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PRIORITIZATION OF SUB-WATERSHEDS FOR SOIL CONSERVATION MANAGEMENT USING MORPHOMETRIC CHARACTERISTICS

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ABSTRACT

Water crisis is major drawback for this generation and every drop of water should be utilized wisely. To overcome this situation, various methods available to replenish the water should be looked into. One such resource is maintaining the storage capacities of dam structures by decreasing the sediment load which indirectly effects the productivity of soil. The main objective of this paper is to prioritize the sub-watersheds of Manjira river basin, a tributary of Godavari basin near Nizamsagar reservoir which is highly affected in terms of storage capacity using Morphometric Characteristics in ArcGIS software and Compound Factor method to identify the Sub-Watersheds which are susceptible to soil erosion. The inputs required are Digital Elevation Model (DEM) and a pour point. ALOS PALSAR 12.5m resolution DEM was used to extract the watershed and stream order. The results of prioritization of sub-watersheds betokened that using Compound Factor method, sub-watershed (SW) 7 located around Akkannapet, region, Medak District, Telangana was critical with respect to erodibility.

Keywords: *Sub-watersheds, Prioritization, Morphometric Analysis, Arc GIS, Compound Factor, Soil Conservation*

1. INTRODUCTION

Earth land mass consists of 39% of total land area out of which 2% of global land mass is being supported by India. Many studies have been conducted to know the soil erosion statistics of India which concluded that an average annual rate of 16 tons per hectare which is equivalent to 5300 million tons per year of soil erosion. Of that eroded land mass 29 percentage is permanently lost to the sea and about 10 percentage is deposited in reservoirs, which gives an idea of storage capacity reduction to an extent annually. Soil erosion is a form of soil degradation by the movement of the upper layer of soil from one place to another place. It may occur due to both natural process and artificial developments. The natural process is associated with geomorphic processes or agents such as running water, winds, coastal waves and glaciers. Soil erosion is usually a slow process which may be unnoticed but few times it may be alarmingly speed and measures should be taken accordingly to improve its productiveness.

Soil erosion effects the environment in different ways such as loss of arable land, clogged and polluted waterways, increased flooding, loss of natural nutrients, removal of seeds, transport of organic matter, change in soil quality and structure. Expansion of urban area and population in countries like India results in erosion stress increment and also ground water resources due to increase in demand of water for requirements such as irrigation and industrial (Singh, Thakur, & Singh, 2013). One of the concerned effects of soil erosion is deposition of soil under dam structure and thereby decreasing the storage capacity of the reservoirs. The estimation of soil erosion can also be achieved by Revised Universal Soil Loss Equation (RUSLE), an empirical formula which considers factors such as Rainfall erosivity factor(R), Soil erodibility factor(K), Topography, Soil surface cover(C), Conservation practice factor(P). The quantification of soil erosion could not give an idea of management studies of the watershed which is affected. One such study which help with the watershed management against soil erosion is Morphological study. The term morphology is defined as the study of the forms of things with respect to any parameter it may be life cycle parameters or soil structure parameters. The morphological study deals with the morphometric parameters which include Basin aspect, Linear aspect, Shape and Landscape factors. The irrigation projects in India are running on low efficiency due to application and conveyance losses, improper reservoir operation and poor maintenance of regulator and outlets. Most of the reservoirs are multipurpose including flood control, hydropower generation, water supply, navigation, restoration, etc. The situation of too much water in the rainy season and too little water in the dry season causes many difficulties in reservoir operation. Due to changes of hydro-meteorological conditions and shifting goals of water requirements from one region to the others, the reservoirs have different operation rules. Prioritization of sub-watersheds using Morphometric parameters and LU/LC analysis (Javed, Khanday, & Ahmed, 2009) for Kenera Watershed of Guna District Madhya Pradesh. For Morphometric analysis, they have sub divided the parameters which effects directly and inversely the erodibility. The ranks collectively were added up to give a Compound Ranking. SRTM Dem based hydrological evaluation was used for watershed delineation (Meshram & Sharma, 2017). On total 14 morphometric parameters were considered. Followed same pattern (Javed et al., 2009) and computed Compound Value. Given an idea of starting the analysis with stream order calculation. Equilibrium of the watershed was calculated using Hypsometric analysis. The comparison of Morphometric analysis using Compound Ranking method and using Principal Component Analysis based method was carried out in this study. Quantification of morphometric parameters is dedicated by morphometry (Clarke, 1966). Indices of shape gives an idea for depicting the hydrological qualities of watershed for quantification of basin shape (Strahler, 1957). To understand the topology and landform developments, soil and erosional properties, drainage morphometry is necessary (Rai, Chaubey, Mohan, & Singh, 2017). The present study area, Manjira river basin which originates from Ahmednagar, Maharashtra is drained for various agricultural, industrial needs along with the major water source for water supply to Maharashtra, Telangana and Karnataka.

2. MATERIAL AND METHODS

2.1 Study Area

A watershed located on Manjira river, a tributary of Godavari river, between Achampet and Banjepally villages of the Nizamabad District, Telangana. The watershed is situated at 144 km north-west from Hyderabad city and consists of about 5,570 sq.km area of catchment. The watershed is lying between 77° 45’ 00“E and 78° 40’ 00“E longitude and 18° 30’ 00“E and 17° 25’ 00“E latitude (Fig. 1) and comes in the Survey of India topographic sheet 56F_12, 56F_16, 56K_7, 56K_11. The maximum and minimum elevation of the study area is 603m and 322m respectively.

Since the study is based on morphometric parameters which can be extracted from a DEM, ALOS PALSAR 12.5m resolution dataset is used provided by NASA (*https://search.asf.alaska.edu*) for delineating and extracting morphometric parameters. The pour point of study area is selected at Nizamsagar Dam. Arc Hydro tools are used to delineate the watershed and total 19 Sub-watersheds were created for this study area. The outlet of the study area drains into the Manjira river at Nizamsagar Dam, from where it takes north - westerly course and joins into the Sriramsagar project in Nizamabad, Telangana. Nizamsagar Dam is the oldest dam in the state of Telangana. The annual average rainfall of the study area is 1086.1mm. Recent studies concluded that the soil erosion rate at Nizamsagar dam basin increased about 1650 percentage after construction.

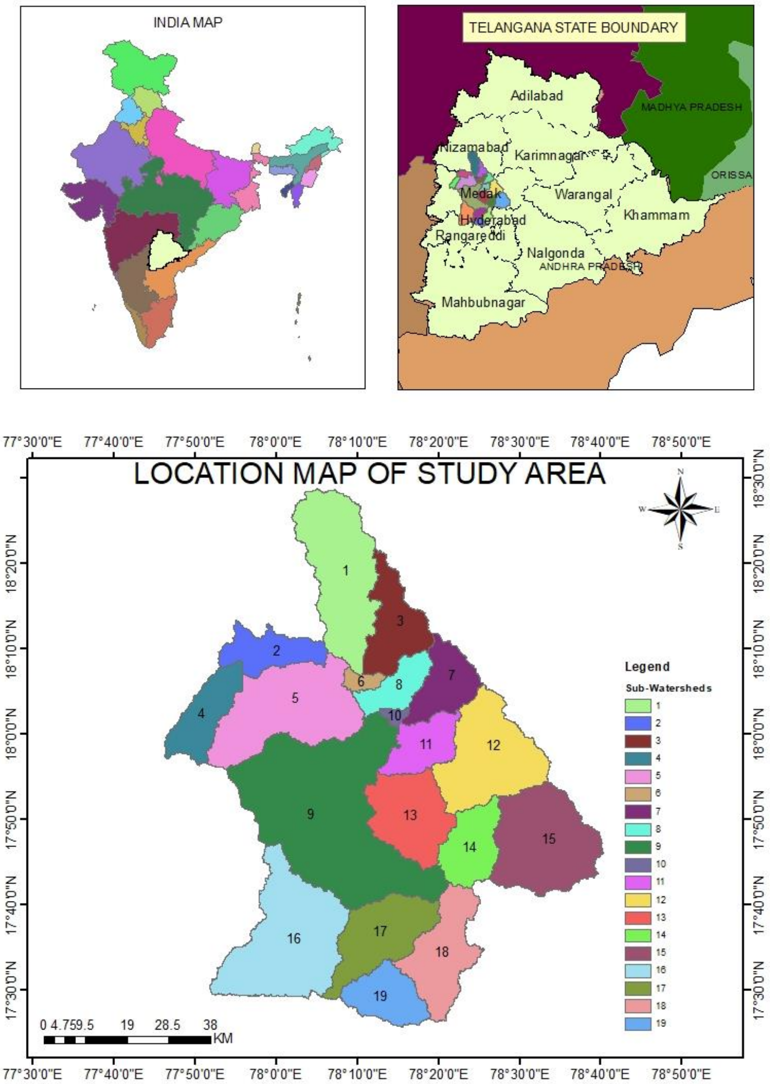

Figure 1 Study Area

2.2 Morphometric Analysis

The quantification of soil erosion could not give an idea of management studies of the watershed which is affected. One such study which help with the watershed management against soil erosion is Morphological study. The term morphology is defined as the study of the forms of things with respect to any parameter it may be life cycle parameters or soil structure parameters. The morphological study deals with the morphometric parameters which include Basin aspect, Linear aspect, Shape and Landscape factors. The present study focuses on sub-watersheds wise analysis and prioritization based on 21 morphometric parameters of the Manjira river basin, Telangana, India, using Remote Sensing and Geographic Information System using Compound Factor Method (CF).

2.3 Compound Factor Method

This model is based on the principles of knowledge-driven modelling and converts the qualitative understanding of a phenomenon by scientific knowledge into a quantitative estimation. In this method, the total number of ranks assigned is based on the number of options.

Table 1. Basin, Area, Length and landscape morphometric parameters used for Manjira river basin

S.no	Aspect	Parameter	Formula	References
1	Basin	Basin Area (A)	Area enclosed within the watershed boundary (km^2)	
2		Basin Perimeter (P)	Perimeter of watershed (km)	
3		Stream Order (N)	Hierarchical order	Strahler (1957)
4		Stream Length (L_s)	Length of Stream (km)	Horton (1945)
5		Number of Streams (N_s)	Total stream number of all orders	Strahler (1957)
6		Basin Length (L_b)	Longest dimension of the basin parallel to the principal drainage line (km)	Schumm (1956)
7		Bifurcation ratio (R_b)	$R_b = N_u / N_{u+1}$ Where N_u and N_{u+1} are total no. of stream segments of order 'u' and stream segments of next higher order	Schumm (1956)
8	Linear	Mean Bifurcation Ratio (R_{bm})	Average of Bifurcation ratio of all orders	Strahler (1964)
9		Drainage Density (D_d)	$D_d = L_s / A$ Where L_s is total stream length of all orders	Horton (1945)
10		Stream Frequency (F_s)	$F_s = N_s / A$	Horton (1945)
11		Texture Ratio (R_t)	$R_t = N_s / P$	Horton (1945)
12		Length of Overland Flow (L_{of})	$L_{of} = 1 / 2D_d$	Horton (1945)
13		Constant of Channel Maintenance (C_{cm})	$C_{cm} = 1 / D_d$	Horton (1945)
14	Shape	Form Factor (F_f)	$F_f = A / L_b^2$	Horton (1945)
15		Elongation Ratio (R_e)	$R_e = \sqrt{4A / \Pi L_b^2}$	Schumm (1956)
16		Compactness Coefficient (C_c)	$C_c = 0.2821 \left(P / A^{0.5} \right)$	Horton (1945)
17		Circulatory Ratio (R_c)	$R_C = 4\Pi A / P^2$	Miller (1953)
18	Landscape	Basin Relief (R)	$R = H_{max} - H_{min}$ Where H_{max} = Maximum elevation H_{min} = Minimum elevation	Moore (1991)
19		Ruggedness Number (RN)	$RN = D_d \times (R / 1000)$	Horton (1945)
20		Relief Ratio (R_r)	$R_r = R / L_b$	Schumm (1956)
21		Relative Relief (R_{rf})	$R_{rf} = R / P$	

The average of ranks of all the parameters is designed as compound value and represents the collective impact of all the parameters. This model calculated as

$$CF = \frac{1}{n} \sum_{i=1}^{n} R_i \qquad (1)$$

Where CF is Compound Value, R_i is rank of options, and n is number of parameters.

3. RESULTS AND DISCUSSIONS

The total basin area of Manjira river basin is 5,570 km^2. ALOS PALSAR dataset DEM was used to extract the watershed and drainage pattern which depends upon the topography of the area. The stream order of Manjira basin is indicated as sixth order basin. This sixth order basin is used to understand the morphological parameters as given in Table 1. In this study, the analysis of 19 Sub-watersheds of Manjira watershed were carried out to calculate the morphometric characteristics. In this regard 21 morphometric parameters that represent the basic, linear, shape and landscape characteristics of the watershed were examined.

3.1. Stream Order

Designation of stream order of a drainage basin is initial step in morphometric analysis. Stream ordering suggested by Strahler (1957) is used for the study. Basically, Strahler stream ordering works as two streams of same orders meet it results in giving next order stream. The stream originating at a source are defined as first order and two first order streams combine to form second order streams and similarly for higher order. Post analysis of the drainage pattern, Manjira river basin highest order is of sixth order which is given by its highest stream as shown in fig 2.

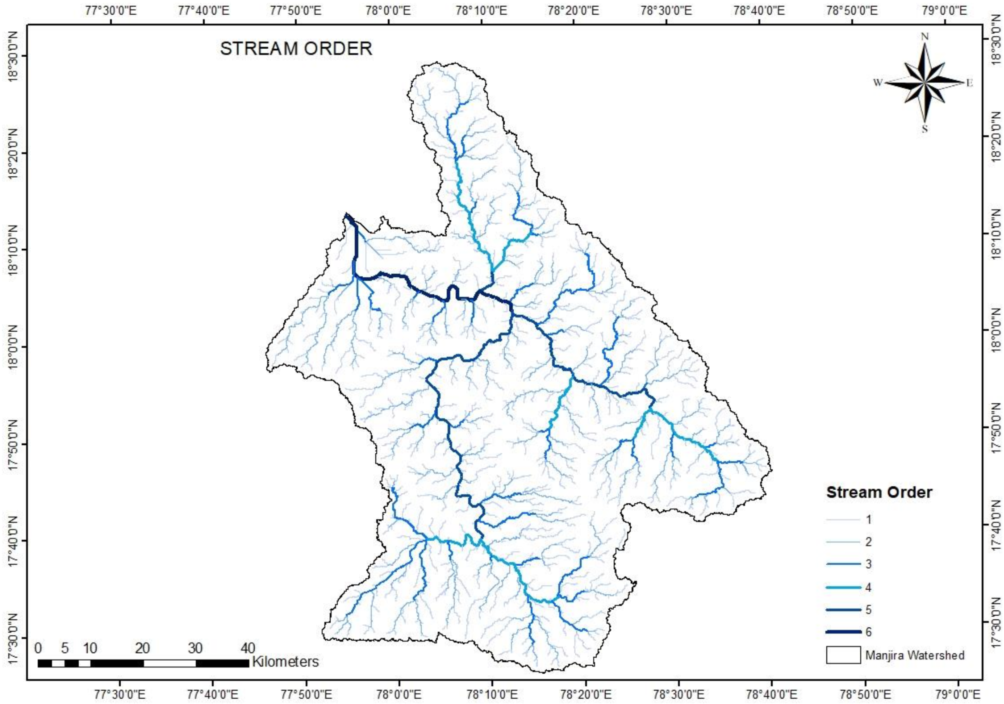

Figure 2 Stream Order of Manjira river basin

3.2 No of Streams

It is the number of segments of streams of all orders and its indirectly proportional to the stream order. From table 3, it can be perceived that maximum frequency is in the case of first order streams. As the stream orders decreases, the number of streams are decreasing and for few sub-watersheds they are nil. The number of streams for each order have been calculated using ArcGIS for each sub-watershed. Sub-watershed 5, 9, 11, 12 is being contributed by maximum number of different orders.

3.3 Length of Streams

Stream length refers to the length of streams of all orders in a specific sub-watershed which are measured using GIS software. From table 2 it is evident that SW9 (580.075 km) has the maximum stream length and SW10 (10.989 km) has the minimum stream length.

3.4 Basin Length

Schumm (1956) defined the basin length as the longest dimension of the basin parallel to the principal drainage line. Gardiner (1975) defined basin length as the length of the line from a basin mouth to a point on the perimeter equidistant from the basin mouth in either direction around the perimeter. From table 2, it can be observed that SW1, SW9 have greater basin length whereas SW6, SW10 have least basin length.

3.5 Bifurcation ratio

Horton (1945) considered R_b as index of relief and dissertation. Bifurcation ratio is a dimensionless number which shows the level of reliability existing between streams of orders in a basin. Bifurcation ratio do not strictly continue constant from one order to the next order, because of change of variations in watershed geology and lithology. Higher the bifurcation ratio, early the peak of hydrograph of that basin and higher the probability of occurrence of flash flooding (Howard,1990; Rai et al, 2017). In Manjira river basin, the maximum and minimum bifurcation ratio is corresponding to SW5.

3.6 Mean Bifurcation ratio

It is the average of Bifurcation ratio of all orders in a basin. The Mean Bifurcation ratio is represented in table 3. From the data it is apparent that SW4 has the high R_{bm}. It is inversely proportional to the erodibility, viz., higher the Mean Bifurcation ratio, higher is the erodibility and hence will be given primary priority accordingly. It has inferences as if $R_{bm} < 3$ then the region is Flat. If R_{bm} lies between 3 to 5 then the geological structure does not distort the drainage pattern. If R_{bm} is greater than 5 then it is lithological and structurally control.

3.7 Stream Frequency

Stream Frequency depends upon the rate of recurrence of the streams viz., frequency and area of the sub-watershed. This morphometric parameter is direct relationship with the erodibility. Higher the Stream Frequency, higher will be erodibility. SW10 has the maximum F_s and SW2 has minimum F_s as shown in table 4.

3.8 Texture ratio

Texture ratio is crucial consideration in drainage analysis depending on the relief aspect of the terrain, infiltration capacity and lithology. The maximum texture ratio is with respect to SW9 refers to high sensitivity to erosion and minimum texture ratio is with respect to SW10 refers to low sensitivity to erosion table 4.

3.9 Drainage Density

Drainage density depends on permeability of sub-surface elements, type of vegetation and terrain relief. Drainage density is directly in relationship with relief and indirectly in relationship with permeability and vegetation. Greater the drainage density, greater is the relief with low permeability and vegetation density. From table 4, SW19 has maximum D_d and SW10 has minimum D_d.

Table 2 Basic parameters for Manjira river basin

SW	Basin Area	Basin Perimeter	Number of Streams	Basin Length	Stream Length
1	459.868	179.450	84	41.366	256.010
2	153.657	116.525	18	12.979	74.126
3	216.241	138.325	41	23.971	118.068
4	176.375	106.625	27	26.557	96.072
5	489.184	192.625	88	29.664	279.997
6	30.670	44.225	6	5.886	18.857
7	171.488	104.425	28	20.263	96.666
8	116.072	91.200	21	13.139	68.062
9	1013.596	310.025	164	43.734	580.075
10	16.029	32.575	4	5.370	10.989
11	151.640	102.400	27	11.739	86.932
12	399.070	156.725	56	24.591	223.048
13	283.582	131.600	49	21.098	162.906
14	182.578	104.125	32	21.852	104.990
15	427.142	148.100	73	27.440	232.045
16	554.163	203.850	92	19.814	317.713
17	283.472	145.975	43	13.949	174.543
18	276.832	157.700	45	20.780	157.974
19	168.686	99.425	24	15.074	90.951
Sum	5570.355		922		

Table 3 Mean Bifurcation ratio of Manjira river basin

SW	No of Streams of each order						Mean Bifurcation ratio
	I	II	III	IV	V	VI	
1	67	13	3	1	-	-	4.162
2	14	2	1	-	-	1	3.333
3	30	8	2	1	-	-	3.25
4	22	4	1	-	-	-	4.75
5	65	16	5	-	1	1	3.315
6	4	-	-	1	1	-	2.5
7	22	5	1	-	-	-	4.7
8	15	3	1	-	1	1	2.5
9	129	27	6	1	1	-	4.069
10	2	-	1	-	1	-	1.5
11	21	3	1	1	1	-	3
12	42	11	2	2	1	-	3.772
13	38	8	2	1	-	-	3.583
14	24	5	2	1	-	-	3.761
15	53	15	4	1	-	-	3.761
16	73	14	4	1	-	-	4.238
17	31	9	2	1	-	-	3.314
18	33	8	3	1	-	-	3.263
19	17	6	1	-	-	-	4.416

3.10 Length of Overland flow

It is the flow length over the surface before reaching to the stream channels. Length of overland flow (Horton, 1945) is the length, projected to the horizontal, of non-channel flow from a point on drainage to a point on the stream channel. Greater the length, greater is the tendency of erosion since the flow period drives the soil in the respected path. From table 4, maximum L_{of} occurs in SW2 with highest priority and minimum L_{of} occurs in SW10 with least priority.

3.11 Constant of Channel Maintenance

Higher the value of C_{cm}, higher will be the permeability of rocks. From table 4, maximum C_{cm} corresponds to SW2 with high priority and minimum C_{cm} corresponds to SW6 with least priority. Higher value of C_{cm} is dependent on high basin area and vice versa.

3.12 Form Factor

Form Factor is given by ratio of diameter of a circle of the same area of basin to the maximum basin length (Schumm, 1956). The maximum F_f occurs in SW17 with least priority refers to circular shape of basin and minimum F_f occurs in SW4 with high priority refers to elongated shape of basin.

Table 4 Linear, Shape and Landscape parameters of Manjira river basin

SW	D_d	F_s	R_t	L_{of}	C_{cm}	F_f	R_e	C_c	R_c	R	RN	R_r	R_{rf}
1	0.556	0.182	0.468	0.898	1.796	0.268	0.585	2.361	0.179	245	0.136	5.923	1.365
2	0.482	0.117	0.154	1.036	2.072	0.912	1.078	2.652	0.142	142	0.069	10.940	1.219
3	0.546	0.189	0.296	0.916	1.831	0.376	0.692	2.654	0.142	246	0.134	10.262	1.778
4	0.544	0.153	0.253	0.918	1.835	0.249	0.564	2.265	0.195	164	0.089	6.171	1.538
5	0.573	0.179	0.457	0.874	1.747	0.555	0.841	2.457	0.166	189	0.108	6.371	0.981
6	0.614	0.195	0.136	0.813	1.626	0.891	1.065	2.253	0.197	89	0.055	15.171	2.012
7	0.563	0.163	0.268	0.887	1.774	0.417	0.729	2.250	0.198	222	0.125	10.956	2.126
8	0.586	0.180	0.230	0.853	1.705	0.672	0.925	2.388	0.175	228	0.134	17.352	2.500
9	0.572	0.161	0.529	0.874	1.747	0.529	0.821	2.747	0.133	231	0.132	5.282	0.745
10	0.685	0.249	0.123	0.729	1.458	0.555	0.841	2.295	0.190	145	0.099	27.001	4.451
11	0.573	0.178	0.264	0.872	1.744	1.100	1.184	2.346	0.182	158	0.091	13.459	1.543
12	0.558	0.140	0.357	0.895	1.789	0.659	0.917	2.213	0.204	186	0.104	7.564	1.187
13	0.574	0.172	0.372	0.870	1.740	0.637	0.901	2.205	0.206	193	0.111	9.147	1.467
14	0.575	0.175	0.307	0.869	1.738	0.382	0.698	2.174	0.212	164	0.094	7.505	1.575
15	0.543	0.170	0.493	0.920	1.840	0.567	0.850	2.021	0.245	138	0.075	5.029	0.932
16	0.573	0.166	0.451	0.872	1.744	1.411	1.341	2.443	0.168	184	0.105	9.286	0.903
17	0.615	0.151	0.295	0.812	1.624	1.456	1.362	2.446	0.167	154	0.095	11.040	1.055
18	0.570	0.162	0.285	0.876	1.752	0.641	0.903	2.674	0.140	150	0.086	7.218	0.951
19	0.539	0.142	0.241	0.927	1.854	0.742	0.972	2.160	0.214	125	0.067	8.292	1.257

3.13 Elongation ratio

The Elongation ratio gives an idea of the shape of the basin and relates it to the soil erosion. Usually, R_e value ranges between 0.5 to 0.9 for places where shape is more or less elongated. The inferences (Strahler, 1964) are if R_e (>0.9) then the shape is circular, R_e (0.8-0.9) then the shape is oval, R_e (0.7-.08) then the shape is less elongated, R_e (0.5-0.7) then the shape is elongated. R_e (<0.5) then the shape is more elongated. From table 4, SW2, SW6, SW8, SW11, SW12, SW13, SW18, SW19 are more than 0.9 and refers to circular shape while other SWs come under different categories. Least R_e refers to high priority and vice versa.

3.14 Compactness coefficient

It is calculated as ratio of basin perimeter to the circle perimeter of same area of watershed (Horton, 1945). It develops the relationship between actual hydrologic basins and circular basin having same areas. It is directly proportional to erodibility. Maximum C_c value occurs in SW9 with least priority and minimum value occurs in SW15 with high priority.

3.15 Circulatory ratio

Circulatory ratio is calculated as ratio of area of basin to the area of circle having equivalent circumference to the perimeter of basin. If basin tends to circular in shape then R_c tends to unity. In the Manjira watershed, the values of R_c ranges from 0.133 and 0.245 with being low is of least priority (SW9) and indicates that all the basins are elongated in shape.

3.16 Relief

Relief is the elevational difference of the terrain giving the height of terrain from lowest point to highest point. From table 4, SW6 has the least relief and SW3 has the highest relief.

3.17 Ruggedness Number

Strahler (1957) and Melton (1958) defined ruggedness number (RN) a dimensionless number, which can be obtained by product of relief (R) and drainage density (D_d) in same unit. The maximum value of RN occurs in SW1 where R and D_d both are almost high and its of high priority. Similarly, minimum value of RN occurs in SW6 where R is very low and its of least priority.

Table 5 Prioritization and final ranking of Sub-watersheds

SW	R_{bm}	D_d	F_s	R_c	F_f	R_e	R_t	L_{of}	C_c	RN	R_r	R_{rf}	C_{cm}	CF	Priority
1	5	14	4	11	2	2	3	6	11	1	17	10	6	7.076	2
2	10	19	19	16	16	16	17	1	16	17	7	12	1	12.846	17
3	14	15	3	17	3	3	9	5	17	2	8	5	5	8.153	3
4	1	16	15	8	1	1	14	4	8	14	16	8	4	8.461	4
5	11	9	6	15	8	8	4	11	15	7	15	15	11	10.384	12
6	18	3	2	7	15	15	18	17	7	19	3	4	17	11.153	16
7	2	12	12	6	5	5	12	8	6	5	6	3	8	6.923	1
8	17	4	5	12	13	13	16	16	12	3	2	2	16	10.076	11
9	6	10	14	19	6	6	1	10	19	4	18	19	10	10.923	13
10	19	1	1	9	7	7	19	19	9	10	1	1	19	9.384	8
11	16	8	7	10	17	17	13	12	10	13	4	7	12	11.230	15
12	7	13	18	5	12	12	7	7	5	9	12	13	7	9.769	9
13	9	6	9	4	10	10	6	14	4	6	10	9	14	8.538	5
14	15	5	8	3	4	4	8	15	3	12	13	6	15	8.538	6
15	8	17	10	1	9	9	2	3	1	16	19	17	3	8.846	7
16	4	7	11	13	18	18	5	13	13	8	9	18	13	11.538	16
17	12	2	16	14	19	19	10	18	14	11	5	14	18	13.230	19
18	13	11	13	18	11	11	11	9	18	15	14	16	9	13	18
19	3	18	17	2	14	14	15	2	2	18	11	11	2	9.923	10

3.18 Relief ratio

The Relief ratio is an indicator of erodibility in a watershed which measures the steepness of watershed. High value of R_r represents the hilly region and vice versa. Maximum value occurs in SW10 with highest priority and minimum value occurs in SW9 with least priority. Thus, it can be said that R_r has a direct correlation with the erodibility.

3.19 Relative Relief

Relative relief is given by ratio of relief to the perimeter of watershed. From table 4, SW10 has the maximum R_{rf} with highest priority and SW9 has the minimum R_{rf} with least priority.

From Table 5, the prioritization of each watershed of each parameter has been done and the Compound Factor (CF) has been calculated using eq (1). The SW1, SW3, SW4, SW7, SW13 have been ranked least and are at high risk to erosion.

4. CONCLUSIONS

The prioritization of Manjira watershed is done using Compound Factor method by Morphometric analysis. The results shown above give an idea of erodibility with respect to morphometric parameters and the prioritization technique. From the results it can be incurred that SW1, SW3, SW4, SW7, SW13 are at high risk which is being contributed by 1307 km^2 (23.47% of total area). Whereas, SW2, SW11, SW16, SW17, SW18 are at low risk with respect to erosion contributed by 1419 km^2 (25.48% of total area) while other watersheds are at moderate risk. Best management practices (BMP's) can be adopted in the places at high risk. In Compound Factor method, the average of the all parameters ranking is being calculated and ranked but there is no correlation between the morphometric parameters to get the prioritization done. It is one of the drawbacks of this method but we can rely on this method since it gives an idea of the erodibility nature of each sub-watershed.

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