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Morphometric Characteristics of a Twin River Coastal Watershed: Implication for Watershed Management: A Case Study from the Mulki-Pavanje Rivers, Karnataka, India

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ABSTRACT

Morphometric investigation is a substantial means for prioritization of watersheds/sub-watersheds for their management. In the present paper Mulki-Pavanje twin rivers in the coastal Karnataka is studied for their conjunctive watershed management based on morphometric analysis is carried out using remote sensing and GIS. In this study the different morphometric properties of the watershed such as Areal, Relief and Linear aspects has been carried out using SRTM (DEM) data of 30m resolution. The Mulki-Pavanje streams originate at 240 and 200m above MSL on the western part of the western ghat, and together drain area of 581 Square Kilometres and seam the Arabian Sea through a common estuary. Morphometric analysis has revealed that the area is having moderate slope and infiltration rate, hence groundwater recharge is limited, while presence of lineaments indicates local percolation. Hence both surfaces harnessing of the water resources followed by local recharge is suggested.

KEYWORDS: *Morphometry, Twin River, SRTM, Estuary, Drainage, Watershed Management*

INTRODUCTION

Coastal Karnataka, in particular Southern Karnataka is urbanising rapidly posing problems of water resources for drinking and other needs. Coastal Karnataka although receives high rainfall, due to hard rocks in the coastal belt, groundwater recharge is limited. Due to salt water intrusion although local, inhibits large extraction of the groundwater. On the other hand, rivers coming from the western ghat due to sudden change into narrow coastal topography cause heavy were flooding. This warrants conjunctive utilisation of water resources. Due to inadequate hydrological data, management of watershed became a challenging issue.

In the nonappearance of hydrologic data, analysed morphometric parameters serves as an influential means of understanding hydrodynamics of the drainage basin. Morphometric analysis is a significant aspect of the characterization of the watershed which provides the quantitative narration of the drainage pattern of a basin (Strahler, 1964). The topographical appearances of land by way of area, slope, shape, length, etc. are designated by Morphometric study. These parameters affect the catchment stream-flow pattern (Jones, 1999). The flowing pattern of the river and development of drainage system over space and time are influenced by several variables such as geology, geomorphology, structural components, soil, and vegetation of the area through which it flows. In understanding the watershed characteristics and to evaluate and investigate the spatial information of watershed, the Geographical Information System (GIS) techniques have been extensively used (c.f Teajswini et al., 2011, 2018, Montgomery and Dietrich, 2011, Magesh, 2012). Though morphometric analysis of the basin has been studied by Avinash et al (2011) for the basin, the basin analysis for the development of water resources for conjunctive use has not been focussed. In this present paper this characteristic is studied.

The Mulki-Pavanje (M-P) River mouth comprises a part of the Central West Coast of India lies between latitude 12°57' North to 13°12' North and longitude 74°45' East to 75°03' East, in Dakshina Kannada district and part of Udupi district of Karnataka (Fig. 1). It is a twin river system (Hegde et al., 2011) with an over-all catchment area of the basin is 581 Square Kilometres. The Mulki-Pavanje Rivers initiate in the midlands (below the Western Ghats) at an altitude of about 240 and 200 m, respectively, and have a common estuary near the place Mulki. The area encompasses of tropical climate and collects average annual rainfall of ~600 cm. The annual average temperature of the area contrasts from 23° to 30°.

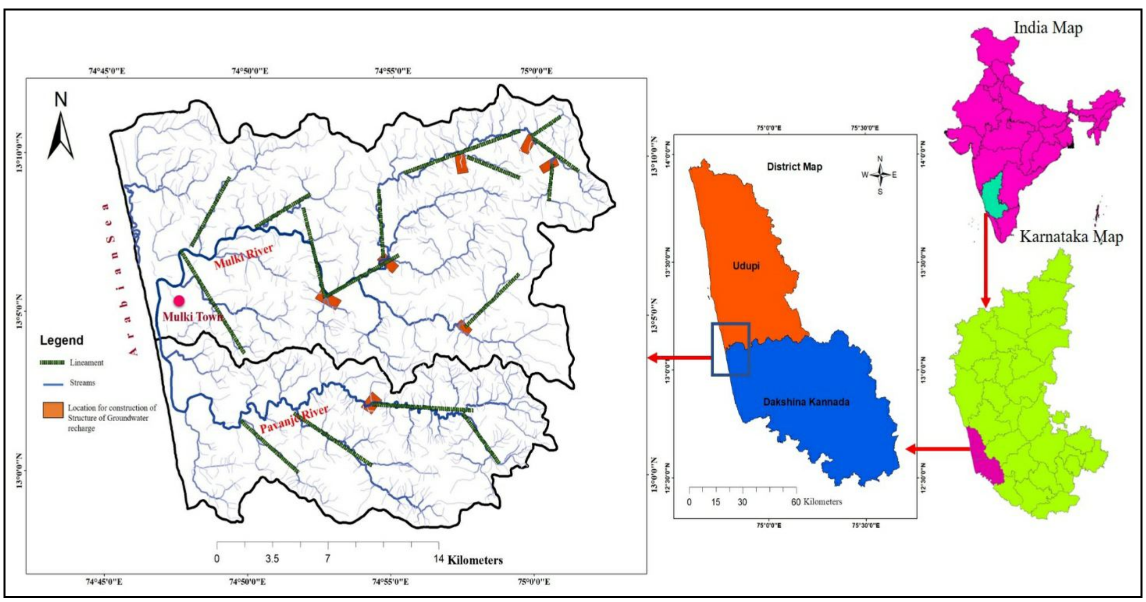

Figure 1: Study Area

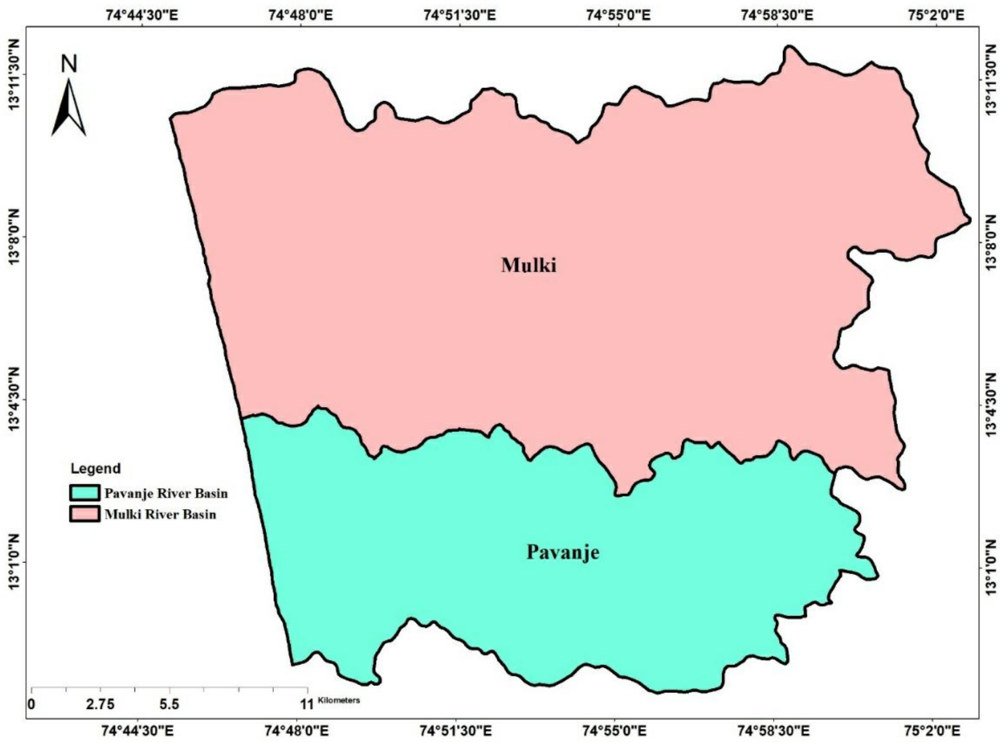

Figure 2: Mulki-Pavanje River Basins

METHODS

This study is grounded on the morphometric analysis, (Horton, 1945; Strahler, 1957) Quantitative analysis of the basin characteristics which have been computed for Linear, Areal and Relief morphometric parameters using the established mathematical equations which are tabulated in the table (Table 1). Drainage network analysis such as drainage density, drainage frequency, drainage ordering and bifurcation ratios were figured for the basins. Further, areal extent of each geomorphic unit has been quantified. Finally, morphometric parameters are used to comprehend the basin characteristics.

Digital elevation model (DEM) is the data-set which becomes prime data. Extracting drainage parameters from DEM is capable, detailed and effective. GIS platform is perfect for morphometric analysis because of its effectiveness in processing and computing topographic data (Altaf et al. 2013; Prakash et al. 2016). The morphometric investigation of the basin using ASTER DEM (30m resolution) is achieved through calculation of Linear, Aerial Relief and gradient of channel network and contributing ground slope of the basin.

Number of studies exposed that Shuttle Radar Topography Mission Digital Elevation (SRTM-DEM) is much better than ASTER DEM because it provides relatively accurate data to morphometric analyses (Farr et al, 2007), hence SRTM-DEM data were chosen in the present study. The basin was demarcated using Survey of India (SOI) topographical map of 2010 in the scale of 1:50,000 (No 48K / 16).

The detailed methodology is presented below.

1. The scanned toposheet is brought to the GIS software environment i.e ArcMap 10.3, Georeferenced by the standard method, and projected to WGS 84 Zone 43N projection.
2. Watershed boundaries for Pavanje and Mulki are delineated first.
3. Different shapefiles are generated for different themes and different thematic maps are generated like Drainage, Watershed, LULC, Lithology, and Geomorphology.

4. Drainage map is further analysed and given the attributes of different orders and stream length is calculated by using geometric calculation tool in the attribute table of that shapefile.
5. SRTM DEM data of 30m resolution of the year 2012 is downloaded from the Earthexplorer USGS website.
6. SRTM data is processed by spatial analysis tool to fill the sinks.
7. Watersheds and streams are delineated for Mulki and Pavanje Rivers to cross verify the watersheds delineated from the toposheet.
8. Slope map is generated using SRTM DEM and also contours of 20 meters' interval are delineated.
9. Linear, Areal and Relief aspects such as Stream length, Stream frequency, Area, Perimeter, Basin length, Stream order, mean stream length, drainage density, elongation ratio, circulatory factor, form factor, bifurcation ratio, basin relief, basin slope, gradient ratio are assessed using this shape files and also the processed SRTM DEM data grounded on the mathematical equations established (Table 1).

RESULTS

Table 1: Established mathematical equations for different morphometric calculations

Sl. No.	Morphometric Parameters	Formulae	Reference
1.	Stream order (u)	Hierarchical rank	Strahler (1964)
2.	Stream length (Lu)	Length of the stream	Horton (1945)
3.	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'	Strahler (1964)
4.	Stream length ratio (RL)	RL = Lu / Lu -1 Where, RL = Stream length ratio Lu =The total stream length of the 'u' Lu – 1 = The total stream length of its next lower order	Horton (1945)
5.	Bifurcation ratio (Rb)	Rb = Nu / Nu +1 Where, Rb = Bifurcation ratio Nu = Total no. of stream segments of the order 'u' Nu +1= Number of segments of the next higher order	Schumn (1956)
6.	Mean bifurcation ratio (Rbm)	Rbm = Average of bifurcation ratios of all orders	Strahler (1957)
7.	Stream frequency (Fs)	Fs = Nu / A Where, Fs = Stream frequency Nu = Total no. of streams of all orders A = Area of the basin (km2)	Horton (1932)
8.	Drainage texture (Rt)	Rt = Nu / P Where, Rt = Drainage texture Nu = Total no. of streams of all orders P = Perimeter (km)	Horton (1945)
9.	Form factor (Rf)	Rf = A / Lb2 Where, Rf = Form factor A = Area of the basin (km2) Lb2 = Square of basin length	Horton (1932)
10.	Circularity ratio (Rc)	Rc = A*Pi*/P2 Where, Rc = Circularity ratio Pi = 'Pi' value i.e., 3.14 A = Area of the basin (km2) P2 = Square of the perimeter (km)	Miller (1953)
	Drainage Density	$Dd = L_u / A$ Where Lu=Total Length of the streams of all orders A=Area of the basin (Km^2)	Strahler (1964)
11.	Elongation ratio (Re)	Re = 2 / Lb Where, Re = Elongation ratio A = Area of the basin (km2) Pi = 'Pi'	Schumn (1956)

		value i.e., 3.14 Lb = Basin length	
12.	Length of overland flow (Lg)	Lg = 1 / D*2 Where, Lg = Length of overland flow D = Drainage density	Horton (1945)
13.	Basin Relief (R)	R=H-h R=Basin Relief H=Maximum elevation in meters h= Minimum elevation in meters	Schumn (1956)
14.	Ruggedness number (Rn)	Rn=R*Dd Rn=Ruggedness number Dd=Drainage density	Schumn (1956)

Table 2: Showing calculated/ analysed values of different morphometric parameters of Mulki-Pavanje river basins

Sl. No.	Morphometric Parameters	Result Pavanje Basin	 Mulki Basin
1.	Stream Order (u)	1 to 5	1 to 6
2.	Stream Number		
	Number of 1st order stream (N1)	368	542
	Number of 2nd Order Stream (N2)	100	152
	Number of 3rd Order Stream (N3)	28	33
	Number of 4th Order Stream (N4)	4	7
	Number of 5th Order Stream (N5)	1	3
	Number of 6th Order Stream (N6)	NIL	1
3.	Total Number of Streams (Nu)	501	738
4.	Stream Length (Km)		
	Length of 1st order streams	211.20	361.36
	Length of 2nd order Streams	79.62	132.74
	Length of 3rd order streams	41.62	79.43
	Length of 4th order streams	20.31	58.13
	Length of 5th order streams	34.47	40.24
	Length of 6th order streams	NIL	22.82
5.	Total Length of the Streams (Lu)	387.22	694.75
6.	Mean Stream Length (Lsm) (Km)		
	Mean Stream Length of 1st order streams	0.57	0.66
	Mean Stream Length of 2nd order streams	0.79	0.87
	Mean Stream Length of 3rd order streams	1.48	2.40
	Mean Stream Length of 4th order streams	5.07	8.30
	Mean Stream Length of 5th order streams	34.47	13.41
	Mean Stream Length of 5th order streams	NIL	22.82
7.	Stream Length Ratio (RL)		
	2nd order / 1st order (RL2)	0.37	0.36
	3rd order / 2nd order (RL3)	0.52	0.59
	4th order / 3rd order (RL4)	0.48	0.73
	5th order / 4th order (RL5)	1.69	0.69
	6th order / 5th order (RL6)	-	0.56
	Mean Stream Length ratio:	0.76	0.58
8.	Bifurcation Ratio (Rb)		
	1st order / 2nd order	3.68	3.56
	2nd order / 3rd order	3.57	4.60
	3rd order / 4th order	7	4.71

	4th order / 5th order	4	2.33
	5th order / 6th order	-	3
	Mean bifurcation ration:	4.56	3.64
9.	Area of the Basin (A) SqKms	195.55	385.812
10.	Stream Frequency (Fs)	2.56	1.91
11.	Drainage Texture (Rt)	6.1	6.61
12.	Form factor (Rf)	0.29	0.44
13.	Circulatory ratio (Rc)	0.37	0.38
14.	Elongation ratio (Re)	0.61	0.75
15.	Drainage density (Dd)	1.98	1.80
16.	Length of overland flow (Lg)	0.25	0.27
17.	Basin Relief	180	220
18.	Relief ratio (Rr)	0.006	0.007
19.	Ruggedness number (Rn)	0.35	0.39

DISCUSSION

The Mulki River which is also called as Shambhavi River is of 6th order stream with an over-all length of 22.82 kilometres and the Pavanje River is of 5th order stream with an over-all length of 34.47 kilometres.

Lithologically the Mulki River basin is dominated by Pink Hornblende Granite while the Pavanje basin is composed of Beach sand, Laterite, Meta Pyroxenite, Gabbro and Serpentine, Migmatites and Granodiorites, Pink Hornblende Granite (Fig. 3).

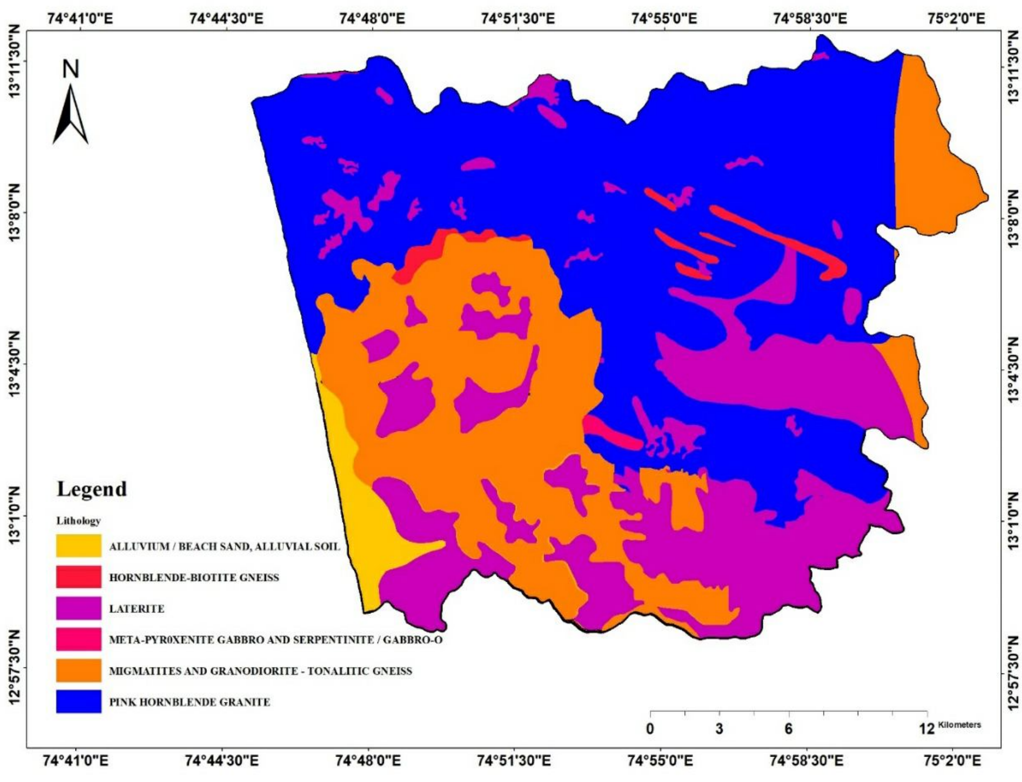

Figure 3: Lithology of the Mulki-Pavanje Basin

Linear Aspects:

The Pavanje basin is 5th order stream and sprawls over 195.55 Sq. kms, while the Mulki basin is 6th order stream and drain area of 385.81 Sq. Kms (Fig 4). The stream number varies from 1 to 368 in Pavanje basin and 1 to 542 in the Mulki basin. In both the basins, the numbers of streams are decreasing with the increase in stream order which implies that there exists homogenous sub surface material and constant variation in relief. Lesser number of streams is the sign of matured topography of sub-basins, whereas the higher number of streams (first and second orders) designates that the area is exposed to erosion (Avinash et al., 2011) Table 2 shows that the length of the stream of each order decreases with increase in the stream order in both the basins excluding the highest order (5th) in Pavanje basin. According to Strahler [1964] the mean stream length of a given order is less than the next higher order while total stream length is maximum in first order and decreases as the stream order increases. This geometric relationship between the logarithm of average number of streams vs stream order for the basins (Fig. 5) designates the number of stream (Nu) decreases as stream order (u) increases which supports the Horton's Law [1932] i.e. geometrical resemblance is preserved in both the basin. The mean bifurcation ratio for both the basins is less than 5. Generally, bifurcation ratio which is higher than 5 are common in drainages which are structurally controlled, while the lower bifurcation in the current instance designates that the drainage in the area is geomorphologically controlled rather than geological structures. The total length of all the streams together of the Pavanje basin is ≈387 kms and that of the Mulki basin is ≈738 kms. The Stream length ratio which shows an increasing trend from lower order to higher order specifies the mature geomorphic stage, whereas, Stream length ratio between successive stream orders differs due to differences in slope and topographic conditions (Magesh et al., 2012). The mean stream length ratio of both the basins varies from 0.58 to 0.76 the Pavanje and Mulki correspondingly.

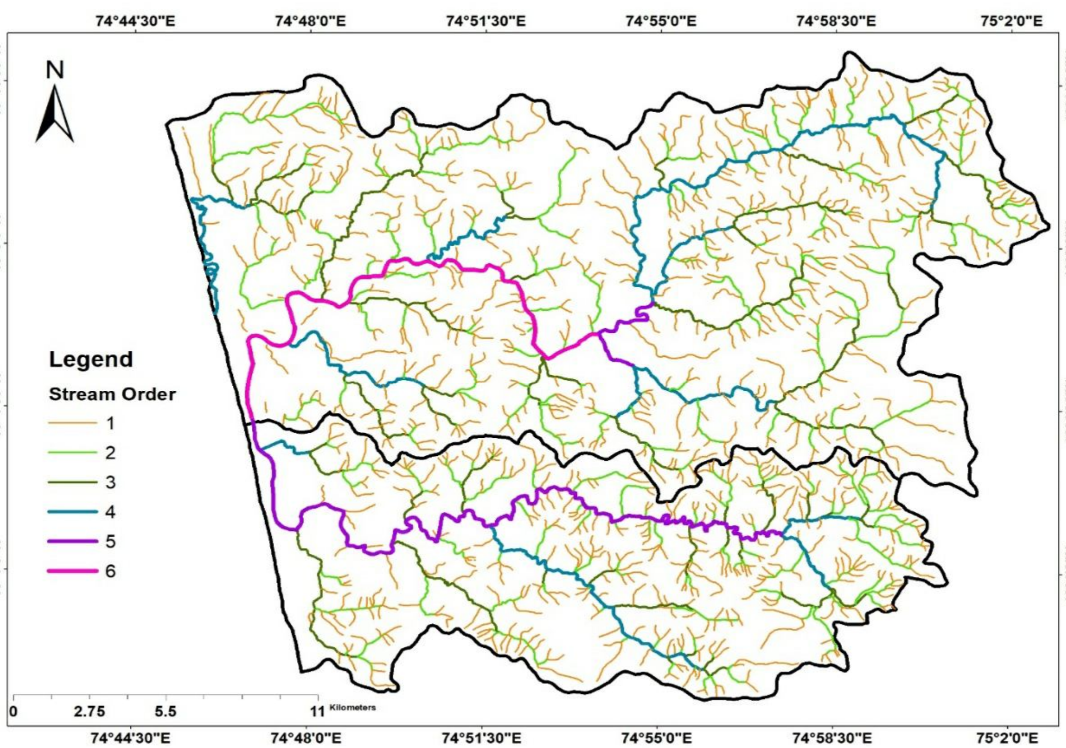

Figure 4: Drainages Map of Mulki and Pavanje River along with lineaments traced

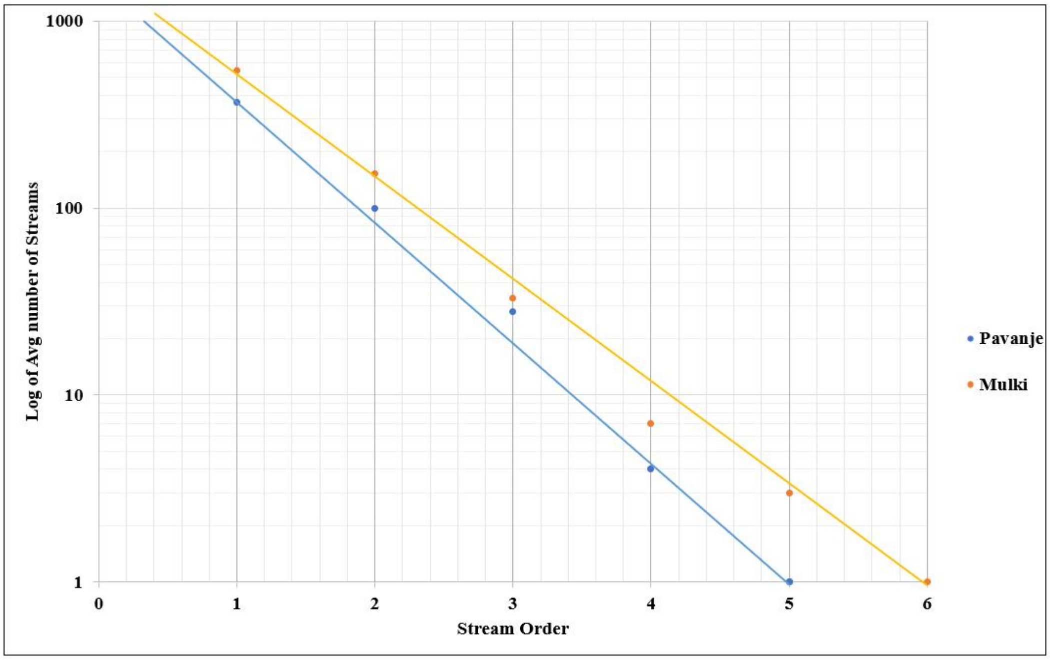

Figure 5: Graph of stream Order vs Log of average number of streams in each order for the Mulki and Pavanje River

Aerial Aspects:

The aerial parameters distress the stream flow of the basin. The calculated standards of aerial parameters are given in table 2. The form factor values for both the basin are 0.29 to 0.44 for the Pavanje and Mulki correspondingly, which designates that the basin is narrow and elongated in form. This specifies that the basins have a flatter peak of flow for longer period. Both the basins are elongated with elongation ratio are 0.61 to 0.75 correspondingly for the Pavanje and Mulki basins. Higher value of Elongation ratio (Re) implies active denudational processes with high infiltration capacity and low run-off in the basin, whereas, lower Re values designate higher elevation of the basin is susceptible to high headward erosion probably along tectonic lineaments (Deepika et al., 2013; Avinash et al., 2011; Obi Reddy et al., 2004 Manu and Anirudhan, 2008). The values of these basins for elongation ratio elect that it is associated with low to moderate relief.

The circularity ratio of both the basin is ~0.38 which designates that the basin is not circular in shape and approves the interpretations made from Re. The circularity ratio is mainly influenced by stream length and stream frequency and gradient of streams of various orders rather than the slope conditions and drainage pattern of the basin (Strahler, 1964). Low, medium and high values of circularity ratio gives an indication of the young, mature and old stages of the streams in the basins, respectively. The low circularity ratio of the twin river system infers young rivers system.

Drainage density of a basin is role of the resistance of surface materials to weathering, permeability of subsurface rock formation, vegetation and climate etc (Dodov et al., 2006). Mostly, if the Drainage density value is low, then the region is underlined by permeable subsurface, low relief and better vegetation cover. Also, if the drainage density value is high then the region is underlined with impermeable subsurface, with high relief and lesser vegetation cover. The low values of drainage density <2 (Table 2) specifies that the area is having resistant/permeable strata under medium to dense vegetation with moderate relief.

Stream frequency is a dimensionless factor. It is mainly dependent on lithology of that particular area, which in turn echoes the texture of drainage network and it relays to permeability, infiltration capacity and relief of that area. The stream frequency value for the area is ≈2.5 which infers that the area is having moderate slope, moderate infiltration. Drainage texture depends on climate, rainfall, vegetation, soil and rock type, relief, infiltration in the area. The average value of drainage texture in the area is ≈6. This shows that the area is having extremely resistant rocks. The length of flow of water over the ground before it becomes rigorous in fixed stream channels is designated by the length of overland flow. It is one of the strongest independent variables, distressing both the hydrological and physiographical progresses of the drainage basins (Horton 1945). The values of Length of overland flow in the area fluctuate from 2.5 to 2.7 which specify the area is having moderate steepness, moderate infiltration.

Relief Aspects:

Slope is a chief factor in controlling and progress of different kinds of landforms. Hence Basin relief (R) is a substantial factor to understand denudational characteristics of the basin, which controls the stream gradient and subsequently influences the flood pattern (Hadley and Schumm, 1961). From the contour map (Fig. 6), generated SRTM DEM data (Fig. 7), it shows that the area is having altitude ranging from 200 to 240 meters. Relief ratio of the area ranges from 0.006 to 0.007 which specifies that the area is having gentle slope. Slope of the area varies from 0% to 50% (Fig. 8). Except a NE trending ridge in the Mulki basin both the basin has low relief. Ruggedness number (Rn) specifies structural complexity of the terrain, relief, drainage density and the area susceptible to soil erosion (Sameena et al., 2009). The ruggedness number is 0.35 to 0.39 Pavanje and Mulki respectively which designates that the area is having low basin relief and drainage density.

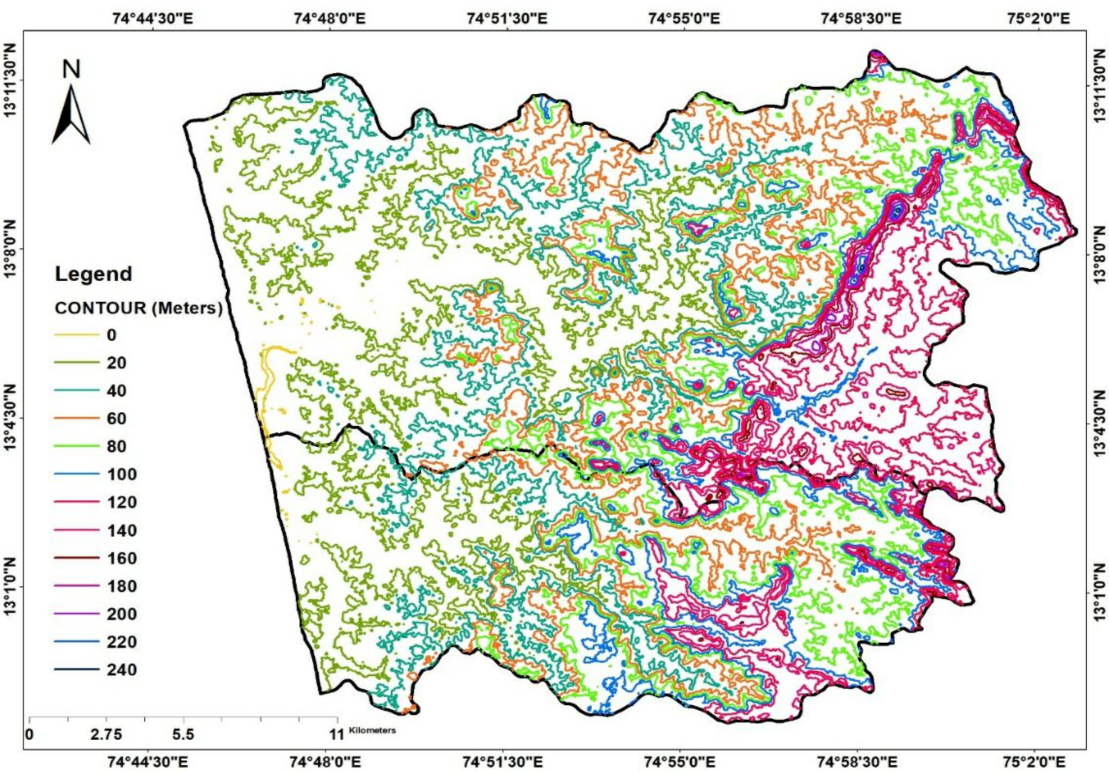

Figure 6: Contour map of Mulki and Pavanje River Basins

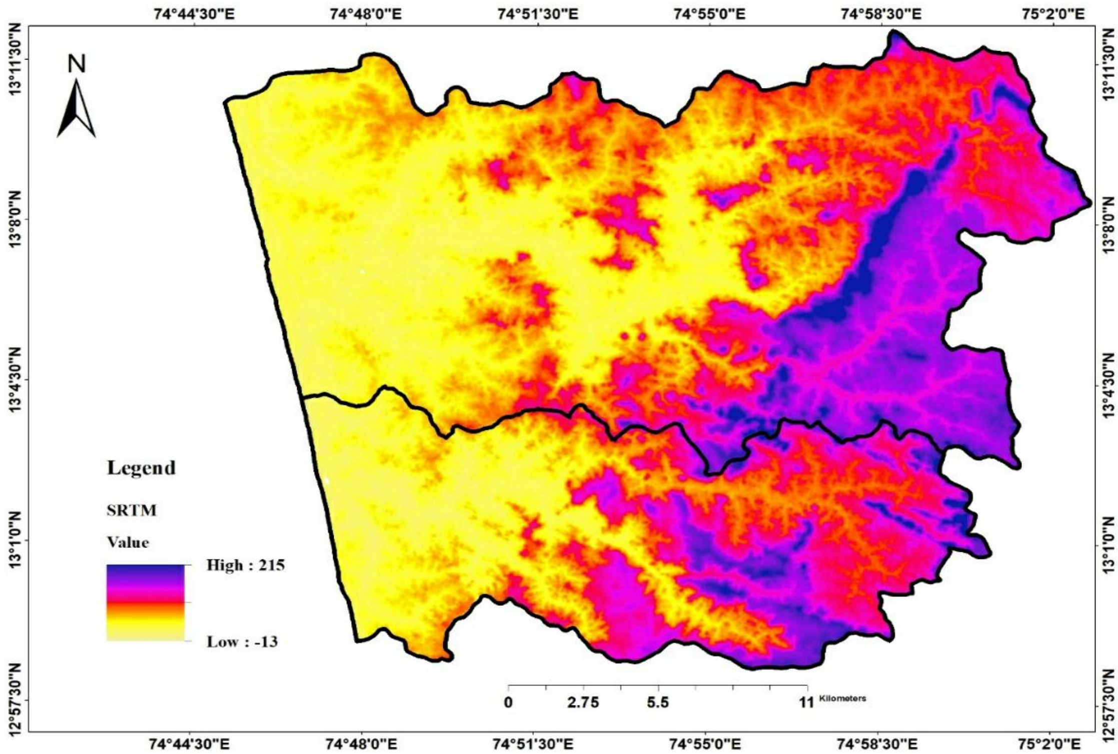

Figure 7: SRTM generated DEM of Mulki and Pavanje River Basins

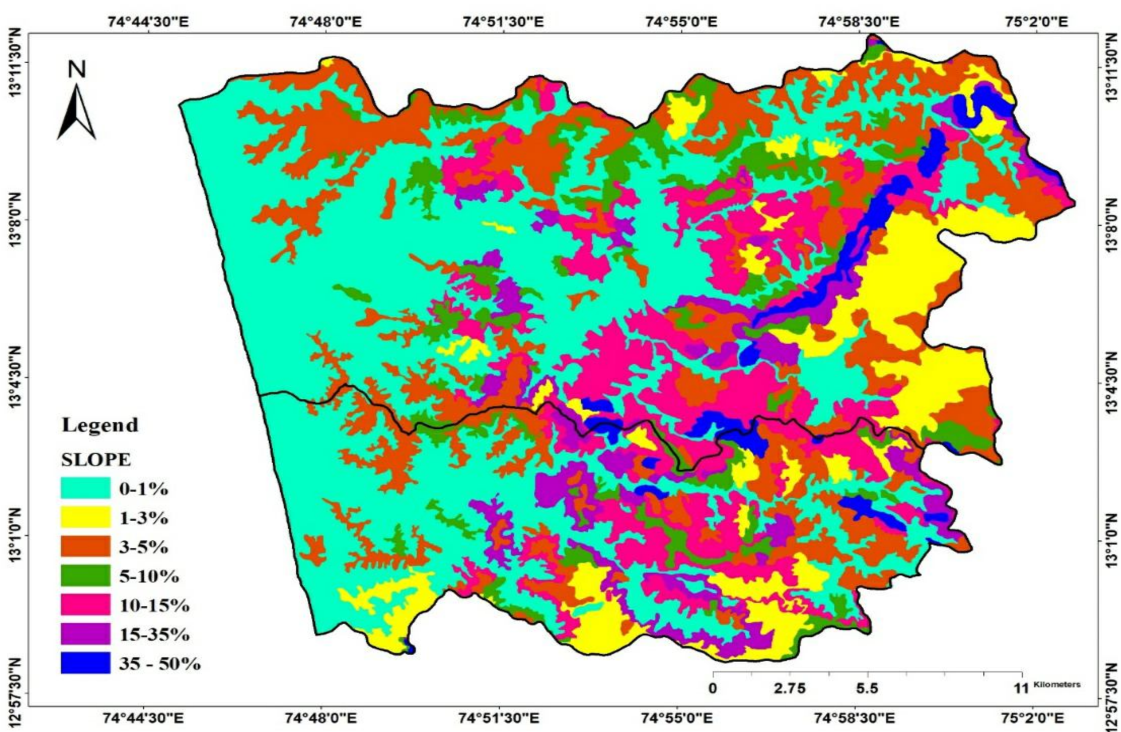

Figure 8: Slope map of the Mulki-Pavanje River Basins

Lineaments: Only few lineaments can be identified with confidence. Apparent lineaments density (number and length) is more in Mulki than in Pavanje and mostly NW trending or NE-E trending. The NW trending follows the Dharwarian trends.

CONCLUSION

Various morphometric characteristics of both the basin indicate low permeable characteristics of the subsurface rocks hence groundwater percolation is limited. However, few lineaments present in the basin are potential sites for percolation. These lineaments coincide with areas of low relief implying wide spread of water if dammed. Although, area has good forest cover, owing to coastal climate evaporation also high. More over in the Mulki River especially in the coastal belt large area consists of sandy alluvium where sea water intrusion is likely. Few lineaments observed in the upper reaches are potential both for surface as well ground water harnessing.

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