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Drainage Basin Delineation and Quantitative Analysis of Panamaram Watershed of Kabani River Basin, Kerala Using Remote Sensing and GIS

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Abstract: The morphometric analysis was carried out to determine the drainage characteristics of Panamaram watershed (PW) of Kabani river basin, Kerala, India with emphasis on fourth order sub-basins (FOSBs) using Geocoded imageries of IRS-IC LISS III FCCs (1997) of 1:50,000 scale, aerial photographs (1990) of 1:15,000 scale and Survey of India toposheets (1968) on 1: 50,000 scale. The main idea was to examine the stream properties based on the measurement of various stream attributes. The different drainage parameters studied and the measurements related to perimeter, area of sub-basins, basin length and number of rivers were determined by using Map Info 6.5 techniques. The drainage pattern of the PW is dendritic, a sixth order stream. There are 587, 135, 36 and 12 first, second, third and fourth order Hortonian streams, respectively in PW. The mean bifurcation ratio indicates that the drainage pattern is not much influenced by geological structures. The shape parameters reveal the elongation of the basin and sub-basins. The applicability of Horton's Laws on Stream numbers, Stream lengths and Stream areas is tested by using the theory of regression by estimating theoretically bifurcation ratio, length ratio and area ratio. For the fourth order sub-basins of 1, 2, 4, 5 and 8 of PW, a second degree polynomial equation seems to be a better model than the Hortonian model.

Keywords: Morphometry, Drainage parameters, Regression analysis, Panamaram watershed, Kerala.

INTRODUCTION

Fluvial landforms are produced by the erosion and deposition of streams that are connected into networks (Strahler and Strahler, 2009). The morphometric studies on river basins were first introduced by Horton (1932) and the idea was later developed by Coates (1958) and Strahler (1964). In India morphometric studies were carried out by Chinnamani and Sakthivadivel (1981) on the Bhavani basin on the East coast, James and Padmini (1983) on Kuttiyadi river basin on the Malabar west coast, Joji et al. (2001) on Vamanapuram river basin and many others. The morphometric analysis of Panamaram watershed (PW) has been examined with emphasis on fourth order sub-basins (FOSBs) using remote sensing and GIS techniques. The drainage parameters studied include drainage pattern, stream order, stream number, strength length, mean stream length, drainage pattern, drainage density, stream frequency, stream length ratio, relief ratio, elongation ratio, bifurcation ratio, form factor and circularity ratio. Quantitative description of basin geometry, river characteristics, initial slope or inequalities in rock hardness, structural controls, recent diastrophism, geological and geomorphic history of the drainage basins can be understood by the morphometric analysis. The relation of infiltration number on depth to the water table (DTW), infiltration and run-off in the area are examined.

STUDY AREA

Panamaram river is a tributary of the Kabani and it rises from Lakkidi in the Western ghats about 1700 meters above mean sea level (mamsl). Important tributaries of Panamaram river are Karanthododu, Venniodupuzha, Karapuzha and Narasipuzha. Below the confluence of Panamaram river at Mananthawady, it is known as Kabani river. Kabani is one among the three east flowing rivers in Kerala, the others being Bhavani and Pampar. The Panamaram watershed (Fig. 1) is a sixth order basin covering an area of 465.1 sq.km lying between latitudes 11°30'7"N and 11°45' 56"N and longitudes 75°53'59"and 76°8'38" E. It is a sub-watershed, and its areal extent is between 10,000 and 50,000 hectares (Anonymous, 1999). The PW is situated in Wyanad district of Kerala and is bounded by Kozhikode district to

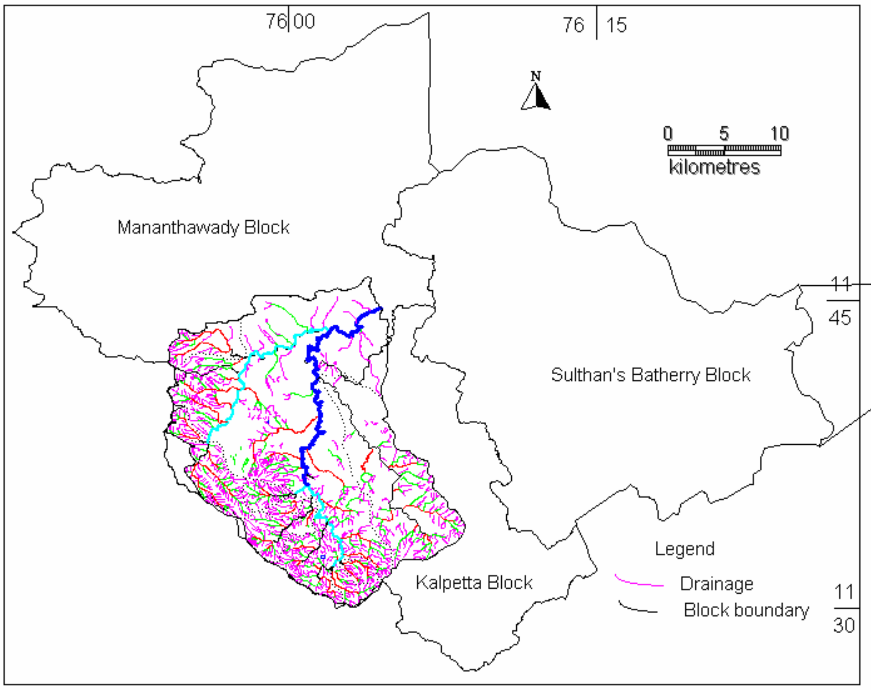

Fig.1. Location of Panamaram watershed in Wynad district, Northern Kerala.

the south and southwest and the remaining portion is in Wyanad district.

The climate of the area is tropical monsoonal with four seasons viz. cold weather (December to February), hot weather (March to May), south-west monsoon (June to September) and north-east monsoon (October to November). It is seen that the southern and southwestern areas of Lakkidi, Padinjarathara (bordering Kozhikode district) receive more than 3000 mm of annual normal rainfall. The SW (80%) and NE (11%) monsoons mainly contribute rainfall in the area. Besides orographic precipitation, pre-monsoon "mango showers" play a role in rainfall availability in the area. The area experiences mild weather throughout the year. The month of march 2004 experienced maximum average temperature of 33.97 °C and minimum average temperature of 13.87 °C. The wind velocity is generally low in the area and ranges between 1.91 and 5.69 km/hr. The monthly average relative humidity in the morning increases from 86.94% (08.30 AM) to 96.16 %. The evaporation in the area is very low during rainy seasons and the monthly mean evaporation ranges between 1.48 and 4.85 mm per day.

The area is characterised by different physiographic zones viz., high ranges with rugged topography, high ranges with moderately rugged topography, intermontane valley and flood plains. High ranges with rugged topography include hill ranges of elevation ranging from 1400 to 2100 m amsl. This area is occupied by dense mixed jungles of rugged topography with steep slopes and narrow valleys as well as hill ranges along the eastern part with isolated hills. In the high ranges with moderately rugged topography, the elevation ranges between 1000 and 1400 mamsl, with moderate slopes. Intermontane valleys are occupied by colluvium formed by depositional processes. Flood plains with apparent alluvial thickness of more than 10 m are quite common and are productive aquifers. The landform units identified in the area are alluvial plain, flood plain, valley fill, linear ridge, hillcrest, sloping terrain, rocky slope (scarp face) and hilly terrain. Flood plains and valley fills are the major fluvial landforms, whereas, moderately sloping terrain (S2), strongly sloping terrain (S3), rocky slope (scarp face), linear ridge and hillcrest are major denudational landform units. The flood plains have relatively smooth valley floors formed by alluviating rivers, which are subject to overflow. Landform unit with the highest slope (90°) identified in the study area is scarp face (rocky cliff). Laterite soil, brown hydromorphic soil, forest loam and riverine alluvium are the different soil types of the area. The lateritic soils are reddish brown in colour, formed under tropical and sub-tropical monsoonal climates with alternate wet and dry conditions. The forest soils are rich in organic matter, nitrogen and humus and is dark reddish brown formed by weathering under forest cover with loamy to silty loam texture. The brown hydromorphic soils are mainly seen between undulating topography. The alluvial soils are found along the banks of the Kabani and its tributaries. The major rock types of the PW are charnockites, migmatites, gneisses and granites.

MATERIALS AND METHODS

Topographical maps of 1:50,000 scale (SOI, 1968) have been used for the preparation of base map and drainage map (Fig.2). Prior to analysis, the map has been projected on [WGS 84] [EPSG: 4326], digitized, edited and given annotations by Map Info 6.5 techniques. Digitisation of the base maps were carried out using Digitiser Drawing Board III (Calcomp) at the Regional Data Centre of Central Ground Water Board (CGWB), Govt. of India, Thiruvananthapuram. The digitized maps were edited. During editing segment checking like intersection, self-overlap and dead-end corrections were carried out. Projection and polygonisation of units followed the editing. After polygonisation annotations were given for different polygons and the maps were ready for analysis. Area, perimeter, length of stream flow and length of different order Hortonian streams were determined by Map Info 6.5 techniques. The statistical treatments were carried out using SPSS 16.0 for WINDOWS and Map Info 6.5. Geocoded imageries of IRS-IC LISS III FCCs (1997) of 1:50,000 scale, aerial photographs (of 1990) of 1:15,000 scale, Survey of India (SOI) toposheets 58 A/1, 58 A/2 and 49M/14 of 1968 on 1: 50,000 scale were utilized for the preparation of lineament map.

Horton (1945) made a quantitative study of some aspects of watershed geomorphology and introduced several quantitative physiographic factors to describe the geometry of river networks. The different factors are the stream order (w) and its relationships with bifurcation ratio (R_b), length ratio (R_l) and area ratio (R_a) as they give quantitative information about the drainage composition. The three deterministic laws of Horton include:

Horton's Law on Stream Numbers states that there exists a geometric relationship between the number of

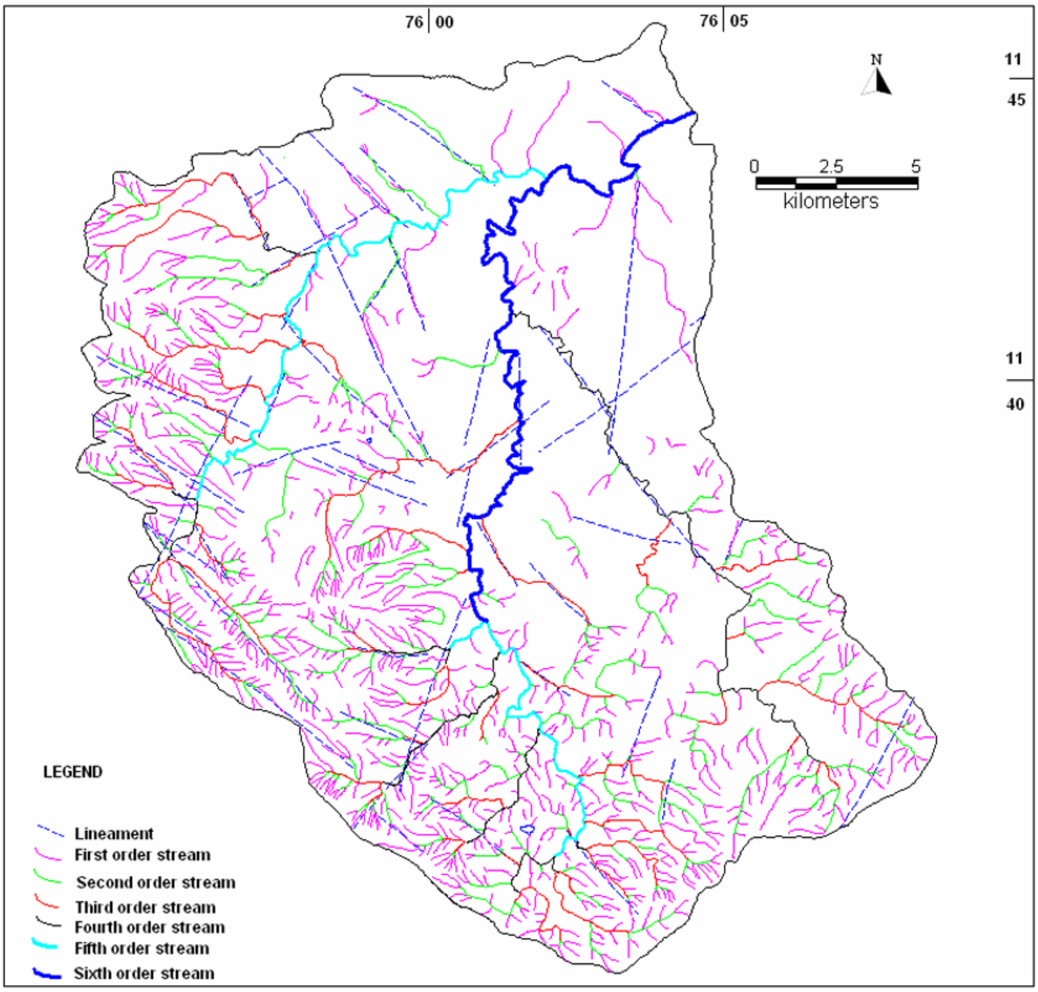

Fig.2. Drainage map of Panamaram watershed.

streams of a given order (N_w) and w. The parameter of this geometric relationship is R_b.

$$N_w = R_b^{\,M-w} \qquad (1)$$

Horton's Law of Stream Lengths states that there exists a geometric relationship between the average length of streams of a given order (N_w) and w. The parameter of this relationship is R_l.

$$\overline{L}_w = \overline{L}_1 R_l^{\,w-1} \qquad (2)$$

Horton's Law of Stream Areas states that there exists a geometric relationship between the average area drained by streams of a given order (N_w) and w. The parameter of this relationship is the so-called Area Ratio, R_a.

$$\overline{A}_w = \overline{A}_1 R_a^{\,w-1} \qquad (3)$$

In the equations (1), (2) and (3) above, w is the order of the basin, and the over-bar indicates the average value of the corresponding variable. Taking logarithm to the base 10 on both sides of equations (1), (2) and (3), respectively, linear relationships in w are obtained. Even though Hortonian laws are exact mathematical relationships between stream orders and stream number, stream length and stream area, the numerical values may not exactly satisfy the three equations given above due to the outcome of chance factors and hence the drainage net itself, as a whole, can be regarded as a consequence of random processes. Therefore, classical regression analysis can be employed for estimating the slope and intercept of the linear regression equation from the sample data. If the theoretically predicted values and the observed sample values do not differ too much, then Hortonian laws can be applied to our data also. The Hortonian model fit can be statistically assessed by coefficient of determination (R^2), which is the simple correlation between model predicted values and observed sample data. If we denote m as the slopes of the corresponding log transformed models in (1), (2) and (3) respectively, then R_b=1/antilog (m), R_l=antilog (m) and R_a=antilog (m).

RESULTS AND DISCUSSION

The different morphometric parameters are examined in detail. The entire area of a river basin whose runoff drains into the river in the basin may be considered as a hydrologic unit (drainage basin/watershed/catchment area) and the boundary line along a topographic ridge separating two adjacent drainage basins as a drainage divide. The PW possesses a leaf shaped catchment with greater flood intensity due to the comparable length of tributaries and run-off reaches almost simultaneously to the outlet. Drainage pattern or drainage arrangement refers to the particular plan or design, which individual stream courses collectively form, and is influenced by factors like initial slope, inequalities in rock hardness, structural controls, recent geologic and geomorphic histories of the drainage basin (Joji et al, 2001). The PW possesses dendritic pattern, characterized by irregular branching of tributaries in many directions, indicating lack of structural control but controlled by lithology (Fig.2). The dendritic pattern develops in areas of massive igneous rocks, on folded or complex metamorphosed rocks, particularly when imposed upon them by superposition (Thornbury, 1954) and it reflects near homogeneous character of the sub-surface lithology. There are 12 FOSBs in PW (Fig. 3) and their linear and areal extensions, morphometric parameters and methodology adopted for various calculations are compiled in (Table 1, 2 and 3).

Stream Order

The first order Hortonian streams do not have any tributary and are the smallest recognisable channels (Chow et al, 1988). A second order Hortonian stream forms when two first order Hortonian streams join and a third order when two second order joins and so on (Strahler, 1964). Where a channel of lower order join a channel of higher order, the channel downstream retains the higher of the two orders

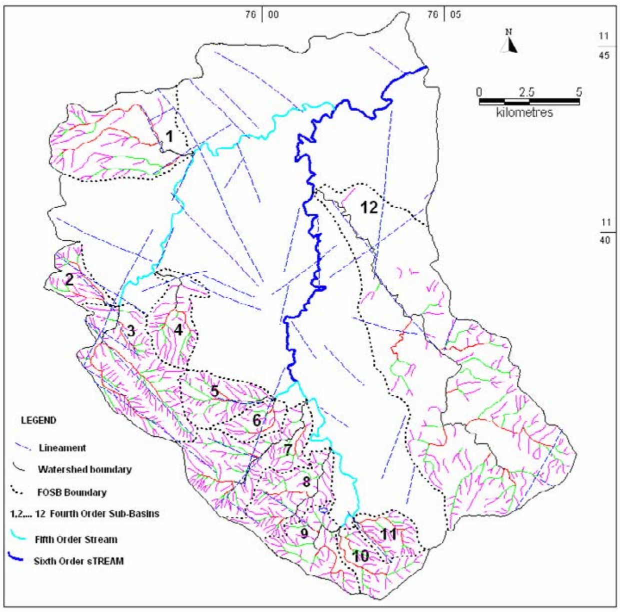

Fig.3. Fourth order sub-basins (FOSB) of Panamaram watershed

Table 1. Perimeter and areal extent of Fourth order sub-basins (FOSB) of Panamaram Watershed

FOSB	Area, km^2	Perimeter, km	Max. length of basin, km
1	24.38	21.38	7.201
2	5.687	11.83	4.18
3	22.96	23.66	7.675
4	9.24	15.14	5.040
5	8.513	12.59	4.942
6	4.463	9.639	3.558
7	19.08	23.36	7.150
8	11.92	18.68	6.11
9	9.853	16.02	3.95
10	7.659	14.21	4.642
11	5.847	10.52	4.123
12	91.92	50.46	19.22
Total	**221.522**	**227.489**	

and the order of the river basin is the order of the stream draining its outlet, the highest stream order in the basin (Chow et al. 1988). The Panamram river is a sixth order Hortonian stream and the sixth order Hortonian stream is perennial and other streams are ephemeral except a few fifth order Hortonian streams. The numbers of first, second, third and fourth order Hortonian streams in PW are 587, 135, 36 and 12, respectively.

Stream Number

The order-wise number of streams is known as the stream number. Table 2 reveals that the number of stream segments decrease with increase in stream order. When a channel of lower order joins a channel of higher order, the channel downstream retains the higher of the two orders (Chow et al, 1988). There are 770 streams in various FOSBs in PW and a few losing streams (influent condition). The losing streams have not been considered for morphometric analysis, as these have not contributed much to river characteristics. The main structural disturbances which occurred in the FOSBs of PW are lineaments (Fig.2).

Stream Length

Horton's law of stream lengths states that the mean lengths of stream segments of each of the successive orders of a basin tend to approximate a direct geometric sequence in which the first order term is the average length of segments of the first order (Horton, 1945). Table 2 shows that in PW, length of streams generally decreases with increase in order of segments except for some FOSBs 1, 2 , 3 and 8, the variation may be due to high relief, or moderately steep slopes underlain by varying lithology (Singh and Singh, 1997). Mean stream length (Lu) is dimensional, revealing the characteristic size of the components of a drainage network and it contributes basin surfaces (Strahler, 1964). In general Lu increases as the order of segment increases. For FOSBs Lu ranges between 0.11 and 6.5 km and the variation in Lu may be due to variation in slope and topography.

Stream Length Ratio (R_L)

Stream length ratio is the ratio of mean length of streams of one order to that of the next lower order that tends to be constant throughout the successive orders of a watershed (Horton, 1945). The highest value of length ratio of FOSBs is 5.1 (indicates lower order sources for the next higher order streams) and the lowest 0.44 (indicates limited length of lower order streams). A large number of smaller streams have developed in the area on less permeable formations of weathered granites and granitic gneisses, high values of R_L have been found at extreme upstream areas on impermeable formations of granites, granitic gneisses and charnockites.

Bifurcation Ratio (Rb)

Bifurcation ratio is the ratio of the number of segments in an order to the number of segments in the next higher order (Horton, 1945); the Rb values range between 3 and 5.0 for watersheds in which geometrical structures do not distort drainage pattern (Chow et al, 1988) and in PW a theoretical minimum value of 2.0 is obtained in seven cases. It is a dimensionless ratio, as drainage systems in homogeneous materials tend to display geometrical similarity; the ratio shows only a small variation from region to region. Abnormal high Rb values might be expected in regions of steeply dipping rock strata where elongated strike valleys are confined between hogback ridges; and high Rb values for first and second order streams reflect their origin from higher levels, and Rb values indirectly reflect the impact of lithology; and for crystalline rocks they are almost identical (Gopalakrishnan et al. 1997).

If within a net, bifurcation ratios are equal, it is called Horton's net. Horton's net condition is not present in any of the FOSBs of PW, the average R_b is 3.66 and lowest 2.00 and highest 8.00 and for FOSBs and the variation is due to lithological and geological development of FOSBs. The lower Rb values are characteristics of structurally less disturbed watersheds without any distortion in drainage pattern (Nag, 1996) and most of the Rb values range between 2 and 5. Highest Rb value of 8 is reported for FOSB-12. The lowest number of streams involved in Rb is 3 and the highest number of streams involved is 146 (FOSB-12). The lowest value of the product of Rb and the number of streams is 6 (FOSB 2) and the highest 626.3 (FOSB-3). Mean Rb value of 3.66 indicates the FOSBs have suffered less structural disturbances and the drainage pattern has not been

Table 2. Drainage parameters of the of Fourth order sub-basins (FOSB) of Panamaram watershed

Sub-basin	Stream order	No. of stream ssegments	Length of stream segments, km	Mean length, km	Length ratio, Order	Bifurcation ratio, Rb	No. of streams involved in Rb	Product of Rb & no. of segments	Drainage density, km / km^2	Drainage frequency, No/ km^2	Infiltration Number
1	1	35	23.64	0.68	2.46	3.9	44	171.11	2.01	1.97	3.96
	2	9	9.62	1.07	0.73	3	12	36			
	3	3	13.13	4.45	5.10	3	4	12			
	4	1	2.58	2.56							
2	1	22	24.25	1.1	2.69	4.4	27	118.8	6.99	5.28	36.91
	2	5	9	1.8	4.5	2.5	7	17.5			
	3	2	2	1	0.44	2	3	6			
	4	1	4.5	4.5							
3	1	100	23	0.23	2.88	5.3	119	626.3	1.52	5.36	8.15
	2	19	8	0.42	4	6.3	22	139.3			
	3	3	2	0.67	1	3	4	12			
	4	1	2	2							
4	1	31	16.5	0.53	2.75	4.4	38	168.3	2.81	4.44	12.48
	2	7	6	0.86	3	3.5	9	31.5			
	3	2	2	1	1.33	2	3	6			
	4	1	1.5	1.5							
5	1	39	20.5	0.53	3.42	4.88	47	229.1	4.41	5.87	25.89
	2	8	6	0.75	1.33	4	10	40			
	3	2	4.5	2.25	0.69	2	3	6			
	4	1	6.5	6.5							
6	1	14	16.3	1.16	2.17	3.5	18	63	7.46	4.71	35.14
	2	4	7.5	1.88	1.25	2	6	12			
	3	2	6	3	1.71	2	3	6			
	4	1	3.5	3.5							
7	1	77	13.5	0.18	1.8	3.85	97	373.5	1.39	5.35	7.44
	2	20	7.5	0.38	1.67	5	24	120			
	3	4	4.5	1.13	4.5	4	5	20			
	4	1	1	1							
8	1	59	29.22	1.01	4.72	5.9	69	348	3.58	6.12	21.91
	2	10	6.19	0.21	2.50	3.33	13	33			
	3	3	2.48	0.86	0.52	3	4	9			
	4	1	4.78	0.17							
9	1	41	18.57	0.64	2.87	4.56	50	187	3.23	5.48	17.69
	2	9	6.47	0.22	1.55	3	12	27			
	3	3	4.17	0.14	1.60	3	4	9			
	4	1	2.60	0.09							
10	1	26	8.5	0.33	3.4	4.33	32	138.7	1.76	4.57	8.04
	2	6	2.5	0.42	1.25	3	8	24			
	3	2	2	1	4	2	3	6			
	4	1	0.5	0.5							
11	1	27	10	0.37	4	3.38	35	118.125	2.61	6.50	16.97
	2	8	2.5	0.31	1.25	4	10	40			
	3	2	2	1	2.67	2	3	6			
	4	1	0.75	0.75							
12	1	116	13	0.11	1.63	3.87	146	564.5	0.27	1.69	0.46
	2	30	8	0.27	3.2	3.75	38	142.5			
	3	8	2.5	0.31	1.67	8	9	72			
	4	1	1.5	1.5							

Table 3. Methodology adopted for computations of morphometric parameters

Aspects	Mophometric Parameters	Formula	Reference
Linear Aspect	Stream Order	Hierarchical rank	Strahler (1964)
	Stream Length (L)	Length of the Stream	Horton (1945)
	Mean Stream Length(Lu)	Lu = ΣL / Nu, where åL is the total length of the stream of particular order and Nu number of stream segment of that order	Strahler (1964)
	Stream length ratio R_L	R_L = L u / Lu-1, where Lu is the mean stream length of order u and Lu-1 is the mean stream length of next lower order.	Horton (1945)
	Bifurcation ratio (Rb)	Rb = Nu / Nu+1, where Nu is the number of segments in an order u and Nu+1 is the number of segments in the next higher order.	Horton (1945)
Aerial Aspect	Drainage density (D)	D_d = ΣL /A, where åL-total length of the streams and A-area of drainage basin.	Horton (1932)
	Stream frequency (D_f)	D_f = ΣN/A, where N is the number of stream segments and A drainage area.	Horton (1932)
Relief Aspect	Relief ratio (Rh)	R_h =H / L_b, where H is the total relief and L_b basin length	Schumm (1956)
Aerial Aspect	Form Factor (R_f)	R_f = A / Lb^2, where A is drainage area and Lb length of river basin	Horton (1932)
	Circularity Ratio (Rc)	Rc = 4 * Pi * A / P^2 where, Rc = Circularity Ratio, Pi = 3.14; A = Area of the Basin (km2) P^2 = Square of the Perimeter (km)	Miller (1953)
	Elongation Ratio (Re)	Re = 2 * Sqrt (A / Pi) / Lb Where, Re = Elongation Ratio A = Area of the Basin (km^2) Pi = 3.14; Lb = Basin length	Schumn (1956)

distorted by structural disturbances (Nautiyal, 1994) and structural control has played a limited role in the development of drainage. Variation of Rb values is due to difference in climatic conditions, geology and structure of rocks, relief and stages of basin development. The Rb values vary from 2.00 in the flat or rolling basin to 3 – 4 in mountainous, highly dissected and intensely fragmented areas (Horton, 1945). It may be concluded that sub-basins 1, 2, 4, 5, 6, 10 and 11 with less Rb values have less structural disturbances exhibiting less lineament density, whereas, the sub-basins 3, 7 and 8 are characterised by high values of Rb with high lineament density.

Drainage Density (D_d)

Drainage density is the ratio of total length of the streams in a given drainage basin to area of the drainage basin (Horton, 1932); the average D_d of FOSBs ranges between 0.27 and 7.46 km/km^2. The highest D_d for FOSB 6 with a value of 7.46 km/km^2 and lowest for FOSB 7 with a value of 1.39 km/km^2 are seen. A close perusal of the D_d values shows that the region with highest rainfall in PW has high D_d values. The sub-basins having highly resistant or permeable soil material under dense vegetation cover and low relief is characterised by low D_d while regions of weak and impermeable sub-surface material, sparse vegetation and mountainous relief display high D_d (FOSBs 2, 4 and 6).

Stream Frequency (D_f)

Stream frequency (D_f) is the number of stream segments per unit area (Horton, 1932, 1945); the lowest D_f value is for FOSB 12 and highest for FOSB 9.58% of FOSBs have stream frequency values more than 5.00 and D_f values vary between 1.69 and 6.5. The variation in D_f occurs due to rainfall, relief, infiltration rate, initial resistivity of the terrain to erosion, total drainage area of the basin and above all the D_d of the watershed itself. The low values of D_f indicate poor stream networks and high values indicate denser networks in the catchment area.

Infiltration Number (IF)

The infiltration number is the product of drainage density and stream frequency, and lower values of IF indicate higher infiltration and low run-off with shallow depth to the water table/DTW (Das and Mukherjee, 2005). The IF values of FOSBs range between 0.46 and 36.91. Water level monitoring has been carried out in selected observation wells in the PW during 2010-11 along with permanent groundwater monitoring wells (GWMWs) established by the CGWB, Kerala region. The observation wells situated within the sub-basins with less IF values have shown shallow DTW with meagre water level fluctuation. The lower values of IF in many of the FOSBs and shallow water level indicate the possibility of more infiltration and less surface run-off. The monthly water level variation, DTW fluctuation, pre- and post-monsoon DTW trends in the observation wells and GWMWs in PW are compiled (Table 4) and depicted (Fig. 4).

Relief Ratio (Rh)

The difference in elevation between the highest and lowest points in a basin is basin relief and it indicates an overall steepness of the drainage basin and the intensity of

Table 4. Monthly depth to the water level variation in key wells of Panamaram Watershed

Location	Depth to water level, mbgl								Fluctuation (May-Oct, 10), m
	May, 10	June, 10	July, 10	Aug, 10	Oct, 10	Nov, 10	Jan, 11	Feb, 11	
Lakkidi Gate	3.42	2.91	1.56	2.62	3.66	3.76	4.9	5.08	-0.24
Lakkidi *	1.37	1.11	1.01	1.19	1.33	1.32	1.56	1.6	0.04
Old Vaithiri	4.54	4.38	4.25	4.76	3.61	4.68	4.95	5.15	0.93
Vaithiri *	6.43	6.78	5.56	5.87	6.48	6.48	7.61	7.68	-0.05
Chundale	2.09	2.25	1.61	1.67	1.83	1.9	2.28	2.5	0.26
Kunnambatta	4.17	4.25	3.86	3.6	3.82	3.85	4.12	4.23	0.35
Kainatti	2.83	2.23	1.27	1.25	1.85	1.51	3.01	3.44	0.98
Pallimukku	16.45	15.89	14.22	12.47	13.3	13.4	14.4	14.8	3.15
Pachilakkad	8.4	8.27	7.31	6.51	7.44	6.83	7.9	8.38	0.96
Echam	13.15	13.03	10.7	6.56	9.62	9.9	12.22	11.64	3.53
Vilambukandam	14.67	13.75	12.01	10.94	12.4	13.06	13.19	14.57	2.27
Thekkumthara	7.02	6.99	6.5	6.24	6.22	6.29	6.56	6.86	0.8
Kottathara	3.8	3.86	3.38	3.39	3.72	3.62	3.73	3.86	0.08
Chennalode	10.34	10.02	6.72	6.08	8.41	8.66	9.39	9.94	1.93
Thariyode	2.08	1.73	1.56	1.47	1.9	1.8	2.18	2.41	0.18
Mothakara	3.65	3.41	3.24	2.76	3.4	3.43	3.77	3.86	0.25
Pinangode	13.58	13.82	9.89	9.67	12.86	12.39	13.81	14.37	0.72
Puzhamudi	2.02	0.9	1.21	0.97	2.01	2.01	1.4	1.73	0.01
Pozhuthana *	6.25	6.33	5.3	1.56	5.88	6.04	6.36	6.43	0.37
Panamaram*	3.69	3.4	3.07	2.89	3.44	2.9	3.52	3.49	0.25
Kambalakkad *	19.49	18.42	17.89	16.41	16.65	16.81	17.78	18.03	2.84
Kalpetta *	1.27	1.18	0.91	0.93	0.95	0.92	1.25	1.53	0.32
Kavumandam *	7.37	7.23	6.73	6.69	6.98	6.88	7.13	7.27	0.39
Padinjarethara*	7.44	7.24	6.26	5.21	6.29	6.25	7.15	7.32	1.15
Taruvana *	5.64	5.44	3.62	2.28	2.47	3.66	3.23	3.67	3.17

the degradation processes operating on slopes of basin and is the ratio between the total relief to its longest dimension parallel to the principal drainage line is relief ratio (Schumm, 1956). The R_h value of PW is 0.405 (Table 5) and low R_h values are the result of resistant bedrock & less slope; and R_h values usually increases with decreasing drainage area.

Form Factor (R_f)

Form factor is the dimensionless ratio of the basin area to the square of basin length (Horton, 1932); the R_f value of 0 indicates a highly elongated shape and the value of 1.0, a circular shape with high peak flows for short duration but for elongated basin with low R_f with a flatter peak flows for longer duration. The flood flows of elongated basins can be easily managed than that of circular ones. The R_f value of PW is 0.19 showing its elongated shape and its flood flows can be managed efficiently than those of the circular basin; and the R_f values of FOSBs vary between 0.25 and 0.63, with an average value of 0.38 (Table 5).

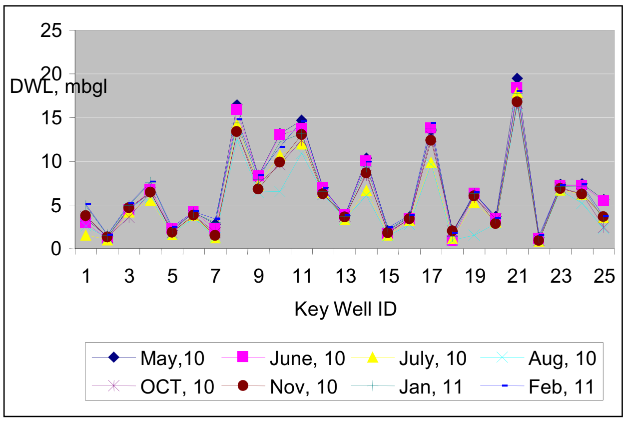

Fig.4. Depth to water table (mbgl) variation in Panamaram watershed.

Circularity Ratio (R_c)

Circularity ratio is the ratio of the area of river basin to the area of a circle having the same perimeter as the basin (Miller, 1953). It is a dimensionless ratio to express outline of basin (Strahler, 1964) and R_c varies between 0.6 and 0.7 for homogeneous rock types, 0.40 and 0.5 for quartzitic terrain and is influenced by length and D_f of streams, geological structures, vegetation, climate, relief and slope of the basin. The circularity ratio of PW is 0.6, indicating that PW is characterized by high relief and the drainage system is structurally controlled; and that of the sub-basins ranges between 0.43 and 0.67 with an average value of 0.54 (Table 5).

Table 5. Form factor, circularity ratio and elongation ratio of sub-basins of Panamaram Watershed

FOSB	Area, km^2	Perimeter, km	Max. length of basin, km	Form Factor $R_f = A / Lb^2$	Circularity ratio $Rc = 4\pi A / P^2$	Elongation ratio $Re = 2*\sqrt{(A / \pi)} \div Lb$
1	24.38	21.38	7.201	0.47	0.67	0.77
2	5.687	11.83	4.18	0.33	0.51	0.64
3	22.96	23.66	7.675	0.39	0.52	0.70
4	9.24	15.14	5.040	0.36	0.51	0.68
5	8.513	12.59	4.942	0.35	0.67	0.67
6	4.463	9.639	3.558	0.35	0.60	0.67
7	19.08	23.36	7.150	0.37	0.44	0.69
8	11.92	18.68	6.11	0.32	0.43	0.64
9	9.853	16.02	3.95	0.63	0.48	0.90
10	7.659	14.21	4.642	0.36	0.48	0.67
11	5.847	10.52	4.123	0.34	0.66	0.66
12	91.92	50.46	19.22	0.25	0.45	0.56
Mean	**18.46**	**18.96**	**6.48**	**0.38**	**0.54**	**0.69**

Elongation Ratio (R_e)

Elongation ratio is the ratio of the diameter of a circle having the same area as of the basin and maximum basin length (Schum, 1956); and is a measure of the shape of the river basin and the value generally ranges between 0.6 and 1. The range from 0.6 to 0.8 represents regions of high relief (many FOSBs of PW) and values close to 1.0 are regions of very low relief with circular shape (FOSB 9), and are much more efficient in the discharge of runoff than an elongated basin because concentration time is less in circular basins. Thus R_e values help in flood forecasting. The elongation ratio of PW is 0.33, indicating its elongated nature with high relief and steep slope and that of the sub-basins with ranges between 0.56 and 0.90 with an average value of 0.69 (Table 5).

STATISTICAL ANALYSIS

The collected data was subjected to statistical analysis using classical regression technique. The results are presented in Table 6. By examining the values of R^2, it is seen that Horton's laws, given in equations (1), (2) and (3) are true for this data also except for those cases given in bold face numbers in Table 6. The estimated values of bifurcation ratio (R_b), length ratio (R_l) and area ratio (R_a) are also well supported by our findings, since the average empirical R_b is approximately equal to the estimated R_b determined from the slope of the regression lines. But R^2 values of FOSB 1 and 4 (area), FOSB 2 and 5 (length) and FOSB 8 (area and length) feebly indicate that Horton's law will not be suitable for describing the characteristics of our data in these sub-basins. In these cases a second degree polynomial curve is a good model as compared to Horton's law (Figs.5 a, b, c, d, e and f). It may also be noted that for FOSB 4 (area) the polynomial equation is not suitable for describing the characteristics.

The FOSBs 1, 2, 4, 5 and 8 are situated in regions of high relief, values of elongation ratio ranges between 0.6 and 0.8 and concentration time for water is less and difficult to manage run-off. Moreover, the variations shown by these

Table 6. Slope, Intercept, R^2 and Ratios of Number, Length and Area

	Number				Length				Area			
	Slope	Inter-cept	R^2	R_b	Slope	Inter-cept	R^2	R_l	Slope	Inter-cept	R^2	R_a
FOSB 1	-0.51	2.02	1.00	3.24	-0.28	1.66	0.76	0.53	-0.13	0.93	**0.12**	0.74
FOSB 2	-0.44	1.69	0.97	2.77	-0.28	1.54	**0.64**	0.52	-0.30	0.74	0.75	0.50
FOSB 3	-0.68	2.64	0.99	4.79	-0.38	1.66	0.90	0.42	-0.37	1.47	0.90	0.42
FOSB 4	-0.50	1.91	0.98	3.18	-0.36	1.52	0.95	0.44	-0.17	0.62	**0.25**	0.68
FOSB 5	-0.54	2.04	0.97	3.45	-0.16	1.29	**0.52**	0.69	-0.32	0.92	0.77	0.48
FOSB 6	-0.37	1.45	0.98	2.37	-0.21	1.38	0.96	0.62	-0.23	0.51	0.73	0.59
FOSB 7	-0.64	2.54	1.00	4.32	-0.36	1.57	0.93	0.44	-0.24	1.15	0.73	0.58
FOSB 8	-0.58	2.27	0.98	3.83	-0.28	1.52	**0.61**	0.53	-0. 23	0.92	**0.64**	0.59
FOSB 9	-0.53	2.09	0.99	3.40	-0.28	1.47	0.95	0.53	-0. 21	0.84	0.90	0.61
FOSB 10	-0.47	1.80	0.98	2.97	-0.38	1.28	0.94	0.42	-0.37	1.01	0.81	0.42
FOSB 11	-0.49	1.88	0.98	3.09	-0.35	1.26	0.93	0.45	-0.31	0.76	0.67	0.49
FOSB 12	-0.68	2.80	0.99	4.75	-0.33	1.48	0.97	0.47	-0.05	1.42	0.05	0.90

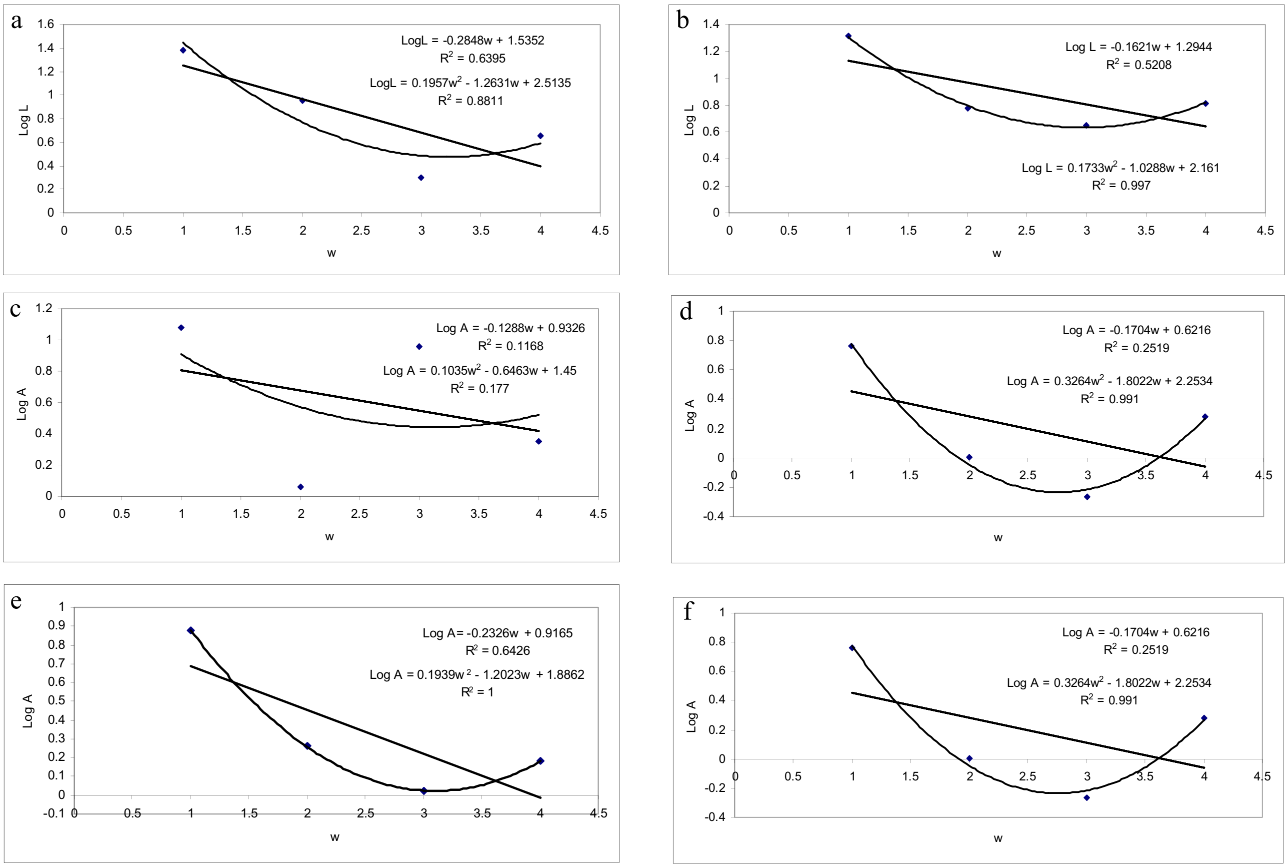

Fig.5. Polynomial and Hortonian fitted models with fitted equations.

sub-basins are influenced by length and D_f of streams, geological structures, vegetation, climate, relief and slope of the basins.

CONCLUSION

Morphometric studies carried out in the Panamaram Watershed with emphasis on FOSBs reveals that the basin is an elongated one and its flood water flows may be managed efficiently. The main structural disturbances occurred in PW are demonstrated through lineaments. Horton's Laws on Stream Numbers, Stream Lengths and Stream Areas are statistically fitted by using the theory of regression; and from the fitted Hortonian model theoretically estimated the bifurcation ratio, length ratio and area ratio. For the FOSBs 1, 2, 4, 5 and 8, a second degree polynomial equation seems to be a good model rather than the Hortonian Model. It is revealed that the infiltration number values of FOSBs range between 0.46 and 36.91 from the observation wells which are situated within the sub-basins with less IF values having shallow DTW and meagre water level fluctuation.

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