

CHAPTER 8. PRINCIPAL CAUSES OF SOIL EROSION IN A WATERSHED: EVIDENCE FROM LAND USE/LAND COVER DYNAMICS

8.1 General

Soil degradation is one of the pressing issues in developing countries like India, where agriculture and farming are the backbones of the country's economy. The primary cause of soil degradation is water erosion (Zhang et al., 2015). India is a rapidly developing country where the urbanization and industrialization are increasing exponentially. Also, the LULC pattern is changing very frequently. The rapid change in land use pattern is resulting in a change in the runoff, soil erosion, and other hydrological processes. So it is imperative to estimate the impact of LULC dynamics for the sustainability of the soil. Soil loss due to erosion is a global problem, on average yearly, about 0.9mm of soil get lost throughout the world. Soil erosion is a critical ecological process that reflects specific characteristics, climate regimes, vegetation cover and land mismanagement depending upon natural and anthropogenic factors (Mancino et al., 2016), so it is essential to apply measures for reducing soil erosion. For applying effective means which can be utilized for the soil conservation, it is necessary to get the proper information in detail about the dominating causes of the soil erosion of that particular area.

8.2 Introduction

Soil erosion depends on many factors like rainfall, runoff, land type, soil type & slope. Assessing the impact of rain, slope gradient (Fang et al., 2015), land use (Zhang et al., 2015), wind effect (Schmidt et al., 2017) it was found that, the more amount of rainfall or runoff would be the more would be the soil erosion. The area which mostly covered by

wasteland and barren land would be more prone to soil erosion. When the soil gradient would be more the soil erosion would be more (Zhang et al., 2015). However, when these factors combined in different watersheds, it is difficult to find out which element is more dominant and which watershed would have more soil erosion, so it is imperative to determine the weight of these factors for effective soil management and to apply effective soil conservation measures. Wynn and Mastaghimi (2006) used multiple linear regression analysis to determine the impact of vegetation and soil type on soil erosion.

This chapter can motivate the experts to formulate and implement effective and sustainable measures to minimize the undesirable effects of LULC dynamics and other causes of soil erosion. Here three cases (Case 1: LULC of 2004 with climate data of 1995 to 2004, Case 2: LULC of 2015 with climate data of 2005 to 2015, Case 3: LULC of 2004 with climate data of 2005 to 2015) were created for modeling impacts of LULC dynamics on sediment yield. Twenty years of daily meteorological data were used to calculate the sediment yield of the study area for all three cases using SWAT 2012. The leading causes of the soil erosion were characterized and to find out principal causes of the soil erosion; multivariate linear regression statistical technique was used. The primary objectives of this chapter are:

- To model the impact of LULC dynamics on sediment yield.
- To find out the highest soil erosion impacted watersheds and find out the most soil erosion-prone soil type and land classes.
- To categorize the causes of soil erosion and give the weight of each cause using multivariate linear regression.
- To validate the result.

8.3 Methodologies Used

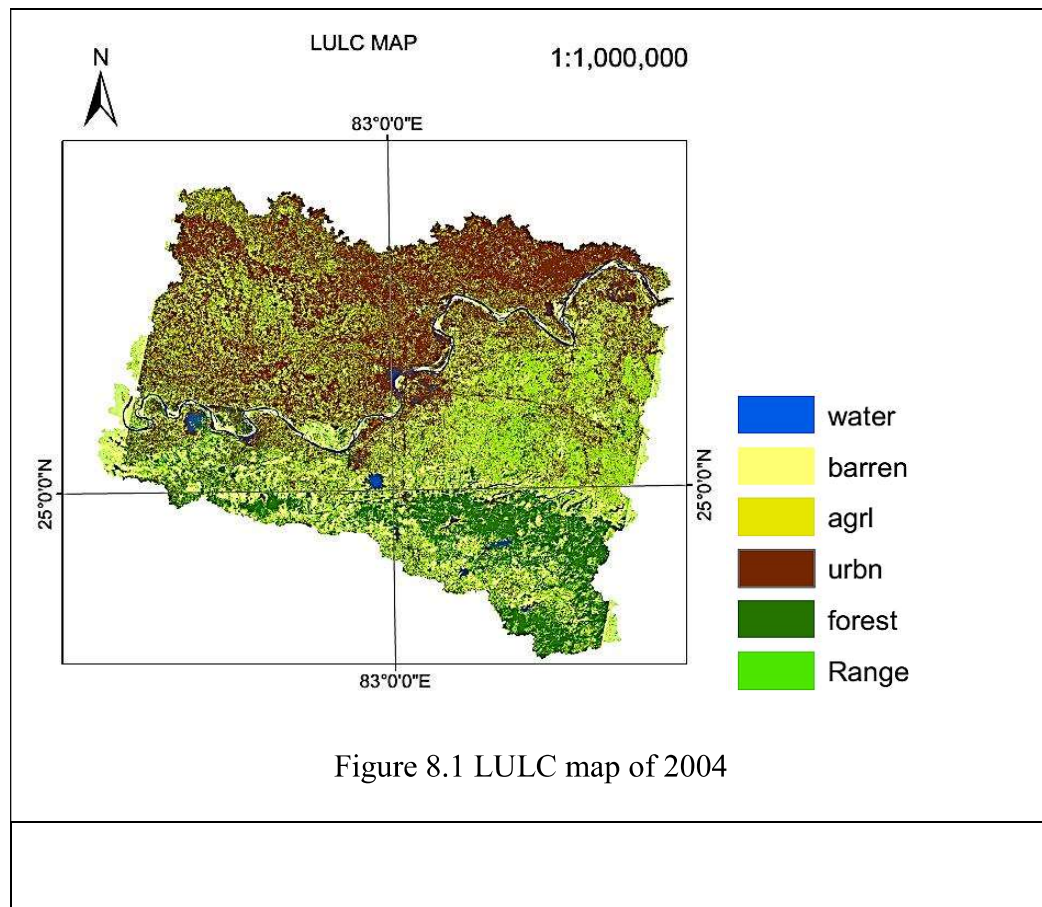
8.3.1 Assessment of the Impact of LULC Dynamics on Sediment Yield

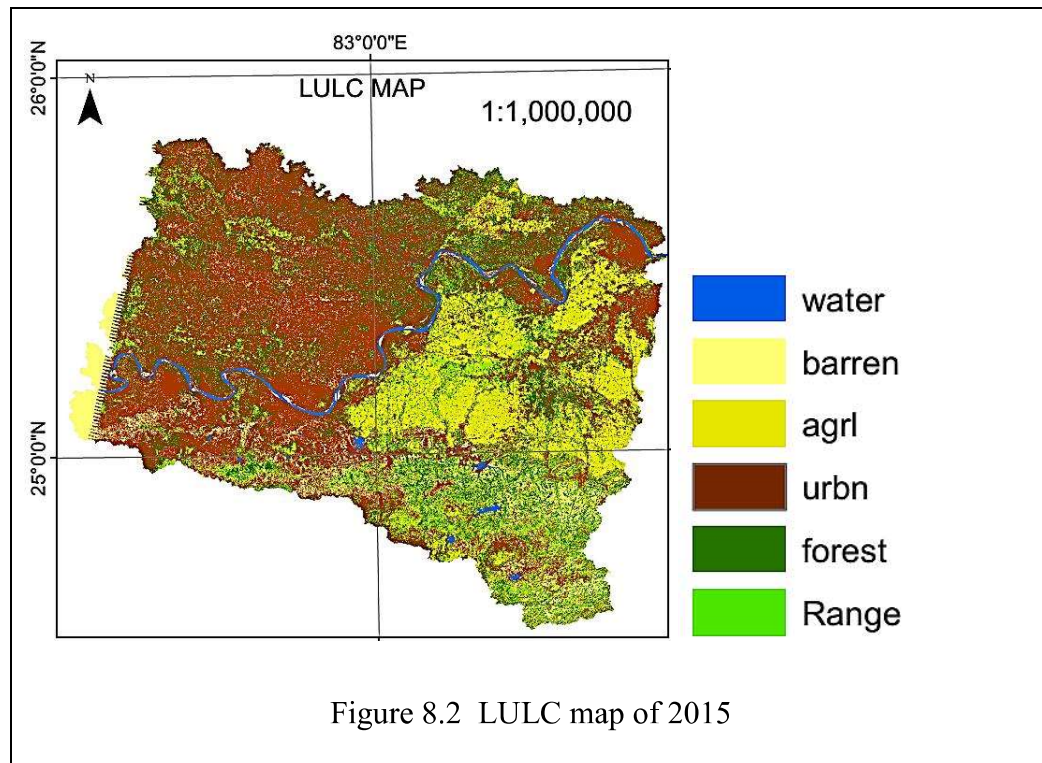
Assessment of the impact of LULC dynamics on sediment yield was done by creating three cases and comparing their results.

Case 1: LULC map of the year 2015 with climate data of the year 2005 to 2015.

This case was prepared as a baseline from which the other cases would be compared for analysis and results.

Case 2: LULC map of the year 2004 with climate data of the year 2005 to 2015. This case was created to assess the effect of Land use land cover change on sediment yield.





Case 3: LULC map of the year 2015 with climate data of the year 1996 to 2005. This case was created to assess the effect of land use pattern along with the climate and other factors affecting soil erosion.

For preparing the LULC map the satellite imagery of Landsat 8 and Landsat 5 for the year 2015 and 2004 respectively were procured from USGS. Supervised image classification was done using Erdas imagine tool. The LULC map for 2004 and 2015 are given in Figure 8.1 and 8.2 respectively. After this, the change detection between two maps was done using ArcGIS, which analyzed the percentage transition of one land type to another. Table 8.1 summarizes the change in LULC map for a different period. After this, the sediment yield modeling was done using ArcSWAT for assessing the impact of LULC dynamics on sediment yield.

Table 8.1 Summary of LULC pattern of a watershed for a different period

SWAT Code	LULC Type	The area referred to year (km ²)				% change
		2004	Total (%)	2015(%)	Total	
WATR	Water body	258	1.65	314.00	2.01	0.36
BARR	Barren Land	1256	8.04	1268.00	8.12	0.08
AGRL	Agriculture	1678	10.75	1071.00	6.86	-3.89
URBN	Urban	5098	32.65	6083.00	38.95	6.31
FRSD	Forest	3839	24.58	2048.00	13.11	-11.47
RNGE	Rangeland	3487	22.33	4833.00	30.95	8.62
	Total	15616	100	15617	100	

8.3.2 Methodology for Estimating the Principal Causes of Soil Erosion

Methodology for estimating the principal causes of soil erosion and steps followed in this study is given in Figure 8.3. At first, the spatial and temporal data were given as inputs in the SWAT model using ArcSWAT. As an output, we got the calculated sediment yield values for the watershed. The calibration and validation step is done using Sufi-2 algorithm and Swat-Cup. Sediment yield for all the sub-watersheds are calculated, and the sub-watersheds were given rank according to these sediment yield values. After this step, all the parameters responsible for soil erosion were categorized. For finding out the weight of these parameters, all the parameters were needed to be in the same unit. So for converting all the parameters in the same unit, sediment yield per square kilometer was estimated for all the soil type, land use land cover classes, and slope classes as shown in Table 8.2. Then

using multivariate linear regression technique, the coefficient of each parameter was calculated using the Matlab tool. After getting the coefficients of each parameter, these Coefficients were multiplied to their respective values of each sub-watershed, and the ranking of each sub-watershed was calculated.

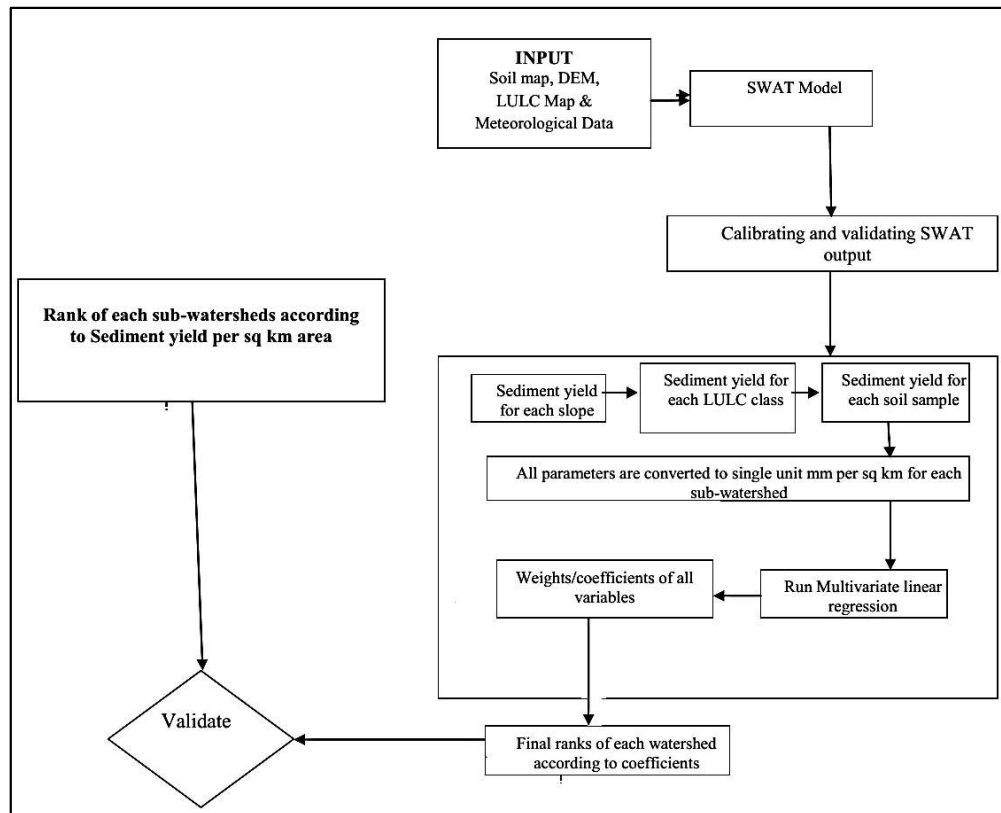


Figure 8.3. Flowchart of Methodology

Table 8.2 Values of Sediment yield (per Km²) of all Subwatersheds for all the parameters responsible for Soil erosion.

SW No.	Soil 1	Soil 2	Soil 3	Soil 4	Soil 5	Forest	Urban	Range	Agriculture	Barren	Slope 1	Slope 2	Slope 3	Slope 4	Slope 5	Slope	Runoff
1	97	0	0	0	3	0	66.80	27.82	1.48	2.64	99.8	0.2	0	0	0	0	16.04
2	99.5	0	0	0	0.5	0	85.96	9.65	0.39	3.28	100	0	0	0	0	0	8.11
3	49	0	0	0	51	0.03	55.00	36.56	3.26	3.88	99.05	0.05	0	0	0	0	12.7
4	40.8	0	0	0	59.13	0	68.43	15.81	3.059	5.69	97.57	2.33	0.10	0	0	0	46.08
5	21.5	64.7	0	0	13.77	0	58.32	21.47	3.84	9.69	98.38	1.61	0.00	0	0	0	48.15
6	100	0	0	0	0	0	77.11	19.62	1.02	1.66	99.5	0.5	0	0	0	0	9.55
7	0	100	0	0	0	0	44.20	24.04	6.62	7.17	93.51	6.30	0.18	0	0	0	161.8
8	0	20.16	0	0	79.83	0.02	73.90	21.52	1.08	1.58	99.09	0.01	0	0	0	0	15.07
9	53.9	0	0	0	46.05	0.02	73.90	21.52	1.08	1.52	91	9	0	0	0	0	14.90
10	8.69	0	0	0	91.31	0.00	69.64	22.39	2.77	1.34	97.71	2.27	0.16	0	0	0	97.8
11	0	0	0	0	100	0.01	66.93	27.65	2.72	2.27	99.98	0.24	0	0	0	0	4.19

12	69.3	0	0	0	0	30.63	0.012	55.17	27.25	3.15	7.55	97.08	2.62	0.28	0.00	0	19.56
13	74.4	0	0	0	0	25.54	0.03	43.99	27.23	6.15	12.74	96.89	3.09	0.01	0	0	35.13
14	0	0	0	0	0	99.9	0.053	57.91	33.79	4.31	3.31	100	0	0	0	0	7.09
15	0	0	0	0	0	100	0.25	51.09	36.8	4.88	6.36	99.97	0.02	0	0	0	7.05
16	0	0	0	0	0	0.1	0.10	54.2	39.07	2.84	3.67	100	0	0	0	0	191.7
17	0	0	0	0	37.54	62.44	0.12	33.31	47.08	12.99	5.47	99.9	0.9	0	0	0	19.69
18	0	0	0	0	0	100	0.67	32.68	54.24	1.28	10.41	99.91	0.08	0.01	0	0	9.78
19	0	0	0	0	0	100	1.931	54.68	31.0	6.26	5.45	99.99	0.01	0	0	0	4.53
20	0	0	0	0	0	100	0.450	61.64	30.67	3.34	2.19	99.77	0.37	0.00	0	0	5.62
21	0	0	0	0	0	100	0.27	63.69	20.28	1.66	6.74	97	3	1	0	0	12.35
22	0	0	0	0	0	100	1.638	19.18	60.75	4.44	13.45	100	0	0	0	0	70.76
23	0	0	32	0	68	0	11.93	16.94	47.16	3.91	19.05	87.92	5.87	2.47	2.52	1.16	75.10
24	0	0	0	0	100	0	4.860	13.09	64.00	7.27	9.64	99.48	0.51	0	0	0	36.59
25	0	0	3.29	63.26	33.48	0	2.11	23.92	57.28	11.34	4.67	100	0	0	0	0	14.24
26	0	0	6.115	0	93.8	0	3.40	19.97	64.63	3.46	7.3	99.71	0.24	0.00	0	0	12.84

27	0	0	0	0	0	100	1.49	58.3	25.34	3.97	3.91	97.77	1.70	0.48	0.04	0	14.44
28	0	0	0	0	0	100	9.713	28.76	21.96	20.20	10.72	96.02	0.54	0.01	0	0	11.29
29	0	0	0	0	0	100	17.76	22.06	21.36	20.90	9.67	92.40	4.40	1.58	1.55	0.05	187.3
30	0	0	0	0	0	100	7.00	43.36	24.91	7.45	7.62	96.50	2.68	0.61	0.12	0	19.97
31	0	0	35.88	0	64.11	26.56	19.88	33.20	4.63	8.07	14.06	92.63	5.55	1.33	0.42	0.05	48.96
32	0	0	46	0	54	10.51	15.02	56.54	8.07	8.693	8.693	90.92	2.09	1.46	2.01	3.49	39.44
33	0	0	70	0	30	24.91	14.76	34.60	6.20	17.61	17.61	90.99	5.50	2.074	1.33	0.09	68.81
34	0	0	0	0	100	3.44	26.56	28.79	27.19	27.19	8.55	97.30	2.45	0.22	0	0	57.3
35	0	0	55.75	3.96	40.28	25.13	16.20	41.91	10.64	10.64	4.65	70.7	9.22	6.57	6.73	6.74	74.72
36	0	0	76	18	6	7.56	10.79	55.30	12.06	12.06	12.83	86.12	2.10	2.10	2.9	6.68	90.93
37	0	0	55.71	0	44.28	21.80	15.24	29.16	16.68	16.68	13.01	93.76	4.65	1.16	0.40	0.002	22.66
38	0	0	17.45	0	82.54	6.44	28.77	32.66	16.19	16.19	9.10	93.14	4.98	1.20	0.60	0.056	47.84
39	0	0	65.79	0	34.20	22.29	10.81	37.77	8.48	8.48	19.71	87.03	8.37	2.94	1.579	0.029	46.79
40	0	0	46.83	0	53.16	16.00	19.49	36.18	7.48	7.48	16.61	83.56	10.19	2.78	2.39	1.06	26.20
41	0	0	33.75	0	66.25	22.69	18.67	35.36	6.45	6.45	14.63	87.90	6.73	2.04	1.97	1.34	38.21

42	0	0	87	0	13	51	4	27	11	5	0	0	58	18	9	40.67
43	0	0	88	0	12	50.55	4.95	26.48	8.35	6.34	51.76	19.88	11.19	11.18	5.967	42.57
44	0	0	35.43	0	64.56	33.95	5.86	34.49	12.00	12.40	86.09	7.78	2.79	1.92	1.39	31.29
45	0	0	41.59	0	58.40	50.97	1.007	25.59	11.23	9.47	62.58	20.44	9.62	6.86	0.49	49.14
46	0	0	45.08	0	54.91	47.08	2.34	26.26	10.03	11.34	73.86	16.57	5.47	3.23	0.84	16.46

8.3.3 Multivariate Linear Regression Technique

In the field of statistics, linear regression is an algorithm of modeling a linear relationship between variables. One of the variables is the result or output variable which depends on one or more input variables or independent variables. The instance when only one variable is related linearly with output variable is called as a simple linear regression. This algorithm tries to model the relationship by fitting a linear equation in the observed data. The equation of the linear regression can be defined as

$$Y = \alpha + \beta X \quad (8.1)$$

Where

Y = output variable

X = independent or explanatory variable

α = constant and

β = coefficient of X

When the case is to relate one dependent variable with multiple explanatory variables linearly, it is called a multivariate linear regression technique. Here the computation would be complex due to added variables and multiple coefficients have to be determined. The equation defined for multivariate linear regression technique is:

$$Y = \alpha + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 \dots \beta_n X_n \quad (8.2)$$

Where

Y = output variable

X_1, X_2, \dots, X_n = independent or explanatory variables.

$\beta_1, \beta_2, \dots, \beta_n$ = Coefficients of explanatory variables and α is the constant.

8.3.4 Estimating the Weight/Coefficients of Parameters

Table 8.3 Land type wise classification showing sediment yield for each LULC class

LULC type	Area (km²)	CN	AWC (mm)	USLE_LS	Precipitation (mm)	SED ton/ha
WATR	414.83	92	104.91	0.67	938.86	0
URBN	5,683.33	83.21	102.13	0.18	917.93	3.45
RNGE	5,233.71	80.43	103.27	0.26	936.31	4.71
AGRL	1,071.01	84.28	105.53	0.48	959.55	11.92
BARR	1,268.02	92.1	106.89	0.31	947.23	29.27
FRSD	1,948.26	80.64	118.56	0.98	1,008.96	1.38

Table 8.4 Soil type wise classification showing sediment yield for each Soil sample

SOIL	AREA	Sed	Sed/sq km	Rank
Soil 3	8396.62	39376.28	4.69	1
Soil 5	8653.68	29262.86	3.38	2
Soil 4	15434.71	42474.61	2.75	3
Soil 1	5540.32	1315.23	0.24	4
Soil 2	912.90	70.08	0.08	5

To find out the impact of the causes of soil erosion, all the principal causes were categorized. Table 8.3 shows the land type wise classification that shows which land type class is more prominent to soil erosion. Table 8.4 shows the soil sample which is more prominent to soil erosion. For finding out the impact of runoff on soil erosion, the

watershed was categorized from ascending order of runoff as shown in Figure 8.4(a) and compared to the Figure 8.4(b) which has given the watershed ascending order of the ranks according to the sediment yield per square kilometer of the watershed. By comparison, it could be seen that when runoff is more the value of soil erosion is also high. However, in some cases where the values of runoff are comparatively less still the values of the soil erosion were high. Which shows that the runoff is not the only dominant cause of soil erosion. Logically it is understood that steep slope will result in more soil erosion. However, it is difficult to find out which parameter among the steep slope, land type classes and soil samples are more dominant parameter responsible for soil erosion.

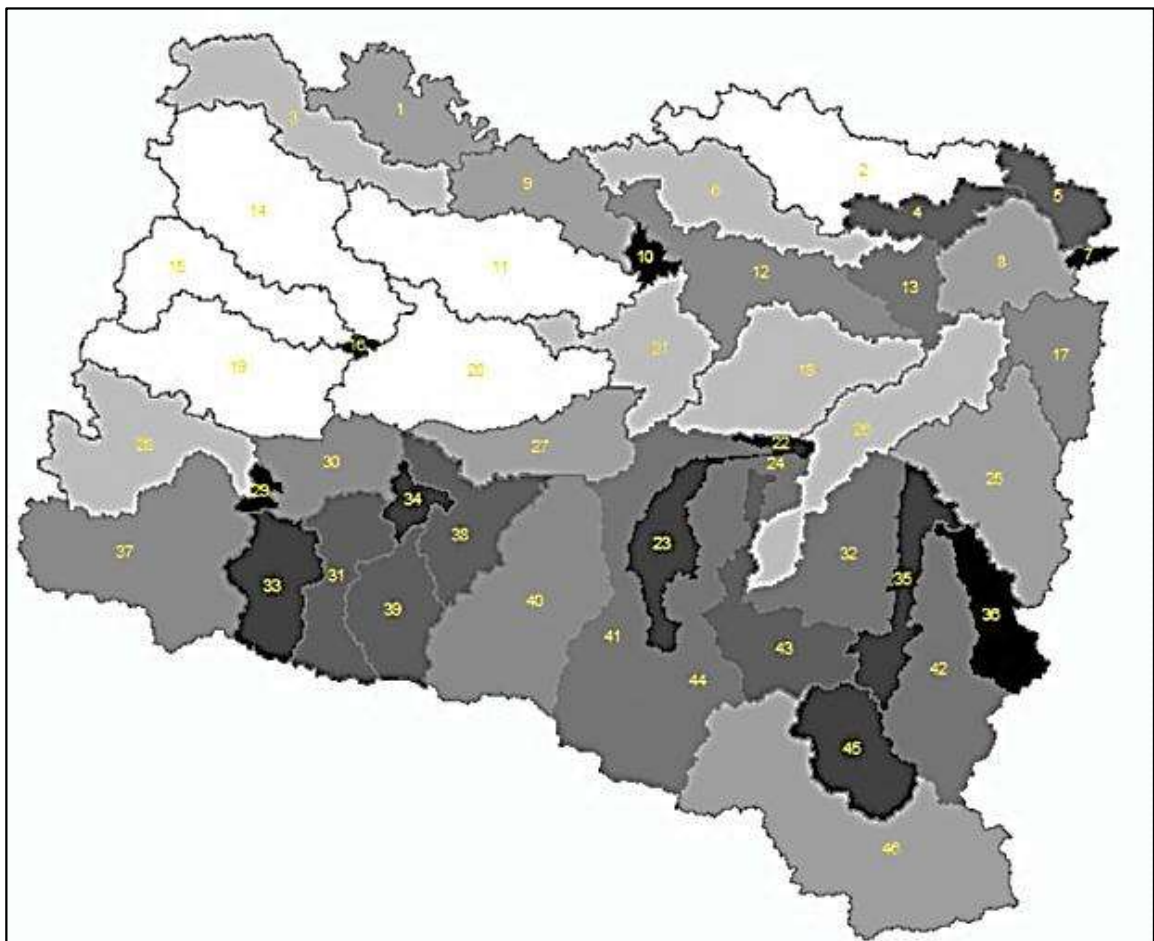


Figure 8.4(a) watershed showing runoff, darker the watershed higher is the value of Runoff.

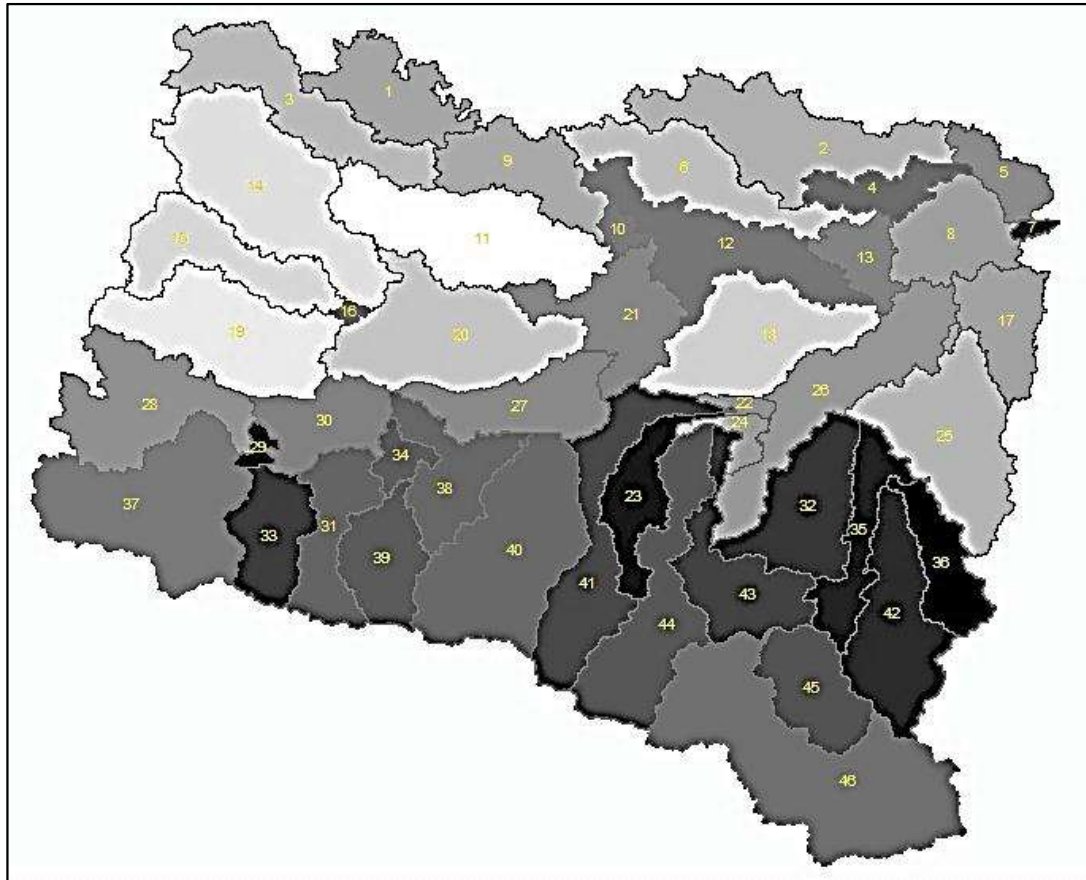


Figure 8.4(b) watershed showing soil erosion, darker the watershed higher is the value of Soil erosion.

To find out the principal cause of soil erosion and the exact weight of these causes the multivariate linear regression analysis was done. For finding out the coefficient of all the parameters, we need to have all the parameters in the same unit. For doing this, as the first step for each watershed the percentage of each soil samples, each LULC classes, and each slope class were determined (calculation for one sub-watershed is shown in Figure 8.5). In the next step, Table 8.2 was created including the values of all the parameters or 46 sub-watersheds.

In the next step, multivariate regression analysis was applied using MATLAB to find out

the coefficient of all the parameters, as the last step the values of all the coefficient were multiplied with their corresponding parameter values, and the compound value for each parameter was calculated. According to these values of each sub-watershed were ranked. Moreover, this rank was then validated with the first rank of the sub-watershed according to their sediment yield values.

8.4 Results

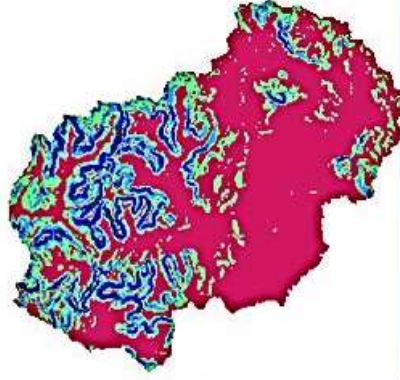
8.4.1 Result Assessment of the Impact of LULC Dynamics on Sediment Yield

Analysis of the impact of LULC dynamics on sediment yield shows that in the period 2004 to 2015, there was a remarkable change found in the land use pattern of the watershed due to urbanization and anthropogenic activities. The significant transitions observed were decreased in agricultural land by 3.8%, increase in the urban land by 6.3%, decrease in forest land by 11% and an increase in range of land by 8.6%. Due to these transitions, the runoff is increased by 13%, and 26% increases sediment yield in these 11 years, which concludes that soil erosion is profoundly impacted by the LULC dynamics. The detailed summary of the model response to land use land cover transition for all three cases is given in Table 8.5.

Table 8.5. Model response to land use change

Temporal Land use	Avg. annual Precipitation (mm)	Average annual Runoff (mm)	Annual sediment yield (ton/ha)
Case I	856.0	416.91	6.79
Case II	856.0	366.55	9.25
Case III	969.8	424.93	10.48
Change (I-II) (%)	0	13.73	26.65
Change (I-III) (%)	11.73	1.88	35.23

Calculating slope%, Soil type % and LULC% for each watershed



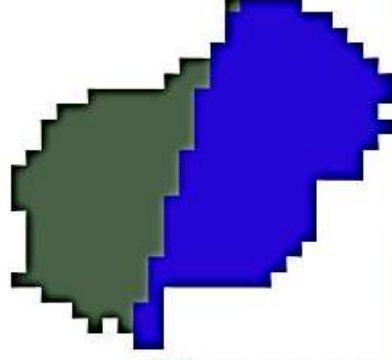
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Rowid	VALUE	COUNT	P
0	1	20820	62.56385
1	2	6805	20.44895
2	3	3204	9.627982
3	4	2283	6.860388
4	999	166	0.498828



soil45

Rowid	VALUE	COUNT	P
0	1	5147	1.718519
1	2	152667	50.97362
2	3	3018	1.007673
3	4	76661	25.59616
4	5	33639	11.23164
5	6	28370	9.472391



soil45

Rowid	VALUE	BIRVALUES	COUNT	P
0	3785		141	41.59292
1	3812		198	58.40708

Figure 8.5. calculating the % of each slope, soil type and LULC class for one sub-watershed

8.4.2 The Result of Multivariate Regression Analysis

The result of multivariate regression analysis is shown in Table 8.6. This table includes the coefficient of all the 15 parameters which are considered as the major causes responsible for soil erosion. They are soil samples (Soil 1 soil 2, soil 3, soil 4 soil 5), land type classes (urban, forest, Barren, agriculture, and range), slope classes (0 to 10, 10 to 20, 20 to 30, 30 to 40 and >40), and runoff. This table also includes the standard error of all the coefficients of each parameter. The results conclude that slope class 5 (Slope > 40), Barren land, agricultural land, soil class 3 and soil class 5 had the highest values of coefficient with values 2.5, 0.49 0.25 0.13 and 0.12 respectively. The R coefficient of the analysis, i.e., the R² value is 0.89, which shows that the analysis is correct. These results show that the slope and land type at the principal causes responsible for soil erosion. The standard errors are very low which shows these values are efficient. After getting the coefficient values, these values were multiplied to the corresponding parameter giving equation as

$$Y = \alpha + 0.081 X_1 + 0.053 X_2 + 0.12 X_3 + 0.13 X_4 + 0.086 X_5 + 0.14 X_6 + 0.21 X_7 + 0.13 X_8 + 0.25 X_9 + 0.49 X_{10} - 0.036 X_{11} + 0.16 X_{12} + 0.087 X_{13} - 1.56 X_{14} + 2.59 X_{15} + 0.06 X_{16}$$

Where,

Y= Sediment Yield,

α = constant,

X₁ to X₅ = Soil classes (Soil 1, Soil 2, Soil 3, Soil 4, and Soil 5)

X₆ to X₁₀= Land type Classes (Forest, Urban, Rangeland, Agriculture, Barren Land)

X₁₁ to X₁₅ = Slope Classes (where X₁₁ is the least slope and X₁₂ is the highest slope)

X₁₆=Runoff.

Table 8.6 Multivariate Linear Regression result

Variables	Coefficients	Standard Error	T Stat	P-Value	Lower 95%	Upper 95%
Soil 1 (X1)	0.08	0.04	1.90	0.07	-0.01	0.17
Soil 2 (X2)	0.05	0.05	1.14	0.27	-0.04	0.15
Soil 3 (X3)	0.12	0.06	1.92	0.06	-0.01	0.25
Soil 4 (X4)	0.13	0.06	2.10	0.04	0.00	0.26
Soil 5 (X5)	0.09	0.04	2.12	0.04	0.00	0.17
Forest (X6)	0.14	0.21	0.68	0.50	-0.29	0.58
Urban (X7)	0.21	0.22	0.98	0.34	-0.23	0.66
Rangeland (X8)	0.14	0.20	0.68	0.50	-0.27	0.54
Agriculture (X9)	0.25	0.27	0.93	0.36	-0.30	0.81
Barren (X10)	0.50	0.32	1.56	0.13	-0.15	1.15
Slope 1 :0-10 (X11)	-0.04	0.82	-0.04	0.97	-1.72	1.65
Slope 2 :10-20 (X12)	0.17	0.76	0.22	0.83	-1.38	1.72
Slope 3 :20-30 (X13)	0.09	1.07	0.08	0.94	-2.11	2.28
Slope 4 :30-40 (X14)	-1.57	1.09	-1.44	0.16	-3.80	0.66
Slope 5: >40 (X15)	2.95	1.11	2.67	0.01	0.69	5.21
Runoff (X16)	0.06	0.02	4.08	0.00	0.03	0.09

After keeping these values in the equation, the compound value of each sub-watershed was calculated, and each sub watershed's rank was calculated. This rank was validated with the original ranks of the sub-watersheds. The result of the comparison is shown in Figure 8.6

as graph calculated rank vs. original ranks

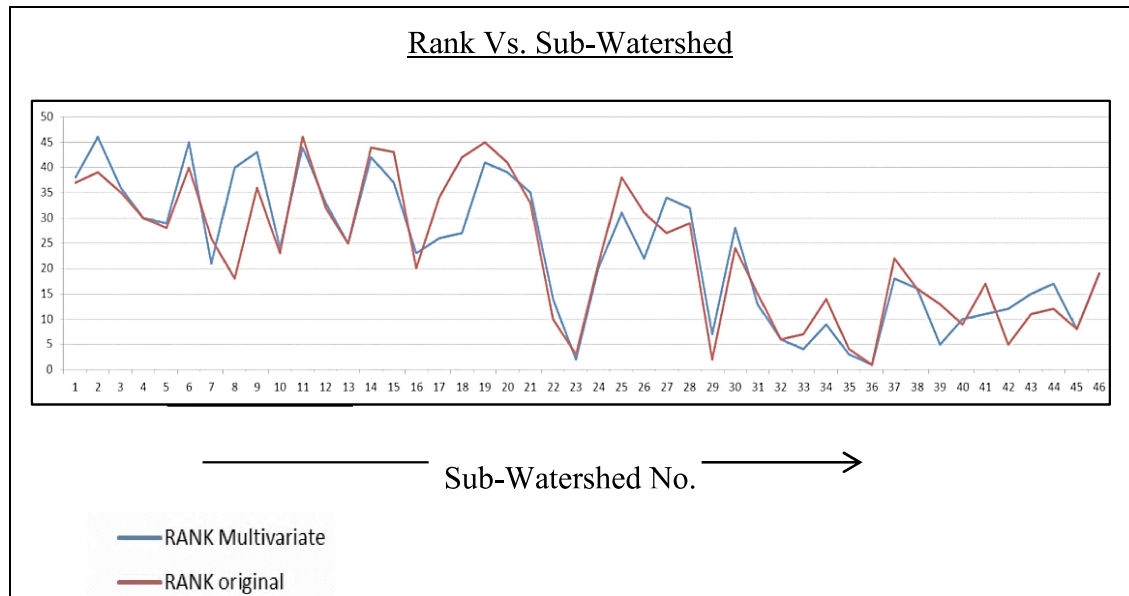


Figure 8.6 Graph of Calculated rank versus original rank

8.5 Comparison of present study with previous studies and Conclusion

To model the remedies of the soil degradation problem, it is imperative to know the main parameters responsible for soil erosion; then only effective measures can be developed. Many researchers have already worked for analyzing the impact of LULC dynamics (Zang et al., 2016), runoff, vegetation (Wynn and Mostaghini, 2006), soil type, slope and rainfall on soil erosion. Gray, (2016), have concluded in his study that conclave slope profile appear to be more stable and generate less sediment than uniform, planar slopes. Fang et al., (2014) concluded that sediment concentration increased on the slope 17.6% and 26.8% and peaked on the slope 36.4% and 46.6% slopes. Zhang et al., (2013) also used SWAT to find the impact of LULC dynamics on soil erosion. He recommended that areas with slope > 25% should be used as forest land to reduce soil erosion. Zhang et al., (2015) used GeoWEPP to model the impact of LULC and slope on soil erosion. Zhang et al., (2018) studied the effects of topographic factors on soil loss.

Till today maximum researchers have analyzed only one or two factors (at a time) responsible for soil erosion. But in this chapter, I have analyzed almost all the factors responsible for soil erosion. The impact of LULC dynamics and Rainfall was also analyzed separately, and then with the help of statistics method i.e. Multivariate Regression Technique and MATLAB the most dominant factor behind soil erosion was determined.

From the results, it could be concluded that there is a high impact of LULC dynamics on sediment yield, as due to LULC dynamics, 26% of sediment yield is increased in 11 years.

It was also estimated that the land type Barren land and Range land are the most dominant factor behind soil erosion, Then the second factor most responsible for soil erosion is slope > 40% then the factors responsible for soil erosion are the soil type, runoff and rainfall.

So the management practices which can directly reduce the impact of slope and land type would be most effective in the case of this study area. The best management practices that can be applied as the remedies of soil erosion problem in this area could be as follows:

- 1) Convert the barren land and agricultural land into a forest or rangeland.
- 3) Also, it is suggested to build some sediment filtration basin structures in the slope area for restricting sediment collection and soil erosion.
- 4) It can also model some runoff control hydraulic structures like bund, check dams, etc.
- 5) Slope stability measures can also be applied.