

# **Quantitative Morphometric Analysis to Infer the Hydrological Behaviour of the East Suvarnamukhi basin in Tumkur district, Karnataka using Remote Sensing, GIS and bAd (bearing, Azimuth and drainage Calculator)**

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**ABSTRACT:** Drainage morphometric analysis of the East Suvarnamukhi river was carried out to understand the quantitative fluvial characteristics for sustainable management of various resources in the basin area. The primary data source used for the delineation of the East Suvarnamukhi basin and also to extract the drainage network by hydrology toolset in GIS environment is CartoSAT-1 DEM. The linear, areal and relief parameters were calculated by using bAd calculator. Spatial thematic maps of various morphometric parameters were constructed using visual basic programme and Arc GIS10 software. The results obtained indicate that the East Suvarnamukhi river is a 6<sup>th</sup> order stream and drainage network in the basin is dendritic to semi dendritic type. The drainage pattern in the basin is not influenced by geologic structure and the basin has moderate permeable subsoil and thick vegetative cover. The values of elongation ratio and circular ratio imply that the basin is elongated. The stream frequency (Fs), bifurcation ratio (Rb) and length of overland flow (Lg) parameters of the basin indicate that the groundwater potential of the area is moderate to good. The present study would help for assessing the suitability of the location for artificial recharge of water and also for soil and water conservation measures in the area.

**KEYWORDS:** Morphometry, East Suvarnamukhi river basin, bAd calculator, CartoSAT-1 DEM and GIS.

## **I. INTRODUCTION**

River basins comprise a distinct morphologic region and have special relevance to drainage pattern and geomorphology (Strahler, 1964). The drainage basin morphometry helps to analyze and compare the form and processes of landscape evolution irrespective of time and space (Easternbrook 1993). The quantitative analysis of a drainage system is an important aspect of watershed characteristics (Strahler, 1964) and the analysis of drainage basin morphometry is considered as an ideal unit for management and sustainable development of natural resources (Faran, et al., 2015). The hydrological behaviour of basin depends on the spatial variations of morphometric parameters (Lazarus et. al., 2014). Pioneering work on the drainage morphometry by conventional method has been done by many researchers in the various parts of the world, significantly by Horton (1945), Strahler (1952, 1964). Fluvial morphometry by using spatial technologies such as remote sensing and Geographic Information System (GIS) has been carried out by recent researchers (Vittala et al. , 2004; Markose and Jayappa, 2011; Kinthada et al., 2013; Altaf et al., 2013, Vinutha and Janardhana, 2013; Ndatuwong and Yadav, 2014) and GIS is a powerful tool for the manipulation of spatial information that provides a flexible environment and insight into hydrologic conditions necessary for developing watershed management strategies.

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The hydrological/physiographic response of a river basin can be interrelated with the morphometric characteristics of the basin, such as size shape, drainage density, stream order, stream length, drainage texture etc. These parameters are useful for drainage network analysis and they provide information concerning hydrological nature, drainage characteristics and exogenic/endogenic processes within the basin. The present paper aims at the computation of morphometric parameters by 'bAd calculator', a new software developed in Visual Basic programme (Dinesh et al., 2012a) and prepare the spatial maps on GIS platform to understand the topographic and hydrologic characteristics of the East Suvarnamukhi basin in order to plan the watershed management. Quantitative analysis of drainage based morphometric parameters can be calculated by using 'bAd calculator' which provides a point-and-click technique for rapid acquisition of watershed parameters within user-specified grids/sub-basins (Dinesh et al., 2012b).

## II. STUDY AREA

The study area, east Suvarnamukhi basin is located in Tumkur district of Karnataka State, extends from 13° 22' 8.414" to 13° 38' 36.68" N Latitudes and from 77° 05' 057" to 77° 22' 12.13" E Longitudes (Figure 1). The total area under investigation covers approximately 270.55 km<sup>2</sup>. The east Suvarnamukhi River which takes birth at Devarayadurga is joined by another major stream Doddahalli at SW of Akkiramapura village. Doddahalla has its origin at Kolikal Range Forest located in the western part of the study area. Suvarnamukhi river flows in NE direction after the confluence then loses its identity after joining Jaimangali river. Geomorphologically, the study area consists of denudational hill, denudational uplands and valley flat. Geologically, the study area consists of enclaves of amphibolites of Sargur group of rocks in a vast expanse of Archaean migmatitic gneisses and younger closepet granite. These rocks are traversed by a number of NE-SW and NW-SE trending basic dykes. The major portion of the study area is covered by gneissic complex represented by banded gneisses, granitic gneisses, gneissic granites and granites. The major types of the soil of the study area are red clay, red sandy and red loamy soil. Suvarnamukhi basin is a 6<sup>th</sup> order drainage basin. The major water bearing formations of the study area are weathered and fractured granitic gneisses and migmatites. Groundwater occurs in unconfined and semiconfined conditions. The normal rainfall in the district is 780 mm. The temperature measures around 34° C in April and declines in the monsoon period. The humidity is lowest during the dry season and highest during the monsoon period (CGWB, 2012).

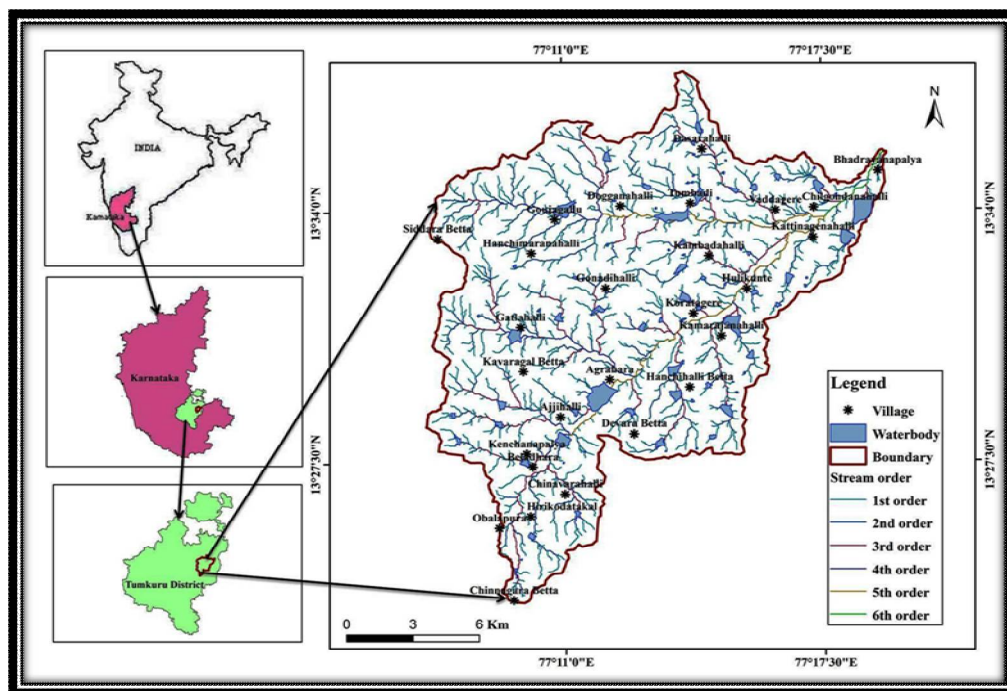


Fig. 1: Location map with drainage pattern of the East Suvarnamukhi basin

**III. METHODOLOGY**

A clear understanding on the linear, relief and areal properties of drainage basin are essential for better understanding of the basin development and management. These morphometric parameters were evaluated by delineating the drainage basin based on topographic divide followed by the computation of various morphometric parameters by using bAd calculator and preparing the required thematic maps in GIS environment for better understanding and interpretation.

The principal source of the data for delineating the basin and extracting the drainage net work is Cartosat-1 DEM with 30 m spatial resolution downloaded from Bhuvan website. The delineation of the east Suvarnamukhi basin boundary was achieved by using snap pour point and extraction of the drainage network using Hydrology tool in ArcMap 10 software such as fill, flow direction, flow accumulation, threshold value (flow accumulation  $\geq 100$ ) stream order and stream to feature (Fig. 2). Then extracted drainage network was converted into text files for the computation of various morphometric parameters by using bAd calculator (Fig. 3).

The bAd calculator was used to compute watershed based drainage morphometric parameters such as stream order, stream length, bifurcation ratio, stream length ratio, basin length, drainage density, stream frequency, form factor, elongation ratio, circularity ratio, length of overland flow, texture ratio, ruggedness number and relief ratio of the basin in different way such as values in user defined grids (e.g. 1 sq km) or at the sub-basin level (Figs 3, 4 and 5.) and finally the spatial maps of the east Suvarnamukhi basin were prepared using Inverse Distance Weighted (IDW) method in ArcGIS-10 software. The formulas used for computation of the morphometric parameters are listed in Table 1.

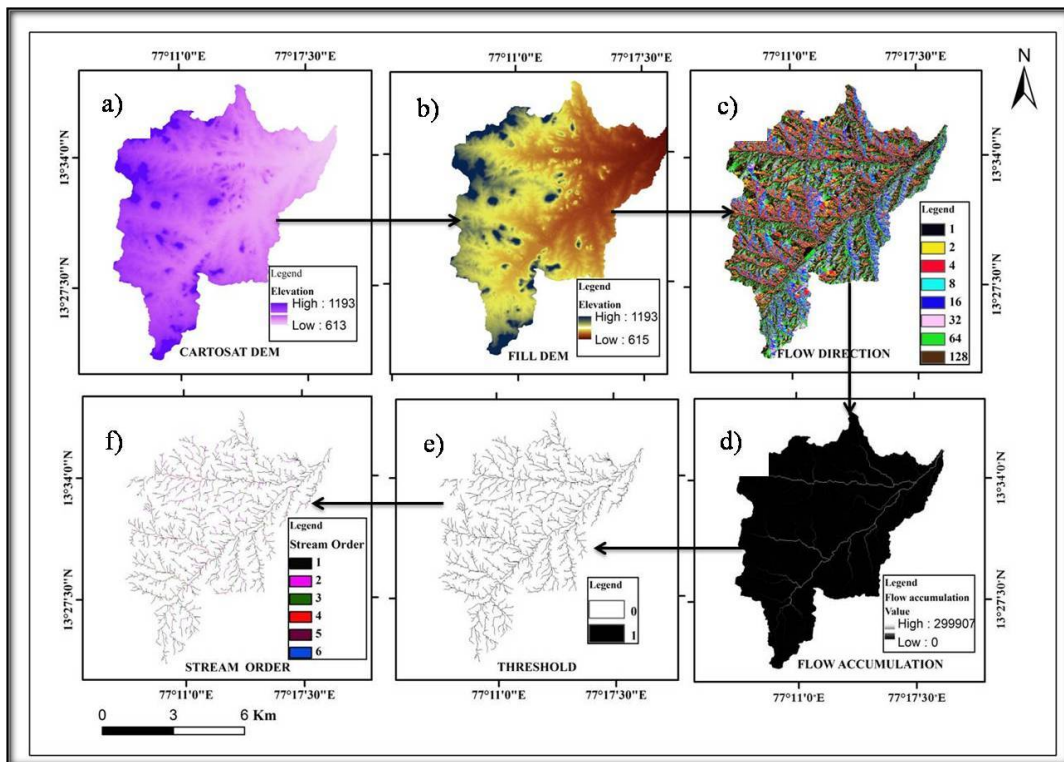


Fig. 2 Methodology for extraction of drainage networks

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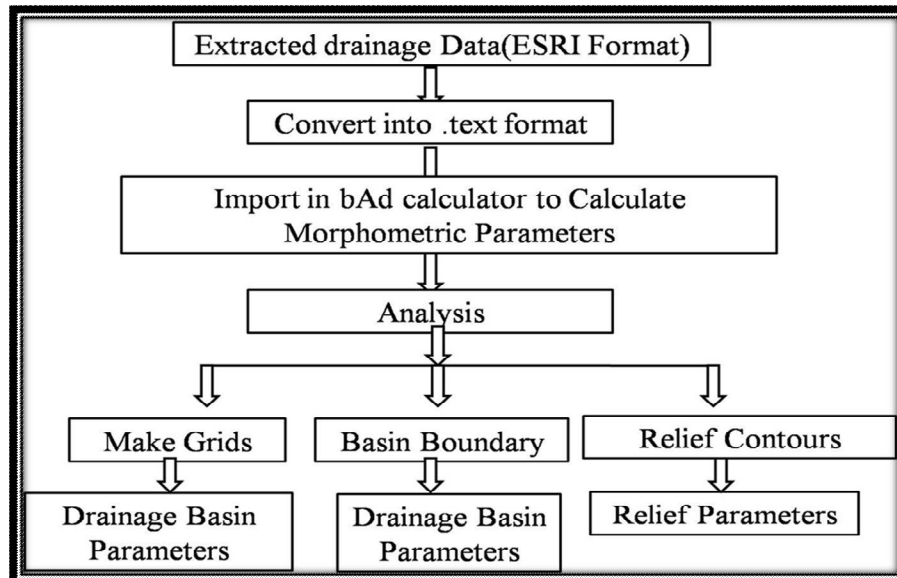


Fig. 3 Flow chart showing the methodology adopted to calculate the drainage morphometric parameters using bAd calculator.

Table 1: List of formulae used in bAd calculator for the calculation of the morphometric parameters

Parameters	Formulae	Reference
Area (A)	Area of the basin	
Perimeter (P)	Perimeter of the basin	
Basin length (Lb)	Maximum Length of the stream	
Stream order(Nu)	$\sum Nu$ where Nu= No. of streams , Hierarchical rank	Strahler (1964)
Stream length (Lu)	$\sum Lu$ where Lu= Length of the stream	
Mean stream length (Lsm)	$Lsm = Lu / Nu$ Where Lsm = Mean stream length, Lu = Total stream length of order 'u', Nu = Total no. of stream segments of order 'u'	Horton (1945)
Stream length ratio(Rl)	$R_L = Lu / Lu - I$ , Where Rl=Stream length ratio, Lu = The total stream length of the order 'u', Lu - I = The total stream length of its next lower order	Strahler (1964)
Bifurcation ratio (Rb)	$Rb = Nu / Nu + 1$ Where Rb= Bifurcation ratio, Nu= Total no. of stream segments of order 'u', Nu + 1 = Number of segments of the next higher order	Horton (1945)
Mean bifurcation ratio (Rbm)	Rbm = Average of bifurcation ratios of all orders	Schumn (1956)
Drainage Density (Dd)	$Dd = Lu / A$ Where Dd = Drainage Density, Lu = Total stream length of all orders, A = Area of the Basin (km <sup>2</sup> )	Strahler (1957)
Drainage Texture (T)	$T = Dd * Fs$ Where T=Drainage Texture , Dd = Drainage Density, Fs = Stream Frequency	Horton (1945)
Texture ratio (Rt)	$Rt = Nu / P$ Where Rt = Drainage Texture, Nu = Total no. of streams of all orders, P = Perimeter (km)	Smith (1950)
Stream Frequency (Fs)	$Fs = Nu / A$ Where Fs = Stream Frequency, Nu = Total no. of streams of all orders, A = Area of the Basin (km <sup>2</sup> )	Smith (1950)
Elongation Ratio (Re)	$Re = 2\sqrt{A / \pi} / Lb$ Where Re = Elongation Ratio, A = Area of the Basin (km <sup>2</sup> ), Lb = Basin length	Horton (1945)
Circularity Ratio (Rc)	$Rc = 4 * 3.14 * A / P^2$ Where Rc = Circularity Ratio, A = Area of the Basin (km <sup>2</sup> ), p2 = Square of the Perimeter (Km)	Schumn (1956)
Form Factor (Ff)	$Ff = A / Lb^2$ Where Ff = Form Factor, A = Area of the Basin	Strahler (1964)



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	(km <sup>2</sup> ), Lb <sup>2</sup> = Square of Basin length	
Length of Overland flow (Lg)	$Lg = \frac{1}{2} Dd$ Where, Lg = Length of Overland flow, Dd = Drainage Density	Horton (1945)
Ruggedness number (Rn)	$Rn = R * Dd$ Where Rn =Ruggedness Number, R= Basin relief, Dd = Drainage Density	Horton (1945)
Relative relief (R)	$R = \frac{H-h}{L}$ Where R=Relative relief, H= Maximum elevation, h=minimum elevation	Hadley and Schumm (1961)
Relief Ratio (Rh)	$Rh = \frac{R}{L}$ Where, Rh = Relief Ratio, R = Basin relief (Relative relief)of the basin in Km, L = Basin length in Km	Schumm (1963)
Hypsometric integral (Hi)	$Hi = \frac{\text{avg. elev.} - \text{Min. elev.}}{\text{Max. elev.} - \text{Mini. Elev.}}$	Pike and Wilson(1971)
Dissection index (Di)	$\frac{\text{Max. elev.} - \text{Mini. Elev.}}{\text{Max. elev.}}$	Singh and Dubey (1994)

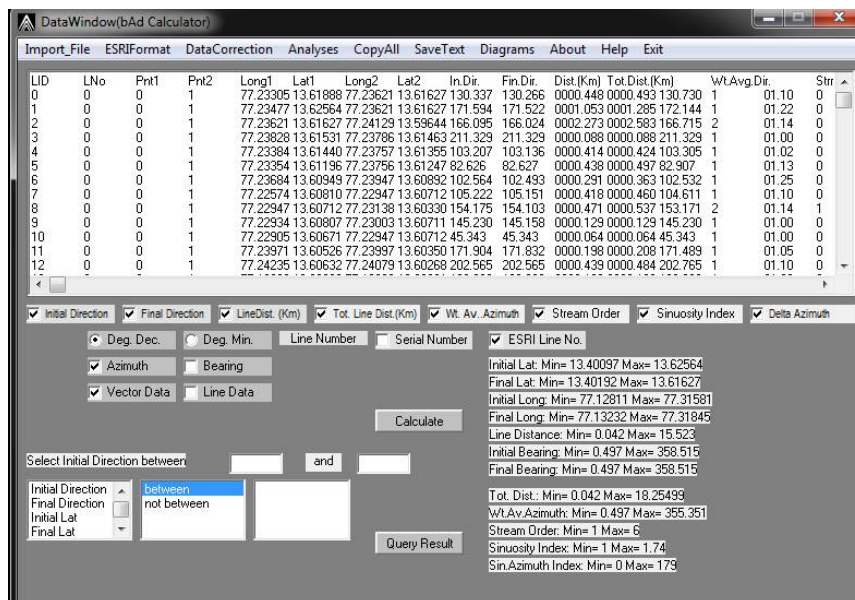


Fig. 4: Data window of bAd calculator showing data processing.

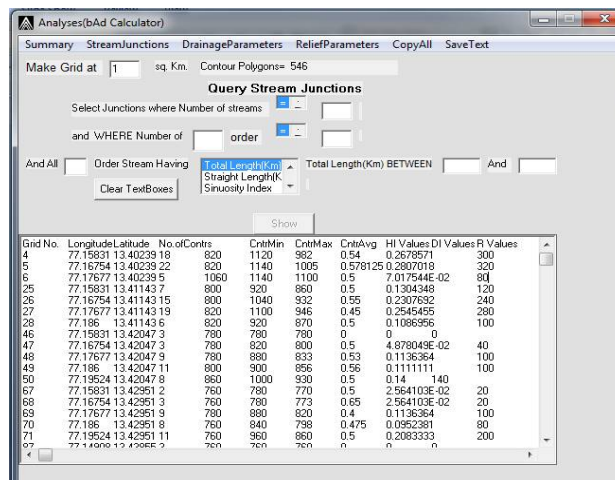


Fig. 5: Analysis window of bAd calculator showing relief parameters.

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## IV. RESULTS AND DISCUSSION

The results of the morphometric parameters viz., linear, areal and relief obtained from the calculation using ‘bAd calculator’ are presented in Table Nos. 2 and 3.

### Linear parameter

The linear parameters include the linear scale measurements of the drainage networks and the dimensionless numbers such as bifurcation ratio and stream length ratio. These parameters have direct relationship with linear erodibility of the basin. The channel segment of the drainage basin has been ranked according to Strahler stream ordering system (Strahler, 1964). The east Suvarnamukhi basin is a 6<sup>th</sup> order drainage basin. In the East Suvarnamukhi basin in all 1002 streams were identified of which 792 are 1<sup>st</sup> order streams, 166 are 2<sup>nd</sup> order streams, 34 are 3<sup>rd</sup> order streams, 7 are 4<sup>th</sup> order streams, 2 are 5<sup>th</sup> order streams. East Suvarnamukhi river, the only the river in the study area belongs to the 6<sup>th</sup> order stream. The drainage pattern of the basin is predominantly dendritic and semi-dendritic pattern is less pronounced. The types of drainage patterns indicate lack of inhomogeneity in the geological formation and structural control. The plotting of logarithm of number of streams against stream order (Fig. 6a) is in conformity with the Horton’s law of stream order which states that the number of stream segment of each order forms an inverse geometric sequence with the number of the stream orders. In the study area, the total length of stream segments is high in first order streams and decreases as the stream order increases (Table 2 and Fig. 6b).

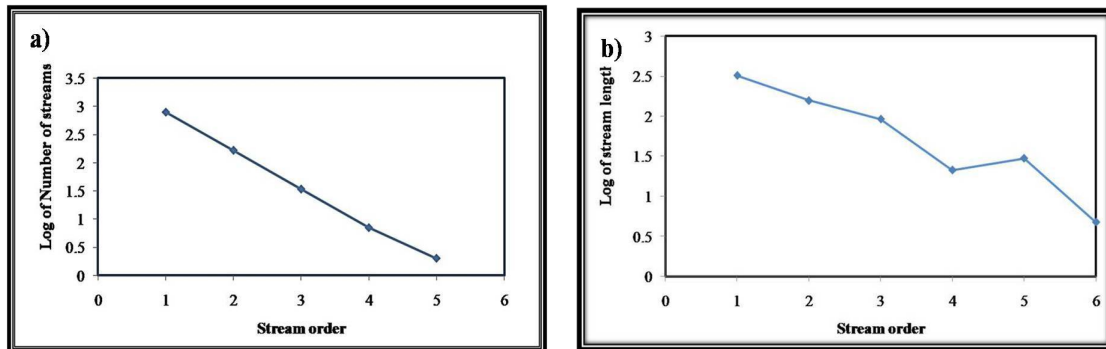


Fig. 6 a) Regression of logarithm of number of streams versus stream order,  
b) Regression of logarithm of stream lengths versus stream order.

Table 2: Determined linear morphometric parameters of the east Suvarnamukhi basin, Karnataka State

Stream order (Nu)						$\sum Nu$	Stream length(Lu)					
1	2	3	4	5	6		1	2	3	4	5	6
792	166	34	7	2	1	1002	314.87	153.25	89.60	20.75	29.22	4.65

Stream Length ratio ( $R_L$ )					Bifurcation ratio ( $R_b$ )				
2/1	3/2	4/3	5/4	6/5	1/2	2/3	3/4	4/5	5/6
0.49	0.59	0.23	1.41	0.16	4.77	4.88	4.86	3.5	2

The total length of the streams is 612.34 km. As can be made out from Table 2, the stream lengths of the higher order in the study area are greater than that of the lower order indicating progressive decline in the slope of the region. The stream length ratio establishes the relationship between surface flow and discharge (Horton, 1945). From the Table 2, it is evident that the values of the stream length ratio show an increasing trend from higher order to lower order excepting the stream length ratio of 1<sup>st</sup> and 2<sup>nd</sup> order. The mean stream length ratio of east Suvarnamukhi basin is 0.57

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(Table 2 and 3). Generally the total length of stream segments decreases with an increase of stream order. Deviation from this general trend indicates a regional upliftment across the drainage basin (Chatterjee and Tantubay). The results of the fifth order stream lengths not conforming to the general trend and significant variation in the stream length ratio of the stream order may probably indicate an event of regional upliftment in the present study area.

Bifurcation ratios characteristically range between 3.0 and 5.0 for basin in which the geologic structures do not distort the drainage pattern (Strahler 1964, 1957). The mean bifurcation ratio value for the study area is 4.00 (Table 3), which indicates that the geological structures are less disturbing the drainage pattern. This is also evident from the observed dominant dendritic drainage pattern in the study area. The value of bifurcation ratio also indicates the shape of the basin (Vasudevan, 2015). High value of the bifurcation ratio is basically an indicator of elongated basin while low values indicate circular basins. The value of bifurcation ratio of the present study area implies that the basin is oblate.

### Areal parameter

The areal parameters include basin area, drainage density, stream frequency, texture ratio, form factor, circularity ratio, elongation ratio and length of the overland flow. Area of a basin and perimeter are the important parameters in quantitative morphology. The area of the basin is defined as the total area projected upon a horizontal plane contributing to cumulate of all stream order of the basins. Perimeter is the length of the boundary of which can be drawn from topographical maps. The perimeter of the east Suvarnamukhi basin is 99.24 km (Table 3). Basin area is hydrologically important because it directly affects the size of the storm hydrograph and the magnitudes of peak and mean runoff. It is interesting that the maximum flood discharge per unit area is inversely related to size (Chorley, et al., 1957). The length of the basin (L<sub>b</sub>) is measured parallel to the main drainage line. The basin length of east Suvarnamukhi basin is 27.10 km (Table 3). Drainage density of the study area is 2.26 km/sq. km, which indicates that the basin has moderate permeable sub-soil, thick vegetative cover (Strahler, 1957) with moderate relief. Mean stream frequency value of 3.70 (Table 3) implies low to the moderate surface runoff. Drainage texture, form factor, elongation ratio and circular ratio of east Suvarnamukhi basin respectively are 8.38, 0.37, 0.68 and 0.35 indicating the very fine drainage texture, elongate shape of the basin, mature stage of the tributaries of the basin associated with moderate relief and the basin is made up of moderately permeable homogenous geologic materials with moderate discharge (Miller, 1953). The length of overland flow (L<sub>g</sub>) of investigated basin is 0.22 (Table 3) implying low to moderate surface runoff (Horton, 1945).

### Relief parameter

The relief parameters include basin relief, relief ratio, ruggedness number, dissection index and hypsometric integral. The relative relief of basin is 560m (the difference in elevation between the highest and the lowest point of the basin). The relief ratio (R<sub>n</sub>) may be defined as the ratio between the total relief of a basin and the longest dimension of the basin parallel to the main drainage line (Schumm, 1956) and the relief ratio increases with decreasing drainage area with respect to size of investigated drainage basin (Gottschalk 1964). Watersheds having high R<sub>n</sub> values are characterized by dynamic geomorphic processes, long and steep slopes interrupted by sharp breaks of slope due to rejuvenation processes, high susceptibility to soil erosion and mass movement, and high response to an increase in peak discharge (Faran et al., 2015). In the present study the value of relief ratio is 0.021 (Table 3) thus indicating low relief and gentle slope. It is further validated by the ruggedness number value which is 1.3 implying moderate basin relief and the area is less or moderately prone to soil erosion (Pareta and Pareta, 2011). Dissection index is a parameter implying the degree of dissection or vertical erosion and expounds the stages of terrain or landscape development in any given physiographic region or watershed (Singh and Dubey 1994). The dissection index of basin is 0.47 represents the area subjected to moderate dissection and the hypsometric integral value of 0.29 (Table 3) indicates that the basin is passing through old or monadnock stage of landform development (Markose, et al, 2011).

**Table 3:** Computed values of selected morphometric parameters in the east Suvarnamukhi basin

Parameters	Results
Area (A)	270.55 Sq. Km
Perimeter (P)	99.24 Km
Basin length (L <sub>b</sub> )	27.10 Km
Stream order(Nu)	6 <sup>th</sup> order

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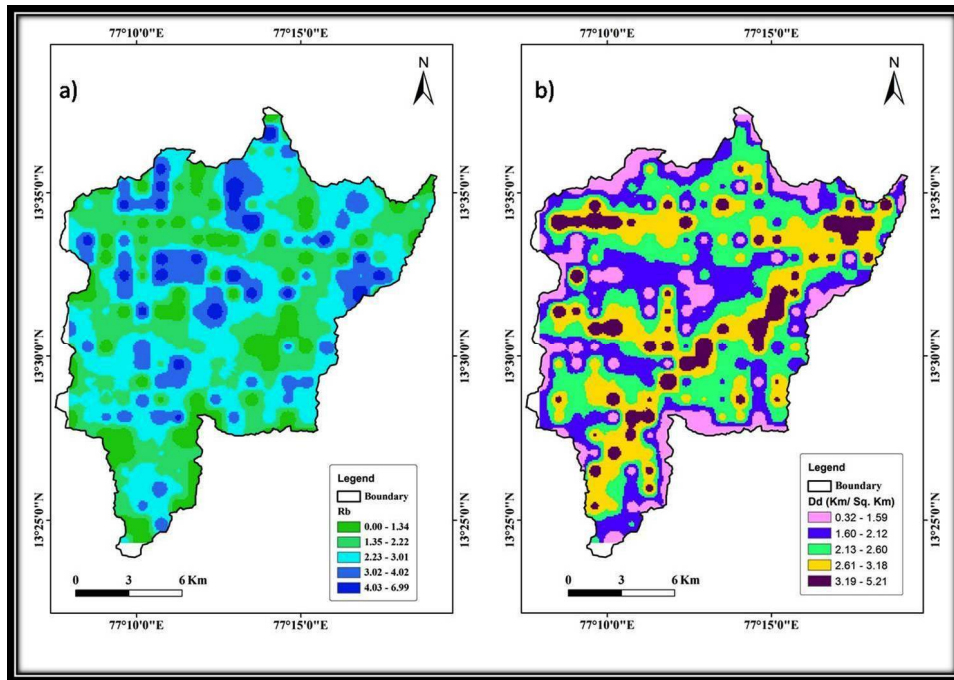
Total stream length (Lu)	612.34 Km
Mean stream length (Lsm)	0.61 Km
Mean stream length ratio(Rlm)	0.57
Mean bifurcation ratio (Rbm)	4.00
Drainage Density (Dd)	2.26 Km/Sq. Km
Drainage Texture (T)	8.38
Texture ratio (Rt)	10.10
Mean stream Frequency (Fsm)	3.70
Elongation Ratio (Re)	0.68
Circularity Ratio (Rc)	0.35
Form Factor (Ff)	0.37
Length of Overland flow (L <sub>o</sub> )	0.22 Km
Relative relief (R)	0.560 Km
Relief Ratio (Rh)	0.021
Ruggedness number (Rn)	1.3
Hypsometric integral (Hi)	0.29
Dissection index (Di)	0.47

### Hydrological behavior of the basin

The quantitative morphometric analysis coupled with limited field studies demonstrate the hydrological nature of the underlying geology, precipitation, exogenic and endogenic forces operating within the basin. The river basin is having moderate slope, showing dendritic drainage pattern and relatively low drainage density values.

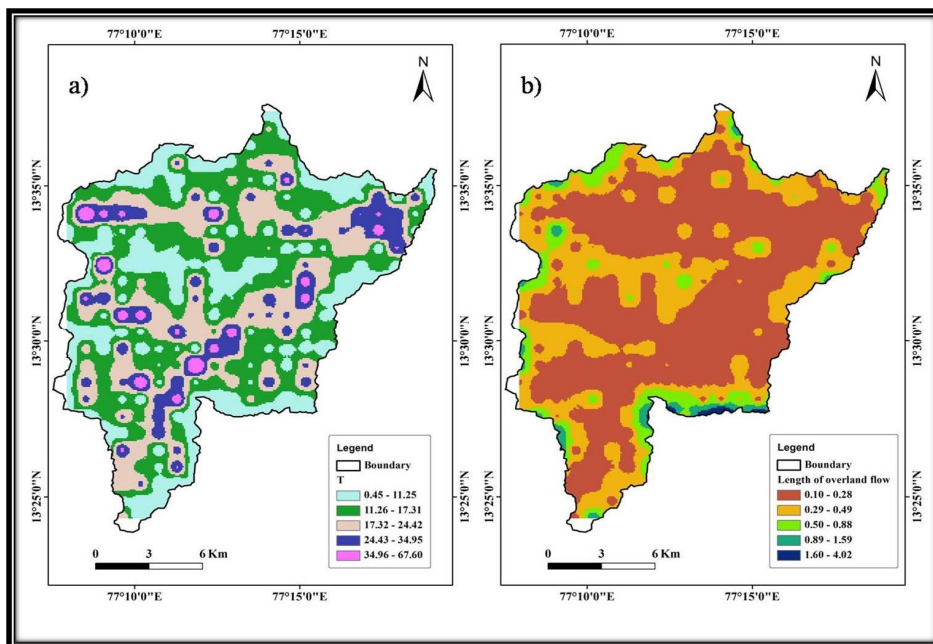
As evident from the spatial distribution map of the values of the Bifurcation Ratio (Fig. 7a), large part of the study area shows lower values of bifurcation ratio indicating significant hydrological potential of the basin. Further, the area is characterized largely by low drainage density values (Fig. 7b) thus validating the high hydrological potential and more infiltration capacity of the basin. The higher value of drainage texture (8.38) (Table 3) shows that the basin has very fine texture (Fig. 8a) indicating the presence of highly resistant permeable material with low relief and longer duration to peak flow. Low to moderate drainage density indicates low relief and permeable surface material and thus the regions characterized by low drainage density values (Fig. 7b) are favourable for groundwater exploration. Lower values of length of overland flow indicate low surface runoff and more elongated shape of the basin. As can be made out from the Figure 8b, most part of the study area shows lower values of overland flow thus favouring infiltration.





**Fig. 7** The map showing (a) Bifurcation ratio and (b) Drainage density of east Suvarnamukhi basin

From the relative relief and slope maps of the East Suvarnamukhi basin (Figs. 9a and 9b), it is evident that most part of the study area, especially eastern part, is characterized by gentle slope topography favouring low runoff and high infiltration capacity of the basin.



**Fig. 8** The map showing (a) Drainage texture and (b) Length of overland flow of east Suvarnamukhi basin

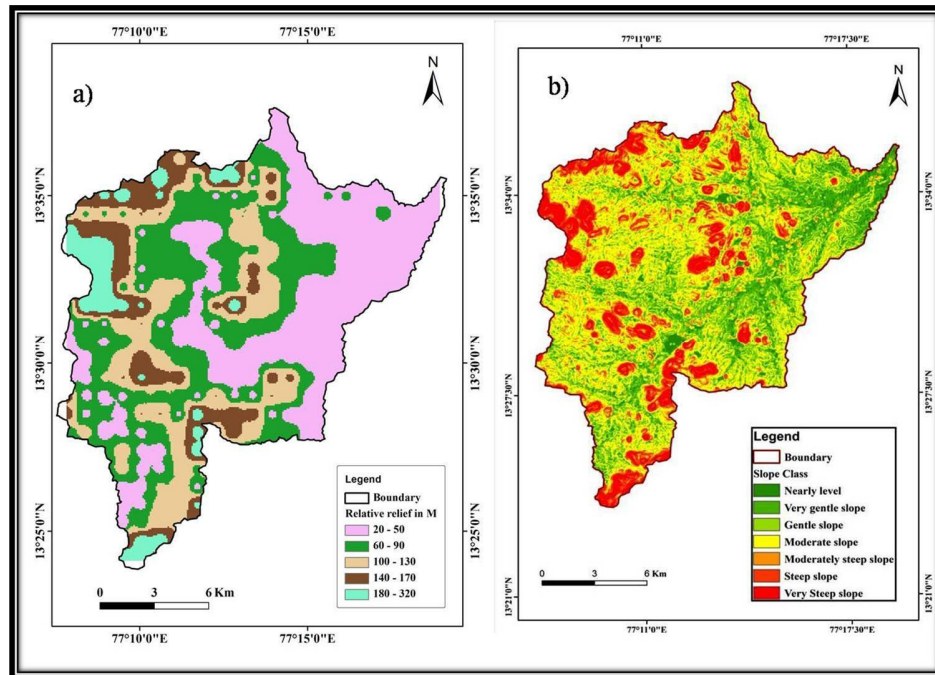


Fig. 9 The map showing (a) Relative relief and (b) slope of east Suvarnamukhi basin.

## V. CONCLUSION

Drainage morphometric analysis was carried out to illustrate the drainage characteristics, morphology and groundwater potential of east Suvarnamukhi basin of Karnataka state. The basic and derived morphometric parameters such as linear, areal and relief aspects of drainage network, for the basin were determined using bAd calculator and CartoSAT-1 DEM with 30 m resolution. These parameters demonstrate the hydrological features of the basin principally drainage network, geometry, texture, and relief characteristics. East Suvarnamukhi basin constitutes a 6th-order drainage basin and characterized by semi-dendritic to dendritic type of drainage patterns. There is no structural or tectonic control over the drainage network in the study area as made out from the drainage pattern. The results of the fifth order stream lengths not conforming to the general trend and significant variation in the stream length ratio of the various stream orders may probably indicate the regional upliftment of the study region. Circularity ratio and elongation ratio show that the shape of the basin is elongated. The  $F_s$ ,  $R_b$ ,  $L_g$  parameters of basin indicates that the area is moderate to good in terms of groundwater potentiality. The  $D_t$ ,  $T$ ,  $R_e$  indicates that the surface runoff is moderate to high in the basin. The  $R_n$  values of the basin indicates the study area is moderate to less susceptible for soil erosion and mass movement, and may show low response to an increase in peak discharge. Findings have revealed that the area of east Suvarnamukhi basin is in the early old-age stage of geomorphic evolution. The present study would help for watershed prioritization for soil and water conservation and for assessing the suitability of the location for artificial recharge of water. This study would help in the identification of the hydrologically potential areas for surface water and groundwater exploration. From the assessment of hydrological characteristics based on morphometric parameters, it is evident that the major part of the east Suvarnamukhi basin has moderate hydrological potential for the sustainable development.

## REFERENCES

- [1] Altaf, F., Gowhar Meraj, and Shakil, A., Romshoo, Morphometric Analysis to Infer Hydrological Behaviour of Lidder Watershed, Western Himalaya, India, *Geography Journal*, 14, 178021, 2013.
- [2] Chatterjee, A. and Tantubay, A., Morphometric Analysis for Evaluating Groundwater Potential Zones, In Kusangai Jor Watershed Area, Dist. Bolangir, Orissa. [www.isprs.org/proceedings/XXXVI/part4/RS-GEO-15.pdf](http://www.isprs.org/proceedings/XXXVI/part4/RS-GEO-15.pdf)
- [3] Chorley, R. J., Donald, E. G., Malm. and Pogorzelski, H. A., "A new standard for estimating drainage basin shape", *Amer. Jour. Sci.*, 255, pp 138141, 1957.

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

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- [4] Dinesh, A. C., Markose, V. J., Jayappa, K. S., , Bearing, azimuth and drainage (bAd) calculator: A new GIS supported tool for quantitative analyses of drainage networks and watershed parameters. *Computers and Geosciences*, 48, 67-72, 2012a.
- [5] Dinesh, A. C., Markose, V. J., and Jayappa, K. S., Drainage Basin Analyses of Kaneri River Basin heef Karnataka, India Using Visual Basic Programme bAd Calculator and GIS, *Indian Cartographer*, 32, 99, 2012b.
- [6] Easthernbrook, D. J., Surface processes and landforms, *Macmillian Pub Co*, New York, 325, 1993.
- [7] Farhan, Y., Anbar, A., Enaba, O. and Al-Shaikh, N., Quantitative Analysis of Geomorphometric Parameters of Wadi Kerak, Jordan, Using Remote Sensing and GIS. *Journal of Water Resource and Protection*, 7, 456-475, 2015.
- [8] Gottschalk, L. C., Reservoir Sedimentation. In: V. T. Chow (ed), *Handbook of Applied Hydrology*. McGraw Hill Book Company, New York, Section 7-1, 1964.
- [9] Horton, R. E., Erosional development of streams and their drainage basins; Hydrophysical approach to quantitative morphology, *Geological Society of America Bulletin*, 56, 275–370, 1945.
- [10] Kinthada, N. R., Murali Krishna Gurrum, Amminedu Eedara, and Venkateswara Rao Velaga., Remote sensing and GIS in the geomorphometric analysis of microwatersheds for hydrological Scenario assessment and characterization – A study on Sarada river basin, Visakhapatnam district, India, *International Journal Of Geomatics and Geosciences*, 4, 1, 2013.
- [11] Lazarus, G., Ndatuwong, and Yadav, Morphometric analysis to infer the hydrological behaviour in part of Sonebhadra district, Uttar Pradesh, India, Using remote sensing and GIS technique, *International Journal of Remote sensing and GIS*, 3(1), 2014.
- [12] Magesh, N. S., Jitheshlal, K. V., Chandrasekar, N., and Jin, K. V., Morphometric Parameters of the Calabar River Basin: Implication for Hydrologic Processes Eze Bassey Eze & Joel Efiog, *Journal of Geography and Geology*, 2(1), 2010.
- [13] Markose, V. J., Dinesh A. C. and Jayappa K. S., Quantitative analysis of morphometric parameters of Kali River basin, southern India, using bearing azimuth and drainage (bAd) calculator and GIS, *Environmental Earth Science*, 72, 2887–2903, 2014.
- [14] Markose, V., J. & Jayappa, K. S., Hypsometric analysis of Kali River Basin, Karnataka, India, using geographic information system *Geocarto International*, 26(7), 553-568, 2011.
- [15] Nag, S. K., Morphometric analysis using remote sensing techniques in the Chaka sub-basin, Purulia district, West Bengal, *Journal of Indian Society of Remote Sensing*, 26(1-2), 69–76, 1998.
- [16] Parameters of Wadi Kerak, Jordan, Using Remote Sensing and GIS. *Journal of Water Resource and Protection*, <http://dx.doi.org/10.4236/jwarp.2015.76037>, 7, 456-475, 2015.
- [17] Pareta, K., and Pareta, U., Quantitative morphometric analysis of a watershed of Yamuna basin, India using ASTER (DEM) data and GIS, *International Journal of Geomatics and Geosciences*, 2(1), 2011.
- [18] Patton, P. C., Drainage basin morphometry and floods. In: Baker VR, Kochel RC, Patton PC (eds) *Flood geomorphology*. Wiley, New York, 51–65, 1988.
- [19] Schumm, S. A., Evolution of drainage systems and slopes in Badlands at Perth Amboy, New Jersey, *Bulletin of the Ecological Society of America*, 67, 597–646, 1956.
- [20] Schumm, S. A., Sinuosity of alluvial rivers in the Great Plains, *Bulletin of Geological Society of America*, vol. 74, 1089–1100, 1963.
- [21] Singh, S., Dubey, A., Geoenvironmental planning of watersheds in India. *Chugh Publications*, Allahabad, 28–69, 1994.
- [22] Smith, K. G., Standards for grading textures of erosional topography, *American Journal of Science*, 248, 655–668, 1950.
- [23] Sreedevi, P. D., Owais, S., Khan, H. H., Ahmed, S., Morphometric analysis of a watershed of South India using SRTM data and GIS, *Journal of Geological Society of India*. 73, 543–552, 2009.
- [24] Strahler, A. N., “Quantitative analysis of watershed geomorphology,” *Transactions American Geophysical Union*, 38, 913–920.
- [25] Strahler, A. N., 1964, Quantitative geomorphology of drainage basins and channel networks, In: V.T.Chow(ed). *Handbook of applied hydrology*. New York: McGraw Hill Book Company, 4-11, 1957.
- [26] Vasudeven, S., Lakes and wetlands. *Partridge publishing*. 356, 2015.
- [27] Vittala S. S., Govindaih, S. and Gowda, H., Morphometric analysis of sub-watershed in the Pavada area of Tumkur district, South India using remote sensing and GIS techniques, *Journal of Indian Remote Sensing*, 32, 351–362, 2004.