GIS BASED EVALUATION OF SOIL-EROSION SUSCEPTIBLE REGIONS AND CONSERVATION PLAN FOR SUSTAINABLE DEVELOPMENT OF WATERSHED

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Abstract

For enhancing groundwater and surface water resources in arid and semi-arid regions watershed management and sustainable development plans are essential. For preparing such plans, understanding the topographical features, erosion status, basin management and physiographic characteristics of the basin is essential. Analysis of morphometric parameters gives an identification of sub-watershed which is erosion prone and requires soil erosion control measures to preserve the land from further erosion. Quantitative description of basin geometry i.e. morphometric analysis was done to find out the drainage characteristics of Shipra River basin located in Madhya Pradesh of Central India using SRTM imageries and GIS techniques. The Shipra River basin is a fairly well-drained basin with a dendritic and parallel drainage pattern. The main stream of the basin is sixth order and lower order i.e. first order stream dominates the basin and stream segment development is affected by slope and local relief. The results revealed that the SW 28 (sub-watershed) has the highest priority while SW 41 has the lowest priority which is based on morphometric parameters. Thus one can say that Sub-watershed 28, 25, 2, 11, and 27 are erosion susceptible and require suitable water and soil erosion control measures to preserve the land from further erosion. It has been well proven in the study that for understanding and computation of various terrain parameters and analysis of basin, Geomatics techniques is an effective tool. Thus, present study finds utility of GIS in river basin evaluation, basin prioritization for soil and water conservation and natural resource management.

Keywords: Morphometric analysis, Soil erosion susceptibility, Prioritization, GIS, Arcgis.

Introduction

Geology, relief and climate are the primary determinants of running water ecosystems functioning at the basin scale (Lotspeich and Platts 1982). Water is the most important natural resource without which life can't imagine. But as population increases demand of water also increases. As the result it is very important to preserve this natural resource in proper and efficient way (sustainable manner). For management of natural resources, watershed is an ideal unit. It also helps in management of land and water resource for achieving sustainable development. Important factors for planning and development of a watershed are physiography of land surface, drainage pattern, geomorphology of river, soil characteristics, land use/land cover of watershed region and available water resources. To prepare a comprehensive watershed development plan, it becomes necessary to understand the topography, erosion status and drainage pattern of the region (Reedevi, Wais, Han & Hmed, 2009) and for this Geomatices Techniques such as Remote Sensing and GIS are the most effective tools. Many studies have been carried out and they have shown very good results. It also helps in prioritization of sub-watersheds for providing the rank to individual sub-watersheds according to their soil erosion status. Morphometric analysis could be used for prioritization of sub-watersheds by studying different linear and aerial parameters of the watershed even without the availability of soil maps (Biswas, 1999). It is also feasible to extract finer details of the surface and provide scope for micro level planning and management due to advancement in satellites and sensing technology,

Recent studies reveled that some of the model inputs related to land use and land cover, soil etc have been successfully derived from remotely sensed data and modeling was carried out in GIS environment (Pandey, Mathur, Mishra & Mal, 2009), (Chatterjee, Krishna & Sharma, 2013).

The present study aims for identification of erosion prone region and also determines the soil erosion susceptibility of drainage basin by prioritization of sub-watersheds based on morphometric analysis using Geomatics techniques.

Study Area

The Shipra, also known as the Kshipra or Avanti nadi, is a river of Madhya Pradesh state of Central India. The Shipra River originates in the Vindhya Range and flows in a northerly direction across the Malwa plateau to join the Chambal River. It has a catchment area of 5423.20 km^2 and lies between latitudes 22°27ˈ29ˈˈ to 23°56ˈ40ˈˈN and longitudes 75°25ˈ04ˈˈ to 76°13ˈ19ˈˈE. The average elevation of the basin is about 500 m above mean seal level. The climate of the study area is semi-arid and receives an average annual rainfall of about 1400 mm. About 90% of annual rainfall of Shipra basin occurs during the southwest and northeast monsoon season spanning over June to December. The average maximum and minimum monthly temperatures of the basin are 37° and 24°C, respectively.

The soils of the area are black, brown and bhatori (stony) soil. The geology classes include sandstone, shale of Mesozoic age; laterite and lateritic gravel having residual soft and porous soft rock of Cenozoic age; epidote-hornblende gneiss and hornblende-biotite gneiss of Archaean age occupying the north, south and western part of the study area, respectively. Figure 1 shows the location map of the study area.

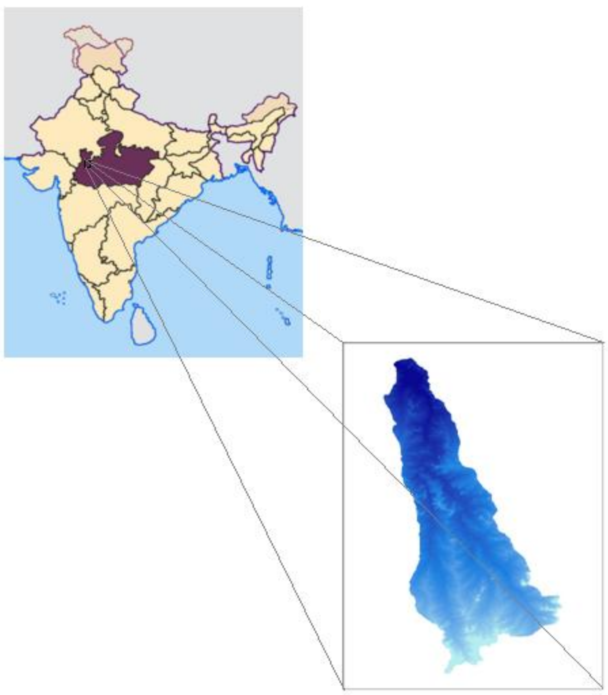

Figure 1. Location Map of Study Area: Shipra Watershed

Data Used

Survey of India (SOI) topo-sheet number 46M/10, 46M/11 and 46M/12 on the scale 1:50,000 have been used for formulation of basic map. The watershed boundary of Shipra basin was automated delineated using Shuttle Radar Topography Mission (SRTM) data which are downloadable from the website http://glcfapp.glcf.umd.edu:8080/esdi/. DEM for the study area is shown if figure 2.

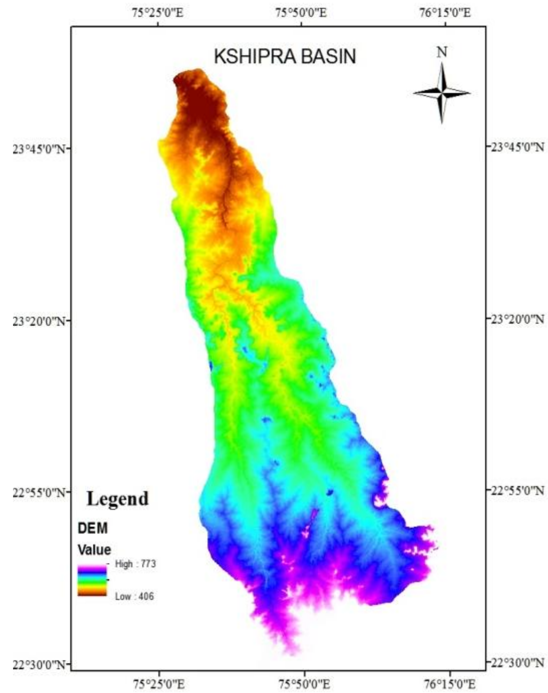

Figure 2. Digital Elevation Model for the Shipra Watershed

Methodology

The whole study was carried out into three parts.
In the first part, extraction of the study area from SRTM DEM with the help of outlet point. After that drainage characteristics information was extracted, such as number of streams, stream length, stream order and some other basic parameters also like area, perimeter of the each sub-watershed using ArcGIS 10. In extraction of drainage information flow direction and flow accumulation map was used. For sub-watershed generation, points are kept at the node of four number stream order.

The next part deals with the various morphometric parameters. Morphometric linear and shape parameters were derived using basic parameters for each sub-watershed. For deriving the morphometric parameters, formula are shown in table 1. These morphometric parameters are very helpful in understanding the hydrological behaviour and soil erosion of the sub-watersheds.

Finally, on the basis of all morphometric parameters all forty-three sub-watersheds are prioritized. On prioritization, sub-watershed which got the lowest rank is the most susceptible to erosion while which got highest rank is less prone to erosion.

Result and Disscussion

The total drainage area of Shipra River basin is 5423.20 km^2. Flow accumulation map are shown in figure 3. Is GIS environment, whole watershed is divided into forty-three sub-watersheds with the help of stream order map and outlet point as shown in figure 5. Extracted basic information for each sub-watershed shown in table 2. Value of all derived morphometric parameters are calculated using formulae listed in table 1. Table 3 & table 4 shows the value of linear and shape parameters respectively. Table 5 contains sub-watershed ranks, according to their value.

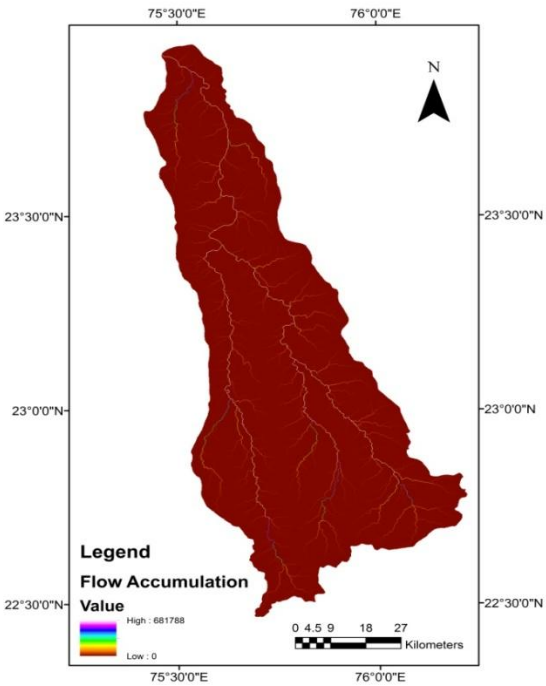

Figure 3. Flow Accumulation Map

The details of stream characteristics confirm to (Horton 1932) ''laws of stream numbers'' which state that the number of streams of different orders in a given drainage basin tends closely to approximate an inverse geometric ratio. It also confirms to (Horton 1932) the ''laws of stream length'' which states that the average length of streams of each of the different orders in a drainage basin tends closely to approximate a direct geometric ratio.

Stream order

The streams of the Shipra River basin have been ranked according to the Strahler's (1964) stream order system. It is based upon a hierarchy of streams ordering. It says if both its un-branched stream have the same order 'a', the order of link will be 'a+1' and in case the two tributaries have different order as 'a' and 'b' with condition a > b, the joined link have order 'a' i.e. higher order. Figure 4 shows the stream order map.

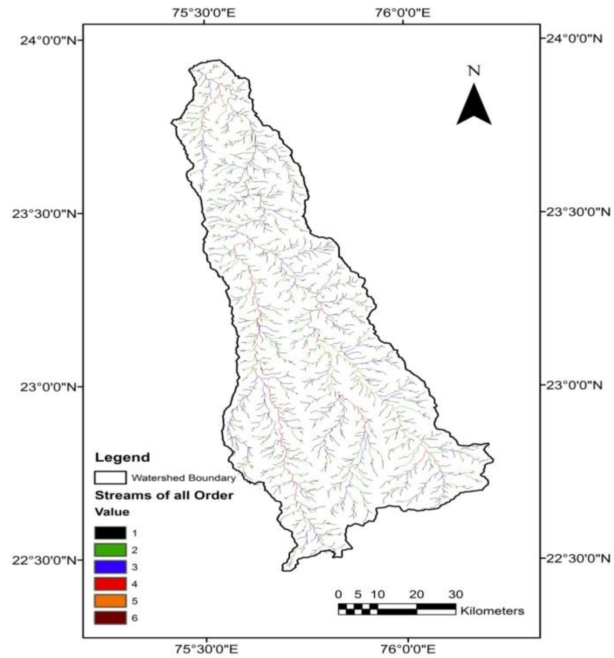

Figure 4. Stream Order Map

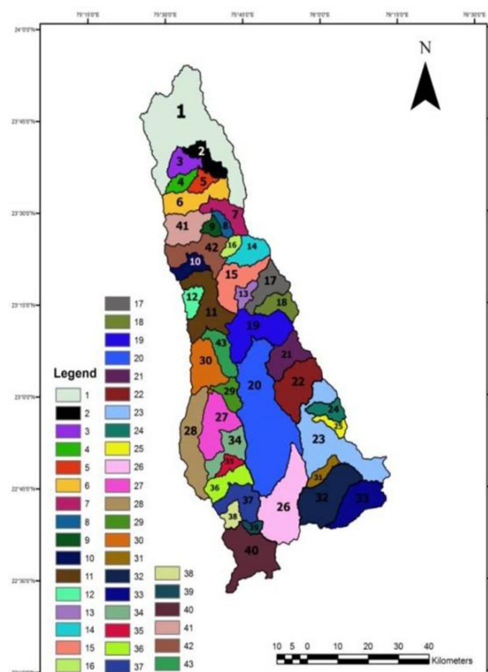

Figure 5. Watershed with 43 Sub-watersheds

Derived parameters are divided into two categories; one is linear and second is shape parameters. In linear parameters drainage density (Dd), stream frequency (Fs) bifurcation ratio (Rb), drainage texture (Dt) and length of overland flow (Lo) comes. While in shape parameters elongation ratio

(Re), basin shape (Bs), circulatory ratio (Rc), compactness coefficient (Cc) and form factor (Ff) comes.

Drainage Density (D_d)

Horton 1932 described the drainage density as the total length of streams per unit area divided by the area of the watershed. In the area of highly resistant and permeable surface with dense vegetation and low relief, low drainage density occurs.
In the present study the drainage density ranges from 0.02 to 11.01 km/km^2. The highest drainage density is observed in SW 8, while SW 41 has the lowest. The values of drainage density for forty-three sub-watersheds are shown in Table 3.

Stream Frequency (F_s)

Horton 1945 defined stream frequency (Fs) as the total number of stream segments of all orders within a watershed and sub-watershed area. Value of stream frequency for all forty-three sub-watersheds shown in table 3 which shows a large variation in stream frequency values (0.68 for SW 34 to 11.10 for SW 15). It means sub-watershed with lower stream frequency value have low relief and permeable surface while, sub-watersheds have higher stream frequency values show high relief, light vegetation and low conducting surface material.

Bifurcation ratio (R_b)

It is a dimensional parameter and can be expressed as the ratio of the number of streams of any given order (Nu) to the number in the next higher order (Nu+1) (Horton, 1945). Lower values of bifurcation ratio occurs in that area which has suffered less structural disturbances and where drainage pattern has not been distorted by structural disturbances (Nag and Chakraborty 2003). Mean bifurcation ratio (Rbm) for the study area varies from 1.77 to 5.46, SW 36 has the lowest value imply a smaller amount of structural disturbance, whereas SW 11 has the highest, suggest that it has structurally controlled drainage pattern. Table 3 shows the bifurcation ratio values of all forty-three sub-watersheds.

Basin Shape (B_s)

Basin shape is the ratio of the square of the basin length to the area of the basin or sub-basin. To calculate basin length, measure the distance between the outlet point of the watershed and the farthest point from the outlet point. It is also called shape factor. Basin shape with low value indicates sharply peaked flood discharge while higher value suggests weaker flood discharge periods.

Length of Overland Flow (L_o)

According to Horton, 1945 Length of overland flow can be defined as the stream over the ground surface before it merged into a definite stream channel like river or lake or ocean. Length of overland flow is inversely related to the average shape of the basin area and is almost identical to the length of sheet flow at a bigger scale. Length of overland flow values of forty-three sub-watersheds are varying from 0.01 for SW 41 to 4.81 for SW 8. Table-3 reveals the value of length of overland flow for each sub-watershed.

Form Factor (F_f)

According to Horton (1932) form factor is the ratio of the watershed area (A) to the square of maximum basin length (L). The value of form factor would always be less than 0.7854 which indicates a perfectly circular watershed. Thus it suggests the shape of the basin. Table 4 shows the value of form factor for forty-three sub-watersheds which is varying from 0.24 for SW 1 and SW 20 to 0.39 for SW 39, suggesting that almost all sub-watersheds is more or less elongated watersheds.

Elongation ratio (R_e)

Elongation ratio can be defined as the ratio between the diameter of a circle with the same area as that of the basin to the maximum length of the basin (Schumm, 1956). Generally it ranges from 0.6 to 1.0 over a wide diversity of climatic and geological environments. In the study area, values of elongation ratio have been shown in table 4. Regions of low relief have values around 1, while strong relief and sheer surface slopes have values in the range of 0.6–0.8.

Circularity ratio (R_c)

Circulatory ratio for the basin can be defined as the ratio of the watershed area to the area of circle having a circumference equal to the perimeter as the watershed (Miller 1953); (Strahler 1957). For showing dendritic phenomenon of watershed it is very important ratio. Value of circulatory ratio of sub-watersheds varies from 0.19 (SW 23) to 0.60 (SW 16) as shown in Table 4.

Compactness Coefficient (C_c)

Compactness coefficient is used in finding out the relationship between hydrological basins with that of a circular watershed having the same area as the hydrological basin. A circular basin is the most risky in terms of drainage point of view because it will give a very short time of concentration before maximum (peak) flow occurs in the watershed. Table 4 shows the variation in the values of compactness coefficient (from 0.01 to 0.06) in the study area.

Drainage texture (Dt)

Smith (1950) stated that drainage texture is the total number of streams of all order within the watershed per perimeter of the watershed area. It is a product form of drainage density and drainage frequency. Smith, 1950 classified drainage density into five categories as;

Very coarse drainage density	(<2),
Coarse drainage density	(2–4),
Moderate drainage density	(4–6),
Fine drainage density	(6–8) and
Very fine drainage density	(>8)

Drainage texture values of the sub-watersheds lie between 0.05 (SW 34) and 24.50 (SW 1) as shown in Table 3.

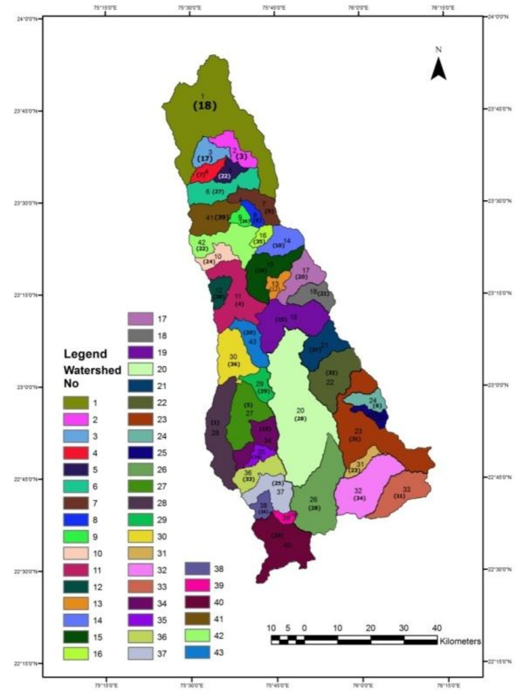

Figure 6. Prioritization Map by Morphometric Analysis

Table 1. Formulae for different Basin parameters with their references

S. No.	Parameters	Formulae	References
1	Stream Order	Hierarchial rank	Strahler (1964)
2	Stream Length	Length of the stream	Horton (1945)
3	Mean Stream Length	Lsm = Lu/Nu	Strahler (1964)
4	Stream Length Ratio	RL = Lu/(Lu -1)	Horton (1945)
5	Bifurcation Ratio	Rb = Nu/Nu+1	Schumm (1956)
6	Mean Bifurcation Ratio	Rbm = average of bifurcation ratios of all order	Strahler (1957)
7	Drainage Density	Dd = Lu/A	Horton (1945)
8	Drainage Texture	T = Dd * Fs	Smith (1950)
9	Stream Frequency	Fs = Nu/A	Horton (1945)
10	Elongation Ratio	Re = D/L = 1.128√(A/L)	Schumm (1956)
11	Circulatory Ratio	$Rc = 4\pi A/P^2$	Strahler (1964)
12	Compactness Coefficient	Cc = 0.2821 P/√A	Strahler (1957)
13	Form Factor	$Ff = A/L^2$	Horton (1945)
14	Length of Overland flow	$Lo = 1/2D_d$	Horton (1945)
15	Relief	R = H-h	Hadley and Schumm (1961)
16	Relief Ratio	Rr = R/L	Schumm (1963)

Table 2. Basic Parameters for Morphometric Analysis

SWS	Area (sq.km.)	Perimeter (km)	Basin Length (km)	Min Elevation(m)	Max Elevation(m)	Total Relief (m)
1	594.44	181.96	49.388	406	507	101
2	66.23	50.57	14.201	433	491	58
3	63.04	41.488	13.808	434	493	59
4	42.90	37.63	11.096	434	491	57
5	39.45	33.18	10.581	434	489	55
6	123.35	70.08	20.216	445	504	59
7	79.02	56.35	15.698	448	523	75
8	27.83	29.35	8.677	453	518	65
9	27.21	24.42	8.568	455	510	55
10	51.76	42.40	12.345	460	517	57
11	185.45	94.63	25.485	466	539	73
12	46.01	32.76	11.546	468	544	76
13	35.98	32.42	10.040	468	522	54
14	83.94	43.72	16.246	461	533	72
15	136.38	69.36	21.403	461	537	76
16	28.73	24.47	8.835	461	520	59
17	100.05	57.77	17.950	473	545	72
18	73.14	44.92	15.023	476	545	69
19	207.01	81.34	27.128	482	546	64
20	574.56	146.90	48.443	486	622	136
21	109.18	55.22	18.862	487	542	55
22	178.50	64.81	24.938	492	539	47
23	334.98	147.67	35.657	500	705	205
24	52.41	37.81	12.433	502	682	180
25	32.47	34.20	9.472	504	696	192
26	271.56	84.54	31.650	519	773	254
27	159.98	67.64	23.434	493	543	50
28	198.41	88.23	26.482	491	563	72
29	54.39	38.86	12.697	492	534	42
30	137.18	64.28	21.474	482	525	43
31	40.88	39.68	10.797	515	561	46
32	219.69	72.26	28.060	520	735	215
33	137.48	59.81	21.501	529	682	153
34	94.07	63.09	17.332	505	556	51
35	31.22	31.72	9.263	511	550	39
36	85.83	54.39	16.452	522	605	83
37	104.45	61.26	18.394	525	617	92
38	37.53	30.46	10.285	531	612	81
39	20.30	21.84	7.254	543	618	75
40	206.89	82.99	27.126	543	760	217
41	113.38	52.38	19.271	455	510	55
42	138.06	79.81	21.552	455	520	65
43	77.78	51.63	15.558	482	539	57

Table 3. Linear Parameters for Morphometric analysis

SWS	D_d	F_s	R_b	D_t	L_o
1	0.16	6.01	5.21	24.50	0.08
2	2.84	3.93	3.60	8.10	1.42
3	2.80	4.95	2.62	3.32	1.40
4	2.77	6.10	3.31	7.48	1.38
5	2.97	2.19	3.29	4.36	1.49
6	0.46	2.38	2.44	2.71	0.23
7	1.76	6.65	1.94	6.12	0.88
8	11.01	5.85	2.22	1.01	4.81
9	2.47	2.61	2.83	1.31	1.23
10	1.65	2.78	3.29	0.24	0.83
11	0.30	4.33	5.46	4.63	0.15
12	0.93	3.84	2.76	3.78	0.46
13	4.67	3.25	2.90	0.06	2.33
14	8.80	3.74	3.92	14.57	4.40
15	0.29	11.10	5.11	8.06	0.14
16	1.37	4.16	2.79	1.17	0.69
17	1.34	2.84	3.43	7.48	0.67
18	1.91	7.24	2.35	8.58	0.95
19	1.45	1.48	3.12	19.68	0.73
20	0.14	1.00	2.96	17.94	0.07
21	1.01	2.31	2.98	4.15	0.50
22	0.40	1.42	3.86	14.82	0.20
23	0.10	4.49	2.87	2.71	0.05
24	5.08	5.39	3.83	0.32	2.54
25	5.12	7.53	3.04	0.27	2.56
26	0.03	5.21	5.20	6.72	0.01
27	1.69	4.29	3.64	5.18	0.85
28	1.41	3.50	4.96	6.12	0.71
29	0.87	4.53	3.63	2.76	0.44
30	0.28	4.33	1.96	6.52	0.14
31	1.07	5.53	3.89	0.20	0.54
32	0.14	3.24	5.36	9.78	0.07
33	1.96	3.42	3.42	8.10	0.98
34	3.89	0.68	2.64	0.05	1.94
35	4.74	3.19	2.92	1.41	2.37
36	1.16	3.78	1.77	2.47	0.58
37	2.04	1.44	2.44	6.67	1.02
38	10.03	4.23	2.20	1.19	4.70
39	2.10	3.62	2.28	1.29	1.05
40	0.22	4.33	3.34	7.37	0.11
41	0.02	2.44	2.16	12.46	0.01
42	1.45	1.67	3.31	1.21	0.72
43	1.31	4.17	5.37	4.30	0.66

Table 4. Shape Parameters for Morphometric Analysis

SWS	F_f	R_c	R_e	B_s	C_c
1	0.24	0.23	0.46	0.75	0.01
2	0.33	0.33	0.57	0.91	0.03
3	0.33	0.46	0.51	1.01	0.03
4	0.35	0.38	0.46	0.82	0.04
5	0.35	0.45	0.76	1.08	0.04
6	0.30	0.32	0.73	0.94	0.02
7	0.32	0.31	0.55	0.75	0.03
8	0.37	0.41	0.47	1.97	0.05
9	0.37	0.57	0.70	0.90	0.05
10	0.34	0.36	0.68	0.73	0.04
11	0.29	0.26	0.54	1.08	0.01
12	0.35	0.54	0.58	1.01	0.04
13	0.36	0.43	0.63	0.65	0.04
14	0.32	0.55	0.58	1.49	0.02
15	0.30	0.36	0.60	1.30	0.02
16	0.37	0.60	0.55	0.78	0.05
17	0.31	0.38	0.67	1.23	0.02
18	0.32	0.46	0.53	1.34	0.03
19	0.28	0.39	0.93	0.79	0.01
20	0.24	0.33	0.42	1.37	0.01
21	0.31	0.45	0.74	1.07	0.02
22	0.29	0.53	0.95	1.42	0.01
23	0.26	0.19	1.37	0.95	0.01
24	0.34	0.46	0.49	0.74	0.03
25	0.36	0.35	0.41	0.73	0.05
26	0.37	0.48	0.49	1.14	0.01
27	0.27	0.44	0.55	1.09	0.01
28	0.29	0.32	0.34	1.09	0.01
29	0.28	0.45	0.53	1.00	0.03
30	0.34	0.42	0.54	1.09	0.02
31	0.30	0.33	0.48	0.66	0.04
32	0.35	0.53	0.63	1.36	0.01
33	0.28	0.48	0.61	1.30	0.02
34	0.30	0.30	1.13	1.36	0.02
35	0.31	0.39	0.63	0.88	0.05
36	0.36	0.36	0.58	0.90	0.02
37	0.32	0.35	0.94	1.09	0.02
38	0.31	0.51	0.55	1.57	0.04
39	0.39	0.54	0.59	0.82	0.06
40	0.28	0.38	0.54	1.17	0.01
41	0.28	0.52	0.72	0.63	0.02
42	0.31	0.27	0.87	0.79	0.02
43	0.30	0.37	0.44	1.07	0.03

Table 5. Final Priority of Sub-Watersheds based on Morphometric Analysis

SWS	Shape Parameters					Linear Parameters					Cp	Final Priority
	F_f	R_e	C_c	R_c	B_s	D_d	F_s	R_b	D_t	L_o		
1	1	5	1	2	39	38	41	4	43	38	21.2	18
2	27	21	24	9	9	10	17	14	17	10	15.8	3
3	28	11	25	30	15	11	26	33	21	11	21.1	17
4	33	6	31	18	11	12	19	18	12	12	17.2	7
5	35	37	32	27	8	9	15	20	25	9	21.7	22
6	16	35	12	7	34	32	23	34	18	32	24.3	27
7	24	17	26	6	16	18	3	42	7	18	17.7	9
8	41	7	38	23	1	1	16	38	8	1	17.4	8
9	42	33	39	42	10	13	6	29	15	13	24.2	26
10	31	32	33	14	24	20	37	21	4	20	23.6	24
11	9	14	2	3	35	34	5	1	26	34	16.3	4
12	32	22	34	39	30	30	28	31	22	30	29.8	38
13	37	28	35	25	6	7	21	27	2	7	19.5	12
14	23	23	13	41	3	3	36	8	39	3	19.2	10
15	15	26	14	15	32	35	1	6	34	35	21.3	19
16	40	18	40	43	23	24	18	30	9	24	26.9	35
17	20	31	15	19	22	25	9	15	33	25	21.4	20
18	26	12	27	31	12	17	2	36	36	17	21.6	21
19	6	39	3	21	19	21	8	22	42	21	20.2	15
20	2	3	4	10	41	39	42	25	41	39	24.6	28
21	18	36	16	28	31	29	40	24	23	29	27.4	37
22	10	41	5	37	33	33	13	10	40	33	25.5	32
23	3	43	6	1	40	41	29	28	19	41	25.1	31
24	30	9	28	32	7	5	38	11	6	5	17.1	6
25	38	2	41	12	4	4	14	23	5	4	14.7	2
26	4	10	7	33	42	42	30	5	31	42	24.6	28
27	11	19	8	26	17	19	11	12	27	19	16.9	5
28	8	1	9	8	21	23	12	7	28	23	14	1
29	29	13	29	29	29	31	24	13	20	31	24.8	29
30	14	15	17	24	36	36	22	41	29	36	27	36
31	34	8	36	11	26	28	35	9	3	28	21.8	23
32	5	29	10	38	38	40	27	3	37	40	26.7	34
33	13	27	18	34	14	16	4	16	35	16	19.3	11
34	21	42	19	5	18	8	43	32	1	8	19.7	13
35	39	30	42	22	5	6	10	26	14	6	20	14
36	22	24	20	16	28	27	34	43	16	27	25.7	33
37	19	40	21	13	20	15	33	35	30	15	24.1	25
38	36	20	37	35	2	2	20	39	10	2	20.3	16
39	43	25	43	40	13	14	7	37	13	14	24.9	30
40	7	16	11	20	37	37	32	17	32	37	24.6	28
41	17	34	22	36	43	43	31	40	38	43	34.7	39
42	12	38	23	4	27	22	39	19	11	22	21.7	22
43	25	4	30	17	25	26	35	2	24	26	21.4	20

Conclusion

For the morphometric analysis of Shipra basin, evaluation of drainage parameters and their influence on landforms and soil-erosion charcteristics is calculated using remotely sensed data and GIS techniques. In this study it was observed that Geomatics techniques are more appropriate than any other available conventional methods. Quantitative morphometric analysis at sub-watershed level helps in establishing the relationship among various aspects of drainage characteristics and also useful in finding out their effect on soil erosion.

The result of this analysis shows that sub-watershed 28, 25, 27, 11 and 2 are prone to relatively higher land and soil erosion. On categorization of the compounded value five sub-watersheds come under severe erosion effected, nine comes under moderate effected, twele comes under less effected and seventeen sub-watersheds are not effected by soil erosion. This can be understood by table 5. Figure 7 shows the erosion susceptible sub-watersheds and this map can be termed as Soil Erosion Map (SEM). Thus, sub-watersheds which are severly effected, suitable water and soil erosion control measures can be provided to control the erosion and preserve the land from further erosion and this can be done by providing soil and water conservation structures such as Check Dam, Groyne, Drop Structure. Consequently, Geomatics techniques can be effectively used for systematic analysis of morphometric parameters and in water-land resources evaluation and their management.

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Biography

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