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Morphometric Analysis of the Paderu Mandal sub-watersheds with Geospatial Approach

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Abstract- The present study deals with Morphometric analysis of a sub-watershed which provides a quantitative description of the drainage system within the Paderu mandal located in the Visakhapatnam district, Andhra Pradesh. There are in total thirteen medium and minor sub-watersheds, whose stream order is up to fourth order, delineated from the drainage map of the study area of 435km^2. Quantitative morphometric analysis has been carried out for linear, relief and aerial aspects for all the sub-watersheds using GIS analysis. In this study, the linear parameters including stream order, stream length, stream length ratio and bifurcation ratio have been calculated to demonstrate the state of each sub-watershed. Aerial parameters include area, perimeter, stream frequency, drainage density, constant of channel maintenance, drainage texture, form factor, elongation ratio and circulatory ratio. The relief aspects include the analysis of maximum relief, relative relief, and ruggedness number. Elongated Ratio (Re), Circulatory Ratio (Rc) and Form Factor (Rf) are used for characterizing drainage watershed shape.

Index Terms- Morphometry; Terrain; Geomorphology; Sub-watersheds; Linear; Aerial; Relief.

1. INTRODUCTION

Morphometry is the measurement and mathematical analysis of the earth's surface, shape and dimension of its landforms. Quantitative morphometric characterization of a drainage basin is considered to be the most appropriate method for the proper planning and management of watershed, because it enables us to understand the relationship among different aspects of the drainage pattern of the basin and also to make a comparative evaluation of different drainage basins, developed in various geologic and climatic regimes. The morphometric analysis gives valuable information about its formation and development because of all hydrologic and geomorphic processes occur within the drainage basin. This requires measurement of linear features, aerial aspects, gradient of channel network and contributing ground slopes of the drainage basin (Nag and Chakraborty, 2003). The study of stream order is the prior important to help in identifying the natural environment with the geological and structural setup of the area; to get idea of the size, shape and strength of specific waterways within drainage network; important component to water resources development and management ; characterization and prioritization of watershed; to understand the behaviour of rivers, its aggregation or degradation, shifting of the river course, erosion of river bank etc and to plan remedial measure for erosion and other related problems. The composition of the stream system of a drainage basin is expressed quantitatively with stream order, drainage density, bifurcation ratio and stream length ratio. It incorporates a quantitative study of the various components such as stream segments, basin length, basin parameters, basin area, altitude, volume, slope and profiles of the land which indicates the nature of the development of the basin.

Many researchers have used the principles of Geographical Information System (GIS) and Remote Sensing techniques using satellite images to quantitatively study the drainage watershed as a convenient tool for morphometric analysis (Sharma 1987; Raj et. al., 1999; Awasthi and Prakash 2001; Phukon 2001; Sinha Roy 2002; Srivastava 1997; Nag 1998; Vittala et al., 2004; Srinivasa et al., 2004; Das and Mukhrjee 2005; Nookaratnam et al., 2005; Thakkar and Diman 2007; Akram Javed et al 2009; Sharma et al 2010; Somashekar and Ravikumar 2011, Jenita Mary Nongkynrih, and Zahid Husain 2011;Yasmin et al 2013). Advancement in Geospatial technology boosts the researcher to add many more variables to understand the interlinked phenomena with drainage morphometry i.e land use and land cover change. The main objectives of the study were to discover holistic stream properties viz linear , aerial and relief aspects from the measurement of various stream attributes for the Paderu Mandal catchment.

2. STUDY AREA

The spatial extent of the catchment lies between latitudes 18° 18'N –17° 56' N and longitudes 82° 32'E –82° 53' E, covering an area of 435 km^2 shown in Figure 1. The study area is a part of the eastern ghats, comprising undulating plains, hills and narrow valleys; altitude ranges from minimum of 200 m to as high as 1,600 m with an average of 904meters with respect to mean sea level.

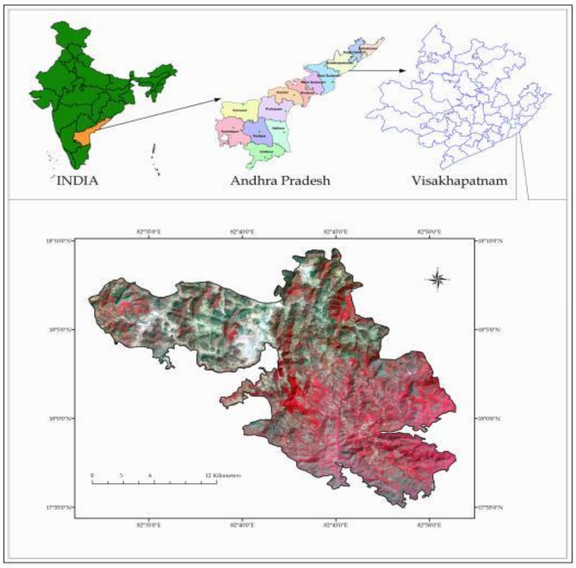

Figure 1: Location Map showing imagery of IRS P6 of the study area

A good number of springs exist in Paderu area, most of the drainage is characterized by sub-dendritic to dendritic nature with coarse texture and density is in the range of 0.6 to 1/Km^2. Many of the hill streams in Paderu valley disappear on entering the plains due to high permeability of the pediment gravels. The valley fill areas underlain by weathered formations in this area possess high infiltration and high permeability. These areas form good to moderate aquifers depending on their thickness. The disappearance of streams in and along the hill slopes is contributing to the ground water, which is again discharged through the silty soils at lower elevations.

3. MATERIALS AND METHODS

The toposheets used in the study (65K9, 65K13, 65J12 & 65J16) are geo-rectified and projected to polyconic projection (The Metric system unit– meter is used in the present study). The Paderu Mandal administrative boundary map has been scanned and saved in .jpg format and then it is imported into a .img format and referenced to polyconic projection using ERDAS Imagine software. Digitized study area boundary and drainage channels in watersheds and sub-watersheds were obtained in due course from a toposheet of scale 1: 50,000 and verified by ground truthing. Necessary corrections were made and checked in the field with the help of GPS. The area (Au), the length of the watershed (Lb) and perimeter (P) of sub-watersheds were also obtained. All the measurements were directly computed from the vector data that were extracted from topographic maps. All the drainage segments were digitized as lines separately for each order. There are totally 13 sub- watersheds streams delineated from the drainage map of Paderu (Figure 2).

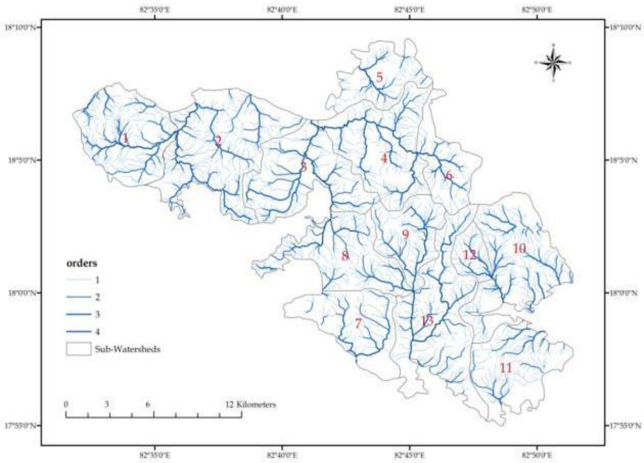

Figure 2: Sub-watersheds delineated from the drainage map of the study area

4. RESULTS AND DISCUSSIONS

The various morphometric parameters of the Paderu Mandal area were determined and are summarized below with Tables 1 to 3.

4.1 Linear aspects

Linear aspects of the basin are related with the channel patterns of the drainage network. This includes stream order, stream length, mean stream length, stream length ratio, bifurcation ratio and mean bifurcation ratio (Table 1).

4.1.1 Stream order (Su)

Strahler's system for ordering streams has been followed. In the present study area it has been retrieved that the highest order is fourth order. The largest area of all the sub-watersheds is of sub watershed 2 which is 55.267 km^2 and the longest perimeter is of sub watershed 13 which is 53.817 km.

4.1.2 Stream number (Nu)

In this present study, all the streams of sub-watersheds are counted and tabulated for the analysis from the Attribute Table of the vector layer. The number of streams N2 is less than N1 but more than N3. The total number of streams decreases as the stream order increases which is observed to be true in all the sub-watersheds. Totally 2052 stream segments exist in the study area, out of which 74.41% of segments (1527) comes under I order stream, 19.20% of segments (394) in II order, 5.40% of segments (111) in III order and 0.97% of segments (20) in IV order stream respectively. Sub-watershed 10 has the highest number of streams (294) whereas sub-watershed 12 has the lowest number of streams (48). In the case of Paderu mandal sub-watersheds, the stream segments of various orders show variation. This change may indicate the flow of streams from high altitude, lithological variation, and moderately steep slopes.

Table 1: Linear morphometric parameters

Sub-basin	**Stream Order (Nµ)**					**Stream Length (Lµ)**					**Mean Stream Length Lsm = Lµ/Nµ**				**Stream length ratio**			**Bifurcation Ratio Rb = Nµ / Nµ +1**			**Mean Bifurcation Ratio**
	1st	2nd	3rd	4th	Total	1st	2nd	3rd	4th	Total	1st	2nd	3rd	4th	1st	2nd	3rd	Rb1	Rb2	Rb3	
1	139	78	9	1	227	71.73	22.36	12.07	6.25	112.41	0.51	0.28	1.34	6.25	0.55	4.79	4.66	1.78	8.66	9.00	6.483
2	219	51	9	2	281	104.12	29.37	21.3	4.5	159.29	0.47	0.57	2.36	2.25	1.21	4.14	0.95	4.29	5.66	4.50	4.820
3	104	26	6	2	138	53.65	20.41	16.32	5.09	95.47	0.51	0.78	2.72	2.54	1.53	3.49	0.93	4.00	4.33	3.00	3.778
4	118	29	9	2	158	68.87	13.16	12.62	3.7	98.35	0.58	0.45	1.40	1.85	0.78	3.11	1.32	4.06	3.22	4.50	3.930
5	89	16	5	1	111	36.55	10.11	2.57	2.17	51.4	0.41	0.63	0.51	2.17	1.54	0.81	4.25	5.56	3.20	5.00	4.588
6	80	16	6	1	103	34.16	7.58	5.18	2.26	49.18	0.42	0.47	0.86	2.26	1.12	1.83	2.63	5.00	2.66	6.00	4.556
7	76	17	9	2	104	37.22	13.01	7.89	2.62	60.74	0.49	0.76	0.87	1.31	1.55	1.14	1.51	4.47	1.88	4.50	3.620
8	119	30	7	1	157	67.18	22.67	11.84	0.7	102.39	0.56	0.75	1.69	0.7	1.34	2.25	0.41	3.96	4.28	7.00	5.084
9	79	19	6	1	105	44.18	12.67	5.98	5.01	67.84	0.55	0.66	0.99	5.01	1.20	1.50	5.06	4.15	3.16	6.00	4.442
10	223	50	19	2	294	100.57	26.14	13.28	0.76	140.75	0.45	0.52	0.69	0.38	1.16	1.33	0.55	4.46	2.63	9.50	5.531
11	106	21	8	1	136	58.68	17.98	4.81	0.42	81.89	0.55	0.85	0.60	0.42	1.55	0.71	0.70	5.04	2.62	8.00	5.224
12	31	9	7	1	48	18.39	4.53	4.69	0.09	27.7	0.59	0.50	0.67	0.09	0.85	1.34	0.13	3.44	1.28	7.00	3.910
13	144	32	11	3	190	74.15	25.74	9.49	6.69	116.07	0.51	0.80	0.86	2.23				4.50	2.90	3.66	3.692
Total	1527	394	111	20	2052	769.45	225.73	128.04	40.26	1163.48											

4.1.3 Stream length (Lu)
The stream length in each order increases exponentially with increasing stream order. The total length of the stream in Paderu basin is 1163.48Km in which the highest first order, then second order, third order, and fourth order stream lengths are 769.45Km, 225.73Km, 128.04Km and 40.26Km respectively which define more undulating topography.

4.1.4 Mean stream length (Lu)
The mean stream length of study area ranges from 0.09km to 6.25km. Highest Lu is noted for 4th order stream. The mean stream length increases with the stream order but in some sub-watershed higher order streams have small mean length.

4.1.5 Stream length ratio (RL)
The stream length ratio of the area varies from 0.13 to 5.06. The change in RL from one order to another indicates their late youth stage of geomorphic cycle of watersheds. The RL between streams of different orders in the study area reveals that there is a variation in each sub-watershed. This variation might be due to changes in slope.

4.1.6 Bifurcation ratio (Rb)
The Bifurcation Ratio is a dimensionless property and generally ranges between 3.0 and 5.0. From the analysis, it is noticed that for all the stream orders in the study area, the Rb is more than 3.0. This indicates that in the study area, the drainage pattern is strongly influenced by its structural elements.

4.2 Watershed geometry
The following are the important parameters which are included in the watershed geometry.

4.2.1 Watershed length (Lb)
The length of the study area was determined in accordance with the Lb definition as suggested by

Schumm (1956) and found to be 413.97 km. Sub-watersheds 2, 10, and 13 have the lengths, the longest of all, i.e. 45.983 km, 43.888 km, and 53.817 km respectively and the watershed 12 has the shortest watershed length of 11.533 km.

Dd is the density of drainage,
ΣLu is the total stream length
A is the watershed area.

Table 2: Areal morphometric parameters

Sub-basin	Area	Perimeter	Stream Frequency Fs = Nμ/A	Drainage Density Dd = Lμ/A	Const. of Channel Maint.	L.O.F L_o (0.5/D_d)	Drainage Texture T (F_u*D_d)	Drainage Texture Ratio T_u (N/P)	Texture of the topography	Form Factor ($R_f = a/l^2$)	Elongation Ratio Re= √A /π / Lb	Shape of Watersheds	Circularity Ratio Rc = 4πA/ P2
1	34.642	23.516	6.552	3.244	0.308	0.154	21.260	9.653	Fine	0.002	0.059	Elongated	0.786
2	55.261	45.983	5.084	2.882	0.346	0.173	14.654	6.111	Fine	0.002	0.053	Elongated	0.328
3	19.916	24.644	6.929	4.793	0.208	0.104	33.215	5.600	Medium	0.002	0.053	Elongated	0.411
4	40.726	32.197	3.879	2.414	0.414	0.207	9.367	4.907	Medium	0.004	0.073	Elongated	0.493
5	39.350	33.241	2.820	1.306	0.765	0.382	3.683	3.339	Medium	0.014	0.138	Elongated	0.447
6	22.82	28.194	4.601	2.197	0.455	0.227	10.109	3.653	Medium	0.009	0.109	Elongated	0.353
7	30.307	25.622	3.431	2.004	0.498	0.249	6.876	4.059	Medium	0.008	0.102	Elongated	0.579
8	34.768	37.968	4.515	2.944	0.339	0.169	13.296	4.135	Medium	0.003	0.065	Elongated	0.302
9	22.559	22.106	4.654	3.007	0.332	0.166	13.995	4.750	Medium	0.004	0.079	Elongated	0.579
10	43.759	43.888	6.718	3.216	0.310	0.155	21.608	6.699	Fine	0.002	0.053	Elongated	0.285
11	32.105	31.248	4.236	2.550	0.392	0.196	10.804	4.352	Medium	0.004	0.078	Elongated	0.412
12	9.923	11.533	4.837	2.791	0.358	0.179	13.502	4.162	Medium	0.012	0.128	Elongated	0.937
13	49.302	53.817	3.853	2.354	0.424	0.212	9.070	3.530	Medium	0.003	0.068	Elongated	0.213
	435	413.957	6.552	3.244	0.308	0.154							

4.3 Areal aspect

The total sub-watershed area was calculated and found to be 435 km^2. The largest area of all the sub-watersheds is sub-watershed 2 (55.267 km^2) and smallest is sub-watershed 3 (19.916km^2). The information of hydrologic importance on fluvial morphometry is derived by the relationship of stream discharge to the area of the watershed. (Table 2).

4.3.1 Drainage density (Dd)

Drainage Density is computed using spatial analyst tool in ArcGIS 10.1. About 18.06 % is under low drainage density (< 2km/km^2), medium (2–3 km/km^2) is 49.67% and high density (> 3 km/km^2) is 32.24 % of total study area .The Dd value of this study area is 2.746 km/km^2, indicating moderate density. The moderate drainage density value suggests that Paderu Mandal has moderately permeable subsoil and a thick vegetative cover. Drainage density is calculated as

$$Dd = \Sigma Lu/A \qquad \text{Eq. (1)}$$

Where,

4.3.2 Stream frequency (Fs)

In the study area, the sub-watershed 3 has high stream frequency of 6.929 and the sub-watershed 5 has low stream frequency of 2.820 .It was also noticed that there is a decrease in frequency as the stream order increases. The sub-watersheds 1, 2, 3, 6, 8, 9, 10, and 12 have very high stream frequency and sub-watersheds 4, 7, 11, and 13 have high stream frequency whereas sub-watershed 5 has moderate stream frequency.

4.3.3 Texture ratio (Tu)

The study reveals that the texture ratio is very fast in dealing with morphometric conditions of a region. Study area shows variations of texture ratio from 3.339 to 9.653. Texture ratio is the highest value 9.653 for sub-watershed 1 and lowest value 3.339 for sub-watershed 5. The study area resides on medium texture. The ratio for course, medium, fine, and ultrafine textured topography was suggested by Smith (1950).According to his classification the sub-watersheds 1, 2, and 10 have fine texture (6.0-30.0) whereas the sub-watersheds 3, 4, 5, 6, 7, 8, 9, 11, 12,

and 13 have medium texture. More is the texture more results in dissection and soil erosion.
Texture Ratio Tu is given as:

$$Tu = Nu/p \qquad \text{Eq. (2)}$$

Where,
Nu is the number of streams of order u
P is perimeter of the watershed

4.3.4 Watershed shape
The shape of the watershed mainly governs the rate at which the water is supplied to the main channel. Three parameters viz. Elongated Ratio (Re), Circulatory Ratio (Rc) and Form Factor (Rf) are used for characterizing drainage watershed shape which is an important parameter from a hydrological point of view.

4.3.5 Elongation ratio (Re)
The value of Elongation Ratio varies from 0 (highly elongated) to 1.0 (circular shape). Values close to 1.0 are typical of regions of very low relief, whereas that 0.05 to 0.13 are usually associated with low relief and narrow ground slope (Strahler, 1964). In the study area all the sub-watersheds have Elongation Ratio less than 0.138, so they are expected to be in elongated shape with low relief.

4.3.6 Circulatory ratio(Rc)
The values of circularity ratio vary from 0(line) to 1(in a circle). The circulatory ratio for all watersheds is in the range of 0.213-0.937.In the study area the sub-watershed 13 shows the lowest ratio 0.213, which results in low drainage pattern, drainage density, stream length, stream frequency and topography slope (Sidhu and Pande, 1974) whereas the sub watershed 12 has the highest value of circulatory ratio 0.937, which implies high drainage pattern, drainage density, stream length, stream frequency and topography slope Naturally, all the watersheds tend to become elongated to get the mature state.

4.3.7 Form factor (Rf or Ft):
In the study area the value of form factor is in between 0.002-0.014. Smaller the value of form factor, more elongated will be the watershed. The watersheds with high Form Factor values have high peak flow of shorter duration, whereas, elongated drainage watersheds with low Form Factors have a lower peak flow of longer duration. So, the Paderu area drainage sub-watersheds have flatter peaks of flow for longer duration that is easier to manage than of circular watersheds.

4.4 Relief aspects
Relief Aspects of drainage watershed relate to three-dimensional features of the watershed involving area, volume and altitude of the vertical dimension of landforms wherein different morphometric methods are used to analyse terrain characteristics. In the present study area the sub watersheds 10 and 13 are having highest relief and sub watershed 2 is having lowest relief (Table 3).

4.4.1 Basin relief (H)
Basin Relief is the elevation difference between the highest and lowest point of the area.
In the study area, the highest basin relief is of sub-watershed 13 (1340) and the lowest basin relief is of sub-watershed 2(483).

4.4.2 Relief ratio (Rh)
In the study area, the maximum relief ratio is of sub-watershed 12(231.48) and the minimum relief ratio is of sub-watershed 2(48.25).The high values of Rh indicate steep slope and high relief and vice-versa. Relief controls the rate of conversion of potential energy to the kinetic energy of water draining through the basin.

4.4.3 Ruggedness number (HD)
In the study area, the highest ruggedness number is of sub-watershed 11 (0.951) and the lowest ruggedness number is of sub-watershed 2 (0.371).Extremely high values of ruggedness number occur when slopes of the basin are not only steep but long as well.

5. CONCLUSION
Watershed morphometry is the most important approach in understanding the existing geomorphic processes operating within the framework of a watershed. It gives quantitative information of the landform. Thus, determination of stream networks' behaviour and their interrelation with each other is of great importance in many water resources studies. Remote sensing satellite data and GIS techniques have proved to be an effective tool in drainage delineation. Their updating in conjunction with old datasets brings a bright picture enabling geomorphologist to infer concrete conclusion about the drainage basin. In the present study, morphometric analysis of the Paderu watershed basin has been delineated based on several drainage parameters using remote sensing satellite data and latest GIS tools. In drainage network analysis, there exists a definite correlation between stream order, stream number, and stream length. Sub-watersheds 2, 3, 4, 8, 10, and 13 only have 4th order .Thus it is inferred that the watershed basin falls under fourth-order basin and is mainly dominated by lower order streams. For all the stream orders in the study area, the bifurcation ratio is more than 3.0. This indicates that in the study area, the drainage pattern is strongly influenced by its structural elements. The drainage density values of the

basin are below 5 revealing that the subsurface area is permeable, a characteristic feature of coarse drainage. The moderate drainage density value suggests that Paderu Mandal has moderately permeable subsoil and a thick vegetative cover. All the sub-watersheds have low Elongated Ratio, so they are expected to be in elongated shape with low relief. Lower Elongation ratio values are also known to be characterized by high susceptibility to erosion and sediment load. The study of the relief aspects of the area, reveals that the sub-watersheds 13 and 10 have highest relief and sub watershed 2 has the lowest relief in the present study area. Due to increase in geometric progression of population growth, change in pattern of agriculture, lack of proper technical know-how's and non-implementation of appropriate technology at the river basin level, an insufficient supply of pure and fresh water has been observed in recent years. morphomertric data generated through this study can be used for planning in conservation and management of water resources in this region.

Table 3: Relief morphometric parameters

No. of Sub-Watersheds	highest	lowest	Basin Length (km)	Dd = Lμ/A	H (Max-Min)	Rh= H/Lb	Ir=Dd*H	Hd= H/Hmax
1	1565	820	7.33	3.244	745	101.64	2416.78	0.476
2	1303	820	10.01	2.882	483	48.25	1392.00	0.371
3	1545	820	8.21	4.793	725	88.31	3474.92	0.469
4	1460	820	8.85	2.414	640	72.32	1544.96	0.438
5	1376	820	5.18	1.306	556	107.34	726.136	0.404
6	1546	840	10.98	2.197	706	64.30	1551.082	0.457
7	1118	100	9.23	2.004	1018	110.29	2040.072	0.911
8	1363	520	11.25	2.944	843	74.93	2481.792	0.618
9	1476	460	6.72	3.007	1016	151.19	3055.112	0.688
10	1274	80	10.88	3.216	1194	109.74	3839.904	0.937
11	820	40	7.34	2.55	780	106.27	1989	0.951
12	1280	280	4.32	2.791	1000	231.48	2791	0.781
13	1420	80	15.15	2.354	1340	88.45	3154.36	0.944

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