Original Research Article

Morphometric Analysis of Nanjannad Hill Watershed of South India using geographical information system

ABSTRACT

Aims: Morphometric analysis of Nanjannad hill watershed using GIS and Remote sensing. To analyze each morphometric parameter and describe the conditions of the watershed. Estimation of Linear aspects, Areal aspects, Relief aspects. Extraction of DEM map, Slope map and Drainage map of Nanjannad watershed

Study design: Field survey is conducted to cross verify the data. Cartosat DEM data and geographical information system is used for the extraction of different maps in Nanjannad watershed.

Place and Duration of Study: The study is conducted Nanjannad watershed in the Otty of Nilgiris district in Tamilnadu, India located in 11˚20' 0" N to 11˚22' 30" N latitude and 76˚37'30" E to 76˚40'0" E longitude.

Methodology: Cartosat DEM file was downloaded from Bhuvan Portal and Ground data of the watershed was collected. ArcGIS 10.3 software is used to delineate watershed areas using Digital Elevation Model and prepared various thematic maps to extract the drainage watershed characteristics required for the morphometric analysis of watershed.

Results: Nanjannad watershed has a drainage area of 434 ha. The watershed is a Fourth-order drainage basin, and the lower order streams are mostly dominating in the watershed. The slope of the watershed varies from 0 to 87%. The mean bifurcation ratio of the entire watershed is 4.38. The watershed elongation ratio is 0.67.

Conclusion: The morphometric analysis of the watershed drainage networks reveals a dendritic to sub-dendritic drainage pattern. The variation in stream length ratio is influenced by slope and topography. The bifurcation ratio in the Nanjannad watershed indicates that geology has little influence on the drainage network. The frequency of streams and the drainage density have a positive correlation. The drainage density is varying between very coarse to coarse textured which implicates the subsurface soil strata are permeable. The moderate value of drainage density, stream frequency and drainage intensity, indicates that runoff is more likely to cause water logging. Relief ratio values implies that the discharge of the Nanjannad watershed is high and groundwater potential is meager.

Keywords: [Morphometric analysis, Geographical information system, Nanjannad watershed, Stream frequency, drainage intensity}

1. INTRODUCTION

A watershed is a physical entity defined as the area drained by a stream in such a way that all flow originating in the watershed area is discharged to a single outlet. Watershed geospatial application improves the accuracy and speed of watershed planning. Remote sensing and geographic information systems aid in creating a watershed database, which is extremely useful for performing spatial analysis. Remote sensing data can provide a quick overview of a large area at once, which is extremely useful in drainage morphometry analysis. The mean bifurcation ratio value indicates that structural disturbances and geological features do not affect the watershed. A permeable subsurface creates the watershed, and runoff is moderate, as evidenced by the low drainage density, stream frequency, and infiltration numbers. The low drainage density indicates that the size is appropriate for constructing water collection facilities in streams [1].

Development of a watershed is very important for proper planning and efficient use of resources in a watershed. Integrated use of remote sensing and GIS techniques can be used in soil erosion assessment and computation of hydrological behavior in a watershed. Hydrological runoff estimation of the watershed is used for the design of the soil and water management structures and flood analysis. Forests and trees are a significant water source for the surrounding regions and are an integral aspect of the Nilgiris hilly environment. Despite the fact that the Nilgiris receives more rainfall with greater intensity, wildlife and vegetation in forest regions endure severe water shortages throughout the summer [2]. Hill watershed is more prone to soil erosion due to heavy steep slopes. So, proper analysis of all the morphometric analysis is required and analysing each morphometric parameter helps to know the problems of the watershed.

This research has made to find out and analyze all the morphometric parameters. This research is useful for design of rainwater harvesting structures and water management strategies of the Nanjannad watershed.

2. MATERIAL AND METHODS

2.1 Study Area

In the present study, Nanjannad watershed of Ooty is taken for morphometric analysis. The various characteristics and details of the study areas are mentioned in the following section. 11˚20' 0" N to 11˚22' 30" N latitude and 76˚37'30" E to 76˚40'0" E longitude. Ooty is located in the Nilgiris hill ranges. The climate in the study area of high elevation results in low temperatures. The day temperature in the Nilgiris district ranges from 22.1°C in the summer to 5.1°C in the winter. At times, the night time temperature drops below 0°C. Summer begins in early March, with the hottest months being April and May. The weather begins to cool slowly around the middle of June, and by January, the mean daily maximum temperature has dropped to 5.1°C. The Nilgiris hill ranges are located in the fragile Western Ghats environment, with elevations ranging from 300 m to 2636 m above mean sea level. The majority of the Nilgiris is covered by forest (56%) followed by plantation crops (20%) such as tea and coffee, and the remaining areas are covered by vegetables. The total annual rainfall is 1204 mm in which, 54 per cent is distributed over four months, from June to September. The remainder is distributed between January to May and October to December.

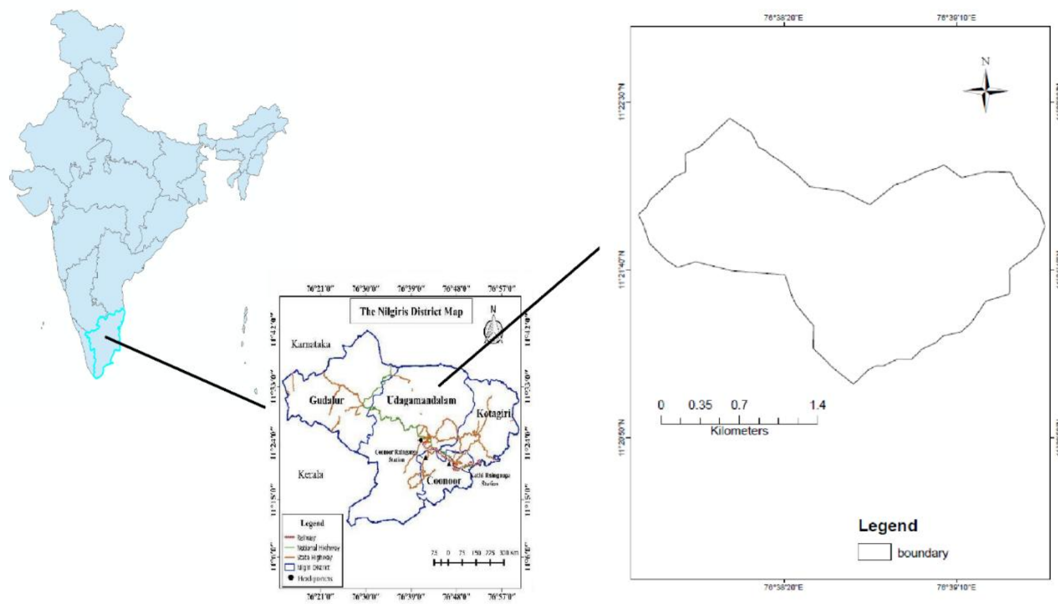

Figure 01: Nanjannad Watershed map

2.2 Soil and geomorphology

The type of soil influences the soil moisture content and the quantity of silt washed down in water harvesting structures and hillsides. Different soils present in the watershed are Lateritic soil, Red sandy soil, red loam, black soil, Alluvial and Colluvial soil. Small patches of red sandy soil and red loams are found. Black soils are formed in the valleys where waterlogging is widespread during the monsoon season. Alluvial soils are found along the valleys and major water courses.

2.3 Land use

Forests plays an important role in the Nilgiris mountainous ecosystem, supplying water to the surrounding areas. Land use has an impact on runoff, infiltration rates, as well as the different types of vegetation cover. Agriculture dominates the watershed area, with shrubs and hill tops. Due to steep slopes and inadequate land use patterns, water erosion is a severe problem in the watershed area. Agriculture practices range from the valley floor to the hilltop, with a broad range of cropping systems and management practices. The main crops cultivated in this watershed area are potato, carrot, cauliflower, cabbage, beetroot and radish.

Table.1 Land use pattern in Nanjannad watershed

S. No	Land use pattern	Percentage (%)
1	Forest	35.4
2	Water bodies	18.2
3	Vegetation	37.3
4	Barren land	9.1

2.4 Geographic Information System (GIS)

A Geographic Information System (GIS) is a computerised tool for analysing, storing, manipulating, and visualizing geographic data. GIS is used to preserve the data on geographic features, their characteristics and produces maps. In the watershed study, ArcGIS 10.3 software is used to delineate watershed areas using Digital Elevation Model and prepare various thematic maps to extract the watershed characteristics required for the morphometric analysis of watershed. The area undertaken for the study has been done the morphometric parameters determined using GIS technique. The area of interest lie in UTM zone 43-N having datum WGS 1984.

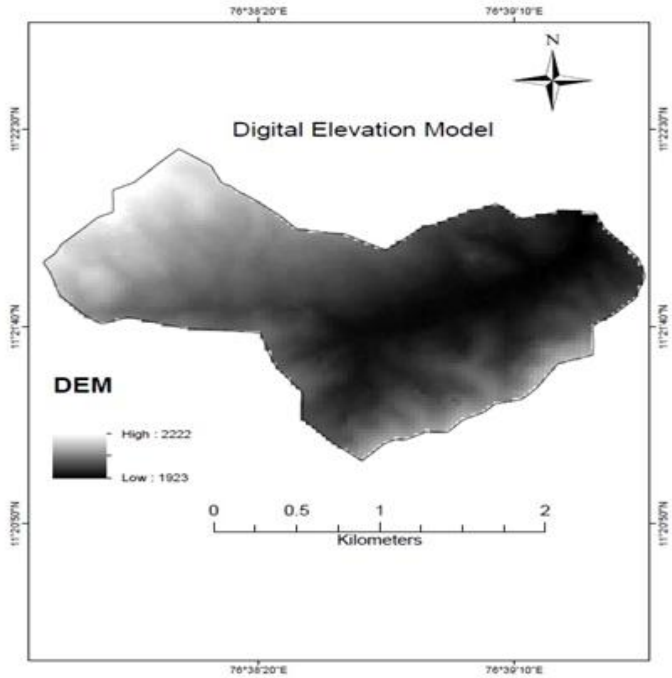

Figure 02: Digital elevation model (DEM) of Nanjannad Watershed

3. RESULTS AND DISCUSSION

The morphometric parameters of Nanjannad watershed have been studied in detail and it was found that the total drainage area is 434 ha. The drainage pattern of watershed is dendritic to sub dendritic in existence and is influenced by area general topography. The drainage pattern indicates the influence of slope and lithology. Dendritic patterns are the most common in drainage watershed composed of relatively homogenous rock with not having control over underlying soil structure. Mean slope of a watershed will be helpful to predict erodibility [3]. Higher the value of slopes, soil erosion will be more, keeping other things as constant. The slope ranged between 0 and 87 %. Maximum slope in the Nanjannad watershed is 87% with average slope of 34.6 %. The watershed slope map is shown in Figure 4. The main cause for erosion is the most part of the area is under steep slopes in the watershed.

3.1 Linear aspects

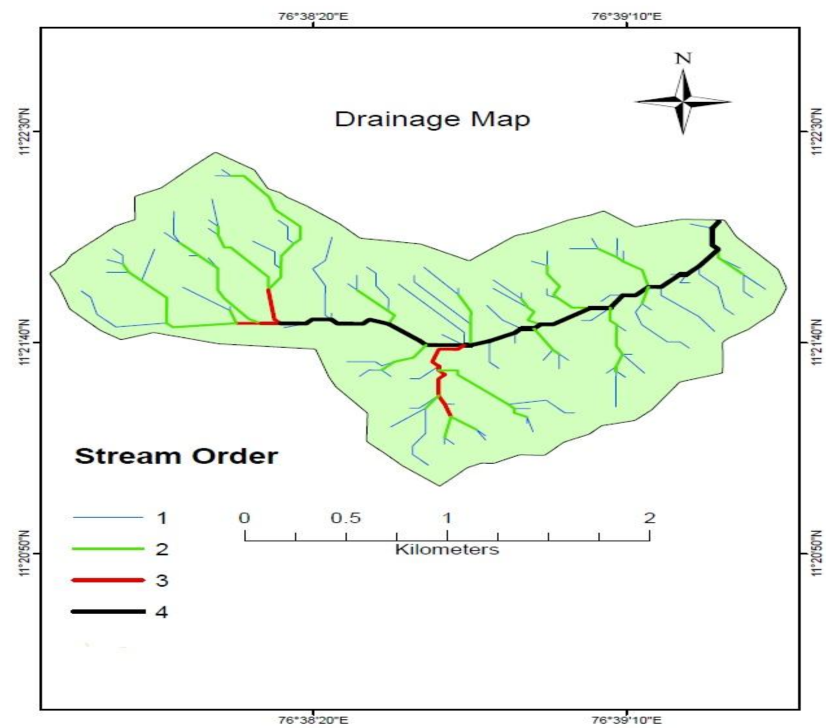

Figure 03: Stream order map

3.1.1 Stream order (S_u)

The designation of streams orders is initial step of watershed drainage analysis. Higher the stream order, indicates that the watershed area is larger. In study area, the orders of streams are 1st order, 2nd order, 3rd order and 4th order so, the watershed is designated as 4th order watershed. The law of stream number [4] and the law of stream length [5] were done by the stream network of the Nanjannad watershed.

Table.2 Stream order, number of streams, stream length, stream length ratio and bifurcation ratios in Nanjannad watershed

S_u	N_u	L_u(m)	L_{um}(m)	L_{ur}	L_{ur-r}	L_{ur}*L_{ur-r}	L_{uwm}	R_b	N_{u-r}	R_b*N_{u-r}	R_{bwm}
1	78	13220.3	169.5				2.42				4.38
2	18	7499.6	416.6	2.46	96	235.99		4.3	96	416	
3	4	1156.4	289.1	0.69	22	15.27		4.5	118	531	
4	1	2718.1	2718.1	9.40	5	47.01		4.0	27	108	
Total	101	24594.5	243.5		123	298.26		12.8	241	1055	

S_u: Stream order, N_u: Number of streams, L_u: Stream length, L_{um}: Mean stream length, L_{ur}: Stream length ratio, L_{ur-r}: Stream length used in the ratio, R_b: Bifurcation ratios, L_{uwm}: Weighted mean stream length ratio, N_{u-r}: Number of streams used in the ratio, R_{bwm}: Weighted mean bifurcation ratio

Table.3 Linear morphometric parameters of Nanjannad watershed

Sl. No.	Morphometric parameter	Method/ Formula	Reference	Result
1	Main channel length (Cl)	GIS analysis	Length	4.09 km
2	Basin length (L_b)	GIS analysis	Schumm (1956) [9]	3.01 km
3	Length from watershed Centre to mouth (L_{cm})	GIS analysis	Black (1972) [23]	2.04 km
4	Weighted mean stream length ratio (L_{uwm})	GIS analysis	Ratio	2.42
5	Weighted mean bifurcation ratios (R_{bwm})	GIS analysis	Ratio	4.38

3.1.2 Stream number (N_u)

Stream number in the watershed explains the number of stream segments present in an order. According to Horton law, any order's stream order and stream number are geometrically inversely connected. The following are stream numbers in various orders in the watershed: Number of first order streams are of 78, the second order streams of 18, the third order streams of 4, and the fourth order stream has a value of 1. More first-order streams indicate a significant runoff load on down streams [6].

3.1.3 Stream length (L_u)

The stream length of the Nanjannad watershed under various orders were computed with the use of attribute table Using GIS. The number of different stream orders in a watershed and their lengths measured, and stream length decreases as stream order increases. The watershed of rising order used to be maintained via geometrical similarities [7]. We calculated the value using Horton's law, which is 24.6 kilometers (Table 2). The overall length of the streams increases in the first order and decreases in the subsequent orders.

3.1.4 Mean stream length (L_{um})

Mean stream length of the watershed is dimensionless property that reveals the typical size of drainage network and the watershed surfaces. The mean stream length of a watershed is computed by dividing total stream length of a specific order to that of total number of streams of that particular order. The Lum can reveal the surface area of the watershed that contributes to the drainage network [7]. The mean stream length of Nanjannad watershed varied from 169 m to 2718 m. The average value of mean stream length for the watershed is 243.5 m (Table 2). The Lum of any of the stream order in a watershed is more than of the lower order stream and less than that of the higher order stream. The size and topography of the watershed govern the value of Lum, which varies between watersheds [6].

3.1.5 Stream length ratio (L_{ur})

The stream length ratio is the ratio of the average length segment of any order to the average length segment of the next lower order, which remains constant in a watershed for successive orders [4]. In the present watershed, stream length ratios were 2.4-9.4 and these values will indicate dependency on both slope and topography. Similar observations are noted in Welmal watershed by Nasir Gabi tukara et al., 2021 [8].

3.1.6 Bifurcation ratio (R_b)

The bifurcation ratio is the ratio of the number of streams in any order to that of number of streams in the next higher order [4]. Bifurcation ratio is a dimensionless property. Except for the powerful geological structure, the bifurcation ratio varies only slightly across regions [7]. Here in our watershed bifurcation ratio ranges between 4.0-12.8.

3.1.7 Weighted mean bifurcation ratio (R_{bwm})

The weighted mean bifurcation ratio is computed by multiplying the bifurcation ratio of a pair order by the total number of streams in the ratio [7]. The Rbwm is the mean of all the sum of the values. The value of Rbwm in the research area was 4.38. The watershed mean bifurcation ratio indicates that there is negligible influence of geological features on the drainage network. Due to the variation in geology and lithology in the watershed, the ratio is not the same for all orders.

3.1.8 Length of main channel (Cl)

The length of the main channel is the distance from the outlet to the channel head along a subjectively defined main channel, or more objectively, the length of the longest flow path to the drainage divide. The computed main channel length by using ArcGIS-9.3 software, which was 4.09 km (Table 3).

3.1.9 Length of the basin (L_b)

The length of the basin is the longest dimension which is parallel in the direction to the main drainage line [9]. It is the length of the line from mouth of a watershed to the point on the perimeter that is farthest from the outlet. The Nanjannad watershed had a basin length of 3.01 km.

3.2 Areal aspects

3.2.1 Watershed area (A)

The drainage area, also known as the watershed area, this is the most important watershed characteristic for the hydrologic analysis. It represents the amount of water that is to be generated by a rainfall and watershed area is critical in determining the drainage network. Total watershed area and total stream length are proportional to one another [9], this is influenced by the areas that contribute to it. Area in Nanjannad watershed was calculated using ArcGIS software and which was found as 434 ha (Table 4).

3.2.2 Watershed perimeter (P)

The watershed perimeter is the outer boundary of the watershed that encloses it's area. The watershed perimeter can be defined as the length of the ridge line that separates the watershed. It also indicates the size and shape of watershed. The basin perimeter is calculated by using ArcGIS-9.3 software, and the value was 9.94 km.

Table.4 Areal morphometric parameters of Nanjannad watershed

Sl. No.	Morphometric parameter	Method/Formula	Reference	Result
1	Mean basin width (W_b)	$Wb= A/L_b$	Horton (1932) [5]	1.43 Km
2	Basin area(A)	Gis analysis	Schumm (1956) [9]	434 ha
3	Basin perimeter(P)	Gis analysis	Schumm (1956) [9]	9.94 km
4	Relative perimeter (P_r)	$P_r=A/P$	Schumm (1956) [9]	0.43
5	Length area relation (L_{ar})	$L_{ar}=1.4*A*0.6$	Hack (1957) [10]	3.62
6	Lemniscate(k)	$K=Lb^2/A$	Chorley (1957) [11]	2.10
7	Form factor ratio (F_f)	$F_f= A/Lb^2$	Horton (1932) [5]	0.48
8	Shape factor ratio (R_s)	$S_f=L_b^2/A$	Horton (1945) [4]	2.10
9	Elongation ratio (Re)	$R_e= 2/ L_b*(A/\pi)^{0.5}$	Schumm (1956) [9]	0.67
10	Texture ratio (R_t)	$R_t=N1/P$	Schumm (1956) [9]	7.84
11	Circularity Ratio (R_{cn})	$R_{cn}=A/P$	Strahler (1957) [18]	0.43

12	Circularity Ratio (R_c)	R_c=12.57*(A/2P)	Miller (1953) [12]	0.55
13	Drainage texture (D_t)	D_t=N_u/P	Horton (1945) [4]	10.15
14	Compactness coefficient (C_c)	C_c=0.2841*P/$A^{0.5}$	Magnesh (2011) [24]	1.36
15	Fitness ratio (R_f)	R_f= Cl / P	Melton (1957) [14]	0.41
16	Wandering ratio (R_w)	Rw = Cl/L_b	Smart and Surkan (1967) [15]	1.36
17	Stream frequency (F_s)	F_s =N_u/A	Horton (1932) [5]	23.47
18	Drainage density (D_d)	D_d = L_u/A	Horton (1932) [5]	5.71 km/ km^2
19	Constant for channel maintenance	Unit A/ Unit L	Schumm (1956) [9]	0.18 Km^2/ km
20	Drainage intensity (D_i)	D_i = F_s / D_d	Faniran (1968) [25]	4.11
21	Infiltration number (I_f)	I_f = F_s*D_d	Faniran (1968) [25]	133.99
22	Length of overland flow (L_g)	L_g = A/2*L_u	Horton (1945) [4]	0.09 km

3.2.3 Length area relation (L_{ar})

This relationship was used for a greater number of watersheds in the United States; stream length and watershed area are related to a power function, which is : Lar = 1.4 * A * 0.6 [10]. Using this relationship, estimated length of the Nanjannad watershed to be 3.62 km, which is exactly the same as the length obtained using the GIS technique.

3.2.4 Lemniscate's (k)

The Lemniscate's value of a watershed is used to determine slope of watershed. The formula is k = L_b^2 / 4 * A, where, L_b is length of watershed (km) and A is area of watershed (km^2) [11]. The Lemniscate (k) value for the watershed was 2.10, indicating that the maximum inception area is made up of a high number of higher-order streams.

3.2.5 Form factor (F_f)

The form factor is important in explaining the drainage basin flow property. The form factor is determined by dividing the watershed area by the square of the watershed length [5]. The form factor value for the perfectly shaped circular watershed is 0.754. However, the value of all natural watersheds will be less than that. The watershed will get increasingly extended as the form factor value drops. The longer the shape, the smaller the form factor. Low runoff will generate over a long period of time, whereas rounded shape watersheds with a high value of form factor experience high runoff over a short period of time and are highly sensitive to flood. The form factor in the current watershed is 0.48, indicating the watershed is moderately elongated and high runoff.

3.2.6 Elongation ratio (Re)

The elongation ratio is the ratio of the diameter of a circle the same size as the drainage basin to the maximum basin length [9]. A circular basin discharges runoff more efficiently than an elongated basin. Elongation ratio values ranges from 0.6 to 1.0 across a variety of climate and lithology conditions. The lowest watershed ratio values imply steep slope and high relief, whereas the highest ratio values suggest plain land with low relief and low slope. The elongation ratio in our current study was 0.67. This reveals that the major portion of the area has moderate relief and steep sloped.

3.2.7 Texture ratio (R_t)

Texture ratio is a key factor in drainage morphometric analysis because it is affected by infiltration capacity and terrain relief. Texture ratio is computed by dividing total number of first-order streams by the watershed perimeter (Rt = Nl / P). The calculated value is 7.84. This value indicating to be very high, implying very coarse texture, and reveals that watershed have high rainfall, a medium infiltration rate, and a high relief.

3.2.8 Circulatory ratio (R_c)

The watershed circularity ratio (R_c) is area of a circle with the same circumference as the watershed perimeter. Circulatory ratio is a vital indicator that is affected by the watershed climate, geological structure, slope, stream frequency, drainage density, and relief. circulatory ratio value ranges from 0 to 1, defining the minimum to maximum circulatory shape. Rc values of high, medium, and low indicate the old, mature, and young stages of the watershed's life cycle, respectively. The circulatory ratio of watershed ranges from 0 to 0.4, which indicates highly elongated and permeable homogeneous geologic materials [12]. The circulatory ratio in this watershed is 0.43, indicating a slightly elongated watershed with slow runoff discharge and highly permeable subsoil.

3.2.9 Drainage texture (D_t)

Drainage texture is calculated as the ratio of sum of total number of streams of all the orders to that of perimeter of watershed. The drainage texture value is influenced by the vegetation, rock, climate, and soil type, as well as infiltration capacity, relief, and development stage. The drainage texture of a watershed is classified into five classes such as very coarse (<2), coarse (2-4), moderate (4-6), fine (6-8), very fine (>8). In the Nanjannad watershed, the overall value of drainage texture was 10.15. This value implies that the watershed has moderate drainage texture. Similar kind of result was observed by Partha Prathim and Jyotiprava Dash ,2018 [13] for Katra watershed of Odhisa.

3.2.10 Compactness coefficient (C_c)

The compactness coefficient is calculated as the ratio of the watershed perimeter to the circumference of a circle which has equal area to the drainage basin. This is unaffected by the size of the watershed and is only affected by the slope. It is the deviation of the watershed shape from a circular watershed. Cc=1 denotes that the basin behaves entirely as a circular basin. Cc>1 indicates that the watershed is deviating from its circular shape. The compactness coefficient in this watershed is 1.89. This value indicates that the basin is deviated from the circular shape and this means it can be used easily for proper grazing.

3.2.11 Fitness ratio (R_f)

Fitness ratio is the proportion of main channel length to the watershed perimeter [14]. This value is used to indicate the topographic fitness of watershed. The fitness ratio in the watershed is 0.41.

3.2.12 Wandering ratio (R_w)

The wandering ratio (Rw) is the proportion of the mainline length to the valley length [15]. The valley length is the straight-line distance from the watershed outlet to the ridge farthest point. The Wandering Ratio in watershed is 1.36.

3.2.13 Centre of gravity of the watershed (G_c)

Center of gravity of watershed is the center point on the watershed. The center of gravity of the watershed was found out by using ArcGIS-9.3 software. In Nanjannad watershed the center of gravity is at 11˚21'40" N latitude and 76˚38'20" E longitude.

3.2.14 Stream frequency (F_s)

The stream frequency of a watershed is defined as the total number of stream segments of all the orders present in a unit area [5]. The relief, permeability and infiltration capacity of the watershed have an influence on stream frequency (Fs). The drainage density, the initial resistivity of the rock, and the amount of rainfall also play a role. The Stream Frequency of our watershed is 23.47. This value implies that increase in the stream population is linked to that of the drainage density.

3.2.15 Drainage density (D_d)

Drainage density is an important landform parameter that represents the density or closeness of the stream network and allows for a quantitative measurement of potential runoff and dissected landscape [16]. Drainage density expresses that the ratio of total length of the stream regardless of stream order to the watershed per unit area. It is an expression for the dissection and analysis of landforms, even though a function of climate lithology and relief of that area. It can be used as indirect indicator to explain those variables and morphogenesis of landforms. The Spatial Analyst Tool in ArcGIS-9.3 is used to calculate drainage density. The drainage density in this study area was 5.71 km/km^2, indicating coarse drainage and permeable subsurface strata [7]. Rajiv Chopra, 2005 [17] found a similar type of finding for the Bhagra phungotri watershed in Punjab, where he found a Dd value of 5.84 km/km^2.

3.2.16 Constant of channel maintenance (C)

Constant of channel maintenance is defined as the inverse of Drainage density and this is a significant aspect of landform. It specifies the number of units of watershed surface that must support one unit of channel [9]. This is primarily determined by the permeability, rock type, climate regime, vegetation cover, and relief, as well as the duration of erosion. The 'C' value refers to the relative size of landform components in a river basin and has a specific genetic significance [18]. The Constant of Channel Maintenance in this Nanjannad watershed area is 0.18 km^2/km.

3.2.17 Drainage intensity (D_i)

The drainage intensity is defined as the ratio of the basin's stream frequency (S_f) to its drainage density (D_d). In this study area, the Drainage Intensity was 4.11. This moderate value of drainage density indicates runoff is more likely to cause water logging.

3.2.18 Infiltration number (I_f)

The infiltration number of a watershed is defined as the product of Drainage density (D_d) and Stream Frequency (S_f) and the infiltration number obtained describes about the infiltration characteristics of the watershed. It is inversely proportional to the infiltration capacity of the watershed. Lower infiltration and higher runoff are associated with a higher infiltration number. The Infiltration Number in the Nanjannad watershed was 133.99. This value indicates lower infiltration and high runoff in the watershed area.

3.2.19 Length of overland flow (L_g)

The length of overland flow is described as length of the flow path which is projected to horizontal, non-channel flow from one point on the stream divide to another point on the neighbouring stream channel [4]. The greater the average slope of the channel, the shorter the length of overland flow. This factor is exactly the same as that of the length of sheet flow. The Length of overland flow is scaled to fit the scale of the first order drainage watershed and is roughly equal to one-half the inverse of the Drainage intensity. In the present watershed the Length of Overland Flow was 0.09 km. This value indicating that the length of overland flow is high.

3.3 Relief aspects

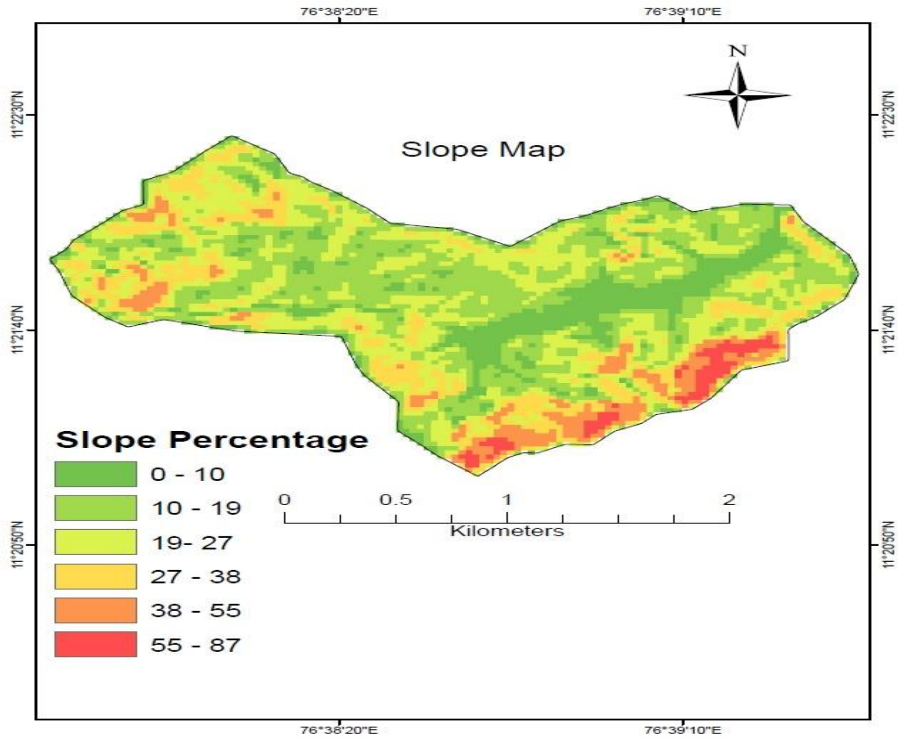

Figure 04: Slope map

Table.5 Relief related morphometric parameters of Nanjannad watershed

Sl. No.	Morphometric parameters	Method/Formula	Reference	Quantitative data
1	Height of basin mouth(z)	GIS analysis/ DEM	height	1928 m
2	Maximum height of the basin(Z)	GIS analysis/ DEM	height	2187 m
3	Relative relief (H)	H=Z-z	Strahler (1952) [20]	259 m
4	Relief ratio (R_{hl})	R_{hl}=H/L_b	Schumm (1956) [9]	0.08
5	Relative Relief ratio (R_{hp})	R_{hp}=H*100/P	Melton (1957) [14]	2.60
6	Gradient ratio (R_g)	R_g= (Z-z)/ Lb	Sreedevi et al., (2005) [22]	86.22
8	Ruggedness number (R_n)	R_n=D_d*H/100	Melton (1965) [16]	1.48

3.3.1 Relief ratio (R_r)

The relief of watershed is computed as the difference in elevation between the highest elevation point and lowest elevation point on the watershed. The elevations in the watershed are used as a key indicator of a drainage system. The Relief ratio is defined as the ratio of total relief to the longest flow length of the watershed parallel to the main stream [9] and it is also proportional to the Length of the overland flow and time to peak. The steepness of the watershed impact on the the watershed erosion intensity. Relief ratios typically increase as drainage area and decrease size. In the present watershed the relief ratio was 0.08. Similar values obtained in some watersheds as the result obtained is lower than the result i.e., 0.12 obtained by Rabindra Tiwari N *et al.,* 2021 [19] at Deonar river basin but higher than the result i.e., 0.04 obtained by Parta pratim and Jyotiprava, 2018 [13] at Katra watershed of Odisha.

3.3.2 Relative relief (R_{rp})

Relative relief is defined as the maximum relief of the watershed, this is obtained from highest point in the watershed perimeter to the point to stream mouth. The difference of highest and lowest elevation points in watershed is referred to as relative relief. Digital elevation model can provide a sense of relative relief for any watershed. The relative velocity of vertical tectonic movements can be calculated using relative relief. Relative relief is used to investigate active tectonic structures, identify paleo surfaces, estimate seismic activity, and investigate the interaction of endo and exogenic processes of orogenesis [13]. The relative relief of the watershed in our study was 259 m.

3.3.3 Ruggedness number (R_n)

Ruggedness number is defined as the product of two parameters i.e., relative relief and drainage density [20]. The ruggedness number denotes the terrain structure and also indicates that the area is susceptible to soil erosion. The ruggedness number computed for Nanjannad watershed is 1.48 (Table 5). These results indicate that the Nanjannad watershed is extremely with high relief and with high stream density. Similar result is obtained i.e., 1.42 which is slightly lower that of the result obtained by Binoy kumar et al, 2021 [21] for a Chite Lui watershed.

3.3.4 Gradient ratio (R_g)

Gradient ratio is a measure of channel slope that allows for the calculation of runoff volume. The gradient ratio is defined as the slope steepness of its vertical intervals reduced to unity. The Gradient ratio is used to calculate the tangent of the watershed angle of slope. The Gradient ratio in a channel slope parameter used in the calculation of runoff volume [22]. The Gradient ratio in the watershed is 86.22. This value indicates that the Nanjannad watershed has high steepness and slope variation.

4. Conclusion:

GIS has been shown to be a useful tool in watershed morphometric analysis. Based on the drainage orders present in Nanjannad watershed, this has been classified as Fourth order drainage watershed. Lower order streams predominate in the watershed. The morphometric analysis of the watershed drainage networks reveals a dendritic to sub-dendritic drainage pattern.

The variation in stream length ratio is influenced by slope and topography of the watershed. The bifurcation ratio in the Nanjannad watershed indicates that geology has little influence on the drainage network. The frequency of streams and the drainage density have a positive correlation. The drainage density is very coarse to coarse textured, and the subsurface soil are permeable. With the moderate value of drainage density, stream frequency, and drainage intensity, runoff is more likely to cause water logging. Relief ratio values implies that the discharge of the Nanjannad watershed is high and groundwater potential is meager. This research is so much useful for design of rainwater harvesting structures of the Nanjannad watershed and also to design better water use strategies for watershed management.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

References

1. Sujit Kumar Roy, Md. Arif Chowdhury, Swapan Talukdar, Md Mostaim Billah, Anik Chandra Banik and Javed Mallick (2022). Comparisons of Watershed Delineation of River Network Representation and Morphometric Analysis in Karnaphuli River Basin, Chittagong, Bangladesh: A study with Different Digital Elevation Model (DEM). Research square. DOI: https://doi.org/10.21203/rs.3.rs-1243899/v1
2. Manivannan, S., Kannan, B., PS Khola, O., & Kasthuri Thilagam, V. (2021). Geospatial Technology Based Water Management Action Plan for South Forest Division of Nilgiris, Tamil Nadu. CJAST, 40(37):12-25, 2021
3. Wentworth, C.K. 1930. A simplified method of determining the average slope of land surfaces. *American Journal of Science*, 21:184-194.
4. Horton, R.E. 1945. Erosional development of streams and their drainage basins. Geological Society of America Bulletin, 56:275-370.
5. Horton, R.E. 1932. Drainage basin characteristics. *Transaction Americam Geophysical Union*, 13:350-61
6. Magesh, N.S., Chandrasekar, N., Soundranayagam, J.P. 2011. Morphometric evaluation of Papanasam and Manimuthar watersheds, parts of Western Ghats, Tirunelveli district, Tamil Nadu, India: a GIS approach. *Environmental Earth Science*, 64:373-381.
7. Strahler, A.N. 1964. Quantitative geomorphology of drainage basin and channel network. Handbook of Applied Hydrology, McGraw Hill Book Company, New York, pp 39-76.
8. Tukura, N. G., Akalu, M. M., Hussein, M., & Befekadu, A. (2021). Morphometric analysis and sub-watershed prioritization of Welmal watershed, Ganale-Dawa River Basin, Ethiopia: implications for sediment erosion. *Journal of Sedimentary Environments*, *6*(1), 121-130.
9. Schumn, S.A. 1956. Evolution of drainage systems and slopes in badlands at Perth Anboy, New Jersey. Geological Society of America Bulletin, 67:597-646.
10. Hack, J.T. 1957. Studies of longitudinal stream profiles in Virginia and Maryland. U.S. Geol. Survey Prof., Paper 294-B.
11. Chorley, R.J. 1957. Illustrating the laws of morphometry. *Geological Magazine*, 94:140-150.
12. Miller, V.C. 1953. A quantitative geomorphologic study of drainage basin characteristics in the Clinch Mountain area, Virginia and Tennessee, Project NR 389042, Tech Rept 3, Columbia University Department of Geology, ONR Geography Branch, New York.
13. Partha Pratim Adhikary and Jyotiprava Dash Ch. 2018. Morphometric Analysis of Katra Watershed of Eastern Ghats: A GIS Approach. *Int.J.Curr.Microbiol.App.Sci.* 7(03): 1651-1665. doi: https://doi.org/10.20546/ijcmas.2018.703.198
14. Melton, M.A. 1957. An analysis of the relation among elements of climate, surface properties, and geomorphology. Department of Geology, Columbia University, New York, USA.
15. Smart, S., Surkan, A.J. 1967. The relationship between mainstream length and area in drainage basins. *Water Resources Research,* 3:963-973.

16. Melton, M.A. 1965. The geomorphic and paleoclimatic significance of alluvial deposits in Southern Arizona. *Journal of Geology*, 73:1–38.
17. Chopra, R., Dhiman, R. D., & Sharma, P. K. (2005). Morphometric analysis of sub-watersheds in Gurdaspur district, Punjab using remote sensing and GIS techniques. *Journal of the Indian Society of Remote Sensing*, *33*(4), 531-539.
18. Strahler, A.N. 1957. Quantitative analysis of watershed geomorphology. *Transactions American Geophysical Union*, 38:913–920.
19. Tiwari, R. N., & Kushwaha, V. K. (2021). Watershed Prioritization Based on Morphometric Parameters and PCA Technique: A Case Study of Deonar River Sub Basin, Sidhi Area, Madhya Pradesh, India. *Journal of the Geological Society of India*, *97*(4), 396-404.
20. Strahler, A.N. 1952. Hypsometric analysis of erosional topography. Geological Society of America Bulletin, 63:1117-42.
21. Barman, B. K., Rao, C. U. B., Rao, K. S., Patel, A., Kushwaha, K., & Singh, S. K. (2021). Geomorphic Analysis, Morphometric-based Prioritization and Tectonic Implications in Chite Lui River, Northeast India. *Journal of the Geological Society of India*, *97*(4), 385-395.
22. Sreedevi, P. D., Subrahmanyam, K., & Ahmed, S. (2005). The significance of morphometric analysis for obtaining groundwater potential zones in a structurally controlled terrain. *Environmental Geology*, *47*(3), 412-420.
23. Black, P.E. 1972. Hydrograph responses to geomorphic model watershed characteristics and precipitation variables. *Journal of Hydrology*, 17:309-329.
24. Magesh, N.S., Chandrasekar, N., Soundranayagam, J.P. 2011. Morphometric evaluation of Papanasam and Manimuthar watersheds, parts of Western Ghats, Tirunelveli district, Tamil Nadu, India: a GIS approach. *Environmental Earth Science*, 64:373-381.
25. Faniran, A. 1968. The index of drainage intensity - a provisional new drainage factor. *Australian Journal of Science*, 31:328-330.