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Remote sensing and GIS in the morphometric analysis of macro-watersheds for hydrological Scenario assessment and characterization - A study on Penna river sub-basin, SPSR Nellore district, India.

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Abstract – *Hydrological assessment and characterization of the macro-watersheds of Pennar river sub-basin is done through the analysis and evaluation of various drainage and topographic parameters. The morphometric approach involving the analysis of Digital elevation model has largely helped in the logical assessment of hydrological character of the basin. The analysis of various linear and areal aspects has revealed that the topographical configuration and geomorphic setting of the basin has assumed a dendritic drainage pattern with 5th order drainage. Consequently, the study helped in the identification and mapping the potentiality of land-water resource majorly contributes for the sustenance of the basin. Based on its natural setting and availability of land-water resource, the entire basin is divided into 20 macro-watersheds which can be further treated as a base unit for the assessment and evaluation of resource potentiality. The study has demonstrated the significance of morphometry as well as utility of remote sensing and GIS technology in hydrological characterization of the basin at micro-watershed level.*

Key Words: Morphometric analysis, hydrological characterization, remote sensing and GIS analysis, macro-watershed assessment, Penna river sub-basin, SPSR Nellore district.

1.INTRODUCTION

According to Chorley et al. (1957), morphometry is the science ''which treats the geometry of the landscape" and quantitative procedure for quantifying the land surface. Several quantitative approaches already been documented to recognize the basin drainage characteristics for understanding the hydrological processes. Since a macro-watershed is considered as the basic unit in hydrology, it could be appropriate to perform morphometric analysis at macro-watershed level as it is comparatively far better than doing the analysis on a specific stream/channel or inconsistent segment area. Morphometric analysis helps in characterizing the watershed by revealing the hydrological and geomorphic processes intertwined and happens in the watershed by means of developing and employing the methods to quantify the land exteriors (Singh, 1992; and Dar et al. 2013). Consequently, the process is responsible for a holistic understanding of hydrologic behavior of a watershed. Similarly, some of the morphometric parameters, like, circularity ratio and bifurcation ratio are input parameters in the hydrological analysis (Jain, 2000 and Esper, 2008) and evaluation of surface water potentiality of an area (Suresh, 2004). A more realistic approach of drainage morphometric analysis is employed by using the drainage network extracted from the Digital Elevation Model (DEM) as suggested by Callaghan, 1984 and Bhat, 2009. In this perspective, this study forms a basis for characterizing hydrologic behavior of Penna river Sub-basin in SPSR Nellore District of Andhra Pradesh, India using morphometric procedures.

1.1 Description of the study area

The Penna River Sub-basin is extended between 14°30'55.12" N to 14°23'21.629" N latitudes and 79°25'38.26" E to 79°36'6.47" E longitudes (Figure 1), covering an area of 137.27 Km^2. Nandi Hills in Chikballapur District of Karnataka state, and runs north and east through the state of Andhra Pradesh to empty into the Bay of Bengal. It is 597 kilometres (371 mi) long, with a drainage basin 55,213 square kilometres (21,318 sq mi) large. This river basin occupies nearly 55,213 km^2 area. Penna is an interstate river with 6,937 km^2 and 48,276 km^2 river basin area located in Karnataka and Andhra Pradesh respectively. The river basin receives 500 mm average rain fall annually. The river basin lies in the rain shadow region of Eastern Ghats. The Penna then flows east through a gap in the Eastern Ghats ranges onto the plain of Coastal Andhra, flowing through Nellore city before it empties into the Bay of Bengal at a place called Utukuru, 15 km east of Nellore. The notable tributaries are Jayamangali, Kunderu, Sagileru, Chitravati, Papagni, Cheyyeru.

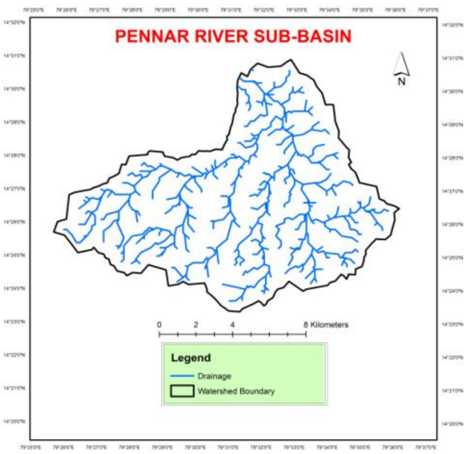

Fig -1: Study area

1.2 Data used and sources

The morphometric analysis of the Penna river sub-basin is carried out on SRTM DEM of 90 m spatial resolution. The stream lengths and basin areas are measured with ArcGIS-10.1 software. Stream ordering is done according to the system proposed by Strahler (1952) using ArcHydro tool in ArcGIS. Several methods are implemented for measuring linear, areal and relief aspects of the basin. Stream number, stream length, stream length ratio, bifurcation ratio, form factor, and stream frequency are measured according to the system proposed by Horton (1932 and 1945). Stream ordering, mean bifurcation ratio, mean stream length and ruggedness number are measured using the methods proposed by Strahler (1952 and 68). Parameters, such as, basin area, length of the basin, elongation ratio, texture ratio and relief ratio are quantified according to Schumm (1956). Other parameters like, circularity ratio as per Miller (1960); drainage texture as per Smith (1939); drainage density as per Melton (1957 and 58) and slope analysis as per Wentworth (1930), are quantified.

2. LINEAR ASPECTS

2.1 Stream order (Su)

Stream ordering is essential for the quantitative analysis of any drainage basin. Horton has pioneered the stream ordering systems in 1945, subsequently, Strahler (1952) has suggested some modifications. The streams of the Penna river sub-basin have been ranked according to the stream ordering system suggested by Strahler (1952). According to the system, the Penna river in the sub-basin was found to be a 5th order drainage basin (Figure 2, Chart-1). It is also noticed that there is a decrease in stream frequency as the stream order increases in the basin.

2.2 Stream number (N_u)

Strahler's scheme of stream ordering system of the Penna river sub-basin has been obtained from SRTM DEM. Maximum frequencies are in first order streams and minimum in the fifth order streams.

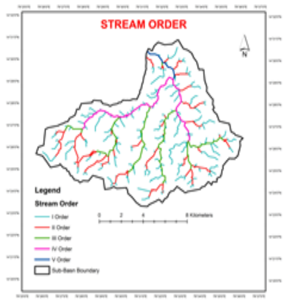

Fig -2: Stream order

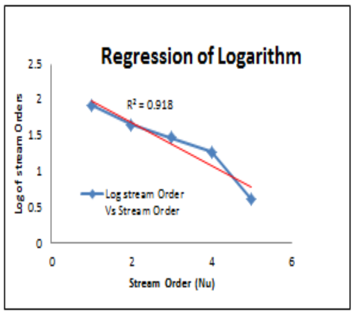

Chart-1: Logarithmic Plots of Stream Order against the Stream Length (in Kms)

2.3 Stream length (L_u)

All the streams of the Penna river sub-basin of various orders have been extracted from SRTM DEM data. Subsequently, orderwise Lu of all streams is computed using ArcGIS v.10.1 software. Horton's law of stream lengths supports the theory that geometrical similarity is preserved generally in basin of increasing order (Strahler, 1952).

2.4 Bifurcation ratio (R_b)

The ratio of number of the stream segments of given order 'Nu' and the number of streams in the next higher order (Nu+1) is called bifurcation ratio. Horton (1945) has well-thought-out the Rb as index of relief and dissertation. The Rb is dimensionless property and generally ranges from 3.0 to 5.0. In the Penna river sub-basin, it is observed that Rb is not same from one order to its next order as these irregularities are dependent upon the geological and lithological development of the drainage basin (Strahler, 1952). The higher values of Rb (Table X) in the basin indicates a strong structural control on the drainage pattern, while the lower values are indicative of basin that are not affected by structural disturbances.

3. BASIN GEOMETRY

3.1 Form factor (F_f)

Horton (1932) has defined the Form Factor as the ratio of basin area to square of the basin length ($Ff=A/Lb^2$). For a perfectly circular basin, the F_f value is always <0.754. If the value decreases, the basin form will be automatically elongated. Basins with high Ff have high peak flows of shorter duration. Ff value of Penna river sub-basin is found to be 0.26 which indicates that the basin is elongated in shape and has the flow of longer duration.

3.2 Elongation ratio (R_e)

Schumm (1956) has defined the elongation ratio as the ratio of diameter of a circle of the same area as the basin and the maximum basin length ($Re=2/Lb*(A\ \pi)^{½}$). Strahler (1952) has classified the elongation ratio as circular (0.9-1.0), oval

(0.8-0.9), less elongated (0.7-0.8), elongated (0.5-0.7), and more elongated (less than 0.5). The Re of Penna river sub-basin is 0.57, which represented the basin is elongated.

3.3 Drainage texture (Dt)

Horton (1945) has expressed the drainage texture as the total number of stream segments of all orders per perimeter area (Dt=Nu/P). Smith (1938) has classified drainage texture into five different textures as very coarse (<2), coarse (2-4), moderate (4-6), fine (6-8) and very fine (>8). The drainage texture value of the Penna river sub-basin is calculated as 4.35, which indicates a moderate drainage texture.

4. DRAINAGE TEXTURE ANALYSIS

4.1 Stream frequency (Fs)

Horton (1932) has introduced the stream frequency as a measurable area parameter of drainage morphometry and defined it as the number of stream segments per unit area (Fs=Nu/A). Frequency of various stream orders of Penna river sub-basin is computed and means stream frequency value is measured as 1.84Km/Km^2. The distribution suggests that topographically, the Penna river sub-basin is in its late youth to early mature stage.

4.2 Drainage density (Dd)

Horton (1932 & 45), Strahler (1952 & 57) and Melton (1958) have defined the drainage density as the stream length per unit area (Dd=ΣLu/A). The Dd is in fact the result of the function of various parameters, such as, climate, lithology, structures and relief history and is an important quantitative parameter in morphometry analysis. The Dd of the Penna river sub-basin has been computed as 1.34 Km/Km^2 indicating a 'less' to 'moderate' density, suggesting for the presence of high permeable sub-soil and a moderate vegetative cover.

5. RELIEF CHARACTERIZATION

5.1 Relief ratio (Rh)

The total relief of the river basin is defined as the difference between the highest point of a basin and lowest point on the valley floor. The Rh is defined as the ratio between the total relief of the basin and longest dimension of the basin parallel to the main drainage line (Schumm, 1956), and is calculated as Rh=H/Lb. High values of Rh indicates steep slope and high relief while lower values indicate the presence of base rocks that are exposed in the form of small ridges and mounds with lower degree of slope. The value of Rh for Penna river sub-basin is computed as 200. It is observed that areas with high relief and slope are characterized by high value of Rh. High value of Rh is mainly due to the presence of low resistant base rocks and high degree of slope in the basin.

5.2 Ruggedness Number (Rn)

The product of the basin relief and drainage density is called ruggedness number (Strahler,1968), and calculated as Rn=Dd*(H/1000). The ruggedness number of Penna river sub-basin is 0.267. Low ruggedness value of the basin suggests that the area is less prone to soil erosion and have intrinsic structural complexity in association with relief and drainage density.

5.3 Slope analysis

Slope is the most important feature of morphometry and is important in hydrological analysis. Maximum slope line is well marked in the direction of a channel reaching downwards on the ground surface. Different methods are existed for representing the slope as proposed by notable authors, like, Wentworth (1930), Raisz and Henry (1937), Smith (1938), Calef and Newcomb (1953), Miller (1960) and Pity (1969). SRTM DEM of 90 m spatial resolution is used for the quantitative analysis and mapping of the slope in the basin. The area represented by each slope category is mapped, measured and frequencies of the individual slope classes are derived. The mean slope is computed in the basin with a range of 1.6° to 23.51°. The slopes have been classified according to the scheme suggested by the Commission on slope evolution by International Geographic Union, 1970.

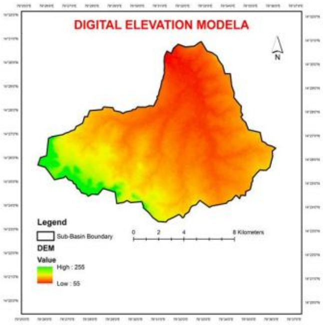

Fig -3: DEM

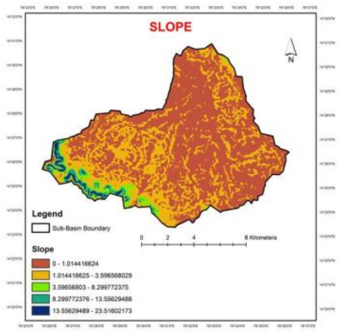

Fig -4: SLOPE

Table -1: Morphometric parameters of Penna river sub-basin*

Parameters	A (km^2)	Lb(km)	P (km)	Stream Order	Lu (km)	Lsm (km)	R_L				R_b			
							Order				Order			
							II	III	IV	V	I	II	III	IV
Penna Sub-basin	137.27	23	58.133	5	183.537	0.388	0.53	0.67	0.64	0.21	2.13	1.15	1.85	3.7

Rbm	Dd	Rr	Fs	Rf	Bh	Re	Rc	Rn	T
2.2	1.33	8.68	1.84	0.25	200	0.57	0.51	0.26	4.35

*Area (A), Basin length (L), Basin perimeter (P), Stream length (Lu), Mean stream length (Lsm), Stream length ratio (RL), Bifurcation ratio Rb), Mean bifurcation ratio (Rbm), Drainage density (Dd), Relief ratio (Rr), Stream frequency (Fs), Form factor (Rf), Basin relief (Bh), Elongation ratio (Re), Circularity ratio (Rc), Ruggedness number (Rn), Drainage Texture (T). Slope (S).

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Table -2,3: Morphometric parameters of Penna river sub-basin macro-watersheds.

Parameters	A(Km2)	P (km)	Lb (km)	Stream order	Lu (km)	Lsm (km)	RL					Rb				
							I	II	III	IV	V	I	II	III	IV	V
WS1	7.04	14.02	3.90	3.00	8.44	0.42	_	0.67	0.06	*	*	1.7	7.0	_	*	*
WS2	5.59	13.27	3.75	2.00	5.16	0.74	_	0.55	_	_	_	2.5	2.0	_	_	_
WS3	7.08	15.88	3.06	3.00	6.88	0.53	_	0.68	0.35	_	_	2.0	4.0	_	_	_
WS4	8.53	13.30	3.94	2.00	8.32	0.44	_	1.14	**	**	**	1.4	_	**	**	**
WS5	4.65	11.29	3.60	3.00	5.56	0.43	_	0.37	0.13	**	**	2.0	4.0	_	**	**
WS6	4.60	8.92	3.70	2.00	4.99	0.42	_	1.00	**	**	**	1.0	**	**	**	**
WS7	4.10	9.19	2.67	2.00	5.15	0.34	_	1.61	**	**	**	1.5	**	**	**	**
WS8	6.37	12.15	4.03	3.00	6.57	0.36	_	0.66	0.94	**	**	1.4	7.0	_	**	**
WS9	6.57	11.43	4.03	2.00	7.67	0.59	_	1.92	**	**	**	1.2	_	**	**	**
WS10	7.46	12.31	4.16	3.00	9.32	0.29	_	0.53	0.53	**	**	1.0	3.5	_	**	**
WS11	5.86	12.21	4.66	2.00	6.01	0.86	_	1.06	***	**	**	1.3	_	**	**	**
WS12	5.21	10.74	4.12	2.00	6.56	0.47	_	1.43	***	**	**	1.3	_	**	**	**
WS13	6.57	11.38	4.67	2.00	8.46	0.40	_	0.39	***	**	**	2.0	_	**	**	**
WS14	9.73	13.29	4.99	3.00	11.79	0.41	_	0.20	2.01	**	**	1.5	0.9	_	**	**
WS15	7.86	14.52	6.87	3.00	9.39	0.55	_	0.91	0.51	**	**	1.3	2.0	_	**	**
WS16	5.62	10.37	4.19	2.00	7.14	0.55	_	0.93	**	**	**	2.3	_	**	**	**
WS17	7.37	11.46	3.98	3.00	10.53	0.40	_	1.82	0.10	**	**	1.3	11.0	**	**	**
WS18	6.28	14.11	3.73	3.00	7.16	0.36	_	0.88	0.10	**	**	1.6	3.5	**	**	**
WS19	7.32	11.99	5.22	3.00	7.45	0.47	_	0.79	0.45	**	**	2.3	1.3	**	**	**
WS20	7.68	13.84	3.90	3.00	9.88	0.49	_	0.84	0.07	**	**	1.4	8.0	**	**	**

Parameters	Rbm	Rank	Dd	Rank	Rr (m/km)	Bh	Re	Rank	Rc	Rn	T
WS1	4.36	1.00	1.20	10.00	11.79	46.00	0.77	8.00	0.45	0.06	1.43
WS2	2.25	8.00	0.92	10.00	4.80	18.00	0.71	7.00	0.40	0.01	0.60
WS3	3.00	5.00	0.97	10.00	12.43	38.00	0.98	10.00	0.35	0.06	0.50
WS4	1.38	10.00	0.98	10.00	9.39	37.00	0.84	10.00	0.61	0.06	1.43
WS5	3.00	5.00	1.20	10.00	5.00	18.00	0.68	6.00	0.46	0.02	1.15
WS6	1.00	10.00	1.35	9.00	7.57	28.00	0.65	6.00	0.73	0.04	1.34
WS7	1.50	10.00	1.26	10.00	13.11	35.00	0.86	10.00	0.61	0.04	1.63
WS8	8.43	1.00	1.03	10.00	9.18	37.00	0.71	7.00	0.54	0.04	1.48
WS9	1.17	1.00	1.47	9.00	9.18	37.00	0.72	7.00	0.63	0.05	1.14
WS10	2.25	8.00	1.25	10.00	10.82	45.00	0.74	8.00	0.62	0.06	2.60
WS11	1.33	10.00	1.03	10.00	10.73	50.00	0.59	4.00	0.49	0.05	0.57
WS12	1.33	10.00	1.26	10.00	10.68	44.00	0.62	5.00	0.57	0.06	1.30
WS13	2.00	9.00	1.29	10.00	6.64	31.00	0.62	5.00	0.64	0.04	1.85
WS14	2.00	9.00	1.21	10.00	7.22	36.00	0.71	7.00	0.69	0.04	2.18
WS15	1.67	9.00	1.20	10.00	23.01	158.00	0.46	1.00	0.47	0.19	1.17
WS16	2.25	8.00	0.69	10.00	37.67	158.00	0.64	5.00	0.66	0.11	1.25
WS17	6.14	1.00	1.43	9.00	15.10	159.00	0.77	9.00	0.71	0.23	2.27
WS18	2.54	7.00	1.14	10.00	36.50	136.00	0.76	8.00	0.40	0.16	1.42
WS19	1.79	9.00	1.02	10.00	32.59	170.00	0.59	4.00	0.64	0.17	1.33
WS20	5.80	1.00	1.29	10.00	14.12	55.00	0.80	9.00	0.50	0.07	1.45

**WS-Watershed*

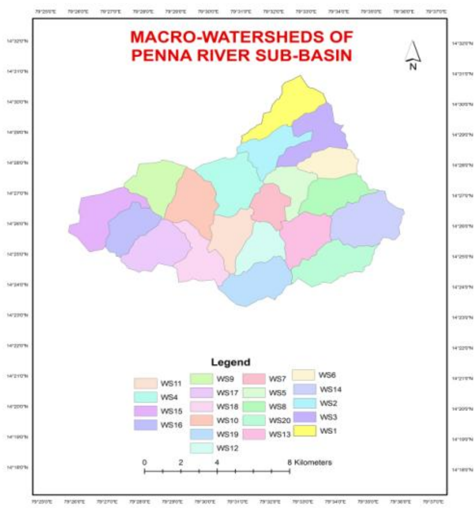

Fig -3: Macro-Watersheds of Penna Sub-basin

5.4 Hydrological potentiality assessment

In order to identify, categorize and map the hydrological potential zones, a comprehensive analysis is undertaken by integrating various macro-watershed level morphometric parameter composites and evaluating them by employing certain evaluation criteria. Weights are assigned to different themes and units depending on their significance in terms of their hydrological potentiality. [Table-4]

Table-4: Hydrological Potential Classes with Micro-Watershed Number

Hydrological Potential Class	Micro-Watershed Number
6	WS17
7	WS1, WS8, WS9, WS15
8	WS5, WS10, WS13, WS14, WS16, WS18, WS19, WS20
9	WS2,WS3, WS6, WS7, WS12, WS13
10	WS4

The subjective weights assigned to different mapping units of each thematic layer are in a scale of 1 to 10, where 1 indicates least while 10 indicates for high significance of the mapping unit.

6. CONCLUSIONS

Remote Sensing and Geographical Information System have proved to be efficient tool in drainage delineation and updating in the present study and this updated drainage has been used for the morphometric analysis. Morphometric analysis is most important parameter for geological studies and structural control. Lower order streams mostly dominate the basin. The quantitative analysis of morphometric parameters is found to be of immense utility in river basin evaluation, watershed prioritization for soil and water conservation, and natural resources management at macro level. The low value of bifurcation ratio is characterize in the high hydrological potential zone because it is depend on geological and lithological development of the drainage basin. Drainage density is less for all the macro-watersheds which reveals that there is more possibility of infiltration, and less surface runoff, thereby increasing hydrological potential area. The slope below than 12^0 have high hydrological potential area to the absence of debris over the slope surface. The morphometric analysis of the drainage networks of all 20 macro-watersheds exhibits the dendritic to sub- dendritic drainage pattern and the variation in stream length ratio might be due to changes in slope and topography. The development of stream segments is affected by slope and local relief (Strahler, 1964) the physiographic structure of the basin area produces low surface runoff values and high infiltration rates. Finally it is evident from the results that Watershed 1 (i.e. WS4) had obtained highest ranking of 10, which means WS4 is the basin with high groundwater potentiality.

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REFERENCES

[1] Bhat, S.A., and Romshoo, S.A., (2009), Digital elevation model based watershed characteristics of upper watersheds of Jhelum basin, Journal of applied hydrology. 21(2), pp 23-34.

[2] Chorely, R. (1971) The Drainage Basin as the Fundamental Geomorphic Unit. In: Chorely, R., Ed., *Introduction to Fluvial Processes*, Methuen and Co. Ltd., London, 30-52.

[3] Chopra, R., Dhiman, R.D. and Sharma, P.K. (2005) Morphometric Analysis of Sub-Watersheds in Gurdaspur District,Punjab Using Remote Sensing and GIS Techniques. *Journal of the Indian Society of Remote Sensing*, 33, 531-539.

[4] Strahler, A. (1964) Quantitative Geomorphology of Drainage Basins and Channel Networks. In: Chow, V., Ed.,*Handbook of Applied Hydrology*, McGraw Hill, New York, 439-476.

[5] Pareta, K. and Pareta, U. (2011) Quantitative Morphometric Analysis of a Watershed of Yamuna Basin, India Using ASTER (DEM) Data and GIS. *International Journal of Geomatics and Geosciences*, **2**, 248-269.

[6] S.K. Nag, "Morphometric Analysis Using Remote Sensing Techniques in the Chaka SubBasin, Purulia District, West Bengal", Journal of Indian society of Remote Sensing, Vol.26,No.1&2, 69-76, 1998.

[7] Miller, V.C. "A quantitative geomorphic study of drainage basin characteristic in the clinch, Mountain area, Verdinia and Tennesser, Project NR 389-042,Tech. Rept.3 Columbia University, Department of Geology, ONR, Geography Branch, New York. (1953).

[8] Schumm, S.A. Evolution of drainage system and slope in badlands of Perth Amboy, New Jersey. Bull.Geol.Soc.Am. 67: 597-46. (1956).

[9] Singh, S. and Singh, M.C.: Morphomertric Analysis of Kanhar River Basin. National Geographical Jour. of India 43 (1):31-43. (1997).