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# Morphometric Analysis and Micro-watershed Prioritization of Peruvanthanam Sub-watershed, the Manimala River Basin, Kerala, South India

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Morphometric analysis is important in any hydrological investigation and it is inevitable in development and management of drainage basin. A critical evaluation and assessment of morphometric parameters and prioritization of micro-watersheds based on water holding capacity of Peruvanthanam sub-watershed have been achieved through measurement of linear, aerial and relief aspects of basins by using remote sensing and GIS techniques, and it necessitates preparation of a detailed drainage map. For prioritization, 9 micro-watersheds are delineated and parameters such as Rb, Dd, Fs,T, Lof and C are calculated separately and prioritization has been done by using the Raster calculator option of Spatial analyst. The analysis reveals that the stream order varies from 1 to 6 and the total number of stream segments of all orders counted as 347, out of which the maximum area (69.16%) is covered by $1^{st}$ order streams and the minimum (0.29%) by $6^{th}$ order. Lower values of Rb (linear parameters) in each order, higher values of Bh (0.90), Rh (0.07) and Rn (3.02) (relief parameters), high values of Dd (3.36), Fs (6.15), T (6.82), low values of Lof (0.14) and C (0.30) (aerial parameters) all together reveal that the sub-watershed has a complex structure, mountainous relief, high runoff and low infiltration. The maximum area is covered by high to medium prioritized zones (19.07km$^2$) followed by low to very low (17.75km$^2$) while a very high to high zone is only 4.72km$^2$.

Key words: *linear parameters, relief parameters, aerial parameters, Peruvanthanam sub-watershed.*

## 1. Introduction

Development of a drainage system and the flowing pattern of a river 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. Geographical Information System (GIS) techniques have already been used for assessing various terrain and morphometric parameters of the drainage basins and watersheds as they provide a flexible environment and a powerful tool for the manipulation and analysis of the spatial information, particularly for the future identification and extraction of the information for better understanding (Vijith 2006). Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimensions of its landforms (Clarke 1996). This analysis can be achieved through measurement of linear, aerial and relief aspects of basins by using remote sensing and GIS. The present study is an attempt to critically evaluate and assess various morphometric parameters of Peruvanthanam sub-watershed of the Manimala river basin. It also involves the prioritization of micro-watersheds based on water holding capacity in the morphometric analysis. The selected area for the present investigation - Peruvanthanam sub-watershed is a typical highland sub-watershed of the Manimala river basin, in Idukki district and it lies between $9^0 30'00''$ to $9^0 36'40''$ N latitude and $76^0 40'50''$ to $76^0 45'50''$ E longitude. Peruvanthanam sub-watershed, a typical highland sub-watershed, is the area under the altitude above 76m of MSL. Main crops cultivated in this region are teak, rubber, pineapple and tapioca. In general, low, medium and high hills with isolated hillocks constitute broad physiography of Peruvanthanam sub-watershed. Peruvanthanam sub-watershed is well drained in nature with the stream order varying from 1 to 5, and the area is characterized by predominance of a dendritic pattern, which as a trellis pattern is less pronounced and is found towards the south west region of Peruvanthanam sub-watershed. Geologically, Peruvanthanam sub-watershed is characterized by charnockite, dolerite and quartzite. A better knowledge about various morphometric parameters such as linear, relief and aerial aspects are vital to an overall understanding of the basin development and management. Thus, the application of various morphometric techniques is a major advance in the quantitative and qualitative description of geometry and network of drainage basins. Morphometric analysis of a drainage basin necessitates preparation of the detailed drainage map order of various streams, measurement of catchment area and its perimeter, stream order, stream length and mean stream length.

## 2. Morphometric analysis

Peruvanthanam sub-watershed and an associated drainage network (Fig. 1) were delineated from SOI topographical maps 58 C/14 and 58 C/15 of 1:50000 scale and were digitized using Arc GIS 9.2 software. Morphometric analysis has been carried out of the following parameters: bifurcation ratio (Rb), (linear parameters), basin relief (Bh), relief ratio (Rh) and ruggedness number (Rn) (relief parameters) and drainage density (Dd), stream frequency (Fs), texture ratio (T), form factor (Rf), length of overland flow (Lof), constant channel maintenance(C) (aerial parameters).

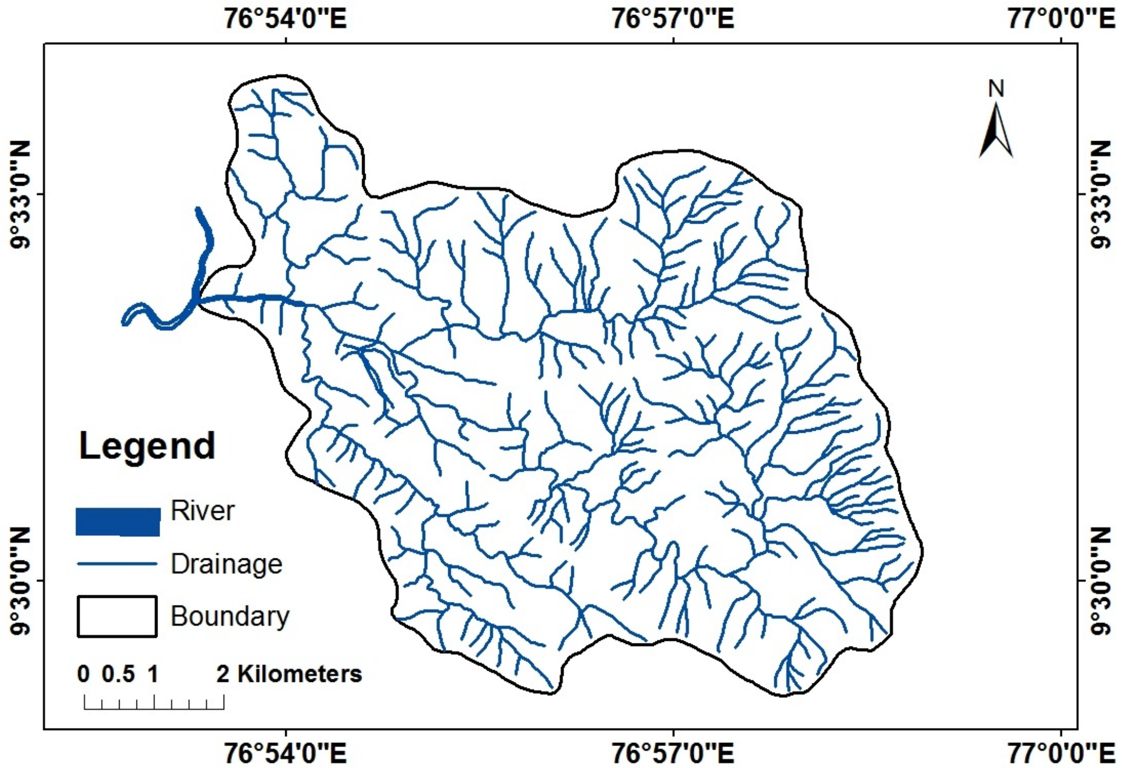


*Fig.1 Drainage map of Peruvanthanam sub-watershed*

The methods adopted for calculating morphometric parameters are given in Table 1. Linear parameters analyzed include: stream orders (Nu), stream length (Lu), mean stream length (Lsm) and bifurcation ratio (Rb). 347 stream segments were recognized in Peruvanthanam sub-watershed, out of which 69.16% (240) is a 1$^{st}$ order, 23.92% (83) is a 2$^{nd}$ order, 4.32% (15) is a 3$^{rd}$ order, 1.73% (6) is a 4$^{th}$ order, 0.58% (2) is a 5$^{th}$ order and 0.29% (1) is a 6$^{th}$ order. Generally, the total length of stream segments is the maximum in first order streams and decreases with an increase in the stream order. The mean stream length (Lsm) is a characteristic property related to the drainage and its associated surfaces and it is varying from 0.47 to 3.50 (Table 2). Results of the morphometric analysis are represented in Table 3. 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 (Shumn 1956). It shows a small range of variation for different regions or for different environment except those where the powerful geological control dominates. 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 (Strahler 1964). A low Rb value (3.18) indicates less structural disturbances in Peruvanthanam sub-watershed.

*Table 1 Methods of calculating morphometric parameters*

| | Morphometric Parameters | Methods | References |
|---|---|---|---|
| LINEAR | Stream order (U) | Hierarchical order | Strahler, 1964 |
| | Stream length (Lu) | Length of the stream | Horton, 1945 |
| | Mean stream length (Lsm) | Lsm = Lu/Nu where, Lu=Stream length of order 'U' Nu=Total number of stream segments of order 'U' | Horton, 1945 |
| | Stream length ratio (Rl) | Rl=Lu/Lu-1; where Lu=Total stream length of order 'U', Lu-1=Stream length of next lower order. | Horton, 1945 |
| | Bifurcation ratio (Rb) | Rb = Nu/ Nu+1; where, Nu=Total number of stream segment of order'u'; Nu+1=Number of segment of next higher order | Schumn,1956 |
| RELIEF | Basin relief (Bh) | Vertical distance between the lowest and highest points of watershed. | Schumn, 1956 |
| | Relief ratio (Rh) | Rh=Bh/Lb; Where, Bh=Basin relief;Lb=Basin length | Schumn, 1956 |
| | Ruggedness number (Rn) | Rn = Bh × Dd Where, Bh =Basin relief; Dd=Drainage density | Schumn, 1956 |
| ARIAL | Drainage density (Dd) | Dd = L/A where, L=Total length of streams;A=Area of watershed | Horton, 1945 |
| | Stream frequency (Fs) | Fs = N/A where, N=Total number of streams; A=Area of watershed | Horton, 1945 |
| | Texture ratio (T) | T = N1/P where,N1=Total number of first order streams; P=Perimeter of watershed | Horton, 1945 |
| | Form factor (Rf) | $Rf=A/(Lb)^2$ ;where, A=Area of watershed, Lb=Basin length | Horton, 1932 |
| | Circulatory ratio (Rc) | $Rc=4\pi A/P^2$ ;where, A=Area of watershed, π=3.14, P=Perimeter of watershed | Miller, 1953 |
| | Elongation ratio (Re) | $Re=2\sqrt{(A/\pi)}/Lb$ ;where, A=Area of watershed, π=3.14, Lb=Basin length | Schumn,1956 |
| | Length of overland flow (Lof) | Lof = 1/2Dd where, Dd=Drainage density | Horton, 1945 |
| | Constant channel maintenance (C) | Lof = 1/Dd where, Dd=Drainage density | Horton, 1945 |

*Table 2 Mean stream length (Lsm) of Peuvanthanam sub-watershed*

| Name | Stream order | Lu | Nu | Lsm |
|---|---|---|---|---|
| Peruvanthanam Sub-watershed | 1 | 112.2 | 240 | 0.47 |
| | 2 | 36.29 | 83 | 0.44 |
| | 3 | 18.89 | 15 | 1.26 |
| | 4 | 20.98 | 6 | 3.50 |
| | 5 | 0.98 | 2 | 0.49 |
| | 6 | 0.73 | 1 | 0.73 |

Lu=Stream length of order 'U' (km)
Nu=Total number of stream segments
Lsm=Mean stream length

*Table 3 Result of morphometric analysis of Peuvanthanam sub-watershed*

| Morphometric parameters | Result |
|---|---|
| Area ($km^2$) | 56.42 |
| Perimeter (km) | 35.15 |
| Basin order | 6.00 |
| Basin length(Lb)(km) | 12.15 |
| Relief ratio (Rh) | 0.07 |
| Basin relief (Bh)(km) | 0.90 |
| Ruggedness number(Rn) | 3.02 |
| Bifurcation ratio(Rb) | 3.18 |
| Drainage density(Dd) ($km^2$) | 3.36 |
| Stream frequency(Fs) ($km^2$) | 6.15 |
| Texture ratio(T) (km) | 6.82 |
| Form factor (Rf) | 0.38 |
| Circulatory ratio (Rc) | 0.57 |
| Elongation ratio (Re) | 0.70 |
| Length of overland flow (Lof) (km) | 0.14 |
| Constant channel maintenance(C) (km) | 0.30 |

Among the aerial parameters analyzed the measurement of drainage density provides a numerical measurement of the landscape dissection and runoff potential. High drainage density of Peruvanthanam sub-watershed (3.36) is the result of 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. The calculated value of stream frequency (Fs) (6.15) is higher in Peruvanthanam 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. Here the higher texture ratio of 6.82 can be attributed to the presence of high reliefs. Peruvanthanam sub-watershed is of a partially circular shape due to higher Rf value (0.38) and Rc value (0.57) greater than 5 per an index. Peruvanthanam sub-watershed has high relief and steep slope due to the lower elongation ratio (0.58).

Length of the overland flow (Lof) is the length of water over the ground before it gets concentrated in to definite stream channels. Peruvanthanm sub-watershed is structurally complex due to the low value of Lof (0.14). The lower value of constant channel maintenance (C) (0.30) indicates that Peruvanthanm sub-watershed is under the influence of structural disturbances having high run off and low permeability.

The statistical analysis of inter relationships of morphometric parameters (Table 4) helps in understanding the terrain characteristics for the watershed management and planning. From the Pearson's correlation matrix for Peruvanthanam sub-watershed (Table 4), total length of the stream is positively correlated with the area (0.974) at 1% level. Mean stream length (Lsm) is negatively correlated with stream frequency (Fs) (-0.868) and drainage density (Dd) is negatively correlated with the length of overland flow (Lof) (-0.980) and constant channel maintenance (C) (-0.989). The length of overland flow (Lof) has significant positive correlation with constant channel maintenance (C) at 1% level (0.985).

The pair-wise relationship of different morphometric parameters of Peruvanthanam sub-watershed (Table 5) reveals that there is a significant relationship between a total number of streams and the total stream length with a coefficient determining the prediction equation (0.946), and it implies that 94% of the variation in the total number of streams is explained by the total stream length. Similarly, 88% of the variation in the total number of streams is explained by the basin area (0.881), 43% of variation in the total number of streams is explained by the perimeter (0.437), 94% of variation in constant channel maintenance is explained by drainage density (0.948), 62% of variation in stream frequency - by drainage density (0.622), 96% of variation in the length of the overland flow - by drainage density (0.960) and 97% of variation in the total stream length - by the basin area (0.978).

*Table 4 Correlation matrix of morphometric parameters*

| | A | P | Lu | Lsm | Dd | Fs | Lof | C | Nu |
|---|---|---|---|---|---|---|---|---|---|
| A | 1 | 0.752* | 0.974** | 0.311 | -0.150 | -0.316 | 0.179 | 0.080 | 0.938** |
| P | 0.752* | 1 | 0.638 | 0.143 | -0.323 | -0.327 | 0.303 | 0.249 | 0.661 |
| Lu | 0.974** | 0.638 | 1 | 0.248 | 0.054 | -0.167 | -0.018 | -0.120 | 0.972** |
| Lsm | 0.311 | 0.143 | 0.248 | 1 | -0.405 | -0.868** | 0.337 | 0.380 | 0.036 |
| Dd | -0.15 | -0.323 | 0.054 | -0.405 | 1 | 0.789* | -0.98** | -0.989** | 0.121 |
| Fs | -0.316 | -0.327 | -0.167 | -0.868** | 0.789* | 1 | -0.726* | -0.764* | 0.003 |
| Lof | 0.179 | 0.303 | -0.018 | 0.337 | -0.980** | -0.726 | 1 | 0.985** | -0.066 |
| C | 0.080 | 0.249 | -0.120 | 0.38 | -0.989** | -0.764 | 0.985** | 1 | -0.187 |
| Nu | 0.938** | 0.661 | 0.972** | 0.036 | 0.121 | 0.003 | -0.066 | -0.187 | 1 |

*Table 5 Coefficient of linear equations between morphometric parameters*

| Relationship between: | Linear regression equations | Coefficient of determinations ($R^2$) | Correlation coefficient (R) |
|---|---|---|---|
| Total number of streams and Total Stream length | y = 2.423x + 3.662 | 0.946 | 0.972 |
| Total number of streams and Basin area | y = 8.141x + 4.170 | 0.881 | 0.938 |
| Total number of streams and Perimeter | y = 4.872x + 0.712 | 0.437 | 0.661 |
| Stream frequency and drainage density | y = 3.738x -3.806 | 0.622 | 0.789 |
| Length overland flow and drainage density | y = -0.0448x +0.298 | 0.960 | 0.980 |
| Constant channel maintenance and drainage density | y = -0.0874x +0.590 | 0.978 | 0.989 |

## 2. Prioritization of micro-watersheds

For prioritization of micro-watersheds on the basis of water holding capacity 9 micro-watersheds (PV1, PV2, PV3, PV4, PV5, PV6, PV7, PV8 and PV9) were delineated from Peruvanthanam sub-watershed (Fig.2) and the morphometric parameters, such as bifurcation ratio, drainage density, stream frequency, texture ratio, length overland flow and constant channel maintenance of delineated micro watersheds, were separately calculated. Then, the calculated values were added as attributed data. It is represented in Table 6. Then the themes, such as bifurcation ratio, drainage density, stream frequency, texture ratio, constant channel maintenance, and length overland flow were converted to the raster format and reclassified by using a Spatial Analyst extension tool of Arc GIS 9.2. Further, specific weight and specific ranks were assigned to each theme while individual layer classes are based on the water holding capacity in relation to morphometric parameters (Javed et.al. 2009) ( Table 7).

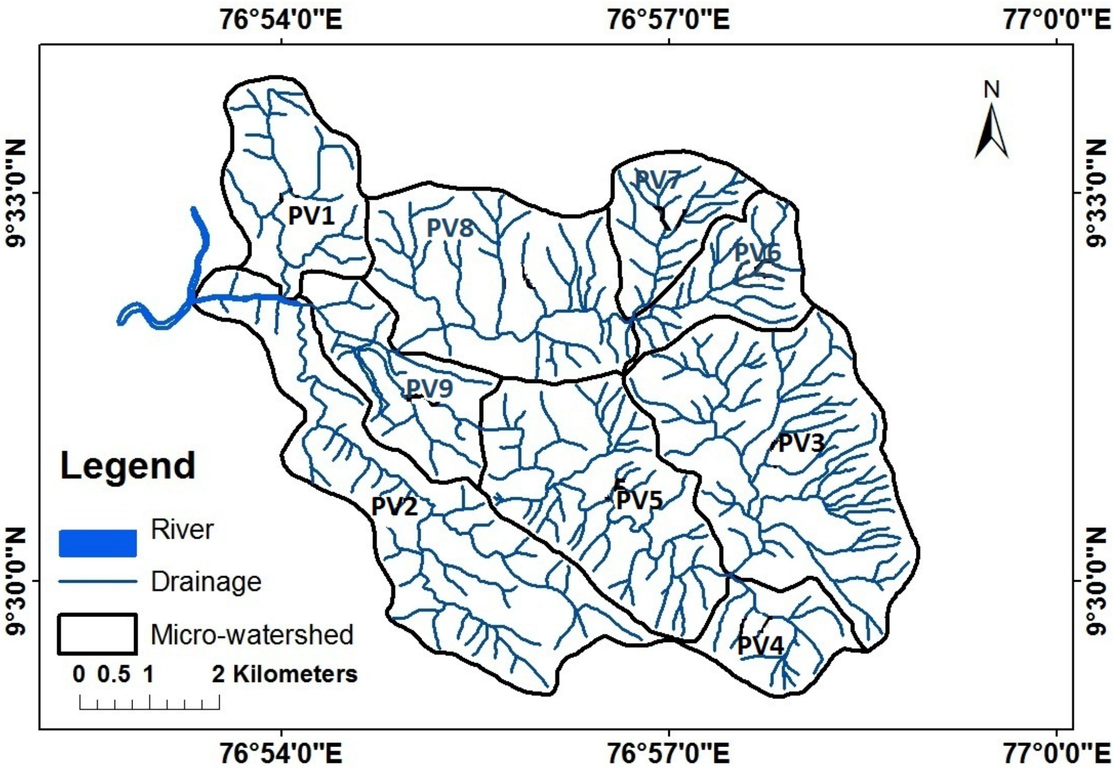


*Fig.2 Map showing micro-watersheds of Peruvanthanam sub-watershed*

*Table 6 Morphometric parameters of micro-watersheds of Peruvanthanam sub-watershed*

| Name | A | P | Lu | Lsm | Rb | Dd | Fs | T | Lof | C |
|---|---|---|---|---|---|---|---|---|---|---|
| PV1 | 4.72 | 9.45 | 12.96 | 0.43 | 1.50 | 2.74 | 6.35 | 1.58 | 0.18 | 0.36 |
| PV2 | 10.59 | 21.05 | 32.19 | 0.37 | 2.50 | 3.04 | 8.02 | 2.09 | 0.16 | 0.32 |
| PV3 | 11.64 | 15.05 | 43.94 | 0.42 | 1.89 | 3.77 | 8.93 | 3.58 | 0.13 | 0.26 |
| PV4 | 2.64 | 7.36 | 8.48 | 0.35 | 3.52 | 3.21 | 9.09 | 1.62 | 0.15 | 0.31 |
| PV5 | 8.25 | 12.18 | 29.95 | 0.34 | 4.40 | 3.62 | 10.46 | 3.44 | 0.14 | 0.27 |
| PV6 | 3.12 | 9.01 | 12.46 | 0.37 | 1.58 | 3.98 | 10.55 | 1.88 | 0.12 | 0.25 |
| PV7 | 2.99 | 7.65 | 11.36 | 0.29 | 1.57 | 3.80 | 12.71 | 2.48 | 0.13 | 0.26 |
| PV8 | 8.48 | 12.16 | 25.82 | 0.45 | 2.81 | 3.04 | 6.72 | 2.38 | 0.16 | 0.32 |
| PV9 | 3.99 | 10.16 | 14.33 | 0.44 | 2.31 | 3.59 | 8.02 | 1.37 | 0.13 | 0.27 |

After assigning the weight and ranks all the themes were reclassified using spatial analyst extension of Arc GIS 9.2 software (Figs 3 – 8). Then the individual themes were normalized by dividing the theme weight by 100. A map algebra (Eq.1) is used in the raster calculator option of a spatial analyst to prepare the integrated final prioritized map (Fig.9).

Prioritized map = = Drainage density x 0.3+ + Bifurcation ratio x 0.25+ + Stream frequency x 0.2+ + Texture ratio x 0.15+ + Length overland flow x 0.1+ +Constant channel maintenance X 0.05

*(Eq.1)*

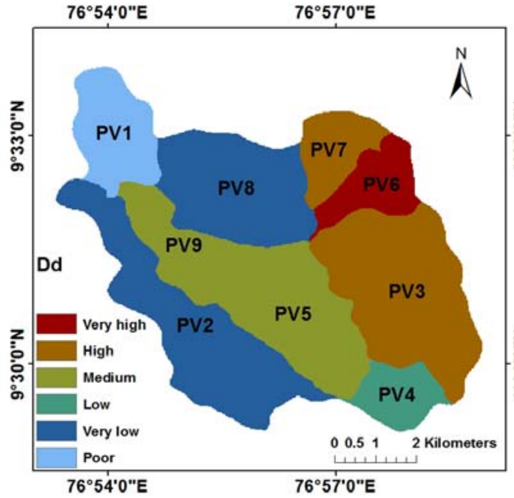


*Fig .3* *Drainage density of micro-watersheds of Peruvanthanam sub-watershed*

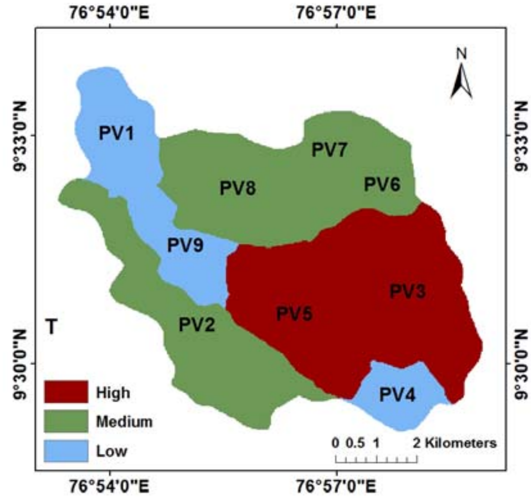


*Fig .6* *Texture ratio of micro-watersheds of Peruvanthanam sub-watershed*

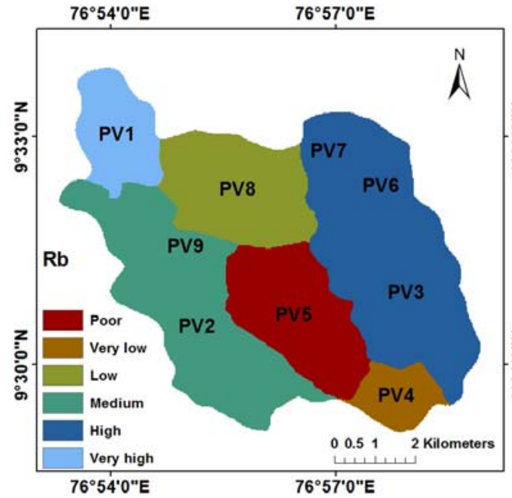


*Fig .4* *Bifurcation ratio of micro-watersheds of Peruvanthanam sub-watershed*

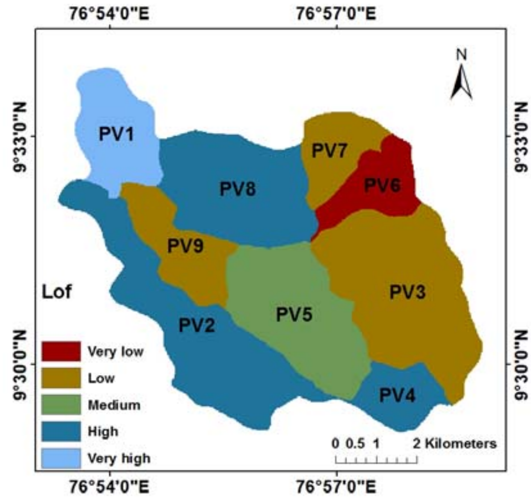


*Fig .7* *Length of overland flow of micro-watersheds of Peruvanthanam sub-watershed*

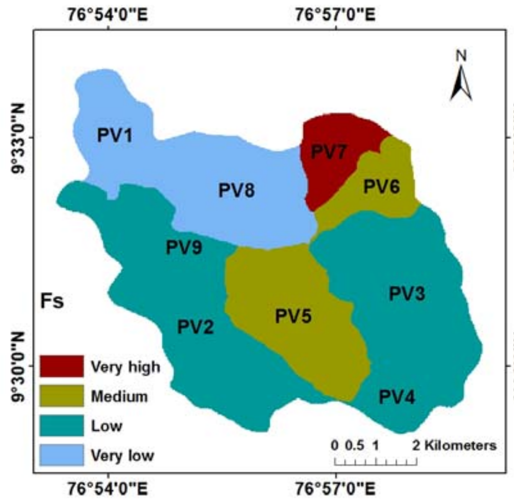


*Fig .5* *Stream frequency of micro-watersheds of Peruvanthanam sub-watershed*

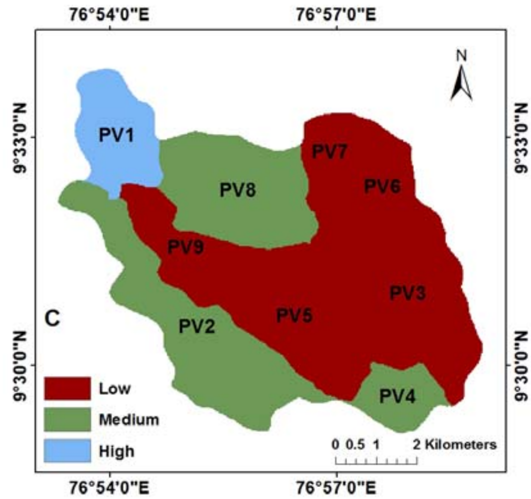


*Fig .8* *Constant channel maintenance of micro-watersheds of Peruvanthanam sub-watershed*

*Table 7 Weight and rank assigned for theme and layer class*

| Themes | Weight | Layer class and its rank |
|---|---|---|
| Drainage density | 30 | 2.70-2.90=10;2.90-3.10=9 3.10-3.30= 8;3.30-3.50=7 3.50-3.70= 5;3.70-3.90=3 3.90-4.10=1 |
| Bifurcation ratio | 25 | 1.00-1.50=1;1.50-2.00=3 2.00-2.50=5;2.50-3.00=7 3.00-3.50=9;3.50-4.00=9 4.00-4.50=10 |
| Stream frequency | 20 | 6.30-7.30=10;7.30-8.30=9 8.30-9.3= 9;9.30-10.30=8 10.30-11.30=5; 11.30-12.30=3 12.30-13.30=1 |
| Texture ratio | 15 | 1.30-1.70=10;1.70-2.10=9 2.10-2.50= 9;2.50-2.90=7 2.90-3.30= 5;3.30-3.70=3 3.70-4.10=1 |
| Length of overland Flow | 10 | 0.11-0.12=1;0.12-0.13=3 0.13-0.14=5;0.14-0.15=7 0.15-0.16=8;0.16-0.17=9 0.17-0.18=10 |
| Constant channel maintenance | 5 | 0.25-0.28=1;0.28-0.31=4 0.31-0.34=8;0.34-0.37=10 |

According to the reclassified theme, drainage density (Dd), the maximum area (33.80%) is covered by a very low zone and the minimum area (4.68%) - by low zone. The analysis has indicated that the micro-watershed PV6 comes under very high zone and PV1 - under poor zone. The reclassification of bifurcation ratio (Rb) shows that the maximum area (31.46%) is occupied by very low zone and the minimum (4.68%) - by high zone. It is also found that very high zone is occupied by PV1 and poor zone - by PV5. Analysis of the reclassified map of stream frequency (Fs) shows that the maximum area (51.15%) comes under low zone and the minimum (5.28%) comes under very high zone. The micro-watershed PV7 changes the zone into very high and very low zone is occupied by PV1 and P8. Reclassification of the texture ratio (T) has shown that the maximum area (44.65%) is covered by medium zone and the minimum (20.10%) - by low zone. Here, PV5 and PV3 come under high zone and low zone occupied by PV1 and PV9. Reclassification of the length of the overland flow (Lof) shows that the maximum area (38.48%) is covered by high zone and the minimum (5.55%) by very low zone. Here PV1 comes under very high zone and very low zone occupied by PV6. According to the reclassified theme of constant channel maintenance (C), the maximum area (53.15%) is covered by low zone and the minimum (8.37%) - by high zone. From the analysis of reclassified maps, it has been found that micro-watershed PV9, PV5, PV3, PV6 and PV7 come under low zone and PV1 comes under high zone.

*Table .8 Details of Prioritized zones of Peruvanthanam sub-watershed*

| Prioritized zones | Area in $Km^2$ | % of Area |
|---|---|---|
| Very low-Poor | 8.25 | 14.62 |
| Low- Very low | 17.75 | 31.46 |
| Medium-Low | 6.63 | 11.75 |
| High- Medium | 19.07 | 33.80 |
| Very high-High | 4.72 | 8.37 |

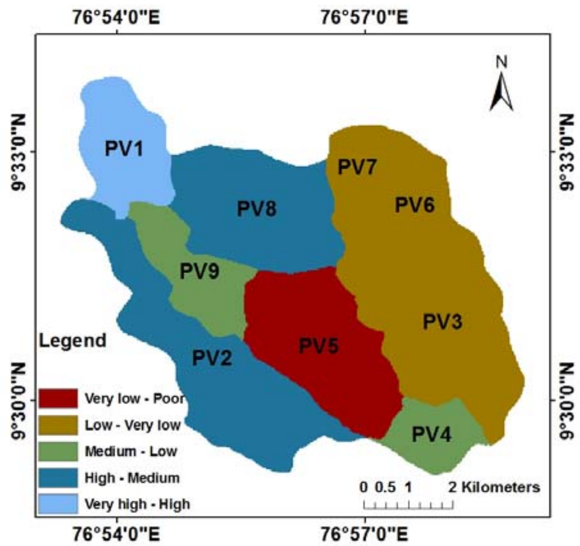


*Fig .9 Prioritized zones of Peruvanthanam sub-watershed*

Details of prioritized zones of Peruvanthanam sub-watershed is represented in Table 8. In Peruvanthanam sub-watershed the maximum area (33.80%) is occupied by high to medium zone. The area of very high to high zone is only 8.37%. The prioritized zones of Peruvanthanam sub-watershed show that micro-watershed PV1 occupies very high to high zone. By considering the relation between these prioritized zones and the selected morphometric parameters it has been found that the micro-watersheds, such as PV1, are the zones having high water holding capacity because of poor zone of drainage density, high zone of bifurcation ratio, very low zone of stream frequency, low zone of texture ratio, high zone of length overland flow and high zone of the constant channel maintenance. All these factors together make these micro-watersheds of very high to high water holding nature. Very low to poor prioritized zone is represented by PV5. These micro-watersheds are characterized by high zone of drainage density, poor zone of bifurcation ratio, high zone of stream frequency, high zone of texture ratio, low zone of length overland flow and low zone of constant channel maintenance.

## 3. Conclusions

Drainage morphometry of a sub-watershed reflects hydro-geologic maturity of that river. Satellite remote sensing has an ability of obtaining the synoptic view of a large area at one time, which is very useful in analyzing the drainage morphometry. GIS has proved to be an efficient tool in drainage delineation and this drainage has been used in the present study. Variation in the values of Rb among the micro-watersheds is ascribed to the difference in topography and geometric development. From the analysis it has been found that PV1 micro-watershed falls into a very high to high priority category based on the water holding capacity in relation to morphometric analysis; hence this micro-watershed may be taken for conservation measures by planners and decision makers in the watershed management. 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 present study will be of assistance in watershed development and management.

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# Morfometrinė analizė ir vandens mikrotakoskyros prioriteto suteikimas Peruvanthann povandeninei takoskyrai Manilos upės baseine (Kerala, Pietų Indija)

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Morfometrinė analizė yra svarbi hidrologiniuose tyrimuose, neišvengiama kuriant ir prižiūrint drenažo baseiną. Upės povandeninės takoskyros drenažo morfometrija parodo jos hidrogeologinę brandą. Naudojant palydovines matavimo priemones, galima vienu metu gauti apžvalginį didelio pločio vaizdą, kuris reikalingas drenažo morfometrijoje. Darbe efektyviai panaudota GIS (geografinė informacinė sistema). Mikrotakoskyrų parametrų įvairovė parodo topografijos ir geometrinės raidos skirtumus. Analizė parodė, kad prioritetą pagal vandens tūrį galima skirti vienai iš devynių takoskyros padalų, būtent PV1, į kurią drenažo specialistai turėtų atkreipti dėmesį ir imtis apsaugos priemonių, kaip ją išsaugoti.

Be to, morfometriniai parametrai, įvertinti naudojant GIS, padeda suprasti įvairius vietovės parametrus: paklotinės uolienos pobūdį, įsisiurbimo mastą, paviršiaus nutekėjimą ir t. t. Taigi šis tyrimas padės plėtoti ir tvarkyti upės takoskyras.