

## **CHAPTER 5. IDENTIFICATION AND PRIORITIZATION OF CRITICAL SOIL EROSION PRONE AREAS USING GEOINFORMATICS TECHNIQUES**

### **5.1 Introduction**

Interest in developing a different algorithm for prioritizing watershed and identifying the critical soil erosion-prone areas has increased from the last few years. The researchers knowing the dangerous effects of soil erosion on water quality and agricultural production are trying to develop specific measures for mitigating these effects. The real challenge for planning and management of natural resources at a micro-level is due to high precision data requirements. Therefore micro-level hydrological units (sub-watersheds) are chosen circumspectly for improved planning and management (Aher et al., 2014). The watershed management practices cannot be carried out for the full watershed. It should get started from the most sensitive sub-watershed. Welde (2016) has divided the watershed into 47 subwatershed and then with the help of SWAT 2009 identified and prioritize the most sensitive watershed. Comin et al., 2014 have prioritized watershed for water quality improvement in an agricultural watershed.

Soil erosion assessment has gained attention because it can be used as a base for developing effective soil and water conservation plans (Ali and Hagos, 2016). Estimation of soil erosion and identification of critical soil erosion prone area for implementation of sediment filtration basins and other Best Management Practices (BMPs) is central to the success of soil conservation program (Ganasri and Ramesh, 2016). Sediment filtration basins are the structural BMPs to mitigate non-point source pollution of urban areas (Jeong et al., 2012). The hydraulics engineers give high priority to the study of geotechnics of soil erosion as the soil erosion is the leading cause of bridge scouring. Various methodologies have been

applied for the soil erosion assessment. The SWAT model is a beneficial tool for identifying and prioritizing soil erosion-prone areas (Ghafari et al., 2017). Naqvi et al., 2015 used Sediment Yield Index (SYI) method for prioritizing the watershed to know the extent of soil loss. There are many factors which are affecting soil erosion directly or indirectly. Soil erosion is changed by the impact of Land use and soil management (Vanwalleghem et al., 2017). Land management is undoubtedly the key factor to minimize a wide range of damaging effects of soil erosion. To implement BMPs, it needs to determine soil loss tolerance and identify and prioritize vulnerable and high-risk zones (Ghafari et al., 2017). To determine soil erosion, the model should be capable enough to satisfy the requirements of universal acceptability (Pandey et al., 2016). The most widely used method for estimating soil erosion is the Universal Soil Loss Equation (USLE) (Mancino et al., 2016). Singh and Panda (2017) used USLE to assess the soil erosion potential to identify the soil erosion-prone areas in Kapgari watershed of India. USLE and USLE-M model for predicting maximum annual values of event soil loss, according to him USLE based models are attractive from the practical point of view as the input data are easy to obtain (Bagarello et al., 2017). Ganasri and Ramesh (2016) has integrated revised USLE model with GIS to estimate soil Loss. Morphometric characterization is essential to recognize the hydrological behavior of the basin for carrying out management strategies (Aher et al., 2014). Prioritization only by Morphometric analysis is not reliable enough as it does not consider land use land cover and soil characteristics, therefore, in this study along with Morphometric analysis we used USLE, and Land use Land cover based prioritization to identify the critical soil erosion-prone areas. In this study, the first time the morphometric, LULC and USLE model were considered together to estimate the soil edibility of the study area. The main objectives of this chapter are:

1. To analyze the morphometric parameters of the study area.
2. To estimate the soil loss using USLE with the help of rainfall data, DEM and Land Use/Land Cover map.
3. To find out the erosion prone area by prioritizing the sub-watershed.

## **5.2 Data**

For land use land cover analysis Landsat-8 Thematic Mapper (TM) multispectral images of November 2015 and 2016 were procured from earth explorer USGS. Row and path of the images are (141, 42), (141, 43) and (141, 42). For morphometric analysis Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) with the 30 m resolution was used to delineate Watershed. Daily Rainfall data of twenty years from 1996 to 2016 was procured from Indian Meteorological Department. Soil data of Uttar Pradesh was obtained from National Bureau of Soil Survey from USLE prioritization.

## **5.3 Methodology**

After procuring the required data, first of all, the data preprocessing were done, in which the satellite images were mosaicked. Also, the DEM data was mosaicked. Then watershed delineation was done using the DEM through hydrology tool of ArcGIS 10. As the first step of the watershed delineation the Fill, Flow direction, and Flow accumulation map were generated. Using Flow direction map and Flow accumulation map the stream map was created. Then finally by giving Stream map and Flow accumulation map as the input Watershed was delineated. In the watershed delineation, the study areas have been grouped into 17 sub-watersheds shown in Figure 5.1.

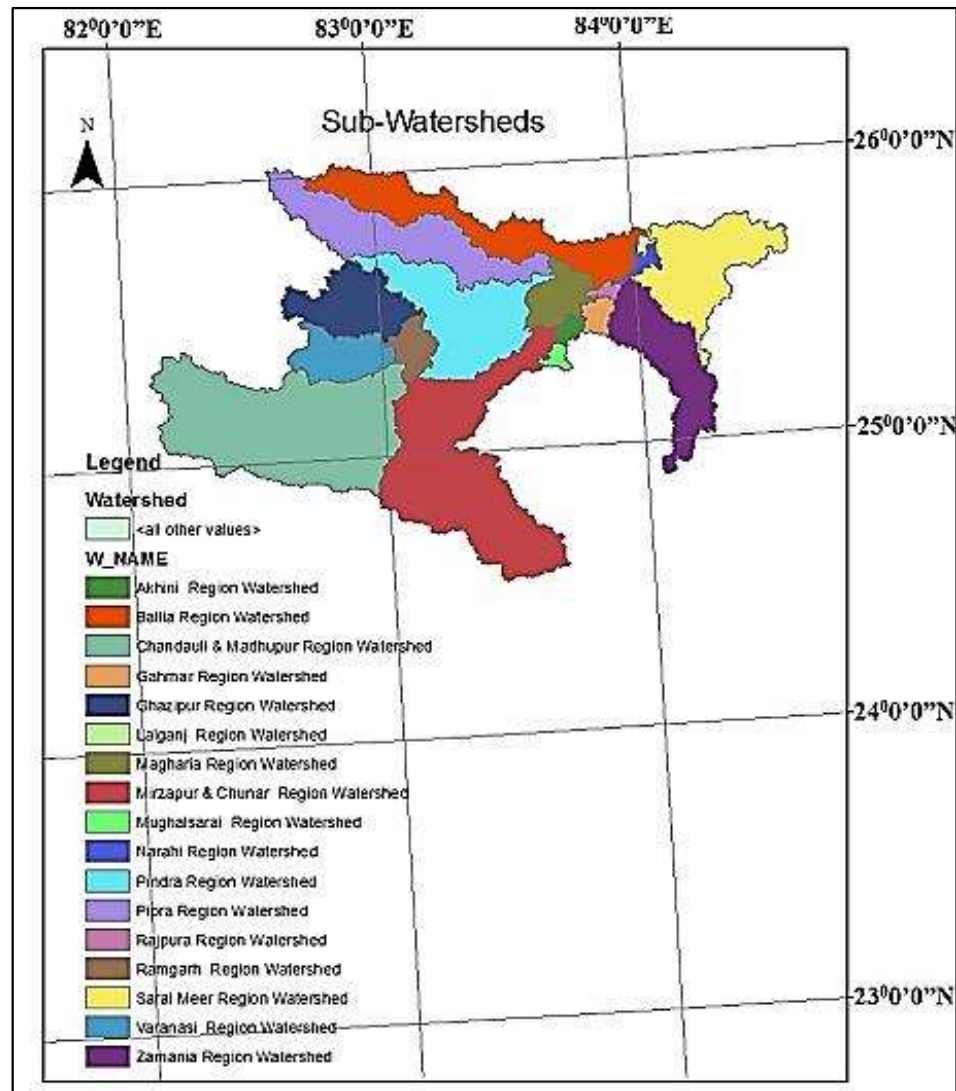


Figure 5.1. Sub-watersheds of the study area

The following methods are adopted to assign the rank to individual sub-watershed:

### 5.3.1 Prioritization Based on Morphometric Analysis

Figure 5.2. describes the complete steps followed for prioritization using Morphometric analysis. After extraction of the drainage characteristics for sub-watersheds during watershed delineation process. We get the attribute values for various parameters such as area, the perimeter of each sub-watershed, maximum and minimum relief (Hadley and

Schumm 1961), and basin length (Nookaratnam et al., 2005), the number of streams, stream order, and stream length, by analyzing the each sub-watershed in GIS environment. Parameters such as drainage density, bifurcation ratio, drainage frequency, texture ratio, form factor, circulatory ratio are responsible for soil loss erosion and termed as erosion risk assessment parameters. Hence, analysis of these parameters helps to prioritize sub-watersheds for soil water conservation practices. These parameters can divide into two categories one in Linear Parameters and second is Shape Parameters.

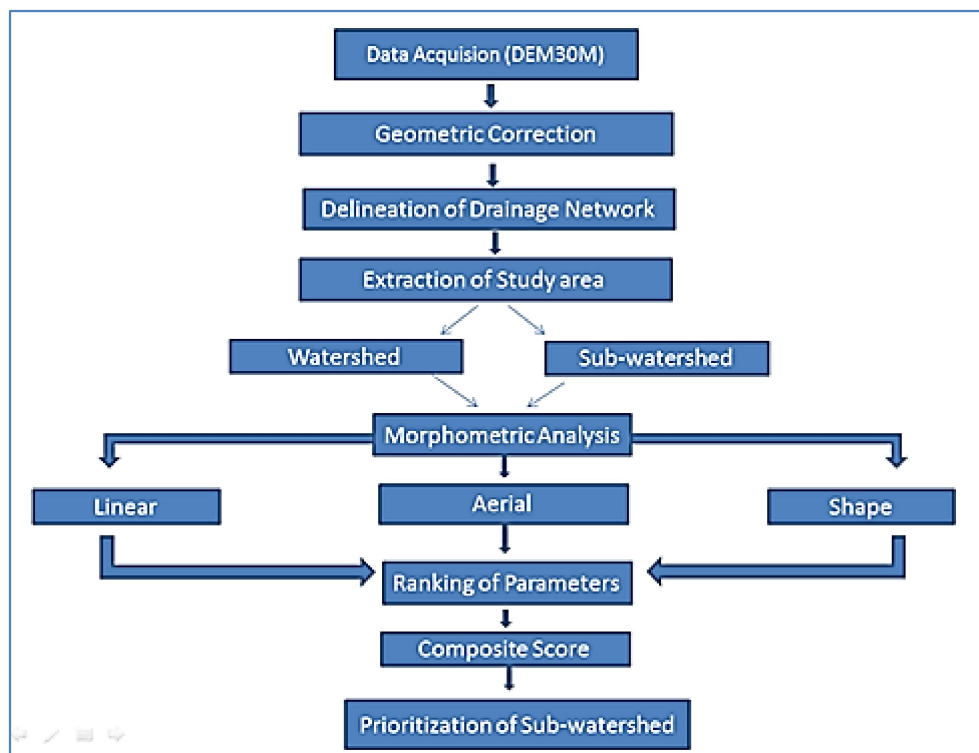


Figure 5.2. Flow chart of Prioritization using Morphometric analysis

The parameters which come under linear parameters are Drainage density (Horton 1945), Stream frequency (Horton 1945), Bifurcation ratio (Schumm 1956), Texture ratio (Horton 1945) and Length of Overland flow (Horton 1945). In general, the shape of the watershed affects the stream flow hydrology and peak flows. Essential parameters which recognized as shape parameters are Form factor (Horton 1945), Circularity ratio (Strahler 1964),

Elongation ratio (Schumm 1956), Compactness coefficient (Horton 1945) and Drainage Texture (Smith 1950). +Hence calculate all these Linear as well as Shape parameters with the help of basic parameters using different formulas. Figure 5.3 shows the shape and streams of the Ramgarh Region sub-watershed, similarly stream of all the sub-watersheds and their area, and perimeter and other parameters were estimated which helped in calculating the morphometric parameters (using formulas given in Table 4.1). Table 5.1 shows the morphometric parameters for all seventeen sub-watersheds.

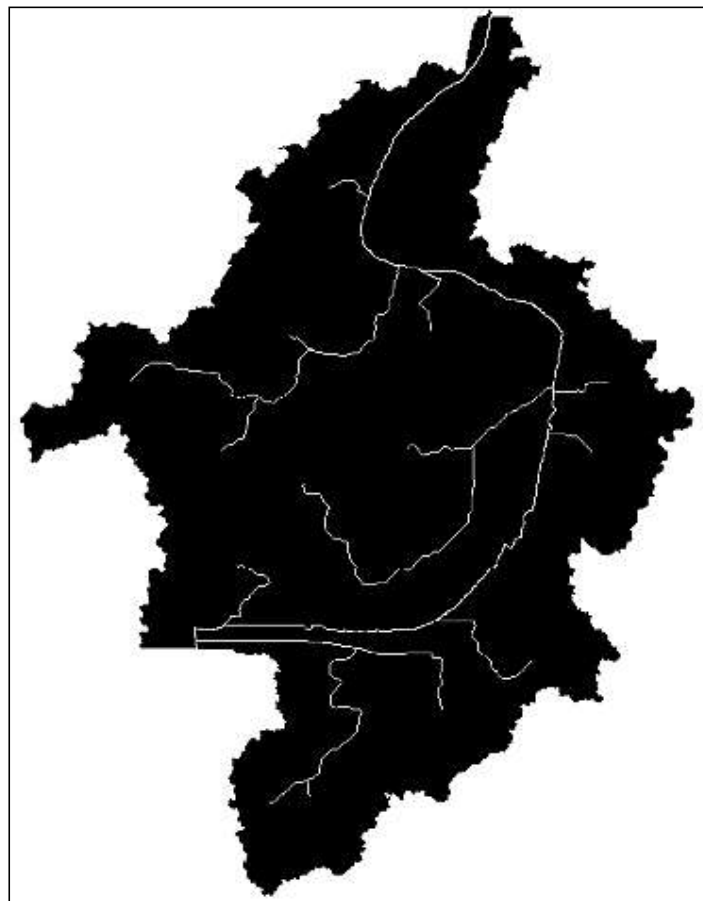


Figure 5.3 streams and shape of the Ramgarh Region Watershed.

Table 5.1 Linear and Shape parameters for all seventeen sub-watersheds

<b>Sub-Watershed no.</b>	<b>Sub-Watershed Name</b>	<b>Drainage Density</b>	<b>Bifurcation Ratio</b>	<b>Stream Frequency</b>	<b>Circulatory Ratio</b>	<b>Form Factor</b>	<b>Texture Ratio</b>	<b>Compactness Coefficient</b>	<b>Relief Ratio</b>
<b>1</b>	Sarai Meer Region Watershed	0.88	1.93	1.52	29.06	0.08	3.51	4.94	0.26
<b>2</b>	Lalganj Region Watershed	0.80	1.61	1.41	35.22	0.12	3.95	4.14	0.43
<b>3</b>	Ballia Region Watershed	0.81	3.22	1.30	40.01	0.22	4.15	3.43	0.64
<b>4</b>	Pipra Region Watershed	0.60	5.14	0.89	8.34	0.15	0.59	4.18	1.33
<b>5</b>	Narahi Region Watershed	0.50	3.33	0.62	7.36	0.35	0.36	2.93	2.80
<b>6</b>	Rajpura Region	0.03	4.21	0.05	39.73	0.21	0.16	3.22	3.84

	Watershed												
<b>7</b>	Magharia Region Watershed	0.46	7.43	1.03	10.32	0.24	0.85	2.60	1.75				
<b>8</b>	Zamania Region Watershed	0.80	1.68	1.46	25.49	0.29	2.97	3.01	0.87				
<b>9</b>	Ghazipur Region Watershed	13.62	3.45	1.45	43.04	0.32	4.98	3.46	0.63				
<b>10</b>	Gahmar Region Watershed	0.76	2.31	1.24	17.03	0.66	1.68	2.52	1.68				
<b>11</b>	Pindra Region Watershed	1.53	1.41	3.41	38.64	0.33	10.49	2.88	0.64				
<b>12</b>	Akhini Region Watershed	0.62	2.82	0.78	14.30	0.37	0.89	2.39	1.14				

<b>13</b>	Ramgarh Region Watershed	0.68	2.28	0.97	11.72	0.40	0.90	2.63	1.02
<b>14</b>	Varanasi Region Watershed	0.73	2.18	1.47	33.41	0.35	3.92	2.67	0.94
<b>15</b>	MughalSarai Region Watershed	0.64	2.30	0.72	22.44	0.35	1.29	2.71	1.34
<b>16</b>	Chandauli & Madhupur Region Watershed	0.77	1.79	1.13	60.51	0.14	5.45	3.37	3.76
<b>17</b>	Mirzapur & Chunar Region Watershed	0.77	1.81	1.34	80.76	0.37	8.60	2.66	2.57

After calculating all Morphometric parameters, I prioritize sub-watersheds according to following steps:

Linear parameters are proportional to the soil erosion, means it has a direct relationship with soil erodibility. A Higher value represents more erodibility than a lower value. Hence, to determine the priority sub-watersheds, the highest value of the linear parameters was evaluated as rank 1, the second highest value was estimated to rank 2 and so on, and the lowest value was estimated to last in priority or rank.

Shape parameters are inversely proportional to the soil erosion, means it has an inverse relationship with the erodibility (Nookaratnam et al., 2005). Thus lower the value indicates more erodibility. Hence the lowest value of shape parameters was assigned as rank 1, the next lower value was assigned as rank 2 and so on and the highest value was assigned last in rank. Thus the priority of sub-watersheds was assessed by assigning the high rank by the highest value in the case of linear parameters and the lowest value in the case of shape parameters.

### **5.3.2 Methodology for Land Use/ Land Cover**

Figure 5.4. describes the complete steps followed for prioritization using LULC analysis. Change in Land Use /Land Cover(LULC) is an essential and sensational issue in the current scenario as population increases rapidly. So analysis and mapping of LULC became an essential part of any study. It is a critical component that can help in developing various indexes for the conservation of natural resources when it integrates with other studies. Vegetation, an essential aspect of LULC, is defined as the environmental condition of the earth surface and sub-surface. This term refers to vegetation type land cover that includes agricultural land and other physical aspects, such as biodiversity, soil surface, and human settlement.

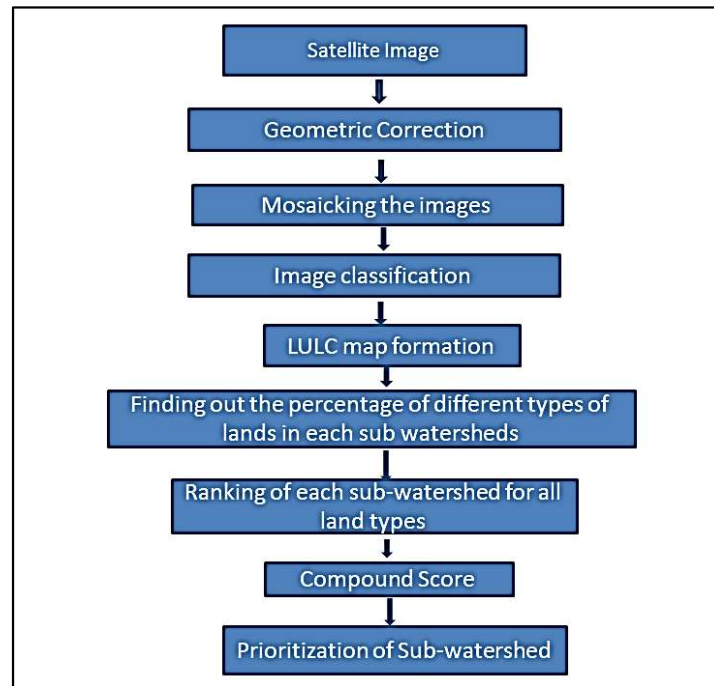


Figure 5.4 Flow chart of Prioritization using LULC analysis

The methodology can be segmented into three parts:

- Image Interpretation and Mapping of LULC
- Extraction of class information for individual sub-watersheds
- Assign rank according to their compound values

The classes which are taking into account for prioritization of the sub-watersheds are cultivable land, agriculture, forest cover (dense as well as light), urban land, water body, and barren land. India is a dominant agricultural country, so cultivable land gets the highest priority. Javed et al., (2011) stated that industrialization and urbanization growth lead to decrease in forest and vegetation, cause degradation of the environment; hence natural vegetation and forest cover is an important feature which plays a critical role in the prioritization of the sub-watersheds. As barren land reformation is one of the essential phenomena for watershed development and management plan, hence it is also considered an essential aspect for the prioritization. Figure 5.5. shows the LULC map of the watershed.

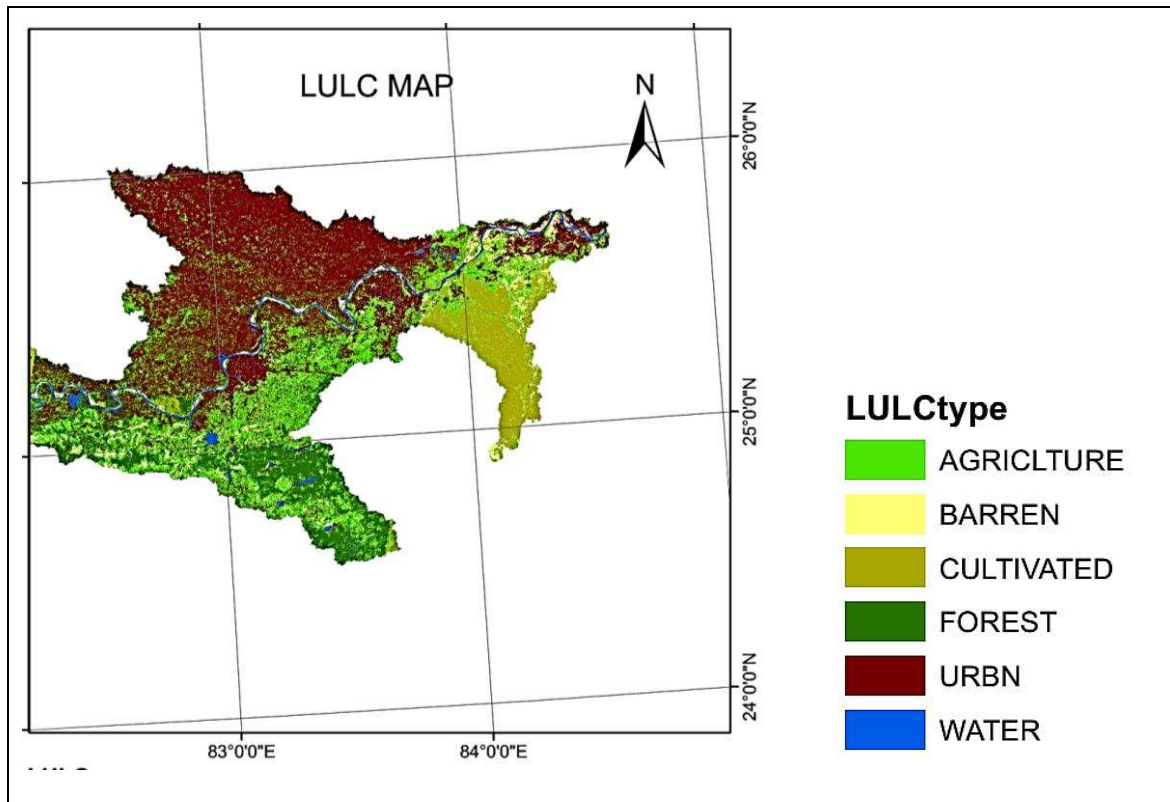


Figure 5.5. LULC map of the study area.

### 5.3.3 Methodology for Prioritization by Universal Soil Loss Equation (USLE)

Figure 5.6. describes the complete steps followed for prioritization using USLE analysis. Universal Soil Loss Equation was developed by Wischmeier and Smith, 1978. Mathematically it has the general form

$$A = R * K * L * S * C * P$$

Where,

A= average annual soil loss, (in tons per hectare per year) from a specific field,

R = a factor is expressing the erosion potential of average annual rainfall in the area, called index of erosivity or erosion index. It is also called erosive rainfall factor

K = the soil erodibility factor (in tons hour per megajoules per millimeters)

L = Slope Length factor

S = slope steepness factor

C = cover and management factor or cropping factor

P = erosion control supporting conservation practice factor

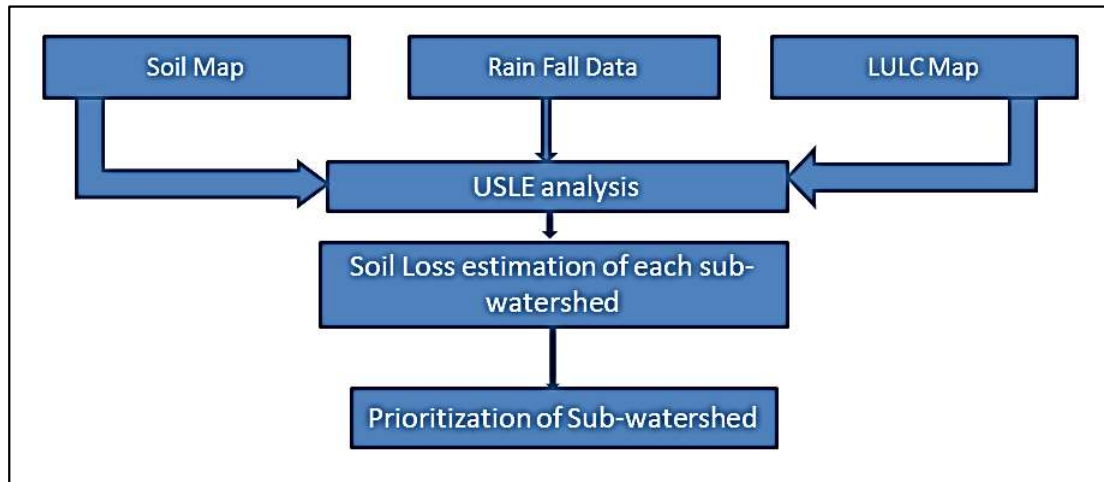


Figure 5.6. Flow chart of Prioritization using USLE analysis

Prioritization by Universal Soil Loss Equation can be done by calculating the soil loss for individual sub-watersheds using ArcSWAT model and then according to their soil loss values assign the rank to each sub-watershed. Table 5.2 shows the Soil Loss of each Sub-watershed which was calculated using SWAT.

Table 5.2 Soil Loss of each Sub-watershed.

<b>Sub-Watershed no.</b>	<b>Sub-Watershed Name</b>	<b>Soil Loss(T/Ha)</b>
<b>1</b>	Sarai Meer Region Watershed	174.85
<b>2</b>	Lalganj Region Watershed	167.28
<b>3</b>	Ballia Region Watershed	231.29
<b>4</b>	Pipra Region Watershed	180.31

<b>5</b>	Narahi Region Watershed	325.27
<b>6</b>	Rajpura Region Watershed	987
<b>7</b>	Magharia Region Watershed	178.76
<b>8</b>	Zamania Region Watershed	211.52
<b>9</b>	Ghazipur Region Watershed	786
<b>10</b>	Gahmar Region Watershed	548
<b>11</b>	Pindra Region Watershed	471
<b>12</b>	Akhini Region Watershed	592
<b>13</b>	Ramgarh Region Watershed	574
<b>14</b>	Varanasi Region Watershed	501
<b>15</b>	Mughal Sarai Region Watershed	692
<b>16</b>	Chandauli & Madhupur Region Watershed	1187
<b>17</b>	Mirzapur & Chunar Region Watershed	751

Table 5.3 The preliminary and final ranking of sub-watersheds with morphometric analysis.

<b>Sub-Watershed Name</b>	<b>C. Ratio</b>	<b>Form Factor</b>	<b>C. Coefficient</b>	<b>R. Ratio</b>	<b>D. Density</b>	<b>B. Ratio</b>	<b>S. Frequency</b>	<b>T. ratio</b>	<b>Compound Value</b>	<b>Rank</b>
<b>Sarai Meer Region Watershed</b>	9	1	17	1	3	12	2	7	52	17
<b>Laiganj Region Watershed</b>	11	2	15	2	5	16	6	5	62	14
<b>Ballia Region Watershed</b>	14	6	13	5	4	6	8	4	60	15
<b>Pipra Region Watershed</b>	2	4	16	10	14	2	13	15	76	8
<b>Narahi Region Watershed</b>	1	11	9	15	15	5	16	16	88	2
<b>Rajpura Region Watershed</b>	13	5	11	6	17	3	17	17	89	1
<b>Magharia Region Watershed</b>	3	7	3	13	16	1	11	14	68	10
<b>Zamania Region Watershed</b>	8	8	10	6	6	15	4	8	65	11
<b>Ghazipur Region Watershed</b>	15	9	14	3	1	4	5	3	54	16
<b>Gahmar Region</b>	6	17	2	12	9	8	9	10	73	9



## 5.4 Results and Discussion

### 5.4.1 Results of Prioritization Based on Morphometric Analysis

The results obtained from the morphometric analysis of study area are given in Table 5.3, which indicates that SW 6 got the highest rank followed by SW 5, SW 15, SW 16 while SW 1, SW 3, SW 9 get the least priority. This result shows that Sub-watersheds which got the highest priority are the most susceptible to erosion whereas; Sub-watersheds which receive the least priority are the least erosion or no erosion.

Categorization of the result provides the following data, which are tabulated in Table 5.4.

Table 5.4 Soil erosion effect on each sub-watershed.

Soil Erosion Effect	Sub-Watersheds	No of SWs
Severe Effected	6,5,15,16,17	5
Moderate Effected	13,12,4,10,7,8	6
Less Effected	14,11,2,9	4
Not Effected	3,1	2

### 5.4.2 Results of Prioritization Based on Land Use/Land Cover

On prioritization of sub-watersheds by LULC Analysis is given in Table 5.5 which suggests that the SW 4 got the highest priority whereas SW 11 & 2 got the lowest priority. These results show that SW 17, SW 16, SW 4, SW 7 and SW 5 are the most sensitive areas while SW 11, SW 1, SW 2, SW 13, and SW 14 are erosion fewer regions. The results of the ranking by LULC are given below:

Table 5.5: Preliminary and final ranking of sub-watersheds with LULC analysis

SW No.	Barren	Clayey	Agricultural	Forest	Water Body	Urban	Compound	Final
	Land	Land	Land	Cover		Land	Value	Rank
<b>Sarai Meer Region</b>	1	9	2	8	8	16	115	15
<b>Lalganj Region</b>	2	1	1	7	3	17	53	17
<b>Ballia Region</b>	15	14	7	2	11	8	251	4
<b>Pipra Region</b>	16	13	12	3	17	3	297	1
<b>Narahi Region</b>	17	12	6	4	14	6	262	3
<b>Rajpura Region</b>	7	17	3	5	1	1	145	12
<b>Magharia Region</b>	13	15	15	1	16	4	297	2
<b>Zamania Region</b>	10	8	11	9	12	11	215	8
<b>Ghazipur Region</b>	8	5	9	14	10	12	171	10
<b>Gahmar Region</b>	14	16	13	6	5	5	246	5
<b>Pindra Region</b>	3	3	5	10	4	15	88	16
<b>Akhini Region</b>	6	2	16	11	6	10	150	11

<b>Ramgarh Region</b>	5	4	17	12	2	9	137	14
<b>Varanasi Region</b>	4	7	8	15	7	14	140	13
<b>MughalSarai Region</b>	9	6	4	13	15	13	188	9
<b>Chandauli &amp; Madhupur Region</b>	11	10	14	17	9	2	219	7
<b>Mirzapur &amp; Chunar Region</b>	12	11	10	16	13	7	239	6

Categorization of the result of LULC analysis provides the following data, which are tabulated below:

Table 5.6 Soil erosion effect on each sub-watershed according to LULC analysis.

<b>Soil Erosion Effect</b>	<b>Sub-Watersheds</b>	<b>No. of SW</b>
Severe Effected	4,5,7,10,3,17	6
Moderate Effected	16,8,15,9	4
Less Effected	12,6,14,13	4
Not Effected	1,2,11	3

#### **5.4.3 Results of Prioritization Based on the Universal Soil Loss Equation**

Prioritization of sub-watersheds with the help of Universal Soil Loss Equation is an efficient and quite reliable method because it considers all the factors which may cause soil erosion. So for prioritization highest priority was given to the sub-watersheds which have highest soil loss and least priority was given those sub-watersheds which have the lowest. This results revealed that SW 16, SW 6, SW 9 and SW 15 are the most erosion-prone areas whereas SW 1, SW 2, SW 3 and SW 8 are the least prone to erosion or can say not affected by erosion.

Table 5.7 Soil erosion effect on each sub-watershed according to USLE soil loss estimation

<b>Soil Erosion Effect</b>	<b>Sub-Watersheds</b>	<b>No. of SW</b>
Severe Effected	16,6,9,17,15	5
Moderate	12,13,10,14,11,5	6

Effectuated		
Less Effectuated	3,7,4,8	4
Not Effectuated	1,2	2

### 5.5 Final Result and Validation of Results

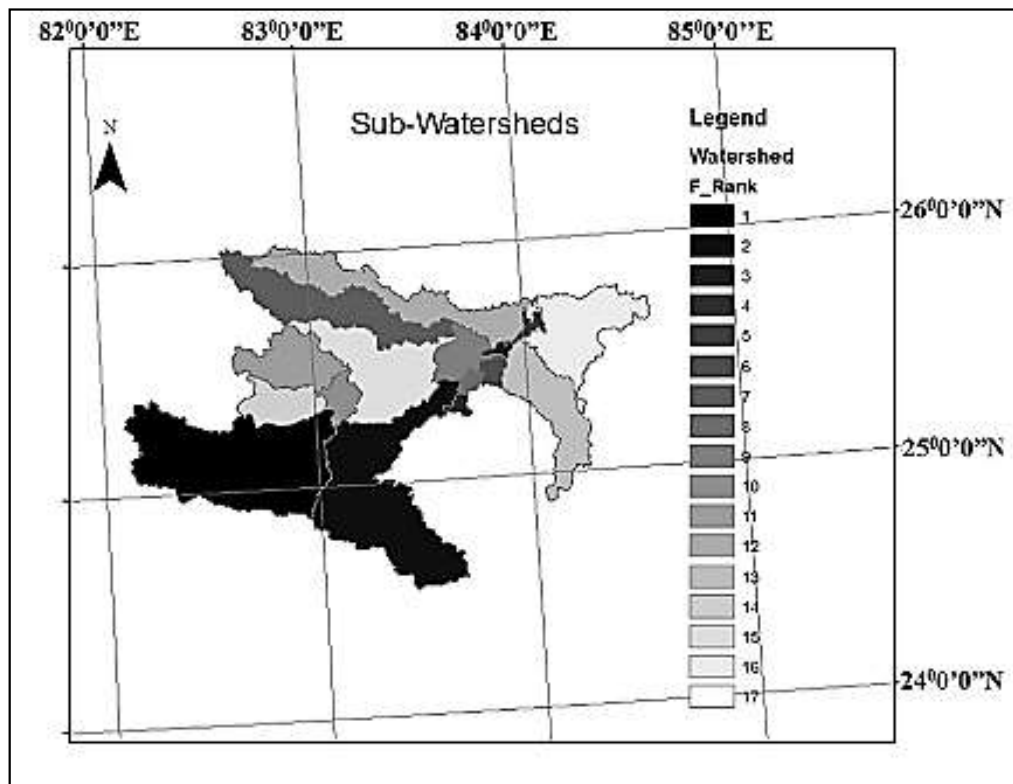


Figure 5.7. Map of the study area with final prioritization of the Sub-watersheds

Figure 5.7. shows the result in map format, which tells the integrated result of all the three prioritization methods. This map clearly shows that the Mirzapur Region is the highest soil erosion prone area. For validating the result, I have made field visits in the different sites of the study area to check the scenario of soil erosion in different sites. By the field visit, I found that the Mirzapur region is really soil erosion prone area as shown in Figure 5.8. It was also found that significant erosion was on the foothills of the area. It was also seen

during the field visit that the area covered with barren land have suffered very high soil loss whereas soil erosion is less in forest land and agricultural fields. Further, the erosion map was also compared with the data obtained from the results of the National Bureau of Soil Sciences (NBSS) Shown in Figure 5.9. As per the comparison, the Mirzapur and Chandauli region is more affected by soil erosion than other parts of the southern Uttar Pradesh. Hence after ground truthing and comparison of my results with the data of NBSS-LUP, it can be concluded that the results obtained from the study are accurate.

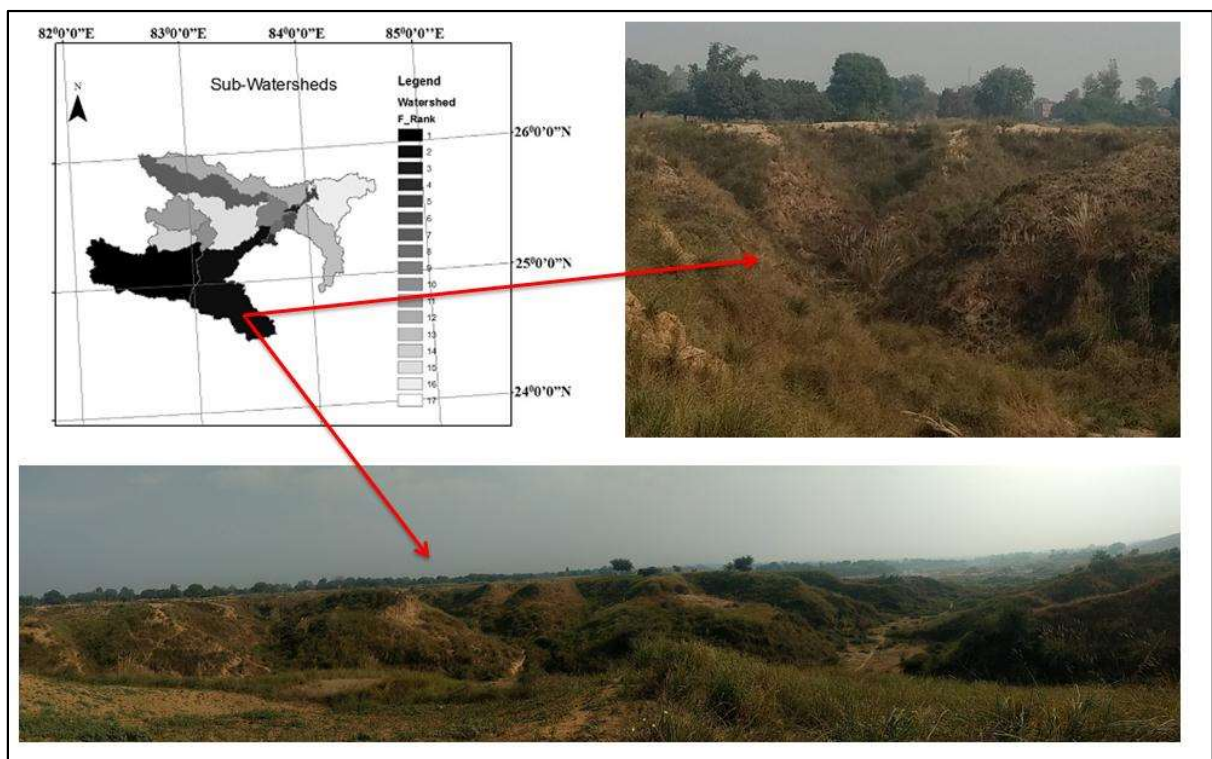


Figure 5.8. Validation of results by site visiting

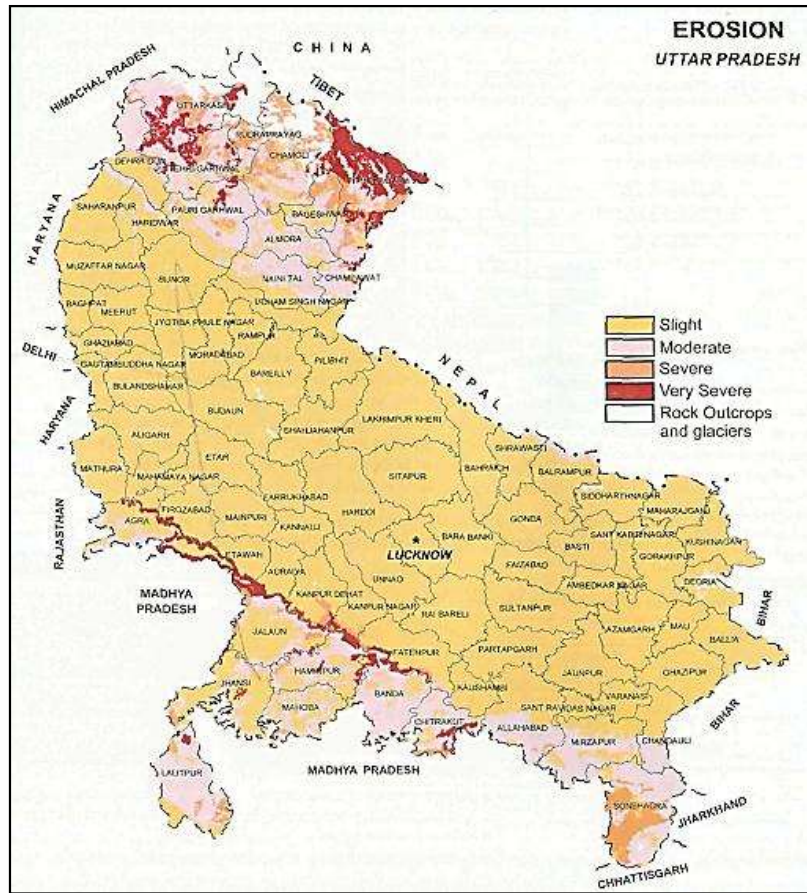


Figure 5.9. Validation of results by NBSS data

## 5.6 Conclusion

Prioritization of sub-watersheds can be done by any one method, but in that case, the reliability of the result is very less. Hence in this study, all three methods of prioritization were adopted, so that integration of these methods can provide a more accurate and reliable result. The results reveal that according to Morphometric analysis out of 17 sub-watersheds, sub-watersheds 6,5,15,16 are subjected to more soil erosion, and sub-watersheds 1,3,11,2 are subjected to least soil erosion. Whereas according to LULC and USLE analysis sub-watersheds 5,17,10 and 16,6,17,15 are likely to be subjected to more soil erosion respectively. And sub-watersheds 1,2,11 and 1,2,7,4 are subjected to least soil erosion

according to LULC and USLE analysis respectively. Integrating all the three methods we found that sub-watersheds 6,16 and 15 (Rajpura Region watershed, Narahi Region watershed and Mughal Sarai Region watershed) are suffering from severe soil erosion problem and sub-watershed 1,2 and 11 (Sarai Meer Watershed, Lalganj Region watershed and Ghazipur Region watershed) have least soil erosion. These results can be further used for soil erosion and sediment yield modeling projects.

Conventional methods of finding out erosion-prone areas are time-consuming and required so much of data as input as lithology map, geological map, etc., but with the advancement, in the field of Remote Sensing and Geographical Information System (GIS), this problem can be overcome. Hence the integration of the results by all three methods suggests that the lower portion of this watershed are more likely to erosion susceptible.

## **CHAPTER 6. UTILIZING SOIL AND WATER ASSESSMENT TOOL (SWAT) FOR HYDROLOGICAL MODELING**

### **6.1 Introduction**

Water & soil are primary resources for sustainable economic and social development. Over the years, because of the anthropogenic activities such as growing population, land-use change, environmental pollution, climate change, etc. Water scarcity, flood and soil erosion have become the significant hitches for the sustainable development of communities all over the world. The need of the hour is to find ways to conserve and manage these resources such that future generation can also make use of them.

During the past few years, many hydrological models such as Agricultural Non-Point Source Pollution (AGNPS), System Hydrologic European (MIKE SHE), and Soil and Water Assessment Tool (SWAT) have been developed and are used to simulate hydrological processes (Young et al., 1987, Tripathi et al., 2003). For example Measurement and modeling of soil erosion and sediment yields in a vast cultivated land of south Brazil was done using WATEM and SEDEM model (Didone et al., 2017). WEPP cannot perform better than MUSLE for soil loss estimation; he used three methods USLE-M, RUSLE-2, and WEPP for erosion management (Yesuf et al., 2015). In Chinese Loss Plateau soil erosion estimation was done using three methods Si Model, WEPP, MMF and then the results were compared (Li et al., 2017). WEPP is the model which can be successfully used for both runoff and sediment estimation using GIS and remote sensing techniques (Pandey et al., 2008). SCS-CN method is the most widely used method for Runoff estimation and watershed management (Shivhare et al., 2018). Unit Sediment Graph is the better process than Modified USLE and WEPP when Climate change factor is