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Site Selection for Soil Conservation by Geometric Analysis of Watershed in the Southeastern Part of Aravalli Mountain Range Using Remote Sensing and GIS

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ABSTRACT

Remote sensing and GIS is very valuable and time saving techniques for drainage analysis. The purpose of the study is to locate the area susceptible to soil erosion and to mitigate the hazards by improving soil conservation. Drainage channel and Watershed boundary were demarcated by using topographic map, SRTM DEM of 1 arc resolution and satellite data (Landsat 2008 and Google earth image) under GIS environment. Linear, shape and relief parameter has been computed for each sub-watershed using arc map 10.2 and assigned rank based on the relationship with erodibility so as to arrive at a compound value for the final rankings of each sub-watershed. Value of compound parameter and priority for soil conservation are inversely proportional to eachother . On the basis of compound value the Ahar watershed has been classified into three classes (high, medium and low) in terms of priority for soil conservation and management. On the basis of the compound parameter the eleven sub-watersheds have been classified into three priority zone. The sub-watersheds UDSW3, 5, 8, 9 and 11 of the western part of the area consist of steep slopes, high drainage density, high stream frequency, low form factor and low elongation ratio are fall in high priority zone with respect to soil erodibility. Subwatershed UDSW6 and UDSW10 belongs to the eastern side of study area is fall in low priority zone. So the five sub-watersheds of high priority need to give the highest priority for land, soil erosion and rock fall prevention practice.

Keywords : Soil conservation, prioritization, Aravalli, Udaipur, Remote Sensing, GIS

I. INTRODUCTION

Fluvial landscape is directly involved with stream channel so watershed can be considered as a basic erosional landscape element. People are closely associated with the proper development and conservation of natural resource like Soil and water; hence natural resources have prime importance (Panhalkar, et al 2012). A watershed is an ideal unit for the management of natural resources like land and water and for mitigation of the impact of natural disasters for achieving sustainable development (Ali and Ikbal, 2015). The quantitative analysis of geomorphic indices is of mammoth utility in watershed prioritization for soil and water conservation as well as natural resources management at micro level. Morphometric analysis of a watershed provides a quantitative description of the drainage system, which is an important aspect of the characterization of watersheds (Strahler 1964). Morphometry is the mathematical analysis can be used to design of the earth's surface, shape and dimension of its landforms (Horton, 1945; Clarke, 1966; Obi Reddy *et al* 2002; Iqbal et al., 2013). The morphometric study involves the evaluation of stream parameters through the measurements of various stream properties (Kumar et al., 2000; Ali et al., 2003; Ali & Pirasteh 2005). The proper management of watershed needs utilization of various aspects like, land, water, soil, and forest resources of a particular watershed for better production and lesser hazard to natural resources (Biswas et. al., 1999). Remote sensing and GIS is considered as valuable tool in the study of watershed development and its management. Recently different terrain and watershed analysis by morphometric parameters is done by GIS techniques, as they supply a flexible environment and a influential tool for the treatment and analysis of spatial information. Thakkar et. al., (2007) analyzed eight mili watershed for prioritization and shows that shape parameters has a negative relation with runoff as well as soil erosion. Morphometric analysis of banas river basin was studied by Ali ad Khan, 2013. The study of landuse/ landcover change to determine the socioenvironmental impact in Ethiopia highland with the help of remote sensing and GIS has been carried out (Ali and Tesgaya, 2010). Morphometric analysis of river basin of different area has been carried out usinf remote sensing and GIS techniques (Ali, 1988; Ali and Khan, 2013; Ali and Ali, 2014, Ali et al., 2016; Ikbal et al., 2017). Watershed prioritization is the ranking of different sub-watersheds according to the order in which they have to be taken for treatment and soil conservation measures. Morphometric analysis could be used for prioritization of micro-watersheds by studying different linear and aerial parameters of the watershed even without the availability of soil maps (Biswas et. al., 1999). In the present study drainage analysis was carried out using remote sensing and GIS techniques for the proper planning of soil conservation by watershed prioritization method.

Study Area

The study area falls in the Girwa block of Udaipur district situated southeastern part of Aravalli range (Fig 1). The area bounded by the geographical co ordinate 24°29'49.18"N to 24°47'35.31"N and 73°31'46.49"E to 73°45'21.65"E. Ahar river coming from the elevation of 852 meters and crosses the area NW-SE direction moving downstream through Udaipur city of 563 meters of elevation. Several artificial lakes such as Bari lake, bari madar, choti madar, fateh sagar lake, lake pichola, Udaisagar lake etc. found along the course of the main Ahar river and its tributaries. Existing geological map (Roy and Jakhar, 2002) and ground survey was carried out to distinguish different geological units (fig 2). Dominance of Paleoproterozoic rock of Aravalli Supergroup overlain by Ahar river granite of BGC age. The area covered with granite, quartzite, phyllite, gneiss, schist, dolomite, metavolcanics rocks. Numerous faults, joints, lineaments are present in the highly deformed rocks in this area (Paliwal, 1988; Sharma et al., 1988; Bhu et al, 2014).

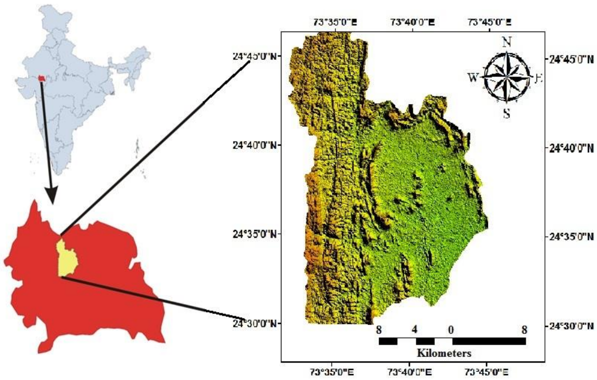

Figure 1 : Location map

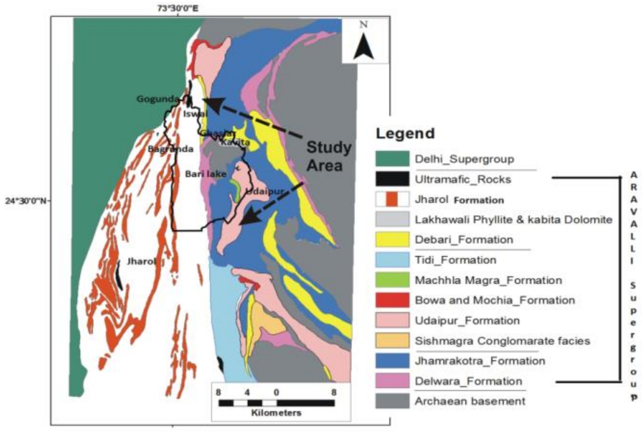

Figure 2 : Geological map (Roy and Jakhar, 2002)

II. METHODS AND MATERIAL

Survey of India toposheet map (1:50000), ASTER DEM (30 meters) and SRTM DEM (1 arc) has been used for analysis. Stream network was delineated using topographic map with the help of Arc GIS 10.2 softwware (Fig 3). DEM data is used to demarcate the watershed as well as the sub watershed boundaries. Soil erosion has influenced by height and slope of a watershed so elevations map (Fig 4a) and slope map (Fig 4b) has been prepared using SRTM data to understand the watershed morphology. Length and number of stream, area and perimeter of the subwatersheds were obtained directly from the GIS software. The various linear (stream frequency, drainage density, bifurcation ratio, drainage texture, length of overland flow) and shape parameters (form factor, shape factor, elongation ratio, circularity ratio, compactness coefficient) were computed on the basis of formula suggested by different scholars ((Horton, 1945; Miller, 1953; Schumn, 1956; Strahler, 1964). As shape parameters have an inverse relationship with erodibility (Nookaratnam et. al., 2005), so lower the value, more is the erodibility. The compound parameter values are calculated in which lowest value has given highest priority. Based on compound value the 11 subwatersheds were classified into three categories for priority such as high priority, medium priority and low priority. The high priority indicates need of recovery process and action plan for soil conservation and Landslide mitigation.

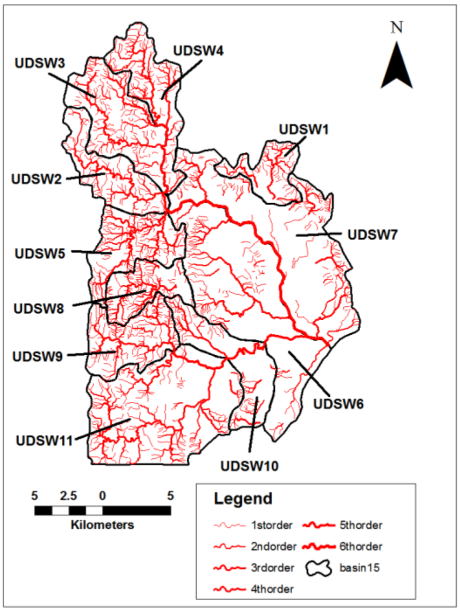

Figure 3 : Drainage map

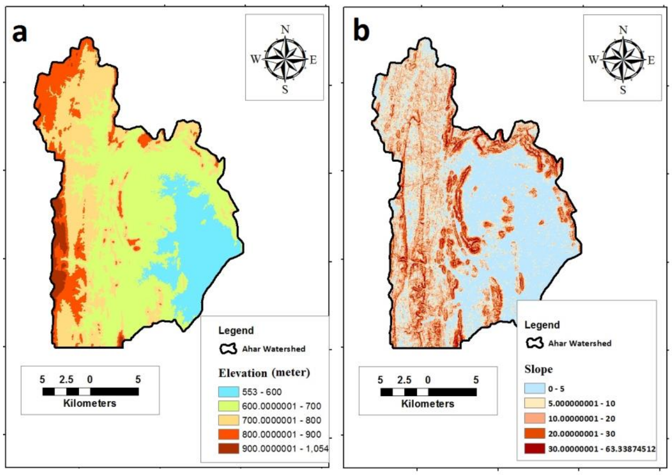

Figure 4 : (a) Elevation map (b) Slope map

III. RESULTS AND DISCUSSION

Strahler's (1964) method of stream ordering has considered here. Total of 1425 stream segments with highest 6th order stream found in the study area where 77.05% stream falls under 1st order, 17.61% falls in 2nd order, 3.93% in 3rd order, 1.12% in 4th order, 0.21% in 5th order and 0.07% fall under 6th order stream. The total length of the entire streams is 999.97 kms in which 579.85 kms is 1st order, 195.89 kms is 2nd order, 97.12 kms is 3rd order, 82.41 kms is 4th order, 24.03 kms is 5th order and 20.67 kms is 6th order. The number and length of streams is gradually decreases with increasing order.

Linear parameters

Drainage density, drainage texture, Stream frequency, bifurcation ratio, length of overland flow was analyzed.

Drainage Density (Dd)

Drainage density is an important parameter for morphometric analysis as it can be correlated to the dynamic nature of the stream and the area of the basin. It can be define as the total length of streams divided by area of the watershed and expressed as the equation-1

Dd=Lu/A……….. (Equation 1)

Where, Lu is the total stream length of all orders (Km) and A=Area of the Basin (Km^2). Langbein (1947) suggested that the Dd value varies between 0.55 and 2.09 km/km2 in humid regions. This parameter is considered as an important indicator of the linear scale of land form elements in stream eroded topography. Drainage density of the total area is 2.28 km/km^2 which fall under medium drainage density category. Individual subwatershed wise study reveals that Sub watersheds UDSW6, UDSW7 and UDSW10 possess low drainage density with value 1.29, 1.5 and 1.92 km/km^2 respectively indicate permeable sub surface (Table 2). Subwatersheds having high drainage density are UDSW4 (3.22 km/km^2), UDSW5 (3.43 km/km^2), UDSW8 (3.46 km/km^2) and UDSW9 (3.32 km/km^2) indicates more surface runoff and suitable place for maximum soil erosion.

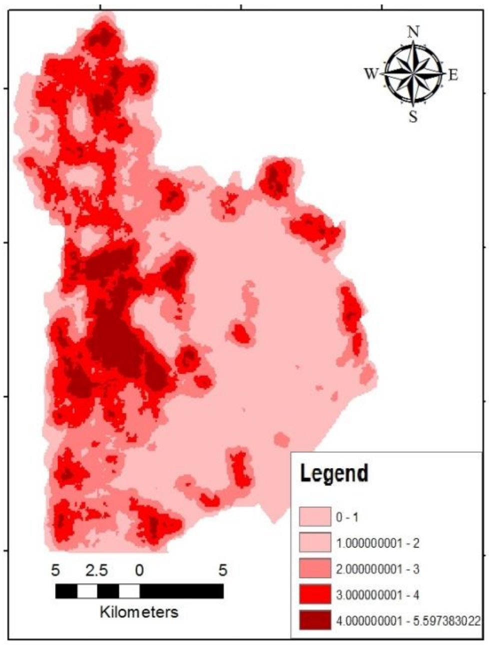

Figure 5 : Drainage density map

Drainage Texture (T)

Drainage texture is the ratio of stream numbers of a watershed and the perimeter of that particular watershed and can be expressed as the equation 2

T=Nu/P ……………. (Equation 2)

Where, Nu is the total number of streams of all orders and p is the Perimeter (Km). . It describes relative spacing of drainage lines, which are more prominent in impermeable material compared to the permeable ones. Drainage texture (T) depends upon a number of natural factors such as climate, rainfall, vegetation, lithology, soil type, infiltration capacity, relief and stage of development (Smith, 1954). The drainage texture less than 2 indicates very coarse, between 2 and 4 is related to coarse, between 4 and 6 is moderate, between 6 and 8 is fine and greater than 8 is very fine drainage texture (Smith, 1954; Ali and Ikbal, 2015). Based on smith classification UDSW1, UDSW2, UDSW4, UDSW6, UDSW7 and UDSW10 have coarse drainage texture. UDSW3, UDSW5, UDSW8, UDSW9, UDSW11 have moderate drainage texture (Table 2).

Stream Frequency (Fs)

Stream frequency is the total number of stream segments of all order per unit basin area. Stream frequency can be computed by equation 3

Fs =∑Nu/A………. (Equation 3)

Where, Fs is Stream frequency, ∑Nu is the total number of streams of all orders and A is the area of the Basin (km^2). A higher value of stream frequency reflects greater surface runoff. Hypothetically, it is possible to have a watershed of same drainage density may differ in stream frequency and similarly different watershed having same stream frequency may differ in drainage density (Chow, 1964).

The values of stream frequency in the study area vary from 1.55 (UDSW6) to 6.77 (UDSW8) (Table 2). Stream frequency values of all sub watersheds are almost directly proportional to drainage density. Sub watersheds UDSW6, UDSW7, UDSW11 and UDSW10 possess lower stream frequency as well as lower drainage density and UDSW9, UDSW5, UDSW8 show higher stream frequency as well as higher drainage density. Though sub watershed UDSW11, UDSW4 has lower stream frequency as compare to sub watershed UDSW10 and UDSW8 respectively but they possess higher drainage density. High stream frequency with high drainage density is responsible for more soil erosion.

Bifurcation Ratio (Rb)

The bifurcation ratio (Rb) is the ratio between stream numbers of a particular order and next higher order (Horton, 1945; Schumm, 1956) which can be expressed as equation 4

Rb=Nu/Nu+1 ………….. (Equation 4)

Where, Rb is Bifurcation ratio, Nu is total no. of stream segments of order ‘u’ and Nu+1 is the number of segments of the next higher order. Horton (1945) considered dimensionless parameter as an index of relief and dissections. Irregular values of Rb from one order to next order is indicates geological and lithological development of a drainage basin (Strahler, 1964).

bifurcation ratio in the study area varies from 1 (UDSW2, UDSW6 and UDSW10) to7.33 (UDSW6). Higher Rb values of more than 5 in UDSW3 ($1^{st}/2^{nd}$ order and $2^{nd}/3^{rd}$ order), UDSW6, UDSW7 and UDSW8 ($2^{nd}/3^{rd}$ order), UDSW11 ($3^{rd}/4^{th}$ order) and Ahar ($4^{th}/5^{th}$ order) sub watershed indicates highly structural controlled drainage pattern (Table 1). Mean bifurcation ratio ranges between 3.20 to 4.72 indicates mature topography and strongly structural controlled drainage pattern (Nag, 1998, Ali and Khan, 2013).

Table 1: Subwatershed wise value of bifurcation ratio

Sub-Watershed	$1^{st}/2^{nd}$	$2^{nd}/3^{rd}$	$3^{rd}/4^{th}$	$4^{th}/5^{th}$	$5^{th}/6^{th}$	Mean Bifurcation ratio (Rb)
UDSW1	4.9	3.33	3			3.74
UDSW2	4.5	4.67	3	1		3.29
UDSW3	5.04	6	2	2		3.76
UDSW4	4.14	3.67	3	2		3.20
UDSW5	4.36	3.5	4	2		3.46
UDSW6	4.41	7.33	3	1		3.94
UDSW7	4.48	5.8	5			5.09
UDSW8	4.17	6	4			4.72
UDSW9	4.82	4.6	2.5	2		3.48
UDSW10	4.5	3.5	4	1		3.25
UDSW11	3.71	3.73	5.5	2		3.73
Ahad Watershed	4.37	4.48	3.5	5.33	3	4.14

Length of Overland Flow (Lg)

It is the mean horizontal length of flow path from the water divide to the stream in a first order basin and indicates the amount of stream spacing and degree of dissection (Kedareswarudu et al., 2013) which affect both the hydrologic and physiographic development of drainage basins (Horton, 1945). Lg can be calculated through the equation 5

Lg =1/2Dd ……………… (Equation 5)

Where, Lg is the length of overland flow and Dd is the drainage density. So it can be defined as The average length of overland flow is half the average distance between stream channel and is approximately equal to half the reciprocal of drainage density (Horton, 1945; Chorley., 1957). Low value of length of overland flow is an indicative of high relief (Parveen and Kumar, 2012).

The length of overland flow (Lg) values of sub watersheds ranges from a lowest of 0.14 (UDSW8) to a highest of 0.39 (UDSW6) (Table 2). The Lg value of Ahar watershed is 0.22. The sub watersheds having lower Lg value indicates that they are under the influence of structural disturbance, low permeability, moderate to steep slope and high surface run-off.

Shape parameter

Shape parameters include form factor, shape factor, elongation ratio, circulatory ratio and compactness coefficient.

Form Factor (Ff)

Form factor of a drainage basin can defined as the ratio between the area of the basin and the square of the basin length and it can be calculated through the equation 6

Ff $=A/L^2$ ……………. (Equation 6)

Where, A is the area of the watershed (km^2), L is the length of watershed (km). The value of form factor would always be less than 0.754 (for a perfectly circular watershed). With higher value of form factor have high peak flow for short duration. Only sub-watershed USDW1, situated eastern side of the watershed, is nearly oval or circular in shape and the remaining sub-watersheds as well as Ahar watershed (0.41) are moderately circular to elongated in nature.

Shape factor (Sb)

Shape factor is the ratio of the square of watershed length to the area of watershed which can be expressed as equation 7

$Sb= Lb^2/A$ ……………… (Equation 7)

Where, Lb is the length of the watershed and A is the area. It is inversely proportional to the form factor. UDSW4 shows highest value of shape factor with the value of 5.96 whereas UDSW1 possess lowest value and the value is 1.48 (table2).

Elongation Ratio (Re)

Elongation ratio can be defined as the ratio between the diameter of the circle of the same area as the drainage basin and the maximum length of the basin (Schumn, 1956).

$Re =2\sqrt{(A/\pi)} \div L$ ……………… (Equation 8)

Where, Re is Elongation ratio, A is the area of the watershed (km^2), $\pi = 3.14$, L is the length (km) of the watershed.). Values close to 1.0 are normally found in region of very low relief, whereas 0.6 to 0.8 are usually associated with the region of strong relief and steep ground slope. Higher Re value shows high infiltration capacity and low run-off whereas low value is characterized by high susceptibility to erosion and sediment load (Reddy et al., 2004). The value of Re in the study area lies between 0.46 (UDSW4) and 0.93 (UDSW1) (Table 2). Sub watershed wise analysis reveal that except UDSW1 and UDSW9, the remaining sub watersheds show more or less elongated in shape, moderate to high relief, steep ground slope, and some of them are tectonically slightly active.

Circularity Ratio (Rc)

Circularity ratio is the ratio of the basin area to the area of a circle having the same circumference perimeter as the basin, which is dimensionless and expresses the degree of circularity of the basin (Miller, 1953; Ali and Ikbal, 2015). The formula is as follows

$Rc =4\pi A/P^2$…..…….. (Equation 9)

Where, Rc is Circularity ratio, π=3.14, A is the area of the watershed (km^2), P is the Perimeter of watershed (km). According to Miller (1953) the circulatory ratio having basin ranges 0.4 to 0.5 indicates basin is strongly elongated and highly permeable homogeneous geologic material. Circularity ratio is affected by length and frequency of channel, geological structure, land use/land cover, climate, relief and slope of the basin (Chopra et al., 2005). The circulatory ratio of Ahar watershed is 0.45 and Sub watershed wise the value is fluctuates from 0.25 (UDSW7) to 0.67 (UDSW11) (Table 2), indicating their elongated in nature.

Table 2 : Subwatershed wise value of linear and shape parameters

Sub-watershed	UDS W 1	UDS W 2	UDS W 3	UDS W 4	UDS W 5	UDS W 6	UDS W 7	UDS W 8	UDS W 9	UDS W 10	UDS W 11	Ahad Watershed
Area (Km^2)	15.72	25.69	36.94	27.34	27.95	80	74.9	19.04	27.19	27.77	76.43	437.92
Perimeter (Km)	23.07	28.82	32.47	36.43	29.07	52.56	60.73	22.94	26.77	31.56	37.85	110.24
Length of watershed (Km)	4.83	10.84	11.32	12.76	8.86	18.9	18.62	7.13	7.19	11.69	12.54	32.52
Drainage Density	2.63	2.58	2.87	3.22	3.43	1.29	1.5	3.46	3.32	1.92	2.1	2.28
Drainage Texture	2.73	2.85	4.68	3.35	5.54	2.36	2.72	5.62	5.30	2.63	5.47	12.93
Stream Frequency	4.01	3.19	4.11	4.46	5.76	1.55	2.20	6.77	5.22	2.99	2.71	3.25

Sub-watershed	UDSW 1	UDSW 2	UDSW 3	UDSW 4	UDSW 5	UDSW 6	UDSW 7	UDSW 8	UDSW 9	UDSW 10	UDSW 11	Ahad Watershed
Form Factor	0.67	0.22	0.29	0.17	0.35	0.22	0.21	0.37	0.53	0.20	0.48	0.41
Shape factor	1.48	4.57	3.47	5.96	2.81	4.46	4.63	2.67	1.90	4.92	2.06	2.41
Elongation Ratio	0.93	0.53	0.61	0.46	0.67	0.53	0.52	0.69	0.82	0.51	0.79	0.73
Circularity Ratio	0.37	0.39	0.44	0.26	0.41	0.36	0.25	0.45	0.47	0.35	0.67	0.45
Length of overland flow	0.19	0.19	0.17	0.15	0.15	0.39	0.33	0.14	0.15	0.26	0.24	0.22
Compactness coefficient	1.64	1.6	1.51	1.97	1.55	1.66	1.98	1.48	1.45	1.69	1.22	1.49

Compactness coefficient (Cc)

It is defined as the perimeter of a watershed divided by the circumference of a circle to the same area of the watershed and the formula is given below.

$Cc = 0.2821\sqrt{(P/A)}$

Where, P is perimeter and A is the area of the watershed. Cc value is 1 for perfect circular watershed. Here Cc value ranges between 1.22 (UDSW11) and 1.98 (UDSW7) (table 2). The variation of Cc value among the subwatersheds is not so much. High value of compactness coefficient indicates that low peak flows for longer duration.

Prioritization for Soil conservation

Linear parameters are directly related with erodibility and for prioritization the highest value among the eleven sub-watersheds was ranked as 1, next higher value was ranked as 2 and so on whereas shape parameters are inversely related with erodibility and consider the lowest value was ranked as 1, next lower value was ranked as 2 and so on (Table 3). On the basis of compound parameter the eleven sub-watersheds have been classified into three priority zone shown in Table 3 and Fig 6. The sub-watersheds UDSW3, UDSW 4, UDSW5, UDSW7 and UDSW8 are fall in high priority zone. These watersheds generally consist of steep slopes, high drainage density, high stream frequency, low form factor and low elongation ratio. So these five sub-watersheds need to give highest priority for land conservation from further degradation and soil erosion prevention practice.

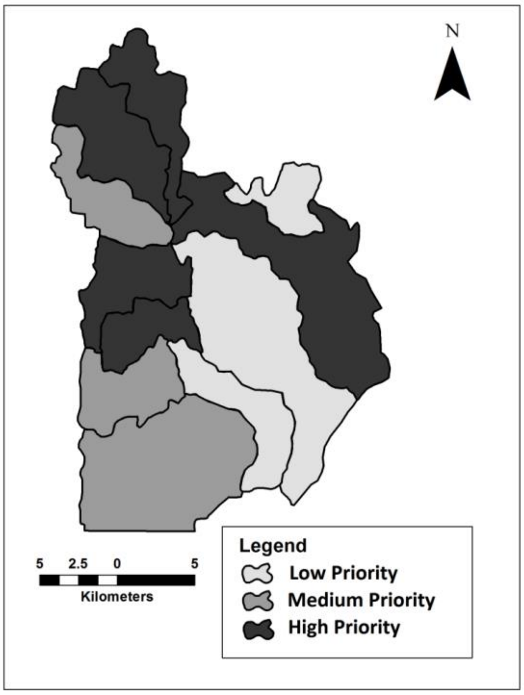

Figure 6 : Final priority to soil conservation

Table 3 : Value of Compound parameter and classification based on final priority to soil conservation

Sub-Watershed		UDS W1	UDS W2	UDS W3	UDS W4	UDS W5	UDS W6	UDS W7	UDS W8	UDS W9	UDS W10	UDS W11
Linear Parameter	Drainage density (Dd)	6	7	5	4	2	11	10	1	3	9	8
	Stream frequency (Fs)	8	7	5	6	2	11	9	1	4	10	3
	Mean bifurcation ratio (Rb)	5	9	4	11	8	3	1	2	7	10	6
	Drainage texture (T)	6	7	5	4	2	11	10	1	3	8	9
	Lenth of overland flow (Lg)	6	5	7	8	9	1	2	11	10	3	4
Shape Parameter	Form factor (Ff)	11	4	6	1	7	5	3	8	10	2	9
	Shape factor (Sb)	1	8	6	11	5	7	9	4	2	10	3
	Elongation ratio (Re)	11	4	6	1	7	5	3	8	10	2	9
	Circularity Ratio (Rc)	5	6	8	2	7	4	1	9	10	3	11
	Compactness coefficient (Cc)	7	6	4	10	5	8	11	3	2	9	1
Compound Parameter (Cp)		6.6	6.3	5.6	5.8	5.4	6.6	5.9	4.8	6.1	6.6	6.3
Final Priority		Low	Medium	High	High	High	Low	High	High	Medium	Low	Medium

Field Verification

Field survey was done for ground check for validity of the above result comes through remote sensing and GIS. Eroded soil and rock fragments as well as rock fall found in the places fall under high priority zone for soil conservation. 6 Km near to Madar lake or geographically at 24o38.305N and 73o37.062'E fall in UDWS8, where soil has eroded more at barren land as compare to vegetation covered area indicates that de-vegetation is responsible to soil erosion (Fig 7a). Erosion of rock fragments and soil at high slope area at 24o30.452N and 73o38.256E fall in subwatershed UDSW11 (Fig 7b), weathered metavolcanics at 24o42.080N and 73o38.286E fall in Subwatershed UDSW7 (Fig 7c), on river bed of Kotra nadi which is a tributary of Ahar river at 24o32.357N and 73o37.581E (Fig 7d) and rock fall at 24o43.65N and 73o34.49E of subwatershed UDSW3 (Fig 7e) found in the area where more priority is needed for soil conservation and rock fall prevention practice.

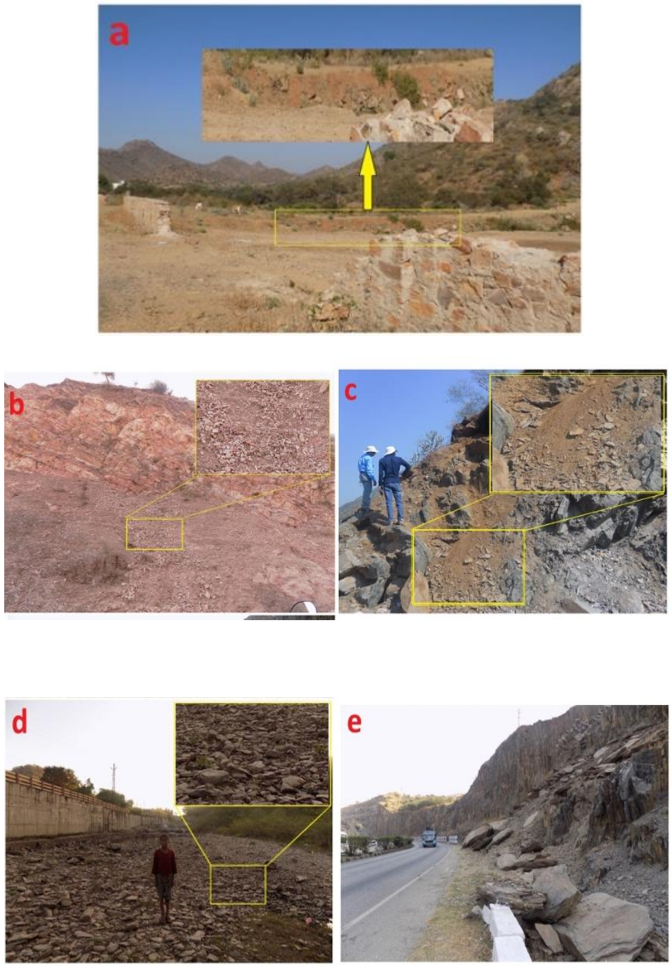

Figure 7 : Field photograph (a) soil erosion at de-vegetation area (b) erosion at slope (c) erosion at deformed weathered metavolcanics (d) eroded rock fragment on river bed (e) Rock fall beside highway

IV. CONCLUSION

Remote sensing and GIS is very useful techniques for morphometric analysis to assess high priority area for soil and water conservation. The morphometric parameters of every subwatershed show their relative behavior with respect to hydrologic response of the watershed. The watersheds which fall in high priority category are UDSW3, UDSW 4, UDSW5, UDSW7 and UDSW8. These watersheds usually consist of steep slopes, high drainage density, high stream frequency, low form factor and low elongation ratio. High priority means more soil and it becomes potential candidate for applying soil conservation measures. Therefore, urgent attention is needed for soil conservation measures in these watersheds to preserve the land from further erosion and to prevent natural hazards caused by soil erosion.

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