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Watershed development prioritization of Tandava River Basin, Andhra Pradesh, India – GIS Approach

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ABSTRACT: the amount and tendency of sedimentation and siltation reduces the efficiency of the reservoir; for this, the local farmer dwells in the reservoir face water scarcity. The main objective of this study is to give priority for river sub -basins development by determine the hydrological parameters. Toposheet 65 k/5, k/6, k/7, k/10 and k/11 with scale 1:50,000 were used for drainage analysis. In this study, drainage network delineation and morphometric parameters were performed using onscreen digitization on 1:50,000 topographic maps through GIS environs. Sub-basins 9, 11, 13, 14, 17 and 21 obtained high priorities for soil conservation and management program. The study reveals watershed prioritization would be very useful in number of watershed management practices and soil conservation program for reducing rates of deposition and sedimentation in the basin especially in the reservoir.

Keyword: Morphometry, Tandava river basin, GIS technology, watershed prioritization

I. INTRODUCTION

Land is the scarce resource in the earth planet and hence it requires intensive conservation, preservation and management action. Watershed prioritization is the practical application for soil conservation and management development. A river is the general term for a channel and the water in it. The area supplying water into a channel is a drainage basin. The boundary between drainage basins is a water divide. A river system is composed of the main stream and many tributaries. However, there are many cases where several tributaries have similar length and flow, and it is difficult to determine which main stream drainage pattern is a plan of a river system. The significance of these landscape parameters was earlier pointed out by Morisawa [9], who observed that stream flow can be expressed as a general function of geomorphology of a watershed. The assertion still stand valid following Jain and Sinha [6], Okoko and Olujimi [11] and Ifabiyi [5] who reported that the geomorphic characteristics of a drainage basins play a key-role in controlling the basins hydrology.

Morphometric analysis of drainage basins thus provides not only an elegant description of the landscape, but also serve as a powerful means of comparing the form and process of drainage basins that may be widely separated in space and time [2]. A great step forward was made by Horton [3] when he crystallized previous works added new measures and proposed general methods for the description of drainage basins characteristic. Morphometric characteristics of drainage basin has exhibit spatial-temporal variation, hence the need for detail investigation of basin characteristics, not only from one area to another, but also from time to time. This is because, the form of a basin in terms of its morphometric characteristics determine the processes operating in such a basin. This study is intended to present the watershed priority of Tandava River Basin (TRB) for better land resource usage and appropriate application.

II. Study Area

The area of study is bounded by latitudes $17^0 3`$N and longitudes $82^0 36`00``$ E. It forms part of Survey of India Toposheets 65 K/5, K/6, K/7, K/10 and K/11 and covers an area of 1283 km^2. Major part of the area is in Visakhapatnam district but adjacent part of East Godavari district is also included to see the total morphometry of the river basin (Fig.1).

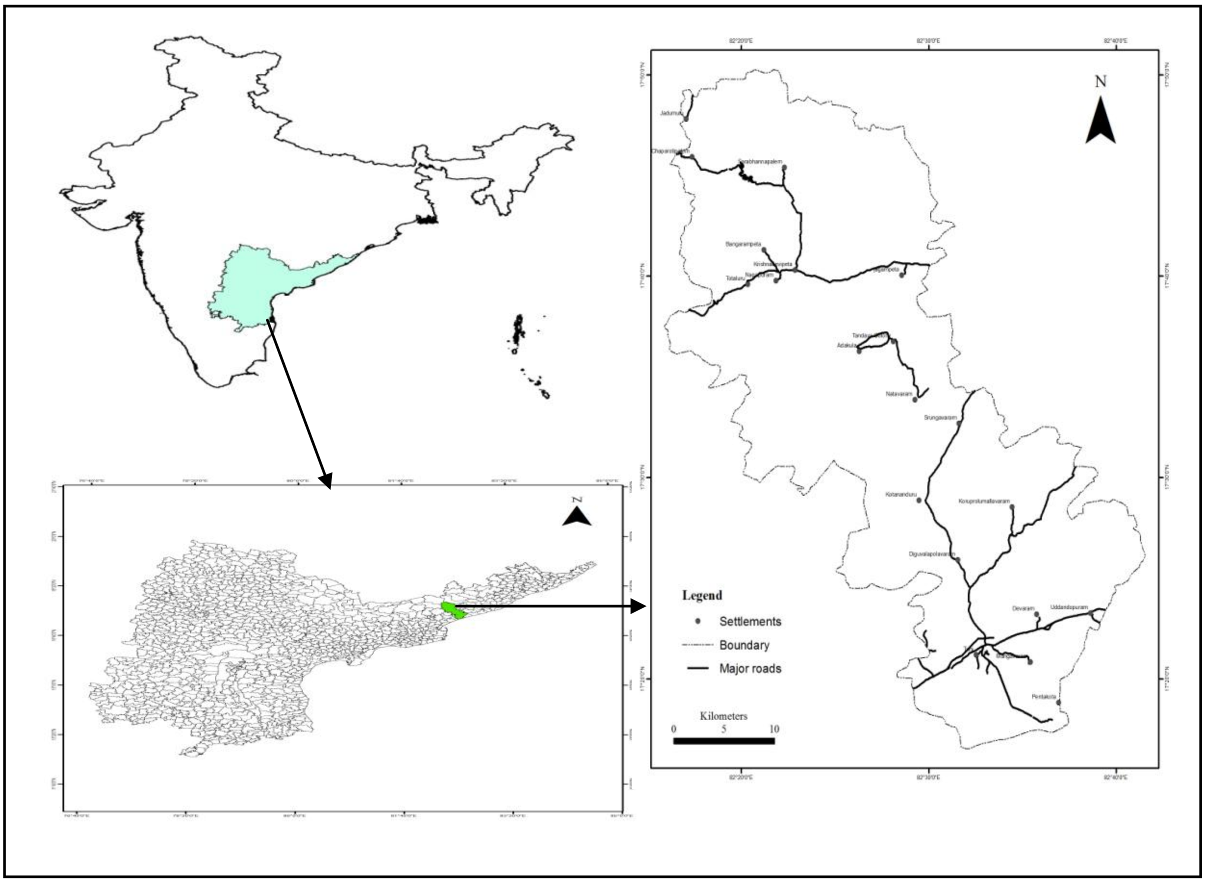

Figure 1: Location map of the study area

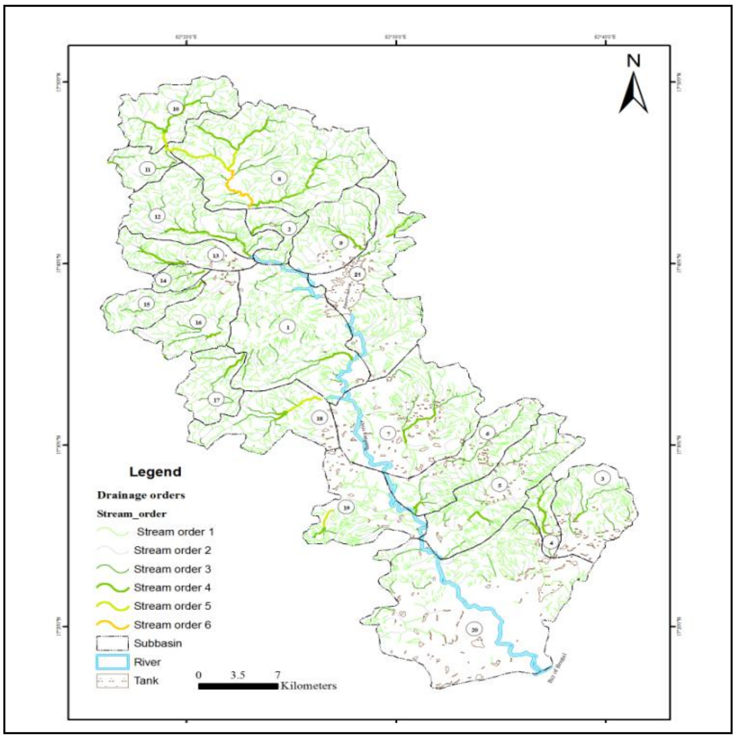

Figure 2: Drainage network of Tandava river basin

III. METHODOLOGY

This work is based on map analysis carried out onscreen digitization. Toposheet number 65; K/5, K/6, K/7, K/10 and K/11 with the scale of 1:500,000. (Survey of India) were mosaic to subset the study region. The subset image is geometrically corrected through the process of rectification. Strahler's, Horton's and Schumm's methods have been employed to assess the fluvial characteristics of the study region [4, 15 and 15]. The maps were georeferenced and digitized using the Arc GIS 9.3 and Erdas Imagine 9.1 GIS software's and attributes were assigned to create the digital database. The map showing drainage pattern in the study area (Figure 2) was prepared after detailed inspection view with ASTER 30m resolution DEM and SRTM 90m resolution data. Morphometric analysis was carried out at sub basin level in the Spatial Analysis GIS System (ArcGIS version. 9.3). Based on the drainage order, the drainage channels were classified into different orders [18]. In GIS, drainage channel segments were ordered numerically as order number 1 from a stream's headwaters to a point downstream. The stream segment that results from the joining of two first order streams was assigned order 2. Two second order streams formed a third order stream and so on. The sub basin area, perimeter, cumulative length of streams and basin length were measured in GIS and are expressed as A, P, L and L_b respectively. Parameters such as drainage density, bifurcation ratio, stream frequency (F_u), texture ratio, form factor (R_f), circulatory ratio (R_c), elongation ratio (R_e) and constant of channel maintenance (C) were evaluated with established mathematical equations [15]. Watershed prioritization has been done based on the value obtained from Morphometric parameters.

IV. RESULTS AND DISCUSSIONS

Various morphometric result of Tandava river basin using ArcGIS 9.3 and watershed prioritization has been generated. The basin area is divided into 21 sub-basins of fourth order streams. Orders above the fourth were disregarded because the relatively small sample of these streams is less reliably representative than those of the lower order [14].

Table 1: Area and perimeter of sub-basin of Tandava River Basin

Sub-Basin	Area	Perimeter
1	113	49
2	17	25
3	51	31
4	14	20
5	74	47
6	54	41
7	61	39
8	111	44
9	140	56
10	74	43
11	46	35
12	17	20
13	60	43
14	30	30
15	10	13
16	23	24
17	43	32
18	31	27
19	53	41
20	55	39
21	206	74

IV.I LINEAR ASPECT

The first step in drainage basin analysis is designation of stream orders. The channel segment of the drainage basin has been ranked according to Strahler stream ordering system using ArcGIS 9.3. The study area is 6^{th} order drainage basin [15] (figure 2). The total number of (3882) streams identified of which 2851 are 1^{st}

order which is 73.44%, 828 are 2nd order which amounts 21.32%, 176 are 3rd order which is 4.53% and 27 in 4th order which is 0.69% .

Stream length is one of the most significant hydrological features of the basin as it reveals surface run-off characteristics streams of relatively smaller lengths are characteristics of areas with larger slopes such as sub-basin 2, 4, 10, 11, 14, 15 and 18 shows large slope and finer texture. Longer lengths of streams are generally indicative of flatter gradients. Generally the total length of streams segments is maximum in first order streams and decreases as the stream order increases. The relationship between stream order Vs log of number of stream and log of total length was examined (fig. 3a & b), it seems to be in geometric progression and agree with Horton's law of stream length, which states that the "The Cumulative Length of stream segment of successive orders tend to form a geometric series beginning with the mean length of the first order segment and increasing according to a constant length ratio". Slight deviation from its general behavior between the third and forth orders and between the fourth and fifth orders indicate that the terrains is characterized by variation in lithology and topography. The stream length (L_u) of order U is obtained by the total length of streams of order U divided by the number N_U. Horton [4] reveals the characteristic size of components of a drainage network and its contributing basin surface. The total length of stream decreases with increasing order of stream.

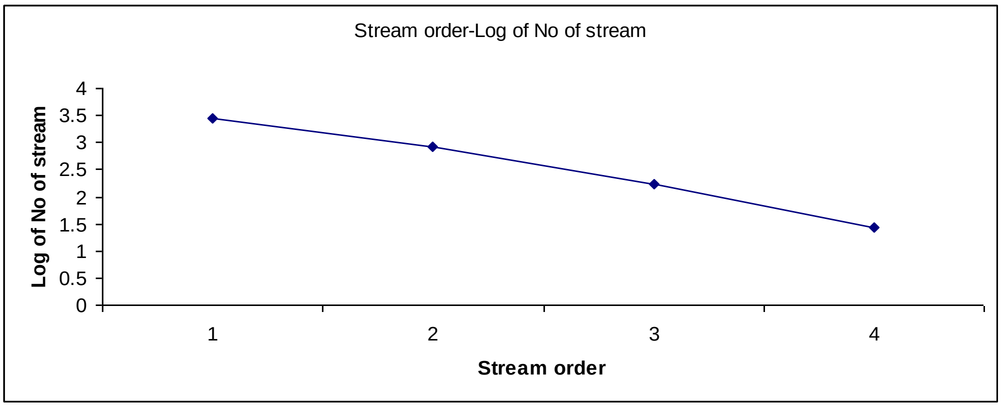

Figure 3: a) Stream order VS Log of No. of streams

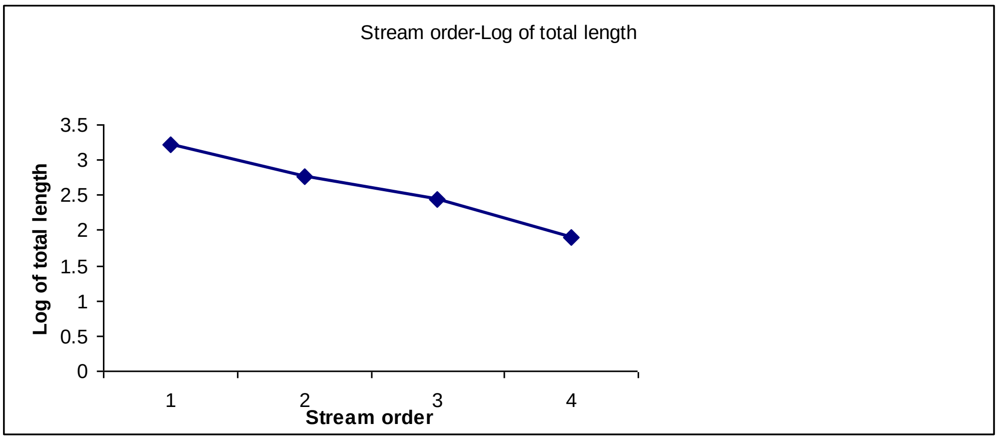

Figure 3: b) Stream order VS log of total length

IV.II Areal Aspects

IV.II.I **Drainage density (D_d):** Drainage density is the total length of all the streams in the watershed to the area of watershed. It helps in determining the permeability and porosity of the watershed and an indicator of landform elements in stream eroded topography. Thus, it concludes that the drainage density increase with the decrease in areal coverage and the soil moisture in the region remains more. Similarly, as the drainage density decrease the area of the intrabasin increase and soil moisture decreases and the area occurs and agriculture depends on rainfall. The drainage density of the Tandava River basin is 0.702 km^{-1}. High drainage density is the result of weak or impermeable surface materials, sparse vegetation, and mountainous relief. Low drainage density leads to coarse drainage texture [15].

The drainage density of the study area is 0.702 km/ km^2. This value indicates that for every square kilometer of the basin, there is 0.702 kilometer of stream channel. In other word, 0.702 is the mean length of stream channel for each unit area. According to Deju values of drainage density under 0.5 are poor density; those with values of 0.5 to 1.5 are medium density basins while basins with values above 1.5 are excellent (high) density basins [1]. From this classification, Tandava River Basin falls into the group of medium density basins. It is suggested that the poor (low) drainage density in sub-basin 8, 9, 10, 11, 13, 14, 17, 19 and 21 indicates the sub-basins is highly permeable subsoil and thick vegetative cover [10].The type of rock also affects the drainage density.

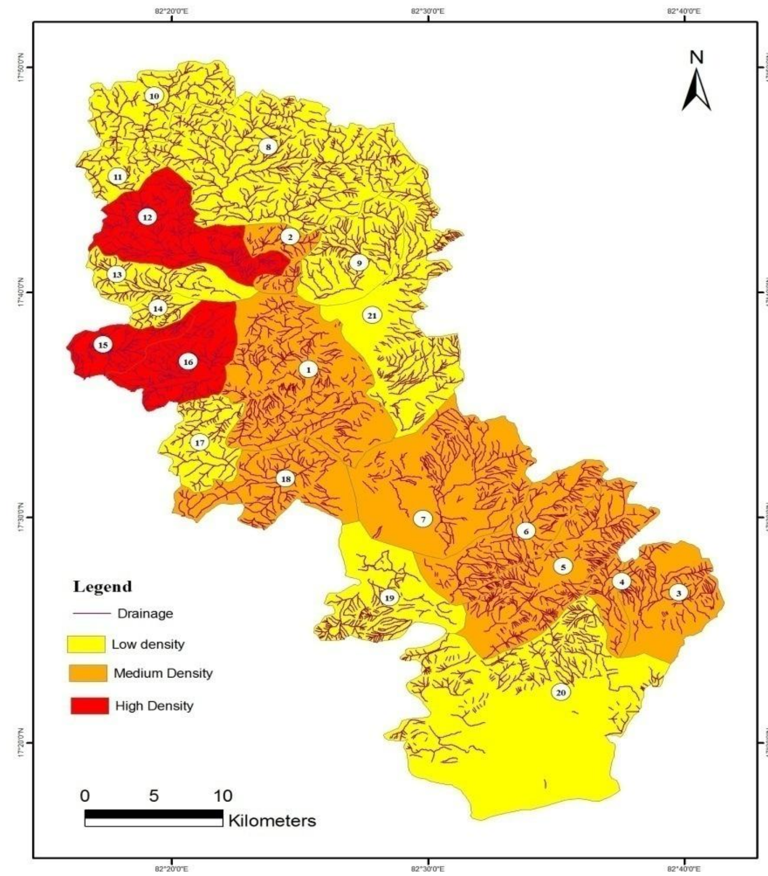

Figure 4: prioritized Drainage density of Sub - Basins

IV.II.II **Stream frequency (Fu):** Stream frequency is the ratio of number of streams in a watershed to the area of the watershed [5]. The Tandava area has a stream frequency of 85.267 streams per km. The value of stream frequency for the basin exhibit positive correlation with the drainage density value of the area indicating the increase in stream population with respect to increase in drainage density.

IV.II.III **Drainage Texture (T):** The drainage texture may be defined as the relative spacing of drainage lines. The drainage density and drainage frequency have been collectively defined as drainage texture. Based on the values of T it is classified as [13]:

0 – 4 – Coarse
4 – 10 – Intermediate
10- 15 – Fine
>15 – Ultra Fine (bad land topography)

IV.II.IV **Texture ratio:** Texture ratio is obtained by dividing the number of streams of the given basin by the perimeter of the same basin and is measured in streams per Km. The texture ratio in the present area has been calculated by taking first order intrabasins as the smallest unit. The first order streams being the maximum in number, they are considered to be equivalent number to crenulations in the present investigation. The texture ratio directly or indirectly reflects the drainage density. It has been generally marked that the texture ratio increases with the increase in the area of the intrabasins.

The texture and texture ratio are calculated for the 21 sub-basins. The value varies from low of 0.193 for Sub-basin No. 9 to high 31.71 for Sub-basin No. 12. For Tandava basin the mean drainage texture ratio is 3.765 indicating the massive and resistant rocks cause coarse texture. Coarse drainage density is likely to appear in areas of permeable rocks and low rainfall intensity. A drainage basin in humid regions often shows medium drainage density. The value of Weighted mean texture ratio(T_m) for Tandava river basin is 0.174. Thus, the weighted mean topographic texture (0.18) of Tandava river basin is a coarse texture.

IV.II.V **Bifurcation ratio (Rb):** Horton [4] had defined the bifurcation ratio as the ratio of the number of streams of an order to the number of those in the next higher order. According to Strahler [15], the values of bifurcation ratio characteristically range between 3.0 and 5.0 for watershed in which the geological structures do not disturb the drainage pattern. The bifurcation ratio varies with the variations in watershed geometry and lithology and displays geometric similarity. The bifurcation ratio is estimated to be 5.17; on the average, there are 3 times as many channel segments of any given order as of the next higher order. It varies between 2.97 and 10.60, which indicates the control of the lithology and geologic structures giving rise to the distorted trellis drainage pattern and the geological disturbances such as faults and folds are encountered frequently in the sub-basin 1, 5, 6, 7, 8, 11, 12, 20 and 21 and hence, the mean bifurcation ratio of all 21 sub-basin lies between 2.97 and 10.60.

Miller [7], Strahler [15], opined that lithological variations do not cause differences in bifurcation ratio. Because of chance of irregularities, bifurcation ratio between successive orders differ within the same basin even if a general observance of a geometric series exists [12], thus, the bifurcation ratio of the first, second and third orders differ from each order in each of the sub-basin. In the present study, the higher values of Rb indicates strong structural control on the drainage pattern, while the lower values indicative of sub -basin that are not affect by structural disturbances.

IV.II.VI **Elongation Ratio:** Basin elongation is the ratio between the diameter of the area occupied by the basin and the maximum length measured for the same basin. In other words elongation ratio is the representative of the shape of the basin. It is a very significant index in the analysis of basin shape which helps to give an idea about the hydrological character of a drainage basin. Values of elongation ratio ranging between 0 and 0.6 indicate rotundity and low degree of integration within a basin and values between 0.6 and 1.0 assumes pear shaped characteristics of a well integrated drainage basin [15]. Smaller the fraction more elongated is the shape of the basin, and larger the fraction the more circular is the shape of the basin. It is generally marked that the elongation ratio remains high where rock strata is hard and slope remains steep. The elongation ratio value of the study area is 0.172; the basin in the study area assumes a rotundity and low degree of integration characteristics.

IV.II.VII **Circulatory ratio (R_c):** Miller [8] defined circulatory ratio R_c, as the ratio of basin area A_u to the area of circle A_C having the same perimeter as the basin. The circulatory ratio of the Tandava River Basin is 0.505. He described the basin of the circularity ratios range 0.4 to 0.5 which indicates strongly elongated and highly permeable homogenous geological materials. The circularity ratio value(0.505) of the basin does not corroborates the Miller's range which indicated that the basin is weakly elongated in shape, high discharge of runoff and highly impermeability of the subsoil condition but rather the basin of the study area is rotundity and low degree of integration characteristics.

IV.II.VIII **Form factor (R_f):** The ratio of the basin area to the square of basin length is called the form factor. The form factor of the Tandava River Basin is 0.12 km^{-1}. It is used as a quantitative expression of the shape of basin form which is stretched elliptical. The form factor for all sub-basins varies from 0.01 – 0. This observation shows that the sub-basins are more or less circular. The elongated Sub-basins with low value of R_f indicates that the basin will have a flatter peak flow for longer duration. Flood flows of such circular basins are difficult to manage than from the elongated. Among Tandava Sub-basins; Sub-basin 14 with the form factor 0.6 seems to be highly elongated when compared to other Sub-basins of the River basin. Analysis of form factor (R_f) reveals that sub-basins having low R_f have less side flow for shorter duration and high main flow for longer duration. The sub-basins with high R_f have side flow for longer duration and low main flow for shorter duration causing high peak flows in a shorter duration.

Table 2: Morphometric parameters

Sub-Basins	D_b	Average R_b	F_u	R_e	R_f	R_c	T	C
1	0.548	6.242	3.274	0.102	0.033	0.591	5.653	1.825
2	0.829	4.263	4.471	0.215	0.145	0.342	2.200	1.207
3	0.534	4.771	2.549	0.166	0.086	0.667	3.226	1.874
4	0.897	6.657	4.000	0.254	0.203	0.440	1.900	1.115
5	0.683	3.391	4.149	0.104	0.034	0.421	5.170	1.464
6	0.710	3.889	6.259	0.115	0.041	0.403	3.561	1.409
7	0.738	5.954	3.738	0.105	0.035	0.504	4.385	1.354
8	0.282	9.244	4.477	0.071	0.016	0.720	8.705	3.548
9	0.211	7.005	0.914	0.259	0.211	0.561	1.732	4.735
10	0.243	10.605	1.892	0.175	0.097	0.503	2.535	4.119
11	0.175	4.727	1.239	0.331	0.344	0.472	1.200	5.722
12	2.484	3.689	12.765	0.060	0.011	0.534	8.200	0.403
13	0.395	4.299	1.483	0.255	0.204	0.408	1.512	2.534
14	0.341	4.067	1.400	0.438	0.603	0.419	1.033	2.932
15	1.753	4.070	9.800	0.121	0.046	0.743	5.231	0.570
16	1.168	3.254	5.783	0.115	0.041	0.502	4.292	0.856
17	0.486	5.227	2.349	0.204	0.131	0.527	2.469	2.057
18	0.512	5.862	4.419	0.123	0.047	0.534	3.593	1.953
19	0.457	3.857	3.094	0.146	0.067	0.396	3.073	2.187
20	1.035	4.627	6.036	0.080	0.020	0.454	6.821	0.966
21	0.254	2.972	1.175	0.180	0.102	0.472	2.581	3.943

V. WATERSHED PRIORITIZATION

Drainage density, bifurcation ratio, stream frequency, elongation ratio, form factor can be termed as erosion risk assessment Morphometric parameters and have been used to prioritize Sub-basins [17]. Additionally, soil erosion has direct relationship with linear aspects. Therefore, the parameter of higher value indicates the possibility of soil erosion.

The sub-basins of higher value of drainage density, stream frequency and bifurcation ratio are much more susceptible for soil erosion. Consequently, the higher value was rated as rank 1, second highest value was rated as rank second and so on. Shape parameters like elongation ratio, form factor and basin shape have inverse relationship with soil erosion [18]. Thus, lower value of shape parameter is an indication of higher risk of erodability.

Table 3: Final prioritization of Tandava River basin

Sub-Basins	D_b	Average R_b	F_u	R_e	R_f	R_c	T	C	Compound parameter	final priority
1	10	5	12	4	4	18	4	12	8.625	4
2	6	13	7	16	16	1	16	16	11.375	12
3	11	9	14	12	12	19	11	11	12.375	15
4	5	4	10	17	17	7	17	17	11.75	14
5	9	19	9	5	5	6	6	13	9	7
6	8	16	3	8	8	3	10	14	8.75	5
7	7	6	11	6	6	13	7	15	8.875	6
8	17	2	6	2	2	20	1	5	6.875	2
9	20	3	21	19	19	17	18	2	14.875	19
10	19	1	16	13	13	12	14	3	11.375	13
11	21	10	19	20	20	9	20	1	15	20
12	1	18	1	1	1	15	2	21	7.5	3
13	15	12	17	18	18	4	19	7	13.75	17
14	16	15	18	21	21	5	21	6	15.375	21
15	2	14	2	9	9	21	5	20	10.25	9
16	3	20	5	7	7	11	8	19	10	8
17	13	8	15	15	15	14	15	9	13	16
18	12	7	8	10	10	16	9	10	10.25	10
19	14	17	13	11	11	2	12	8	11	11
20	4	11	4	3	3	8	3	18	6.75	1
21	18	21	20	14	14	10	13	4	14.25	18

Based on analysis, ranks have been given to each shape parameter. The ranking values of all the parameters were added to assign final weightage and prioritized classification has been done as per Table 2. The final priority weightage have been divided into 3 major classes (High, Medium & Low Priority). The final prioritization map of study area and prioritization ranks of sub-basins are shown in figure 5. The analysis reveals that, sub-basins 9, 11, 13, 14, 17 and 21 should get a highest priority for basin development and management. Highest priority indicates the greater degree of erosion in the particular sub-basins and it becomes potential area for applying soil conservation measures. Thus, soil conservation to be applied first to 9, 11, 13, 14, 17 and 21 sub-basins followed by other sub-basins.

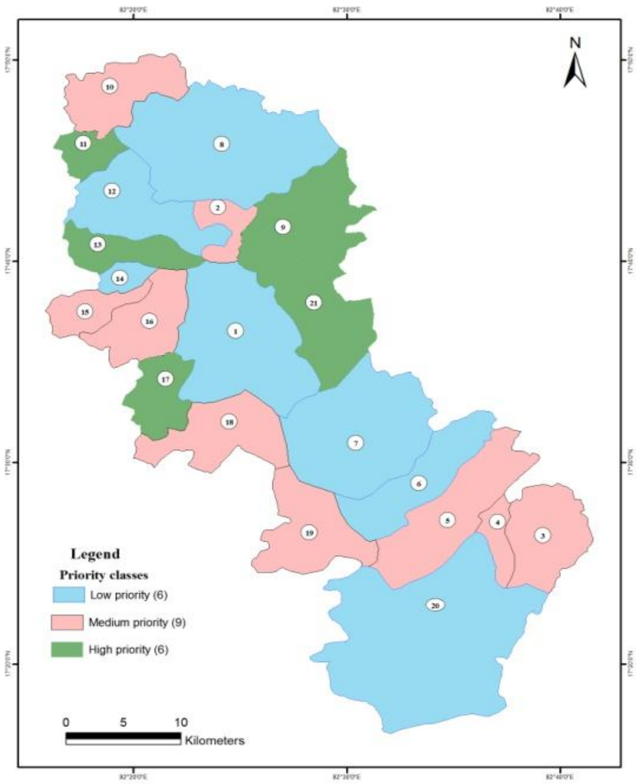

Figure 5: final prioritization of Tandava river basin

VI. CONCLUSIONS

The derived morphometric parameters of the study area are closely following with the values obtained in similar terrain conditions [16]. The morphometric parameters evaluated using GIS helped to understand various terrain parameters which helps prioritization of watershed development. Similar studies in conjunction with Land use land cover and geomorphology help in better understanding the landforms and watershed prioritization development for basin area planning and management.

The study reveals that watershed prioritization study has great used for watershed management, EIA (environment impact analysis), slope stability plan, disaster management plan and prevention . The analysis reveals that, sub-basins 9, 11, 13, 14, 17 and 21 should get a highest priority for basin development and management.

VII. ACKNOWLEDGEMENTS

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