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A comparative study of the Morphometric Analysis of High land sub-watersheds of Meenachil and Pamba Rivers of Kerala, Western Ghats, South India

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ABSTRACT: Morphometric analysis helps to understand the fluvial and structural control of the terrain and the geological and geomorphic aspects of a drainage basin. It is inevitable in developmental and management plan of a watershed. A critical evaluation and assessment of morphometric parameters of Vagamon and Peermade sub-watersheds have been achieved through measurement of linear, aerial and relief aspects of sub-watersheds by using Remote Sensing and Geographic Information System techniques. Detailed drainage map is prepared for both the sub-watersheds using ArcGIS 9.2. The analysis reveals that Vagamon a typical high land sub-watershed of Meenachil river basin is characterized by trellis pattern. Stream order varies from 1 to 3 with total number of stream segments as 43, out of which the 83.72% is by 1st order streams with a minimum 2.33% as 3rd order whereas Peermade sub-watershed, which forms a part of Pamba river basin is characterized by the dominance of dendritic pattern. However the eastern region shows trellis pattern. Out of the 100 stream segments identified, 79.00% (79) is 1st order with only 1.00% i.e., one number is 4th order stream. Vagamon sub-watershed shows typically trellis drainage pattern and structural complexity. Morphometric analysis results reveals that Vagamon sub-watershed has high values of Ruggedness Number (Rn), Length of Overland Flow (Lof), Bifurcation Ratio (Rb) and Constant Channel Maintenance (C) and low values of Elongation Ratio (Re), Circularity Ratio(Rc), and Form Factor (Rf). This indicates the highly elongated shape and the structural complexity which further emphasized by the typical trellis pattern of the of Vagamon sub-watershed. High basin relief and relief ratio of the Vagamon sub-watershed compared to that of Peermade sub-watershed is an expression of the more steep nature of the slopes compared to Peermade, as is evident from field verification. High drainage density (Dd), stream frequency (Fs) and texture ratio (T) of Peermade sub-watershed reveals its low infiltration capacity and impermeable subsurface material.

KEYWORDS: Peermade, Vagamon, dendritic pattern; trellis pattern; structural complexity.

1 INTRODUCTION

Morphometric analysis provides quantitative description of the basin or sub-watersheds and fluvial geometry, structural controls, geological and geomorphic aspect of a drainage basin [1]. The quantitative analysis of morphometric parameters is of much significance in river basin evaluation, watershed prioritization, soil and water conservation, and natural resources management at micro level. It is of great significance in understanding the hydrologic scenario of an area, because a strong mutual relationship exists between morphological variables and hydrological characteristics. Geographical Information System (GIS) is an efficient tool in delineation of drainage patterns, morphometric analysis and water resource management and its planning. Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimensions of its landforms [2]. This analysis can be achieved through measurement of linear, aerial and relief aspects of basins by using Remote Sensing and GIS techniques which has an ability to provide a synoptic view of a large area. The outcome of morphometric analysis is useful in applying proper catchment management practices [3],[4],[5],[6],[7],[8],[9],[10]. The present study is an attempt to critically evaluate and assess various morphometric parameters of Vagamon and Peermade sub-watersheds of the Meenachil and Pamba river basins of Western Ghats South India.

2 STUDY AREA

The areas selected for the present investigation belongs to typical highland sub-watersheds, of Idukki district. Vagamon sub-watershed lies between 9°38'35" to 9°41'42" N latitude and 76°53'9" to 76°55'37" E longitude. In general the area has altitude above 620m of MSL. Peermade sub-watershed lies between 76°56'1"E to 76°59'57" E longitude and 9°34'8"N to 9°36'59" N latitude and the area is characterized by an altitude above 1000m of MSL. Vazhikkadavu Ar, an important tributary of Meenachil river, having stream order varying from 1 to 3 originates from Vagamon sub-watershed. The Vagamon sub-watershed area is characterized by typical trellis pattern, which reveals the strong structural control that prevails in Vagamon sub-watershed.

Azhutha Puzha, an important tributary of the sacred river Pamb having stream order from 1 to 4, arises from Peermade sub-watershed. Unlike Vagamon sub-watershed which is characterized by a typical trellis pattern, the Peermade sub-watershed is characterized by predominance of dendritic pattern. However a less pronounced trellis pattern is observed towards the eastern region. Morphometric parameters such as linear, relief and aerial aspects are vital in understanding of drainage basin, its development and management. Morphometric analysis necessitates preparation of the detailed drainage map, ordering of various streams, measurement of catchment area, its perimeter etc.

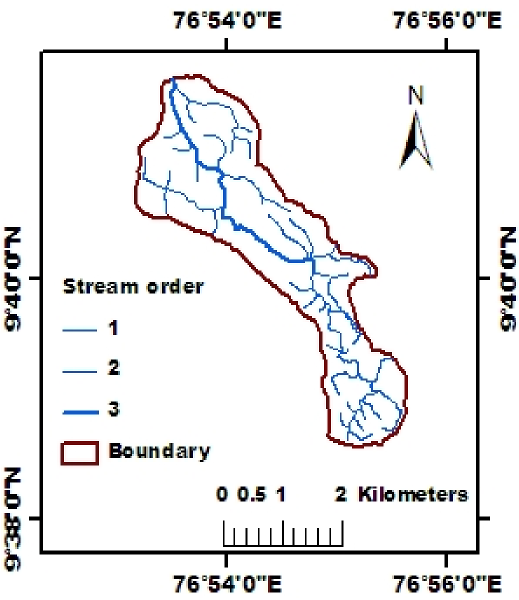

Fig.1 .Drainage pattern of Vagamon sub-watershed

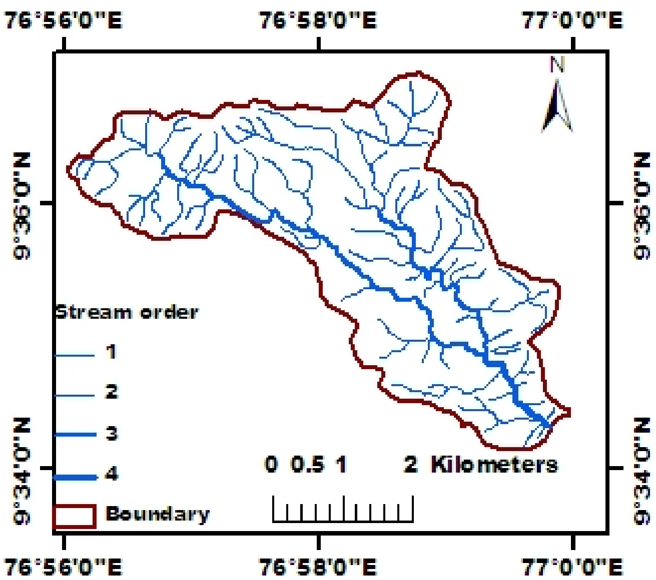

Fig.2.Drainage pattern of Peermade sub-watershed

3 METHODOLOGY

Vagamon and Peermade sub-watersheds and its associated drainage networks (Fig. 1 and Fig.2) were delineated from SOI topographical maps 58 C/14 in 1:50000 scale and were digitized using Arc GIS 9.2 software.

Morphometric analysis has been carried out for the following parameters: stream order(U), stream length (Lu), mean stream length (Lsm), bifurcation ratio (Rb), stream length ratio (Rl) (linear parameters), drainage density (Dd), stream frequency (Fs), elongation ratio (Re), Circulatory ratio (Rc), form factor (Rf), texture ratio (T), length of overland flow (lof), constant channel maintenance(C) (aerial parameters), basin relief (Bh), relief ratio (Rh), ruggedness number (Rn) (relief parameters). The methods adopted for calculating morphometric parameters are given in Table 1.

Table 1. Methods of calculating morphometric parameters

Morphometric Parameters		Methods
LINEAR	Stream Order (U)	Hierarchical order
	Stream Length (Lu)	Length of the stream
	Mean Stream Length (Lsm)	Lsm=Lu/Nu, where ,Lu=Stream length of order 'U' Nu=Total number of stream segments of order 'U'
	Stream Length Ratio (Rl)	Rl=Lu/ Lu-1; where, Lu=total Stream length of order 'U'; Lu-1=Stream length of next lower order
	Bifurcation Ratio (Rb)	Rb= Nu/ Nu+1; where, Nu=Total number of stream segments of order 'U'; Nu+1=Number of stream segments of next higher order
RELIEF	Basin Relief (Bh)	Vertical distance between the lowest and highest points of watershed
	Relief Ratio (Rh)	Rh=Bh/Lb; where, Bh=Basin Relief; Lb= Basin Length
	Ruggedness Number (Rn)	Rn=Bh×Dd; where, Bh=Basin Relief; Dd=Drainage density
ARIAL	Drainage Density (Dd)	Dd=L/A; where, L=Total length of streams; A=Area of watershed
	Stream Frequency (Fs)	Fs=N/A; where, N=Total number of streams; A=Area of watershed
	Texture Ratio (T)	T=N1/P; where, N1= Total number of first order streams; P=Perimeter of watershed
	Form Factor (Rf)	$Rf=A/(Lb)^2$; where, A=Area of watershed; Lb=Basin Length
	Circularity Ratio(Rc)	$Rc=4\pi A/P^2$; where, A=Area of watershed; P=Perimeter of watershed; π=3.14
	Elongation Ratio (Re)	Re=2√(A/π)/Lb; where, A=Area of watershed; Lb=Basin Length; π=3.14
	Length of Overland Flow (Lof)	Lof=1/2Dd; where, Dd=Drainage density
	Constant Channel Maintenance (C)	C=1/Dd; where, Dd=Drainage density

4 MORPHOMETRIC ANALYSIS

Vagamon sub-watershed covers an area of 8.71 Km^2 and Peermade sub-watershed 16.42 Km^2. The basin length of Vagamon sub-watershed is 6.73 Km and that of Peermade sub-watershed is 8.01 Km, and perimeter of 17.42Km and 22.64 Km respectively. In both the subwatersheds, channel segments have been ranked according to Strahler's stream ordering system [1]. Altogether 43 stream segments were recognized in Vagamon sub-watershed. Out of this 83.72% (36 numbers) are 1st orders, 13.95% (6 numbers) are 2nd orders and 2.33% (1) 3rd order.

In Peermade sub-watershed, out of the total 100 stream segments, 79.00% (79) are 1st orders, 18.00% (18) are 2nd orders, 2.00% (2) is 3rd order and 1.00% (1) is 4th order (Table 2). Horton's law of stream numbers [11] states that the number of stream segments of each order forms an inverse geometric sequence with order number. In the present study also, the number of streams decreases in geometric progression as the stream order increases.

Table 2. Mean stream length (Lsm) of Vagamon and Peermade sub-watershed

Name of the sub-watershed	Stream order	Lu(km)	Nu	Lsm
Vagamon	1.00	16.67	36.00	0.46
	2.00	7.75	6.00	1.29
	3.00	4.70	1.00	4.70
Peermade	1.00	37.59	79.00	0.48
	2.00	13.45	18.00	0.75
	3.00	9.88	2.00	4.94
	4.00	1.51	1.00	1.51

Results of the morphometric analysis are represented in Table 2 and Table3. Stream length reveals the surface run off characteristics. The lengths of streams of various orders are measured from their mouth to drainage divide. In both the sub-watersheds, total lengths of stream segments are maximum in first order streams and it decreases as the stream order increases. The mean stream length (Lsm) is a characteristic property related to the drainage and its associated surfaces. This has been calculated by dividing the total stream length of order 'U' by the number of stream segments of order 'U'. Generally Lsm is greater than that of the lower order and less than that of its next higher order. Variation of this may be due to the difference in slope and topography [12]. In Vagamon sub-watershed Lsm varies from 0.46 to 4.70 and in Peermade from 0.48 to 4.94 (Table 2). Lsm of the 3rd and 4th order streams of Peermade show variation from normal pattern. This may be due to the difference in slope and topography. Bifurcation ratio (Rb) is the ratio of the number of stream segments of a given order to the number of segments of the next higher order [13]. Characteristically it ranges between 3.0 and 5.0 for basins in which the geologic structures do not distort the drainage pattern [1]. The Rb is not the same from one order to its next order. These irregularities are dependent on geological and lithological development of the drainage basin [1]. In the present study, Vagamon sub-watershed has higher Rb value (6.00) than Peermade sub-watershed (5.13). This indicates high structural complexity and low permeability of the Vagamon terrain. The trellis drainage pattern of the Vagamon sub-watershed also supports this structural complexity. Stream length ratio (Rl) has an important relationship with the surface flow discharge and erosion status of the drainage basin [14]. It is the ratio of length of a particular order stream to that of next lower orders of stream segment. Both the sub-watersheds of the present study show variation in stream length ratio between streams of different orders. This indicates their late youth stage of geomorphic development [15].

Table 3. Result of morphometric analysis ofVagamon and Peermade sub-watershed

Sub-watershed	Vagamon	Peermade
Area (km^2)	8.71	16.42
Perimeter (km)	17.42	22.64
Basin order	3.00	4.00
Basin length(Lb)(km)	6.73	8.01
Relief ratio (Rh)	0.09	0.06
Basin relief (Bh)(km)	0.58	0.45
Ruggedness number(Rn)	1.92	1.72
Bifurcation ratio(Rb)	6.00	5.13
Drainage density(Dd) (km^2)	3.35	3.80
Stream frequency(Fs) (km^2)	4.94	6.09
Texture ratio(T) (km)	2.07	3.49
Form factor (Rf)	0.19	0.26
Circulatory ratio (Rc)	0.36	0.40
Elongation ratio (Re)	0.49	0.57
Length of overland flow (Lof) (km)	0.15	0.13
Constant channel maintenance(C) (km)	0.30	0.26

Among the aerial parameters analyzed the measurement of drainage density provides a numerical measurement of the landscape dissection and runoff potential. Drainage density is defined as the length of streams per unit of drainage area. Higher this number means closer together are the channels. In the present study Peermade sub-watershed has drainage density 3.80 and Vagamon has 3.35. High drainage density of Peermade sub-watershed may be due to the weak or impermeable subsurface material, sparse vegetation and mountainous relief. Stream frequency (Fs) is related to permeability, infiltration capacity and relief of a sub-watershed. It is the total number of stream segments of all orders per unit area [16]. The calculated value of stream frequency (Fs) of Vagamon and Peermade drainage basins are 4.94 and 6.09 respectively. Fs is higher in Peermade sub-watershed, which can be attributed to high relief and low infiltration capacity. The texture ratio (T) depends on underlying lithology, infiltration capacity and relief aspect of the terrain [17]. It is the ratio between the first order streams and perimeter of the basin. Peermade sub-watershed has higher T value (3.49) than Vagamon sub-watershed (2.07). High texture ratio can be attributed to the presence of high relief of Peermade sub-watershed. Form factor (Rf) is defined as the ratio of mean basin width and the maximum basin length. Generally, Rf is less than 1 because the maximum basin length is longer than the mean basin width. In the present study, the low Rf value (0.19) of the Vagamon sub-watershed reveals that it is more elongated than the Peermade sub-watershed (0.26). Circulatory ratio (Rc) is defined as the ratio of the area of the basin to the area of the circle having the same circumference as the perimeter of the basin. According to Miller, circularity ratios are ranging from 0.4 to 0.5 that indicates strongly elongated and highly permeable homogenous geologic materials [18]. Circulatory ratio values of Vagamon and Peermade sub-watersheds are 0.36 and 0.40 respectively .Low value of the Vagamon sub-watershed reveals the highly elongated shape and highly permeable geological materials. Elongation ratio (Re) is a very significant index in the analysis of the hydrological character of a drainage basin. It is an index which indicates how the shape of the basin deviates from a circle [13]. Analysis reveals that Peermade sub-watershed has high Re value 0.57, while Vagamon sub-watershed has low Re value 0.49. Low Re values of the Vagamon sub-watershed of the present study indicate the highly elongated shape of the drainage basin. Length of the overland flow (Lof) is the length of water flow over the ground before it gets concentrated in to definite stream channels. Length of overland flow was calculated as the half of the reciprocal of the drainage density (Dd). In the present study Vagamon sub-watershed has high Lof (0.15) compared to and Peermade has low Lof (0.13). This indicates the structural complexity of Vagamon sub-watershed. The constant of channel maintenance(C), indicates the minimum area required for the development and maintenance of a unit length of channel [13]. It is the inverse of drainage density. Constant channel maintenance of Peermade sub-watershed is 0.26 which is less than Vagamon sub-watershed (0.30). This reveals the weak or impermeable subsurface material, sparse vegetation and mountainous relief of Peermade sub-watershed.

Relief parameters such as basin relief (Bh), relief ratio (Rh) and ruggedness number (Rn) of Vagamon, and Peermade sub-watersheds are evaluated. Basin relief (Bh) is the maximum vertical distance between the lowest and highest elevation in a basin. The maximum and minimum height of the Vagamon sub-watershed is 1195m and 620m, whereas in Peermade sub-watershed maximum height is 1453m and minimum height is 1000m. Thus the Bh of Vagamon sub-watershed is 0.58km and Peermade 0.45km. Relief ratio (Rh) indicates the overall steepness of the basin, which Includes factors of gradient and elevation. The high Rh values of Vagamon (0.09) is due to steep slope and high relief, while the lower values of Peermade (0.06) may indicate the presence of basement rocks that are exposed in the form of small ridges and mounds with lower degree of slope. Ruggedness number (Rn) is the product of the basin relief and its drainage density. Vagamon has high ruggedness number (1.92). This indicates the structural complexity of the terrain in association with relief and drainage density. It also implies that the area is susceptible to soil erosion

5 CONCLUSIONS

The outcome of morphometric analysis is very much useful in applying proper watershed management practices. The application of various morphometric techniques is a major advance in the quantitative and qualitative description of geometry and network of drainage basins. GIS has proved to be an efficient tool in morphometric analysis. Vagamon sub-watershed shows typical trellis drainage pattern indicating the more structural complex nature. High values of Rn, Lof, Rb and C for Vagamon sub-watershed further emphasis the structural complexity of the sub-watershed. The low values of the morphometric parameters such as Re, Rc, and Rf indicates the highly elongated shape of the Vagamondrainage basin. High values of Bh and Rh for Vagamon reveals the steep slope whereas the low values of Peermade sub-watershed indicates presence of small ridges and mounts. Further the morphometric parameters evaluated using GIS have helped us to understand various terrain parameters such as nature of bedrock, infiltration capacity, surface runoff, etc. The outcome of the present study will help a lot in watershed development and management.

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