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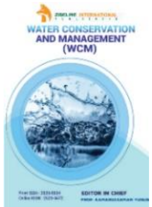

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RESEARCH ARTICLE

PRIORITIZING THE SUBBASINS OF MUVATTUPUZHA RIVER BASIN, KERALA, THROUGH MORPHOMETRIC ANALYSIS WITH SPECIAL REFERENCE TO GROUND WATER CONSERVATION MANAGEMENT

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ABSTRACT

The combined consequences of unregulated farming practices and increasingly erosive precipitations due to climate change pose significant threats to watersheds in tropical regions. Sustainable river basin development can be achieved by implementing water resources conservation and techniques. Morphometric analysis has become an essential step for watershed prioritization in sustainable river basin development. This study investigates the morphometric parameters of four sub-basins within the Muvattupuzha basin to identify potential strategies for water conservation. Geographic Information System (GIS) techniques were employed to analyze various morphometric parameters. Different geo morphometric features were analyzed to assess the susceptibility of the sub-basins regard to groundwater depletion so that locations in need of urgent attention can be given priority. Variables that directly and adversely affect the groundwater depletion risk were used in the ranking of the prioritization process. Ranks for various geomorphometric criteria of each subbasin were averaged to get compound values for final prioritization. Thodupuzha and Kaliyar sub-basins with low compound factor, receive a very high and high priority respectively, while Muvattupuzha and Kothamangalam with higher compound value need moderate priority. The study offers important information to planners and managers of watersheds, where programs and project implementation must be given priority. The same data could be very useful for providing insight into other criteria-specific prioritization in river basin development programs.

KEYWORDS

Groundwater depletion, watershed management, Geographic Information System, morphometric analysis, compound value, prioritization

1. INTRODUCTION

Numerous watersheds across the nation are categorized as being in critical state, while fulfilling various essential domestic needs (Loucks, 2017). Understanding the hydrological behaviour of various watersheds is possible through the linking of geomorphometric parameters in relation to the watershed's hydrological features. A comprehensive examination of the hydrological characteristics of watersheds is essential due to the urgent requirement for watershed management to prioritize initiatives and endeavours aimed at conserving, developing, and ensuring the sustainability of all natural resources (Meshram and Sharma, 2017).

When prioritizing a watershed for resource conservation and protection, geomorphometric characteristics and land use/land cover are crucial (Puno and Puno, 2019). Protection and conservation of watersheds, alongside the restoration of degraded areas, are imperative endeavours aimed at achieving sustainable development. (Puno and Puno, 2019; Francisco and Rola, 2004). Comprehensive geomorphometric and hydrologic characterization of the drainage region is required for integrated watershed management planning (Puno and Puno, 2019).

Morphometric analysis is fundamental to every hydrological investigation for the sustainable maintenance of river basins, can be accomplished by the application of RS and GIS (Rekha et al., 2011; Biswas, 2016). This type of analysis provides valuable insights into the geomorphological and hydrological properties of river systems (Choudhari et al., 2018). An improved understanding of numerous morphometric factors, such as linear, relief, and aerial features, is necessary to the basin's development and management. Prioritizing sub-watersheds has been done using certain geomorphometric parameters known as erosion risk assessment factors in turn affects the recharging, such as bifurcation ratio, drainage density, length of stream, compactness coefficient, stream frequency, texture ratio, length of overland flow, form factor, circularity ratio, and elongation ratio (Choudhari et al., 2018). Understanding the hydrological behaviour of various watersheds is made possible by linking geomorphometric features with their hydrological properties, aids in evaluating watersheds with low water-retention characteristics (Puno and Puno, 2019).

In the prioritization process, numerous studies have been conducted on sub-watershed ranking, utilizing the combined influence of geo morphometric factors and land use/land cover considerations. Numerous methodologies across diverse platforms have been documented to assess the extent of soil erosion within a watershed, forming the basis for prioritizing treatment interventions (Puno and Puno, 2019). Soil erosion in turn badly affects the percolation and infiltration enhancing ground water storage.

Remote sensing and GIS play a pivotal role in characterizing and prioritizing watershed areas based on the extent of erosion and the degree of depletion of soil and water resources. Geomorphometric parameters primarily stem from lithology and geological structures. Therefore, a

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quantitative depiction of geomorphology, hydrology, geology, and stream network patterns is immensely beneficial for conducting a dependable analysis of the watershed (Puno and Puno, 2019).

The study area experiences semi-arid climatic conditions. Owing to erratic rainfall patterns and unregulated exploitation of groundwater resources, there has been a notable depletion in groundwater levels (Narmada et al., 2015). The present study critically evaluates and assesses various morphometric parameters involving the prioritization among the 4 sub-basins of Muvattupuzha River Basin, in relation to the susceptibility to groundwater depletion risk to define a baseline of data. Hence the investigation can be used for the conservation and development of surface and groundwater resources in the river basin area in terms of watershed management and protecting the natural environment (Said et al., 2018).

2. STUDY AREA

The Muvattupuzha River originates from the confluence of three rivers: the Kaliyar River, Thodupuzha River, and Kothamangalam River. It originates from the east of Erattupetta, in Kottayam district 76˚53' E , 9° 43' N with an elevation of 1094m. This river empties into the Arabian Sea after flowing up to Vembanad Lake in Vaikkom. The river basin covers the central Kerala districts of Idukki, Kottayam, Alappuzha, and Ernakulum. The Muvattupuzha river basin was subdivided into four sub- basins including Kothamangalam, Kaliyar, Thodupuzha, and Muvattupuzha sub basins. The river basin lies between 9˚30’49.33” N, 10˚5’17.46’’N latitudes and 76 ˚ 23’ 10.98’’E, 76˚ 24’5.51’’E longitudes with an area of 2670.281 km^2. Survey of India Topographic maps having 1:50,000 scales with toposheet numbers 58B/11, 58B/12, 58B/16, 58C/5, 58C/6, 58C/9, 58C/10, 58C/13, 58C/14 were used for delineating the study area. The annual average rainfall in the basin is above 3000 mm. The region encounters a humid climate, with the normal daily mean temperature in this basin fluctuating between 26°C and 29°C. A major part of the basin covers lateritic soil. Figure 1 displays the location of the Muvattupuzha River basin, while Figure 2 illustrates its drainage map.

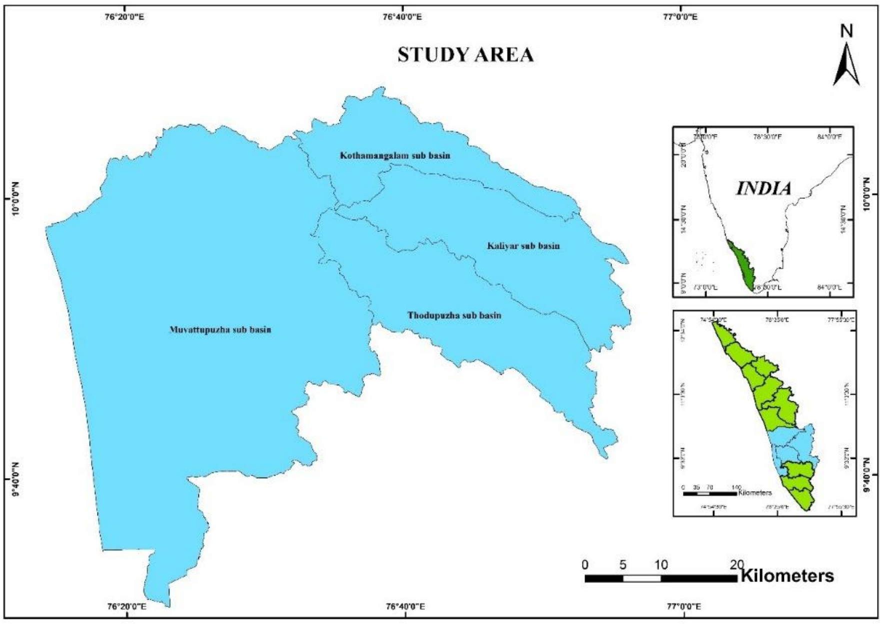

Figure 1: Study area

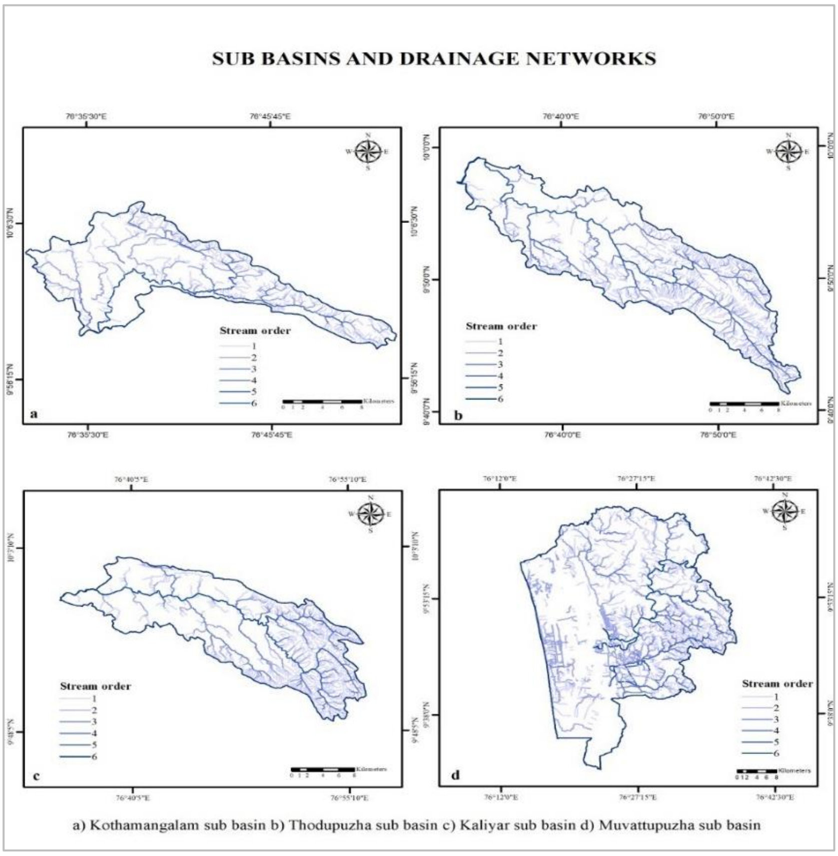

Figure 2: Sub-basins and Drainage networks of sub-basins

3. Methodology

The sub-basins and their corresponding drainage networks were delineated using 1:50,000 scale Survey of India (SOI) topographical maps and digitized within a GIS environment using ArcGIS 10.3 software (Choudhari et al., 2018). Digitization and numbering were done based on Strahler's scheme of ordering. Strahler's system of stream analysis, recognized as one of the simplest and most commonly employed systems, has been adopted for this study (Kanth et al., 2012). Each finger-tip channel is identified as a first-order segment. At the confluence of any two first-order segments, a second-order channel is formed, extending downstream until it meets another second-order channel. At this juncture, a third-order segment is formed, and this pattern continues sequentially (Kanth et al., 2012). Morphometric analysis was conducted using the GIS platform for the parameters such as Stream order (U), Stream length (L_u), Mean stream length (L_{sm}), Stream length ratio (R_l), Bifurcation ratio (R_b), Basin relief (B_h), Relief ratio (R_h), Ruggedness number (R_n), Drainage density (D_d), Stream frequency (F_s), Texture ratio (T), Form factor (R_f), Circulatory ratio (R_c), Elongation ratio (R_e), Length of overland flow (L_{of}) and Constant channel maintenance (C) using the standard methods and formulae with reference given in the Table1(Pawar-Patil and Mali, 2013; Puno and Puno, 2019). SRTM DEM data, an Interferometric Synthetic Aperture Radar (InSAR) of 30 m resolution is used to generate an elevation model of the catchment area using the Arc GIS 10.3 software. The DEM data extracted provides information regarding topography, slope, and measures (Gopinath et al., 2016).

Most relevant morphometric parameters are selected for compound parameter analysis (Singh et al., 2021). Ranking of sub-basin for each parameter is done based on the chance of enhancing groundwater level through infiltration and percolation (Puno and Puno, 2019). For each parameter, the highest rank was given to the sub-basin with unfavourable conditions for groundwater recharging where conservation treatment methods are to be applied (Puno and Puno, 2019). The morphometric characteristics like drainage density, stream frequency, drainage texture, relief, ruggedness number, etc. directly influence the risk of soil erosion/groundwater recharging. Hence subbasins with maximum value for these characteristics are ranked first, and the minimum value is with last ranking. Parameters like circulatory ratio, elongation ratio, form factor, compactness coefficient, etc. indirectly influence the risk of soil erosion/groundwater replenishment (Shekar and Mathew, 2022). Therefore, these characteristics are ranked with the first rank assigned to the minimum value and the last rank assigned to the maximum value. Ultimately, to determine the compound parameter value for each sub basin, the average rank is calculated for each sub basin (Puno & Puno, 2019; Shekar and Mathew, 2022). The sub-basin with the lowest value of compound factor corresponds to the highest rank, indicating first priority for the water conservation treatment plan can be suggested to practice a higher degree of water conservation/artificial recharging measures in contrast to the other sub-basins (Puno and Puno, 2019).The methodology adopted in the study is depicted in the schematic diagram (Figure. 3)

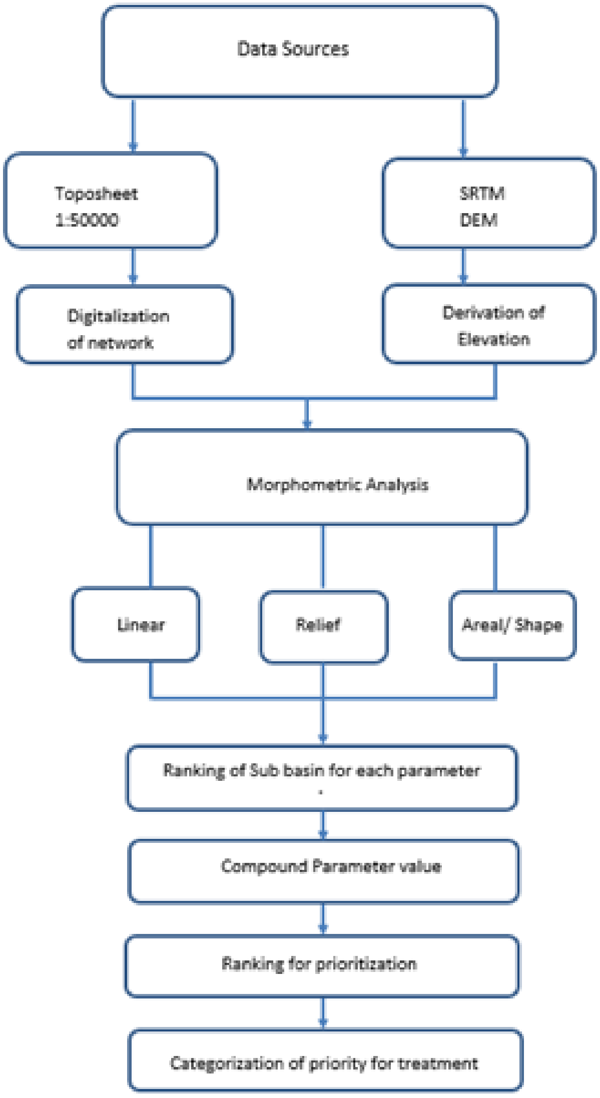

Figure 3: Flow Chart of Methodology Adopted

4. Results and Discussion

4.1 Morphometric Analysis

The morphometric characteristics are calculated using the formulae provided in Table 1.To prioritize sub basins for implementing water conservation techniques, morphometric analysis is used. Morphometric features were categorized into 3 groups namely, linear, areal, and relief aspects and various parameters are discussed below in detail. The details are tabulated in Table 2, Table 3, Table 4, Table 5, and Table 6.

Table 1: Methods for calculating morphometric parameters

	Morphometric parameters	Method	Reference
LINEAR	Stream order (U)	Hierarchical order	Strahler, 1964
	Stream length (L_u)	Length of the stream	Horton, 1945
	Mean stream length (L_{sm})	$L_{sm}= L_u/N_u$; where, L_u=Stream length of order 'U' N_u=Total number of stream segments of order 'U'	Horton, 1945
	Basin Length (L_b)	$L_b = 1.312A^{0.568}$ A=Area of watershed	Horton, 1945
	Stream length ratio (R_l)	R_l=L_u/L_{u-1}; where L_u=Total stream length of order 'U', L_{u-1}=Stream length of next lower order.	Horton, 1945
	Bifurcation ratio (R_b)	R_b= N_u/ N_{u+1}; where, N_u=Total number of stream segment of order 'u'; N_{u+1}=Number of segments of next higher order	Schumn,1956
RELIEF	Basin relief (B_h)	The vertical distance between the lowest and highest points of the watershed.	Schumn,1956
	Relief ratio (R_h)	R_h=B_h/L_b; Where, B_h=Basin relief; L_b=Basin length	Schumn,1956
	Ruggedness number (R_n)	R_n= B_h× D_d; Where, B_h=Basin relief; D_d =Drainage density	Schumn,1956
AERIAL	Drainage density (D_d)	$D_d = L/A$ where, L=Total length of streams; A=Area of watershed	Horton, 1945
	Stream frequency (F_s)	F_s= N/A where, N=Total number of streams; A=Area of watershed	Horton, 1945
	Drainage Texture (R_t)	$R_t = D_d \times F_s$ D_d = Drainage density F_s = Stream frequency	Horton, 1945
	Form factor (R_f)	$R_f=\frac{A}{(L_b)^2}$; where, A=Area of watershed, L_b=Basin length	Horton, 1945
	Circulatory ratio (R_c)	$R_c=\frac{4\pi A}{P^2}$; where, A=Area of watershed, π=3.14, P=Perimeter of watershed	Miller, 1953
	Elongation ratio (R_e)	$R_e=(\frac{2}{L_b})(\frac{A}{\pi})^{0.5}$ where, A=Area of watershed, π=3.14, L_b=Basin length	Schumn,1956
	Length of overland flow (L_{of})	$L_{of}=\frac{1}{2}D_d$ where, D_d=Drainage density	Horton, 1945
	Constant channel maintenance (C)	$L_{of}= 1/D_d$; where, D_d=Drainage density	Horton, 1945
	Compactness coefficient (C_c)	$(C_c) = P/2(\pi A)^{0.5}$; where P=Perimeter of watershed, A=Area of watershed	Horton, 1945

Table 2: Basic parameters of river basin

Sub Watershed	Bifurcation ratio (Rb)					Mean bifurcation ratio (R_{bm})	Basin length L_b(km)	Basin Area (km²)	Perimeter (km)
	I/II	II/III	III/IV	IV/V	V/VI				
Kothamangalam	2.074	2.945	1.146	3.692	4.333	2.823	28.226	239.801	112.145
Thodupuzha	2.003	2.894	4.222	0.771	8.750	3.728	40.072	411.415	141.916
Kaliyar	2.227	2.027	1.613	2.325	2.667	2.174	38.914	390.712	127.781
Muvattupuzha	1.048	5.054	4.392	2.550	1.111	3.154	87.540	1628.352	231.215

Table 3: Basic linear parameters

Sub-watershed	Basin order	Order of streams (U)						Order of streams (U)					
		I	II	III	IV	V	VI	I	II	III	IV	V	VI
		Stream number (N_u)						Steam length (L_u)in km					
Kothamangalam	VI	336	162	55	48	13	3	199.666	89.771	32.816	22.869	22.531	3.312
Thodupuzha	VI	661	330	114	27	35	4	424.580	153.733	86.790	34.370	43.142	4.915
Kaliyar	VI	677	304	150	93	40	15	420.232	130.930	81.400	25.050	19.245	30.405
Muvattupuzha	VI	1186	1132	224	51	20	18	835.437	862.118	190.026	77.515	25.230	64.976

Table 4: Mean stream length / Stream length ratio

Sub Watershed	Mean stream length (L_{sm}) vs. order of streams						Stream length ratio (R_l)				
	I	II	III	IV	V	VI	II/I	III/II	IV/III	V/IV	VI/V
Kothamangalam	0.594	0.554	0.597	0.476	**1.733**	1.104	0.450	0.366	0.697	**0.985**	**0.147**
Thodupuzha	0.642	0.466	0.761	1.273	1.233	1.229	0.362	0.565	0.396	1.255	0.114
Kaliyar	0.621	0.431	0.543	0.269	0.481	2.027	0.312	0.622	0.308	0.768	1.580
Muvattupuzha	0.704	0.762	0.848	1.520	1.262	**3.610**	1.032	0.220	0.408	0.325	2.575

Table 5: Aerial parameters

Sub watershed	Drainage density (D_d)	Stream frequency (F_s)	Drainage texture (R_t)	Form factor (R_f)	Circulatory ratio (R_c)	Elongation ratio (R_e)	Length of overland flow (L_{of})	Compactness Coefficient (C_c)
Kothamangalam	1.547	2.573	3.980	0.301	0.239	0.619	0.774	2.057
Thodupuzha	1.817	2.846	5.172	0.256	0.257	0.571	0.908	1.988
Kaliyar	1.810	3.274	5.926	0.258	0.301	0.573	0.905	1.837
Muvattupuzha	1.262	1.616	2.039	0.213	0.383	0.521	0.631	1.628

Table 6: Relief Aspects

Sub watershed	Maximum elevation (m)	Minimum elevation (m)	Total basin relief (B_h) in km	Relief ratio (R_h)	Ruggedness number (R_n)
Kothamangalam	854	3	0.851	0.030	1.316
Thodupuzha	1091	5	1.086	0.027	1.973
Kaliyar	1174	9	1.165	0.030	2.109
Muvattupuzha	262	1.5	0.261	0.003	0.329

4.1.1 Basic Parameters of River Basin

Table 2 presents the calculated results for the basic parameters of the watershed, which include area, perimeter, and length of the river basin, among others.

The 'area' (A) of the watershed directly impacts the total volume of water (Shekar and Mathew, 2022). The watershed comprises a total area of 2670.281 km², Muvattupuzha and Kothamangalam sub-watersheds are with highest area (1628.352 km²) and lowest area (239.801 km²) respectively among the four sub-watersheds.

Watershed 'perimeter' (P) is the term used to describe the area's outer layer (Khan et al., 2021). Muvattupuzha has the highest perimeter and Kothamangalam has the least perimeter among the four sub-watersheds with 231.215 km and 112.145 km respectively.

The 'length of the watershed/ basin length denoted' is a significant dimension among the major variables that influence the main drainage channel (Nooka Ratnam et al., 2005). The Kothamangalam sub-watershed has a length of 28.226 km while, Thodupuzha, Kaliyar, and Muvattupuzha have a length of 40.072 km, 38.914 km, 87.540 km respectively (Table 2). Relief ratio, form factor, elongation ratio, etc. are calculated using basin length and the influence of the above parameters is discussed in the following sections (Balasubramanian et. al., 2017).

4.1.2 Linear Aspect

Linear aspects include stream order (U), stream length (L_u), mean stream length (L_{sm}), basin length (L_b), stream length ratio (R_l), and bifurcation ratio (R_b) and are shown in Table 2, Table 3, and Table 4.

The 'stream order'(U) as proposed by Arthur N. Strahler, 1957 quantifies the hierarchical ranks of different water courses, is used for main and sub watersheds. It is utilized to compare the geometric characteristics of drainage networks across various linear scales (Hussain et al., 2018). The results (Table 3) indicate that the Kothamangalam, Thodupuzha, Kaliyar, and Muvattupuzha sub-basins are of the 6th order. Typically, as the order of streams increases, the overall number of streams decline (Abdeta et al., 2020). A total of 5698 stream segments within the study area have been identified, with approximately 85 percent falling under either first or second order. The variation in the order and number of streams among the sub-basins is due to the physiographic variations of the region (Balasubramanian et al., 2017). Stream ordering aids in, effectively strategizing conservation initiatives to enhance water storage and capacity within a given area (Hussain et al., 2018).

One of the most important hydrological features of a basin that reveals its characteristics of surface runoff is 'stream length'(L_u). The lengths of streams for all orders in the four sub-basins have been calculated separately according to the law put forth by (Horton, 1945) in GIS platform. Typically, lower-order streams exhibit the maximum total length of stream segments, which diminishes as stream order increases. (Choudhari et al., 2018); and is the same for all sub-basins up to 3rd order. The variations in the trend for higher-order streams could be attributed to physiological and lithological variations within the region (Srinivasa Vittala et al., 2004).

The drainage network and its surface features are characterized by their 'mean stream length' (L_{sm}) (Arthur N. Strahler, 1957). Table 4 reveals that the mean stream length (L_{sm}) varies between 0.269 to 3.610. Generally, L_{sm} of a channel is greater for lower order, but this trend fails in the sub-basins of the study area. This may be attributed to the slope and topographical variances within the study area (Sahu et al., 2017; Srinivasa Vittala et al., 2004; Vijith and Satheesh, 2006).

According to Horton (1945), 'Stream Length Ratio' (R_l) is defined as the ratio mean length of the higher order to the next lower order of stream segment. Table 4 shows that the Stream Length Ratio (R_l) between streams of different order ranges from 0.114 to 2.575. Typically, a rising trend in the stream length ratio from lower to higher orders signifies their progression into a mature geomorphic stage (Abdeta et al., 2020). However, in this particular study area, it can be deduced that the transition between stream orders signifies their advancement towards the late youth stage of geomorphic development (Adhikari, 2020; Sahu et al., 2017; Srinivasa Vittala et al., 2004).

'Bifurcation Ratio' (R_b) according to expresses the ratio of a number of streams of a given order (N_u) to the number of stream segments of the higher order (N_{u+1}) (Schumn, 1956). It is the measure of the degree of branching within the hydrographic network, (Horton, 1945) considered it as an indicator of relief and dissections (Strahler, 1957). Table 2 illustrates that it does not follow a trend from one order to the next order for Kothamangalam, Kaliyar, Thodupuzha, and Muvattupuzha sub-basins. These variations are influenced geological and lithological evolution of the drainage basin (Arthur N. Strahler, 1957; Srinivasa Vittala et al., 2004).

The higher (more than 5.0) the bifurcation ratio, the lesser the probability of flooding indicating the drainage basins are well dissected. The lower values of R_b (less than 5.0) indicates sub-watersheds with less structural disturbances (Arthur N. Strahler, 1957; Sukristiyanti et al., 2018). In the present study referring to the Table 2, the highest value is for the Thodupuzha sub-basin with 3.728, indicating moderate structural complexity and impermeability of the terrain, while the remaining three sub-basins with lower values show that those sub-watersheds are not impacted by structural issues (Srinivasa Vittala et al., 2004). Hence, it can be concluded that a lower value of the bifurcation ratio (less than 5.0) in all the sub-basins contributes to vulnerability towards groundwater conservation due to low permeability (Choudhari et al., 2018).

4.1.3 Aerial Aspect

Aerial aspects include drainage density (D_d), stream frequency (F_s), drainage texture (R_t), form factor (R_f), circulatory ratio (R_c), elongation ratio (R_e), length of overland flow (L_{of}), and compactness coefficient (C_c) are depicted in Table 5.

'Drainage density' (D_d), according to indicates the closeness of spacing between the channels (Horton, 1932). According to it is the total length of stream segments of all orders per unit area (Horton, 1945). The suggests that low drainage density typically occurs in regions characterized by permeable subsoil material, dense vegetation, and low relief (Akram Javed et al., 2009; Dubey, 2020; Nag, 1998; Sahu et al., 2017; Srinivasa Vittala et al., 2004). In the study area, drainage density varies from 1.262 for Muvattupuzha to 1.817 for Thodupuzha. Thodupuzha and Kaliyar with higher value of drainage density (Table 5) are with low permeability for ground water recharging.

As per 'stream frequency' (**F_s**) is the total number of stream segments of all orders per unit area (Horton, 1932). Stream frequency is related to permeability, infiltration capacity, and relief of a sub-watershed (Akram Javed et al., 2009; Rekha et al., 2011). In the study area, stream frequency is relatively higher for Kaliyar at 3.274 and Thodupuzha at 2.846, indicating that they have lower infiltration capacity and moderate relief as compared to Kothamangalam with value 2.573 and Muvattupuzha sub-basins with 1.616 respectively, matches with the inference derived from drainage density.

According to five classes of 'drainage texture' (R_t) are, very coarse (< 2), coarse (2–4), moderate (4–6), fine (6–8), and very fine (>8) (Puno and Puno, 2019). In the present study area, Kothamangalam and Muvattupuzha sub-basins have a coarse texture (2–4), while Thodupuzha and Kaliyar have moderate drainage texture (4–6) since the drainage texture values are 3.980, 2.039, 5.172 and 5.926 respectively (Table 5) refers to less infiltration (Choudhari et al., 2018; Soni, 2017). The value of drainage texture is influenced by underlying lithology, infiltration capacity, and the relief aspect of the terrain as well (Rekha, George and Rita, 2011). Hence Thodupuzha and Kaliyar with higher values of drainage texture (5.172 and 5.926 respectively) depicted in Table 5 prone to soil erosion contributing to less infiltration (Singh et al., 2021).

The value of constant channel maintenance (C) or the inverse of drainage density is affected by lithology, type of surface material, climatic condition etc. (Ahmad Ali & Ikbal, 2015). Here also, Thodupuzha and Kaliyar with higher values of drainage density (Table 5) than the other two watersheds in turn with low channel maintenance contribute to a low infiltration rate.

'Form factor' (R_f) may be defined as the ratio of basin area to the square of the basin length (Horton, 1932). It is a dimensionless quantity that is used to describe the different shapes of the basin (Hussain et al., 2018; Srinivasa Vittala et al., 2004). For a circular basin, the values would always be greater than 0.78. The smaller the value of the form factor, the more elongated will be the basin. (Vinutha and Janardhana, 2007). It can be observed from Table 5 that the form factor (R_f) values are 0.301, 0.256, 0.258, 0.213 for Kothamangalam, Thodupuzha, Kaliyar, and Muvattupuzha sub-watersheds respectively. Lower value of form factor indicates that all four watersheds are elongated in nature, leads to low runoff in long period (Adhikari, 2020; Sahu et al., 2017; Vinutha and Janardhana, 2007).

The 'circulatory ratio' (**R_c**) is mainly concerned with the length and frequency of streams, geological structures, land use/land cover, climate, relief, and slope of the watershed. Circulatory Ratio is defined as the ratio of the area of a basin to the area of the circle having the same circumference as the perimeter of the basin (Miller, 1953). When the basin is shaped like a complete circle, R_c is one, and when it is substantially elongated and made of extremely permeable homogeneous geologic materials, it ranges between 0.4 and 0.5. A circular basin is more efficient in the discharge of run-off than an elongated basin (Adhikari, 2020; Srinivasa Vittala, Govindaiah, & Honne Gowda, 2004; Vinutha & Janardhana, 2007). The Circulatory Ratio of the concerned watersheds varies between 0.239 and 0.383 (Table 5) indicating that they lack circularity, are elongated and dendritic, have little runoff discharge, and can have high subsurface permeability conditions. Moreover, these streams are in their youth and mature stages of their life cycle. (Adhikari, 2020; Sahu et al., 2017).

Schumn, (1956) defined 'elongation ratio' (**R_e**) as the ratio between the diameter of the circle of the same area as the drainage basin and the maximum length of the basin. The varying index of elongation ratio can be classified as; circular (0.9-0.10), oval (0.8-0.9), less elongated (0.7-0.8), elongated (0.5-0.7), and more elongated (<0.5). (Adhikari, 2020; Hussain et al., 2018; Srinivasa Vittala, Govindaiah, & Honne Gowda, 2004). The elongation ratio for Kothamangalam, Kaliyar, Thodupuzha, and Muvattupuzha are 0.619, 0.573, 0.571, and 0.521 respectively (Table 5) illuminating that Muvattupuzha, Kaliyar and Thodupuzha are more elongated indicating, high relief and steep slope as compared to Kothamangalam sub-watershed. High-relief watersheds have a high susceptibility to erosion and in turn risk for groundwater recharge. (Adhikari., 2020; Hussain et al., 2018; Sukristiyanti et al., 2018; Vinutha and Janardhana, 2007).

The 'Length of Overland Flow' (**L_{of}**) is defined as the length of water over the ground before it gets concentrated in main stream which affects the hydrologic and physiographic development of the drainage basin (Horton, 1945). Length of Overland Flow (L_{of}) is greatly influenced by soil infiltration and percolation, both of which vary in time and space (Adhikari, 2020; Srinivasa Vittala et al., 2004; Vinutha and Janardhana, 2007). There are three classes, i.e., low value (< 0.2), moderate value (0.2 – 0.3), and high value (>0.3) (Hussain et al., 2018; Sukristiyanti et al., 2018). The value (L_{of}) for the sub-watersheds varies between 0.631-0.908 (Table 5), representing a long time of flow with high surface run-off having low infiltration. (Shekar and Mathew, 2022). So Thodupuzha and Kaliyar with maximum value will have maximum runoff affects the infiltration rate badly.

'Compactness coefficient' (C_c) is the ratio of the perimeter of the watershed to the circumference of the circle whose area, is equal to the area of the watershed. For a perfect circle, catchment C_c value is 1. A lower the value of imply high runoff and erosion (Farhan, 2017). Muvattupuzha sub basin with the least value (1.628) and highest possibility of risk for water conservation, Kothamangalam with maximum value (2.057), and the other two basins with moderate values are depicted in Table 5.

4.1.4 Relief Aspect

Relief aspects include Basin relief (B_h), Relief ratio (R_h) and Ruggedness number (R_n), the calculated values are depicted in Table 6. The 'basin relief (B_h)' is the difference in elevation between two sites on the valley floor of a basin that are its highest and lowest points. By deducting the elevation of the basin's mouth from its highest point, relief is calculated. It can be seen from the Table 6 that Thodupuzha and Kaliyar sub-basins have a high basin relief of more than 1000 m indicating, low infiltration and high runoff conditions as compared to Kothamangalam and Muvattupuzha sub-basins, while Muvattupuzha sub-basin having the lowest relief (262.0 m) comparatively (Adhikari, 2020; Vijith and Satheesh, 2006) .

'Relief ratio' (R_h) is the proportion of a basin's total relief to its longest dimension that is parallel to its main drainage line. The relief ratio (R_h) indicates overall steepness of a drainage basin and the intensity of the erosional process (Schumn, 1956). R_h high values correspond to steep slopes and high relief, and vice versa. Run-off tends to be faster in steeper basins, resulting in more pronounced peak basin discharges and increased erosive force (Sahu et al., 2017; Adhikari, 2020). The value of Rh ranges between 0.005 (Muvattupuzha sub-basin) to 0.047(Kothamangalam sub-basin). In this study the low values $R_h$indicate moderate slope (Hussain et al., 2018; Srinivasa Vittala et al., 2004).

'Ruggedness Number' (R_n) is the product of maximum basin relief (R_n) and drainage density (D_d). Muvattupuzha having a low ruggedness value (0.329) suggests that the region has low relief and drainage density and is less prone to soil erosion. Furthermore, Thodupuzha and Kaliyar have high Ruggedness numbers (R_n) i.e., 1.973 and 2.109, respectively implying that these areas are more susceptible to soil erosion, contributing less infiltration and hence susceptible to groundwater recharge (Vijith and Satheesh, 2006; Hussain et al., 2018).

4.2 Prioritization of Sub-Basins concerning Groundwater Recharge Vulnerability Based on Morphometric Analysis

Most relevant morphometric parameters selected for this analysis were categorized into 3 aspects namely, linear, areal, and relief. These features are used to prioritize more susceptible watersheds as they are directly or inversely related to peak flow, runoff, and risk of soil erosion/ground water replenishment (Farhan, 2017).

The morphometric characteristics like bifurcation ratio, drainage density, stream frequency, drainage texture, Length of Overland Flow, relief, ruggedness number, etc. directly influence the risk of soil erosion/risk for groundwater recharging. The maximum value of these parameters contributes to the worst condition for groundwater recharging. Hence subbasins with maximum value for these characteristics are ranked first, and the minimum value is the last ranking depicted in Table 7 (Shekar and Mathew, 2022; Singh et al., 2021).

A higher value of parameters like form factor, circulatory ratio, elongation ratio, compactness coefficient, etc., inversely influences the risk of soil erosion and groundwater replenishment (Farhan, 2017; Shekar and Mathew, 2022). Hence these characteristics with minimum value are assigned with first rank and the maximum value with the last rank.

The most relevant ten morphometric parameters (Table 7) are selected for compound parameter analysis (Singh et al., 2021). Rank 1 is assigned to the subbasin where the particular parameter has having greatest risk concerning groundwater recharge vulnerability and rank 4 for the subbasin with the lowest risk. After assigning ranks to the sub basin for each parameter, the ranking values for all subbasins were averaged separately to arrive at a compound value for each sub-basin.

Table 7 depicts the compound value calculated as per the hierarchical ranking given for each parameter. Based on the compound values calculated, the subbasins are categorized into three groups, very high, high, and moderate. The subbasin with the lowest compound value denoted by Prioritized rank 1 needs the highest priority in implementing treatment methods for water conservation; the next higher value is denoted with Prioritized rank 2, and so on. The sub-watershed with the highest compound value has got the last priority number (Abdeta et al., 2020; Ayele et al., 2016; Sheikh et al., 2019) for water conservation strategic planning and implementation techniques.

Table 7: Calculation of ranking, compound parameter, and prioritization

Sub-basin	R_{bm}	D_d	F_s	R_t	L_{of}	R_n	R_h	R_f	R_e	C_c	R_c	Compound parameter	Prioritized rank	Priority
Kothamangalam	3	3	3	3	3	3	1	4	4	4	1	2.909	3	Moderate
Thodupuzha	1	1	2	2	1	2	2	2	2	3	2	1.818	1	Very High
Kaliyar	4	2	1	1	2	1	1	3	3	2	3	2.091	2	High
Muvattupuzha	2	4	4	4	4	4	3	1	1	1	4	2.909	3	Moderate

In this study, Kaliyar and Thodupuzha sub-basins with compound parameters of 1.818and 2.091 respectively receive first and second priority categorized as very high and high while Kothamangalam and Muvattupuzha with the same compound parameters of 2.909 categorized to moderate (Table 7). Hence it can be inferred that water conservative measures need to be implemented in Thodupuzha and Kaliyar subbasins prior to the other two sub-basins.

5. Conclusion

Remote sensing and GIS have been found to effective tools in the entire study for the prioritization of sub-watersheds for the conservation of water. The significant morphological parameters taken into consideration vary in accordance with the geomorphological and topographical changes in the sub-basins. The evaluation of river basins, the prioritizing of watersheds for the protection of soil and water, and the micromanagement of natural resources are all shown to be benefitted greatly from the quantitative study of morphometric characteristics such as linear, relief, and aerial using GIS. It also helps in understanding different topographical characteristics, such as infiltration rate, surface runoff, etc. The study of the Muvattupuzha River basin indicates that the sub-basins are of the 6th order having elongated shapes with a low bifurcation ratio indicating low structural disturbance in all the four sub-basins. The elongated shape of the watershed indicates moderate relief, and higher erosion and sediment transport capacities. The presence of high drainage density in all sub-basins also indicates the region has impermeable subsoil and low vegetative cover (Srinivasa Vittala et al., 2004).

The study involves sub-watershed prioritization based on compound parameters and morphometric analysis with respect to groundwater recharge vulnerability. Thodupuzha and Kaliyar sub-basins with low values of compound parameters receive very high and high priority respectively, as compared to Kothamangalam and Muvattupuzha with high compound parameters classified under moderate priority. This indicates that Thodupuzha and Kaliyar have a higher degree of erosion and vulnerability in regards to groundwater enhancement. Hence these subbasins in particular require soil and water conservative measures in contrast to the other two sub-basins. Moreover, due to the low infiltration capacity of the soil and high run-off, water conservation is also necessary in this study area. Thus, soil and water conservative measures can be first applied to Thodupuzha and Kaliyar sub-basins and then to other mini-watersheds in the order of their priority to preserve the land from further erosion, thereby improving water holding capacity.

Thodupuzha and Kaliyar sub-watersheds with high compound values of high priority need to take management strategies based on improving the significant morphological parameters. Kothamangalam and Muvattupuzha sub-watersheds with moderate priority also require improved conservation strategies for constant maintenance of channels to maintain water holding capacity. The study reveals that watershed managers may utilize to make more informed decisions and take more effective actions when prioritizing watershed projects in the implementation of programs for soil and water conservation under resource constraints. Investments in crucial sub-watersheds should be distributed by decision-makers in a way that is both economically and technically efficient. Finally, monitoring and evaluation have to be done in a way that is socially, economically, and environmentally sounds.

The findings of the current study are helpful for resource planners, decision-makers, or public-private organizations that are trying to exploit soil resources, implement conservation measures, or fix soil and water conservation structures in the study area.

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