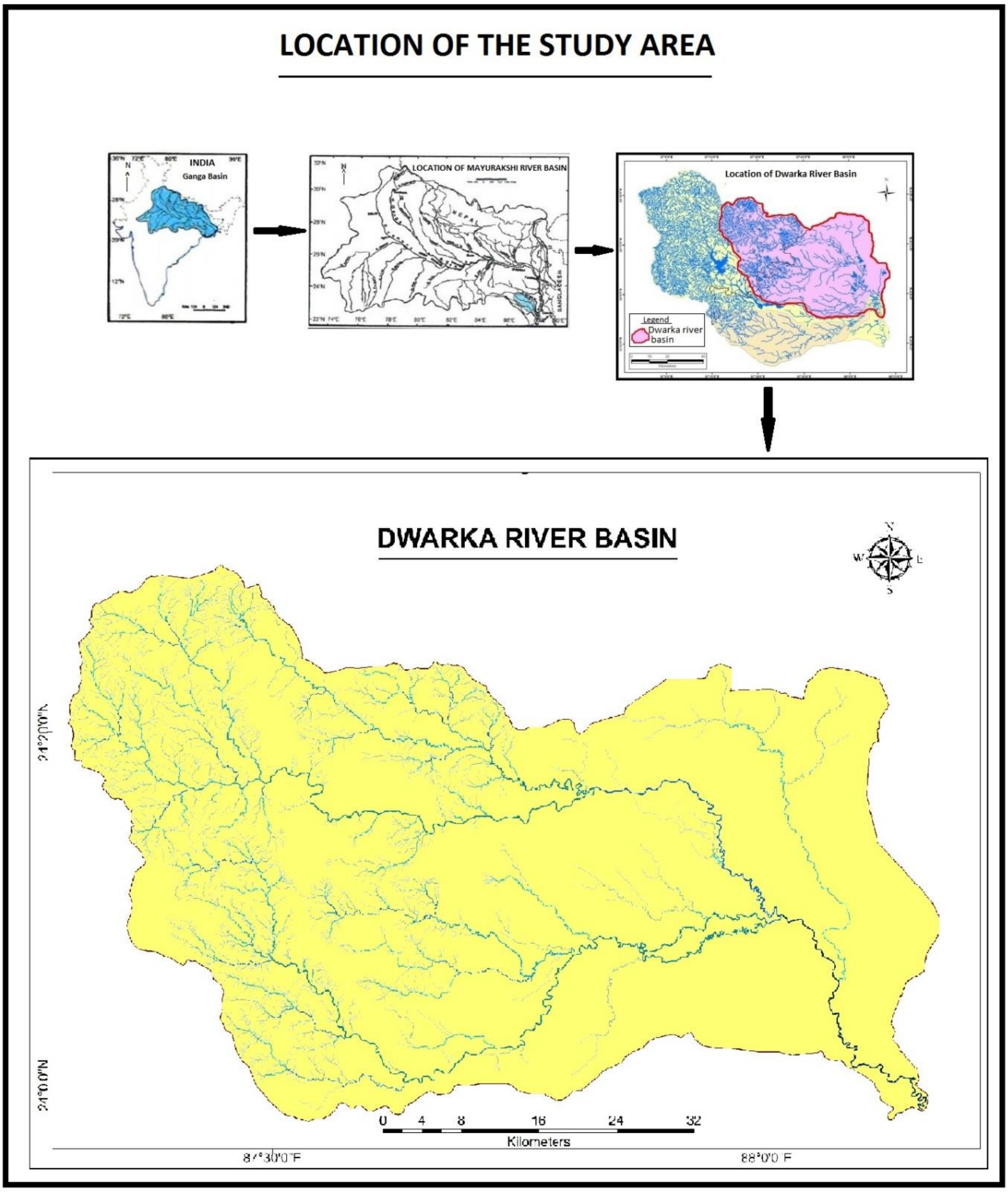


Figure 1: Location of the study area

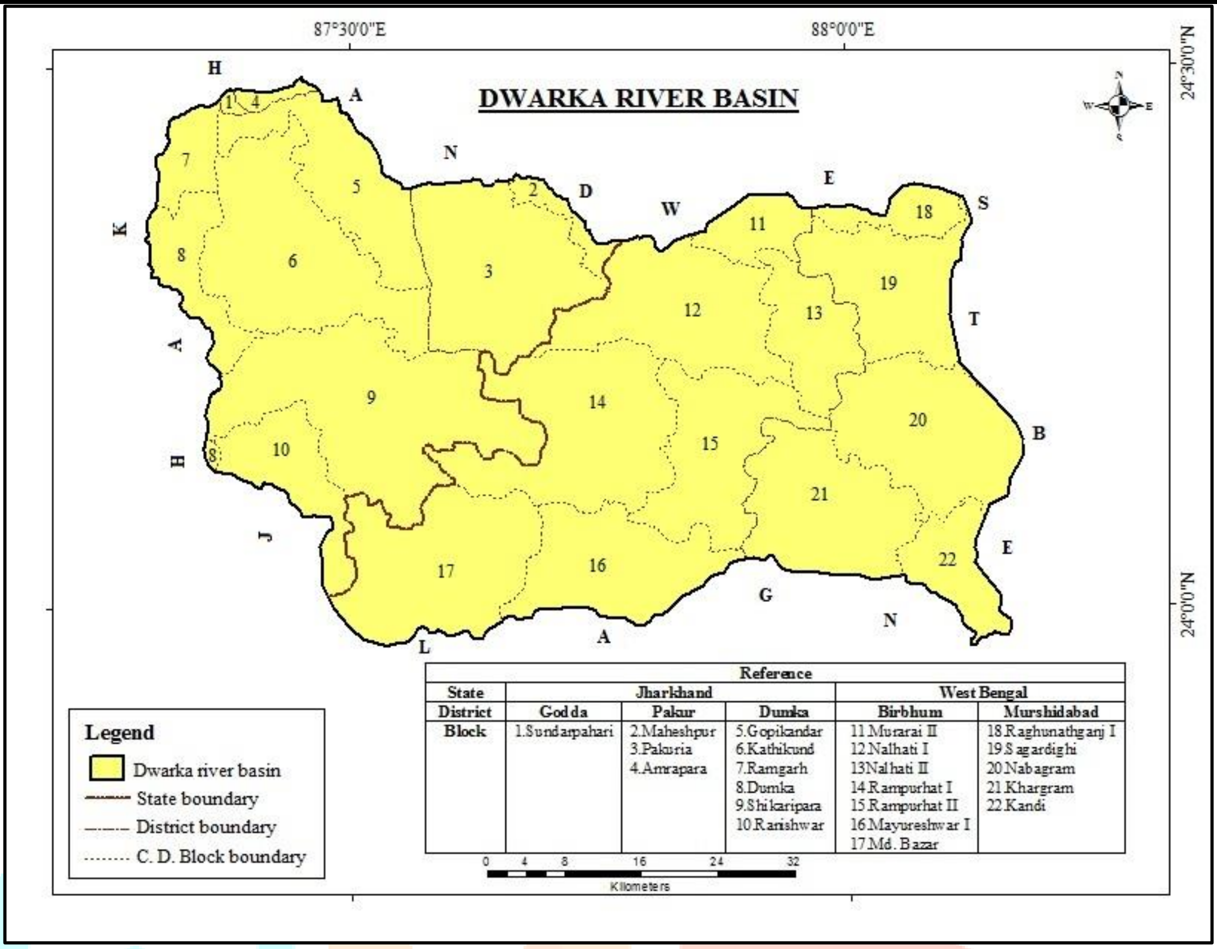
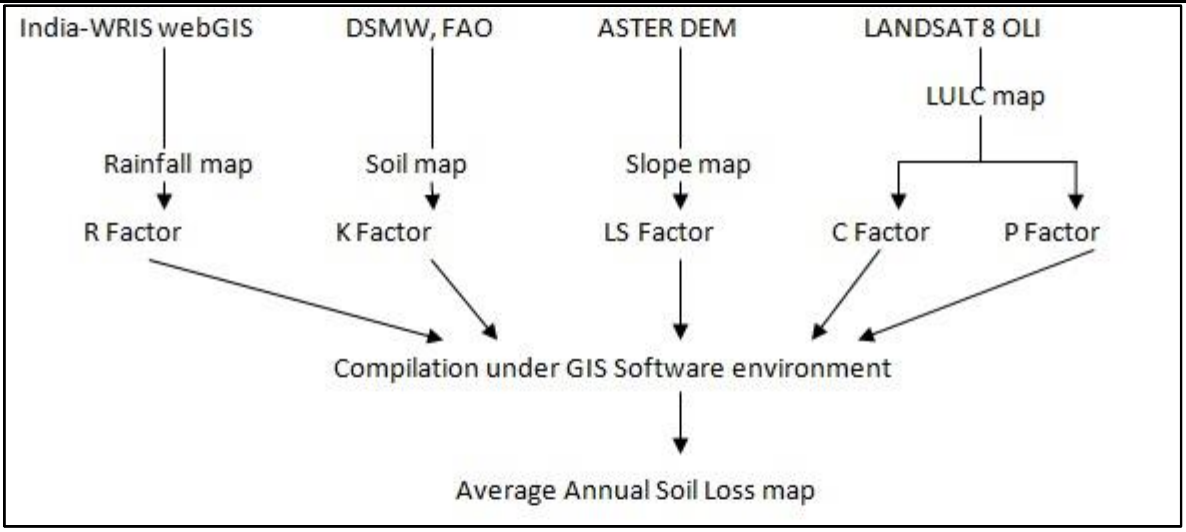


Figure 2: Administrative divisions of the study area

3.2 Physiography: Dwarka River Basin (DRB) includes three broad physiographic divisions namely, highland or plateau fringe, undulating plain and plain. The western part of DRB comes under plateau fringe of Chhotanagpur plateau. In covers Godda district, and some parts of Dumka district of Jharkhand. This segment of the river basin has average altitude of more than 180 meters. Comparatively higher ground slope (near about 1.5 to 8degree) is also found here. Numerous rivulets and small streams cover this portion. In between plateau fringe and plain, an undulating plain segment lies in the DRB. It covers rest of the portion of Dumka and entire Pakur district of Jharkhand and some portion of Birbhum district of West Bengal. Average altitude of this region ranges between 60 to 180 meters. It has a ground slope of mostly 0.3 to 1.17 degree. Source of Dwarka River is situated in this part. The plain covers rest of Birbhum district and entire Murshidabad district of West Bengal. Here average altitude is less than 60meter and ground slope is also very insignificant (0.001 to 0.334 degree). Dwarka river follows its lower reach through this physiographic segment.

4. Database and Methodology

The present work is based on secondary database collected from sources mentioned below. Monthly rainfall data for 2000-2013 has been collected from India- WRIS webGIS official website. From the data annual average rainfall has been calculated and rainfall map for the study area has been prepared by interpolation method with the help of ArcGIS 10.5 software. Soil map prepared by FAO has been consulted to have the soil type and top soil characteristics of the study area. Slope map has been prepared from ASTER Digital Elevation Model. Land use and land cover map has been derived from LANDSAT image. From those maps individual layer of different USLE factors have been prepared with the consultation of concerned literatures in ArcGIS 10.5 software. Compiling all the raster layers of those factors average annual soil loss map has been obtained.



5. USLE parameters

The erosion rate at a given site is determined by the particular way in which the levels on numerous physical and management variables are combined at that site. The USLE is an erosion model designed to predict the long time average soil losses in runoff from specific field areas in specified cropping and management systems (Wischmeier, Smith 1978). Soil erosion depends on various natural and human factors. Accordingly, the USLE is the product of several related physical and human factors. The Universal Soil Loss Equation is

$$A = R*K*LS*C*P$$

Where, A= Average annual soil loss per unit area ($t.ha^{-1}.y^{-1}$), R= Rainfall and Run off factor ($MJ.mm.ha^{-1}.h^{-1}.y^{-1}$), K= Erodibility factor ($t.ha.MJ^{-1}.mm^{-1}$), LS= Slope length and slope steepness factor (dimensionless), C= Cover and management factor (dimensionless) and P= Conservation practice factor (dimensionless).

5.1 Rainfall and Run off factor (R factor): According to USLE method, a rainfall factor used to estimate average annual soil loss must include the cumulative effects of the many moderate-sized storms, as well as the effects of the occasional severe ones (Wischmeier, Smith 1978). The numerical value used for R in the soil loss equation must quantify the raindrop impact effect and must also provide relative information on the amount and rate of runoff as resultant of the rain. But till now that kind of detailed meteorological data is not available for the study area. Instead the following formula has been used for determining R factor in Indian context (Sing et al, 1981; Ghosh et al, 2013)

$$R = 79 + 0.363*P$$

Where, R= R factor, P= mean annual rainfall. Higher value of R factor represents more chances of soil loss through rainfall and run off and vice-versa.

5.2 Erodibility factor (K factor): The soil erodibility factor represents susceptibility of soil erosion. The K factor depends on the texture, structure, organic matter, permeability of soil and many other factors. It is a measure of the total effect of a particular combination of soil properties (Brema and Hauzinger, 2016). For the present study following formula (William, 1995) has been used-

$$K_{USLE} = f_{csand}*f_{cl-si}*f_{orgc}*f_{hisand}$$

Where f_{csand} is a factor that lowers the K indicator in soils with high coarse-sand content and higher for soils with little sand; f_{cl-si} gives low soil erodibility factors for soils with high clay-to-silt ratios; f_{orgc} reduces K values in soils with high organic carbon content, while f_{hisand} lowers K values for soils with extremely high sand content.

$$f_{csand} = 0.2 + 0.3*\exp[-0.256m_s(1-m_{silt}/100)]$$

$$f_{cl-si} = (m_{silt}/\ m_c + m_{silt})^{0.3}$$

$$f_{orgc} = 1-[0.0256*orgC/orgC+\exp(3.72-2.95*orgC)]$$

$$f_{hisand} = 1-\ [0.7(1-m_s/100)/\{\ (1-m_s/100)+\exp(-5.51+22.9(1-m_s/100))\}]$$

Where m_s is the sand fraction content (0.05-2.00 mm diameter) in percentage; m_{silt} is the silt fraction content (0.002-0.05 mm diameter) in percentage; m_c is the clay fraction content (<0.002 mm diameter) in percentage; orgC is the organic carbon content in percentage.

5.3 Slope length and slope steepness factor (LS factor): It expresses the cumulative effects of slope length (L) and slope steepness (S). The longer the slope length, the greater will be the amount of runoff and the steeper the slope of the land, the higher will be the velocity of the runoff which leads to erosion.

5.4 Cover and management factor (C factor): Soil erosion decreases exponentially with increase in vegetation cover (Shit et al, 2013, 2015). The C factor indicates how conservation plans will affect the average annual soil loss and how that soil loss potential will be distributed in time during construction activities, crop rotations or other management schemes (Rahaman et al, 2015, Van der Knijff J M et al. 2000). Plant cover reduces soil erosion by intercepting raindrops, enhancing, infiltration, slowing down the movement of runoff (Shit et al, 2015). Land cover effective for reducing soil erosion has low C factor value.

5.5 Conservation practice factor (P factor): It is the support practice factor. It reflects the effects of practices that will reduce the amount and rate of the water runoff and thus reduce the amount of erosion (Rahaman et al, 2015). There are three major practices, namely, contouring, strip cropping and terracing (Wischmeier and Smith, 1978). Based on the land slope each combination has different P factor values.

6. Result and discussion

6.1 R factor: India WRIS webGIS provided the grid wise monthly rainfall data. With the help the data rainfall erosivity in the study area is interpolated. IDW interpolation method was selected because the influence of rainfall is most significant at the measured point and decreases as distance increases away from the point.

Clearly three distinct zones of R factor can be noticed (fig. 3). The value of Rainfall erosivity index decreases eastward in the study area.

6.2 K factor: After Food and Agricultural organisation (FAO) five type of soil is found in the area under study, namely, Orthic Luvisol (Lo), Eutric Nitrosol (Ne), Chromic Cambisol (Bc), Ferric Luvisol (Lf) and Calcaric Gleysol (Gc). The percentage of sand, clay, silt and organic carbon that are used in calculating K factor are given below.

Soil Type	Sand (%)	Silt (%)	Clay (%)	Organic Carbon (%)	K Factor
Orthic Luvisol	76	9.9	14.1	0.41	0.132221
Eutric Nitosol	68.4	10.5	21.2	0.6	0.137944
Chromic Cambisol	40.1	21.5	38.4	1.44	0.144454
Ferric Luvisol	32.9	9.6	15.9	0.39	0.132647
Calcaric Gleysol	74.6	23.7	43.4	2.02	0.143149

All the fractions of soil are represented to the top soil cover of the watershed because it is affected directly by raindrop energy. Here, highest K factor value is 0.144454 which is associated with Chromical Cambisol and lowest value of 0.132221 is associated with Orthic Luvisol (fig. 4).

6.3 LS factor: It is a function of slope length and slope steepness. Based on local or micro physiographic variation the river basin has different LS factor value scattered in places (fig. 5). Highest values are found in upper DRB moderate to low values are found in middle and lower part of the basin.

6.4 C factor: High C factor values indicate more vulnerability to soil erosion because those are considered to be unprotected land. In the present study, C values are assigned to different LULC classes (fig. 6) as per concerned literature survey.

Type of LULC	C value
Dense forest	0.02
Open/Degraded forest	0.04
Grassland	0.13
Monocrop	0.06
Double/Triple crop	0.09
Waterbodies	0
Fallow and Wastelnd	1.0
Builtup area	0.002

6.5 P factor: P values range from 0 to 1, whereby the value 0 represents a very good manmade erosion resistance facility and the value 1 no manmade resistance erosion facility (Sheikh et al, 2011). In the present study p factor for the whole area has been assumed as 1 because any control practice measures could not be identified.

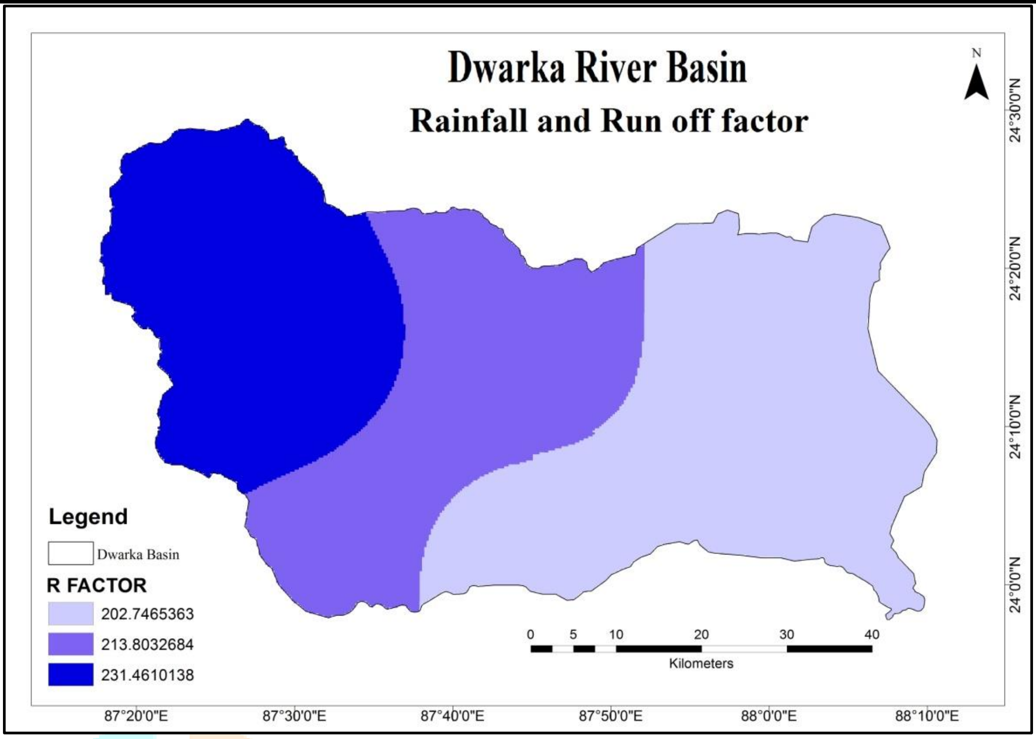


Figure 3: Distribution of Rainfall and Run off factor

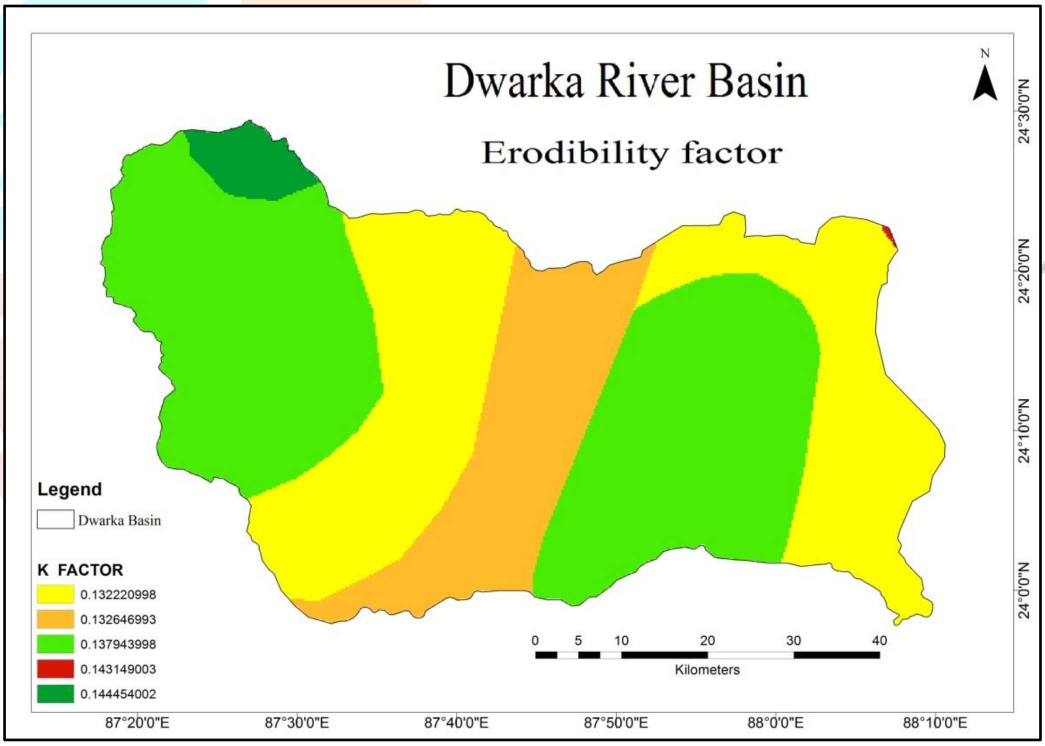


Figure 4: Distribution of Erodibility factor

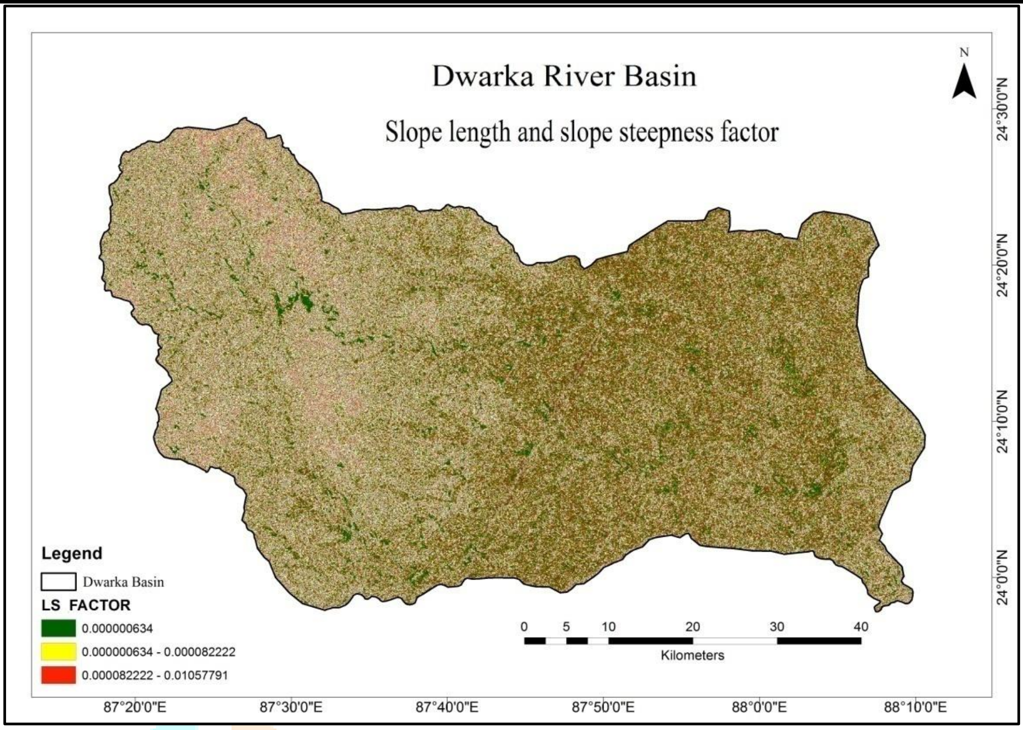


Figure 5: Slope length and slope steepness factor

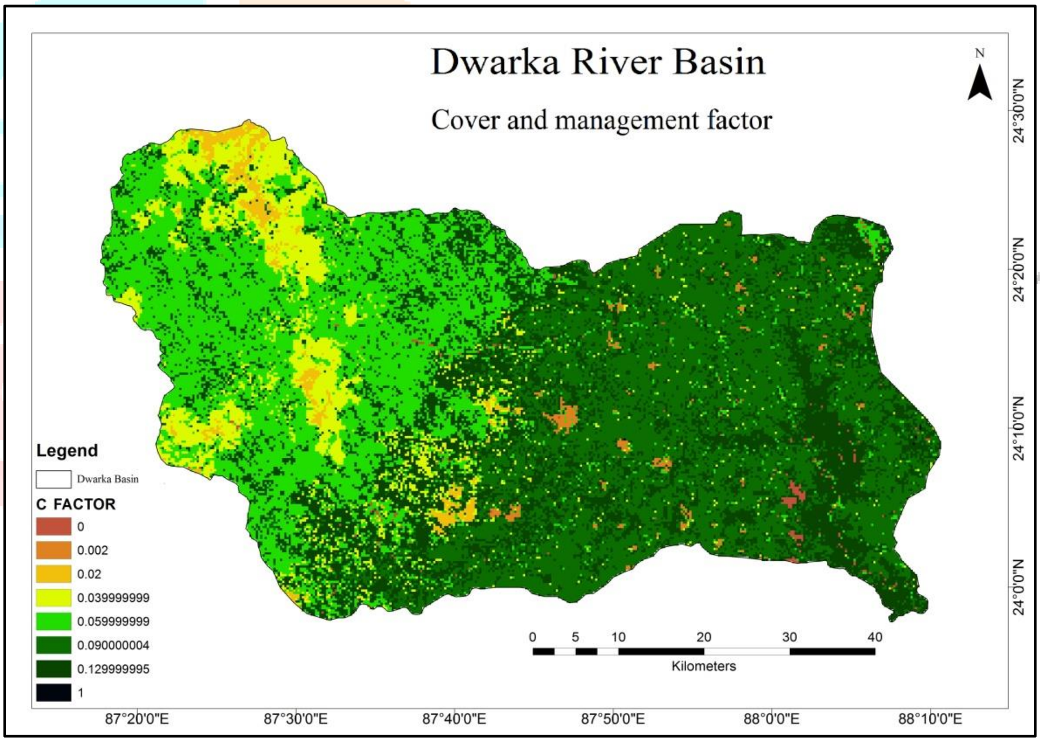


Figure 6: Cover and management factor

6.6 Average Annual Soil Loss prediction: All the previous layers are combined to have a composite layer (fig. 7). From the composite layer we can predict the annual average soil loss of the river basin. The area has a soil loss range of 190 $t.h^{-1}y^{-1}$, the lowest and highest value being 2 $t.h^{-1}y^{-1}$ and 192 $t.h^{-1}y^{-1}$ respectively. Surprisingly, the upper DRB has higher undulation and slope but the highest soil loss prone zone lies in the middle DRB, where slope is not so vivid. The main reason behind this is the land use land cover factor. The upper reach of the study area is under dense and open forest which can resist the splash impact better than the middle reach where the land is utilised mainly for double and triple cropping. On an average, as a function of different controlling factors the lower DRB is low to moderate soil erosion prone, the middle DRB is low to very high soil erosion prone and the upper DRB is high erosion prone. Here is a general account of the nature of predicted annual average soil erosion of the area-

Soil erosion zone	Predicted Soil erosion value ($t.h^{-1}y^{-1}$)	Name of Blocks
Low	< 14	Sundarpahari, Gopikandar (partial), Maheshpur, Pakuria (partial), Shikaripara (partial), Muraraui II, Nalhati I and II (partial), Md. Bazar (partial), Raghunathganj I, Sagardighi, Nabagram, Khargram(partial), Kandi
Moderate	14-32	Gopikandar (partial), Pakuria (partial), Kathikund (partial), Dumka (partial), Ranishwar (partial), Shikaripara (partial), Nalhati I and II (partial), Md Bazar (partial), Rampurhat I (partial), Rampurhat II, Mayureswar I (partial)
High	32-64	Amrapara, Dumka (partial), Kathikund (partial), Ranishwar (partial), Shikaripara (partial), Mayureswar I (partial), Md. Bazar (partial), Kathikund, Ramgarh
Very High	>64	Gopikandar (partial), Kathikund (partial), Shikaripara (partial), Maheshpur (partial), Pakuria (partial), Nalhati I (partial), Rampurhat I (partial), Md Bazar (partial)

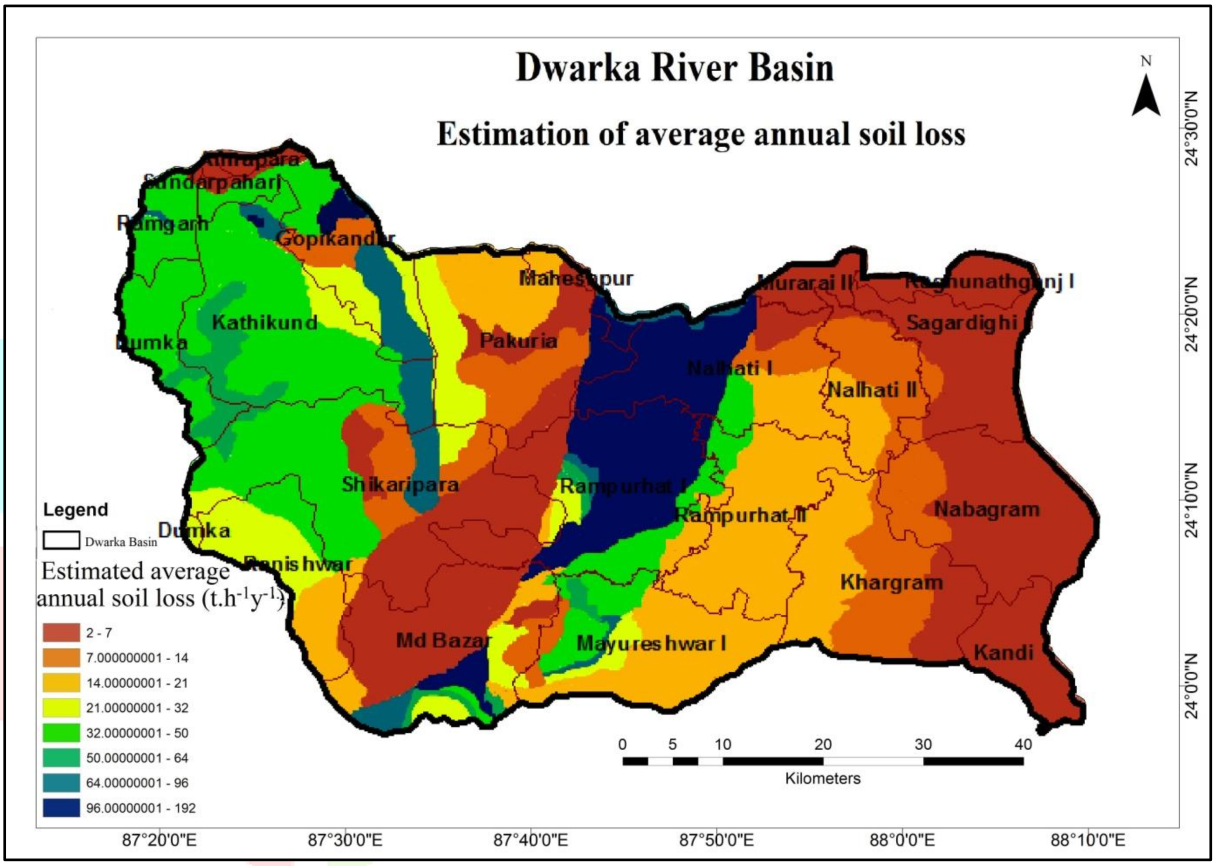


Figure 7: Estimated Soil Loss map using Universal Soil Loss Equation Method

7. Conclusion

The main objective of the study was to predict the average annual soil erosion of the study area. A general notion can be driven out from the present study which will be useful in watershed management planning. It is noticed that the part of DRB in the Murshidabad district, West Bengal is least vulnerable to soil erosion. The basin in Birbhum district, West Bengal, has a mixture of soil erosion vulnerability (medium to very high), whereas Jharkhand part is low to highly vulnerable to soil erosion. Some management strategies are proposed below-

Soil erosion zone	Predicted Soil erosion value ($t.h^{-1}y^{-1}$)	Management Strategies	
		Non structural	Structural
Low	<14	Plantation of soil erosion controlling grasses like Veltiver in fallow and waste lands	Site specific structures like check dam, gabions etc are to be placed in areas with greater slope. Whereas diversion channels, interception ditches etc are to be constructed in the low slope areas.
Moderate	14-32	Mulching in the agricultural field,	
High	32-64	Crop rotation in agricultural field, restoration of degraded forest	
Very High	>64	Crop rotation, Mulching, forestation, restoration of forest	

Proper management strategies should be taken without disrupting the natural environment of the basin. For that, intensive ground field verification is needed because each segment of the basin shows different combination of physical features.

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