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Remote Sensing and GIS based Morphometric Analysis for three Sub-Watersheds of Manair river Basin in Telangana, India

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Abstract: The quantitative analysis of the watershed is vital to understand the hydrological structure of any topography. The present study deals with quantitative assessment of Manair Basin, Telangana, India, based on IRS LISS III satellite data and Cartosat DEM 30m resolution data. Morphometric parameters of the watershed were assessed by computations of linear and areal aspect using standard methodology in GIS environment. ARC GIS software was utilized for morphometric component study and delineation of the watershed using Cartosat digital elevation model (DEM). In this study, the Manair basin, tributaries of Godavari River, has been selected for thorough morphometric analysis. The drainage area of the basin is 6668.76 km^2 and shows sub-dendritic to dendritic drainage pattern. The study area is designated as Fifth order basin with the drainage density value being as 0.41 km/km^2. Three sub-watersheds Upper Manair, Mid Manair and Lower Manair are also delineated within this basin to calculate the selected morphometric parameters, e.g., stream order, stream length, bifurcation ratio, drainage density, drainage frequency, drainage texture, form factor, circularity ratio, elongation ratio, etc. and their hydrological implications were discussed. The generated database of morphometric parameters can provide scientific material for site selection of water-harvesting structures and flood management activities in the basin. The results observed from this work would also be useful in classification of watershed for future water management.

Keywords: Drainage morphometry, Manair basin, Watershed, DEM, GIS

1. Introduction

Morphometry is the mathematical analysis and measurement of the configuration of the earth's surface, dimension of its landforms (Clarke 1996; Agarwal 1998) and shape. The morphometric analysis is done through measurement of aerial, linear, relief, gradient of channel network and contributing ground slope of the basin (Chopra, 2005). The principle of morphometry is that drainage basin morphology reveals various geological and geomorphological processes over time, as indicated by various morphometric studies (Horton 1945; Strahler 1952, 1964; Evans 1972, 1984; Chorley et al. 1984) and are essential for selection of water recharge site, watershed delineation, runoff modelling, watershed modelling, groundwater prospect mapping and geotechnical investigation (Burrough, 1986).

Watershed is a hydrological unit from which all precipitated water flows to a common outlet. Watershed is a hydrological unit from which all precipitated water flows to a common outlet. Watershed is a hydrological unit from which all precipitated water flows to a common outlet. Digital elevation models (DEMs), such as from the Cartosat satellite, Shuttle Radar Topography Mission (SRTM), have been used in various morphometric analysis case studies to extract different geomorphological parameters of drainage basins, including drainage networks, catchment divides, aspect and slope gradient, upstream flow contributing areas. Therefore, the DEM's are very precise tool for morphometric parameter evaluation and watershed delineation for watershed management (Cox, 1994).

Watershed is a hydrological unit from which all the precipitated water flows into a common outlet, Thus the Watershed is a geographic unit, which covers all the land that contributes runoff. The GIS based watershed evaluation using Cartosat data has given a fast, precise, and an inexpensive way for analysing hydrological systems (Dar, 2013; Singh, 2012; Singh, 2015). A drainage map of basin provides a reliable index of permeability of rocks and their relationship between structures, rock type, and their hydrological status. Watershed management requires a detailed information of drainage network, topography, water divide, channel length, geomorphologic and geological setup of the area for proper application of plan for water conservation measures (Singh and Leh, 2018; Sreedevi et al. 2005).

Large number of case studies combining remote sensing, GIS and satellite-borne digital elevation data were used for morphometric analysis and watershed prioritization for different geological and hydrological setups for water resource management and evaluation

(Enschede, 2004; Horton, 1932; Leh et al., 2018; Rai et al. 2014; Singh and Saraswat, 2016). The results of all the studies shows that integrated application of remote sensing and GIS is the potential tool for water resource evaluation and extraction of hydrological parameters of any terrain (Singh and Bhattarai, 2019; Singh and Kumar, 2017).

In the present study, an integrated approach of GIS, remote sensing and DEM have been used for generation and interpretation of drainage parameters for water resource management of Manair Watershed. The watershed selected for the present work is the important source of water for agriculture and domestics purpose in the area.

2. Study area

The study area - Manair Watershed lies between 17.700 N to 18.62$_0$N latitude and 78.22$_0$E to 79.28$_0$E longitude (Figure 1). The total geographical area of the basin is 6668.76 km$_2$. The Manair river flows through the Telangana state, India. The climate of the basin is extreme with hot summers and cold winters. It experiences southwestern monsoon rains in June–September with an annual rainfall of 600 mm. May is the hottest month with a maximum temperature of 44$_o$C and minimum temperature 27$_o$C in the month of December. The average annual rainfall is 907 mm. The river Manair, which is the tributary of Godavari River Basin flowing through Karimnagar urban and suburban area, is the major source of water supply in the area.

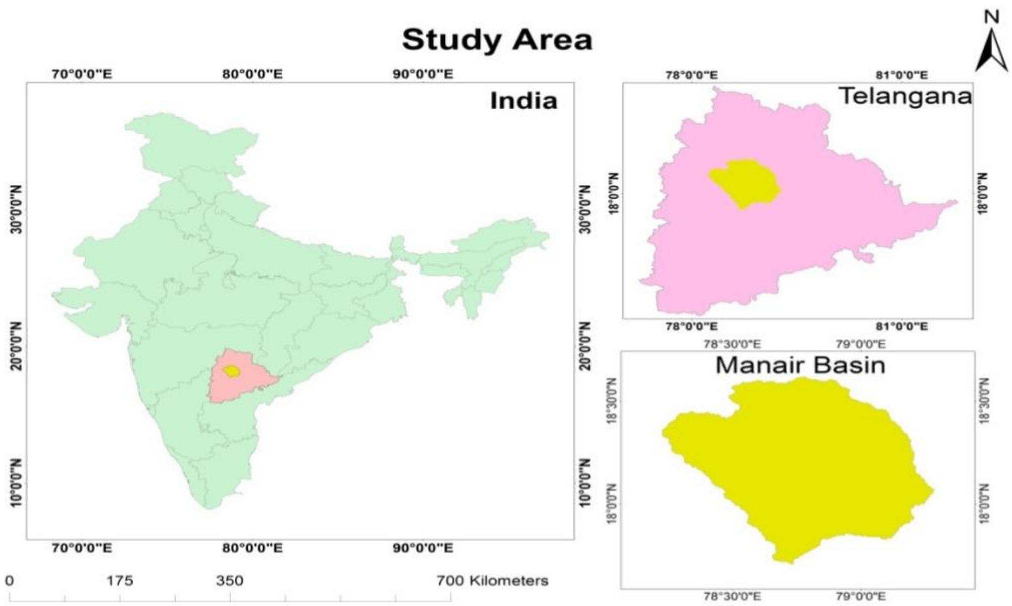

Figure 1. Manair watershed

There are three dams built across the Manair river. The Lower Manair Dam built across this river provides drinking water to Karimnagar, Telangana and also to the NTPC power plant at Ramagundam. Mid Manair Dam was constructed at Manvada village near Sircilla and upper Manair Dam was constructed during Nizam period near Narmala village in Gambhiraopet mandal of Karimnagar district

3. Materials and Methods

Manual extraction of drainage network and assigning the stream order, watershed delineation from a published Survey of India (SOI) topographic map for a large area is a time taking tedious exercise (Table 1). To overcome this problem, Manair River basin's watershed boundaries and drainage/stream network is automatically extracted from the Cartosat DEM data with a spatial resolution of 30 m with the help of various geo-processing techniques in ArcGIS-10.3 and in conjunction with geocoded standard false colour composite remote sensing satellite data (IRS Liss-III images of 23.5 M Spatial resolution of 2015). The extracted results were verified with geo-referenced Survey of India new series toposheets no's (E44G07, E44G08, E44G09, E44G10, E44G11, E44G12, E44G14, E44G15, E44G16, E44M09, E44M10, E44M13, E44H03, E44H04, E44N01 having 1:50,000 scale).

Table 1. The data used for the present study

Type of data	Details	Sources
DEM data, Satellite images	Cartosat DEM 30m Spatial resolution, IRS Liss-III images of 23.5 M Spatial resolution of 2015	Bhuvan portal
Toposheets	1:50,000 scale	SOI

Automatic extraction techniques have been used for assessing the morphometric parameters of a basin. The morphometric parameters such as number of stream segments, stream order, drainage pattern, basin length, perimeter and area were delineated from the Cartosat DEM (30 m) data and verified with Survey of India topographical map (1:50,000). The observed parameters were used for calculation of the morphometric characteristics such as drainage density, stream frequency, bifurcation ratio, form factor, circulation ratio, relief ratio and overland flow using mathematical equations in the GIS environment. Moreover, the slope and relief of the area were extracted from the same data source using spatial analyst tool in ArcGIS 10.3 software (Figures 2-5)

The following procedure was followed for morphometric analysis of Manair watershed:

1. Cartosat DEM data was downloaded from Bhuvan portal and primary processing was performed.

2. Various geoprocessing techniques like Fill, Flow Direction, and Flow Accumulation were applied in GIS environment for delineation of watershed and extracted parameters were correlated with the Geo-referenced Survey of India toposheets.

3. All the extracted parameters from Cartosat DEM, like the number and lengths of streams of each different order, drainage area, basin perimeter and total basin length, and width were calculated using ARCGIS 10.3 software; and were verified with Survey of India topographical sheets.

Basic morphometric parameters such drainage area (A), perimeter (P), basin length (Lb), stream order (Nu) and mean stream length are estimated. Derived parameters like bifurcation ratio (Rb), mean stream length (Rl), drainage density (Dd), elongation ratio (Re), circulatory factor (Rc), form factor (Ff), were calculated from these parameters. The methodologies adopted for the computation of morphometric parameters are given in Table 2.

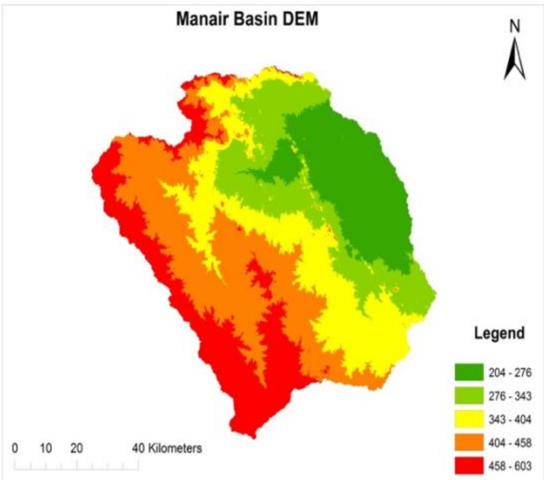

Fig: 2. Cartosat DEM data of Manair Basin

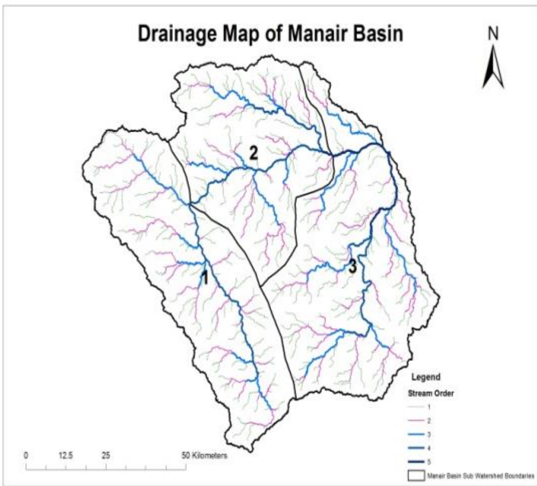

Fig: 3. Extracted Drainage Network and Sub-Watersheds 1-Upper Manair,2-Mid Manair & 3-Lower Manair from delineated DEM data of Manair Basin

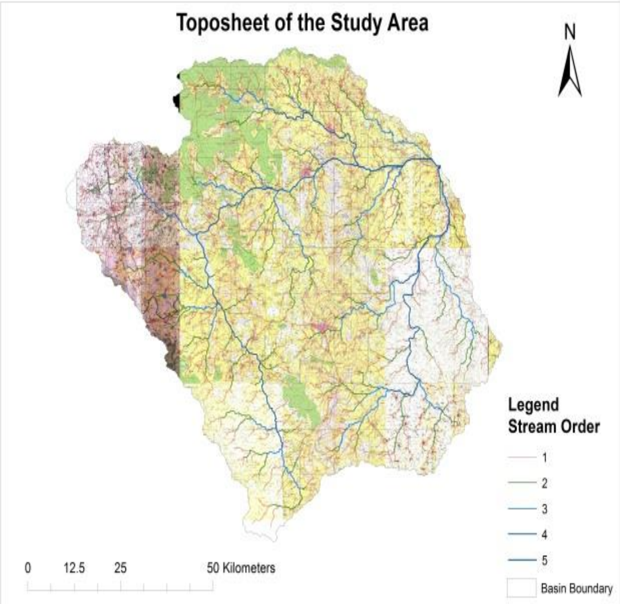

Fig: 4 Extracted Drainage Network overlaid on Toposheets for Verification of Manair Basin

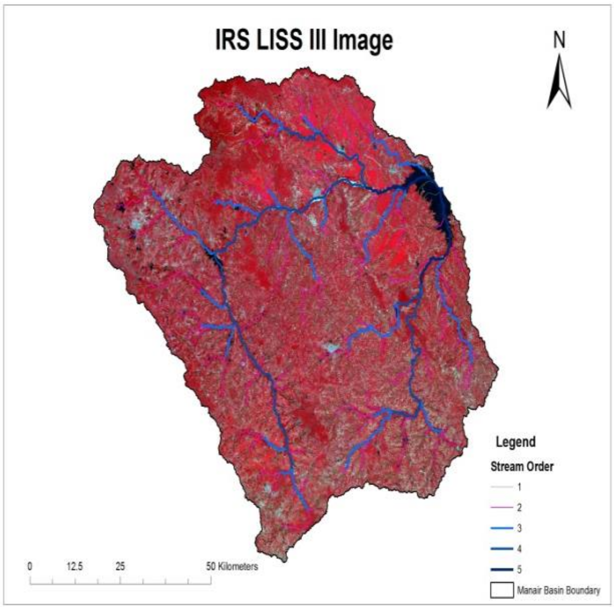

Fig: 5 Extracted Drainage Network overlaid on IRS LISS III Satellite Imagery of Manair Basin

Table 2. The parameters adopted for morphometric parameters computation

S.no.	Morphometric parameters	Calculation Formulae	References
1	Stream order	Hierarchical rank	Strahler (1964)
2.	Stream length	The length of the stream	Horton (1945)
3.	Mean stream length (Lsm)	Lsm = Lu/Nu; Lu = total stream length of order u, Nu = total no. of stream segments of order u	Strahler (1964)
4.	Stream length ratio (RL)	RL = Lu/(Lu - 1); Lu = total stream length of order u, (Lu - 1) = total stream length of the next lower order	Horton (1945)
5.	Stream frequency (Fs)	Fs = Nu/A; Nu = total no. of streams of all orders, A = area of the basin	Horton (1932)
6.	Drainage density (D)	D = Lu/A;	Horton

		Lu = total stream length of all orders,	(1932)
		A = area of basin	
7.	Drainage texture (Rt)	Rt = Nu/P;	Horton
		Nu = total no. of streams of all orders,	(1945)
		P = perimeter of the basin	
8	Bifurcation ratio (Rb)	Rb = Nu/(Nu + 1);	Schumn
		Nu = total no. of stream segments of order u,	(1956)
		(Nu +1) = number of segments of next higher order	
9	Form factor (Rf)	$Rf = A/Lb^2$;	Horton
		A = area of basin,	(1932)
		Lb 2 = square of the basin length	
10	Elongation ratio (Re)	$Re=2\sqrt{(A/\pi)}/Lb$	Schumn
		A = area of the basin	(1956)
		π = 3.14,	
		Lb = basin length	
11	Circularity ratio (Rc)	$Rc = 4\pi A/P^2$;	Miller
		A = area of the basin,	(1953)
		π = 3.14, P = perimeter of the basin	
12	Relief ratio (Rh)	Rh = H/Lb;	Schumn
		H = total relief of the basin,	(1956)
		Lb = basin length	
13	Length of overland	Lg = 1/(2D);	Horton
	flow (Lg)	D = drainage density of the basin	(1945)
14	Relative relief (Rr)	Rr = 100H/P;	Schumn
		H = total relief of the basin,	(1956)
		P = perimeter of the basin	

4. Results

The results of the morphometric analysis of Manair river watershed and sub-watersheds are presented in table 4 and are discussed in the following sections. The total drainage area is divided into 3 sub-watersheds. In general, the watershed exhibits a dominantly dendritic drainage pattern (figure 2)

4.1 Basic parameters

The basic morphometric parameters of the basin include geometry, stream order, stream length and mean stream length.

4.1.1 Basin geometry

Drainage area (A) is a key watershed characteristic for hydrologic analysis and design. Larger area and higher difference in elevation (relief) leads to greater discharge. The total drainage area of the Manair watershed is 6668.76 km2. Lower Manair sub watershed is the largest with an area of 2547.49 km2 and Mid Manair Sub-watershed is the smallest with an area of 1879.69km2. The perimeter of the Manair Watershed is 449.12 km and the Sub watersheds are shown in Table 3.

Table 3 Sub-watershed area of Manair basin

Watershed No	Name of the Sub - water shed	Sub -watershed area(km2)	Perimeter(km)
1	Upper Manair	2241.49	268.24
2	Mid Manair	1879.69	200.72
3	Lower Manair	2547.49	285.44

4.1.2 Stream order (Nu)

Classification of streams based on the number and type of tributary junctions is called stream ordering. It is a useful pointer of stream size, discharge and drainage area (Strahler 1964). The number of streams (Nu) in each order is presented in table 5 for each Sub watershed. The stream characteristics confirm Horton's first law (1945), "law of stream numbers", which states that number of streams of different orders in a given drainage basin tends closely to approximate an inverse geometric ratio. Manair is designated as a Fifth-order basin. Sub-watersheds Upper Manair is of fourth order, while Sub watershed Mid Manair and Lower Manair is of fifth order (Horton 1945; Strahler 1964).

4.1.3 Stream length (LT) and mean stream length (Lu)

The stream length characteristics of the sub-watershed confirm Horton's second law (1945), "law 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. Drainage networks of the watershed and sub-watersheds show a nearly linear relationship with a small deviation from straight line. The total stream length 2759.34 km. The total stream length decreases with the increase in the stream order. The mean stream length of the watershed is 4.78, and that of the Sub watersheds are shown in table 6.

4.2 Derived parameters

4.2.1 Bifurcation ratio (Rb)

Bifurcation ratio (Rb) is a dimensionless parameter that reveals the geometric similarity of the basin and expresses the consequence of the drainage network (Strahler 1964). The mean Rb of the watershed 2.77, which falls within the specified range of natural drainage system as suggested by Strahler (1964). However, the unclear trends in the variation of Rb from 2.6 to 4.32 for the watershed and from 1.5 to 5.71 for the Sub-watersheds and that of the sub watersheds are shown in table 8 between stream orders suggest the influence of geology, structural control and relief on drainage branching. As the geology of the area is uniform, relief plays a dominant role and also indicates substantial structural controls (Verstappen, 1983).

4.2.2 Stream length ratio (Rl)

Stream length ratio displays a substantial relation with surface flow discharge and erosion stage of the basin. The mean stream length of the watershed is 4.78 and that of the sub watersheds are shown in table 7.

4.2.3 Stream frequency (Fs)

Stream frequency parameter depends on the lithology of the basin and is an indication of the texture of the drainage network (Horton, 1945). The stream frequency of Manair watershed is 0.086 km_2, and that of the sub-watersheds is presented in table 5. Sub watershed Mid Manair has the highest stream frequency, followed by two Sub watershed lower Manair and upper Manair.

4.2.5 Drainage density (Dd)

Drainage density is one of the often-used morphometric parameters in the analysis of various environmental variables. It is a measure of the degree of fluvial dissection and be determined by on a number of factors like topography, lithology, climate, pedology and vegetation. The drainage density of the watershed is 0.41 km/km2 while those of the 3 sub-watersheds are shown in table 6.

Table 4. Results of morphometric analysis of the Manair Basin

S. no.	**Parameters**	**Stream orders**				
		I	II	III	IV	V
1.	Stream order (U)	417	121	28	8	3
2.	Stream length (LU)	1474.52	656.42	314.28	262.26	51.52
3.	Mean stream length (km) (Lsm)	3.53	5.42	11.22	32.78	17.17
4.	Stream length ratio (RL)	II/I	III/II	IV/III	V/IV	VI/V
		0.44	0.47	0.83	0.19	-
5.	Bifurcation ratio (Rb)	3.44	4.32	3.5	2.6	-
6.	Mean bifurcation ratio (Rbm)	3.46				
7.	Stream frequency (Fs)	0.086				
8.	Drainage density (D) (km/km_2)	0.41				
9.	Drainage texture (Rt)	1.28				
10	Basin length (Lb) (km)	139.51				
11	Relief ratio (Rh)	2.86				
12	Elongation ratio (Re)	0.66				
13	Length of over land flow (Lg)	1.21				
14	Form factor (Rf)	0.34				
15	Circulatory ratio (Rc)	0.41				

4.2.6 Drainage texture (T)

Drainage texture portrays the relative channel spacing in a fluvial dissected terrain and depends on a number of natural factors like climate, rainfall, vegetation, rock and soil type, infiltration capacity, relief and stage of development of the basin. Soft and weak rocks without a vegetative cover show a fine texture, while massive and resistant rocks produce coarse texture. The drainage texture of the watershed is 1.28 and that of the Sub-watersheds are given in table 5. Drainage texture of Manair watershed and its sub-watersheds can be categorized as ultra-fine.

Table 5. Stream length, Stream frequency and Drainage texture of different sub-watersheds of Manair basin

Watershed number	**Name of the sub-watershed**	**Stream length (km)**					**Stream frequency (Fs)**	**Drainage texture (Rt)**
		I	II	III	IV	V		
1	Upper Manair	460.24	222.64	78.43	111.65	-	0.08	0.68
2	Mid Manair	457.50	179.46	81.13	91.56	3.73	0.09	0.84
3	Lower Manair	556.78	254.32	154.81	59.08	47.77	0.08	0.78

Table 6. Mean stream length (km) & Drainage density of sub-watersheds of Manair basin based on stream order

Watershed number	**Name of the sub-watershed**	**Mean stream length (km)**					**Drainage density**
		I	II	III	IV	V	
1	Upper Manair	3.4	5.56	11.2	55.82	-	0.38
2	Mid Manair	3.75	5.12	9.03	30.52	3.73	0.43
3	Lower Manair	3.4	5.52	12.9	19.69	23.88	0.42

Table 7. Stream length ratio & Relief Ratio of sub-watershed of Manair basin

Watershed number	**Name of the sub-watershed**	**Stream length ratio**					**Total relief (m)**	**Maximum length (km)**	**Relief ratio**
		I	II	III	IV	V			
1	Upper Manair	-	0.48	0.35	1.42	-	222	75.08	2.95
2	Mid Manair	-	0.39	0.45	1.12	0.04	389	46.52	8.36
3	Lower Manair	-	0.45	0.60	0.38	0.80	338	68.93	4.90

Table 8. Bifurcation ratio, Elongation Ratio and Form Factor of sub-watersheds of Manair basin

Watershed number	Name of the sub-watershed	Bifurcation ratio					Elongation ratio (Re).	Form factor (Ff).
		I	II	III	IV	V		
1	Upper Manair	-	3.37	5.71	3.5	-	0.71	0.39
2	Mid Manair	-	3.48	3.88	3	3	1.05	0.86
3	Lower Manair	-	3.47	3.83	04	1.5	0.82	0.53

4.3 Shape parameters

4.3.1 Elongation ratio (Re)

The elongation ratio for the watershed is 0.66 and that of the sub-watershed is shown in table 7. Sub watersheds 1, 2 and 3 are elongated in shape.

4.3.2 Circularity ratio (Rc)

Circulatory ratio is influenced by the lithology of the basin, stream frequency and gradient of various orders (Strahler 1964). It specifies the basin shape, implying the rate of infiltration and time taken for the excess water to reach the basin outlet depending upon the geology, slope and vegetative cover of the area. Rc of the watershed is 0.41, indicating an elongated basin, with a dendritic drainage pattern. Sub-watersheds 1, 2 and 3 have a higher circulatory ratio, it denotes uniform rate of infiltration and hence the excess run-off takes longer time to reach the basin outlet.

4.3.3 Form factor (Ff)

Horton (1945) proposed this parameter to predict the flow intensity of a basin in a defined area. It shows an inverse relationship with square of the axial length and a direct relation with peak discharge. The form factor of the watershed is 0.34 and that of the sub-watersheds are shown in table 7. They have peak flows for longer duration form factor and thereby has the highest peak discharge in the sub-watershed.

Discussion and Conclusions

The results achieved in this study proposes that morphometric attributes defining basin geometry as well as shape length of stream, stream network topology and topography division can be well retrieved from Cartosat-DEM and accomplished to generate data on stream number and basin relief. Various linear, areal and relief parameters of morphometric evolution were computed and reflected with respect to hydrological process. The spatial unpredictability of the morphometric indication evaluated in the present work is quite important. The hydrological behaviour of Manair basin shall have deep influences on the flood susceptibility and flood risk in the downstream region of the Manair river.

Detailed morphometric study of all sub-watersheds shows dendritic to sub-dendritic drainage patterns, which thus indicate homogenous lithology and variations of values of Rb among the sub-watersheds attributed to difference in topography and geometric development. The morphometric parameters evaluated using GIS assisted us to understand many terrain factors such as nature of the bedrock, infiltration capability, surface runoff, etc., and also shown that the stream channel development is immaterial with the Manair basin area and their frequency decreases due to the increasing stream order. The change in discharge variation through study of Manair river morphology and morphometry reveals that the dynamism of river morphology is result of natural processes and also anthropogenic interference. Identification of a suitable hydrological model and simulating the basin area by seeing many topographic attributes would give quantitative relationship between hydrological and morphometric indicators. From the above study, it can be understood that the morphometric information of basin are when integrated with the other hydrological characteristics of the river basin, the plan and policy of siting recharge and water-harvesting measures deliver improved groundwater conservation and management plan. Singh et al. (2018) conducted sensitive analysis of parameters on the watershed outputs. Based on Singh et al. (2018) recommendations, we also plan to conduct a sensitivity analysis of morphometric parameters to analyse the importance of parameters in the Manair watershed.

The used approaches in this study include a comprehensive morphometric analysis that can be applied for any Drainage system elsewhere. They introduce the major elements needed to assess water resources and their Hydrologic regime, thus it is recommended to apply similar studies in anywhere in India. The result calculated in this paper will suggest and recommend developing a better water usage mechanism for proper watershed management in the Manair River.

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