Original Research Article

MORPHOMETRIC ANALYSIS OF CHILENAHALLI MICRO-WATERSHED IN THE NORTH-EASTERN DRY ZONE OF KARNATAKA USING GIS AND REMOTE SENSING TECHNIQUES

Abstract

The structure and land form of watershed and their associated stream networks are described mainly by their morphometric parameters and Watershed analysis based on morphometric parameters is very important for watershed planning since it gives an idea about the basin characteristics regarding slope, topography, soil condition, runoff characteristics, surface water potential. GIS and remote sensing techniques can be employed for the identification of morphological features, drainage pattern and its planning in basin area. The study reveals that Chilenahalli micro-watershed designated as 4^{th} stream order and drainage indicate dendritic pattern with mature geomorphic stage and stream order verifies the Horton's law of stream number. The Mean Bifurcation Ratio was found to be 4.46, which indicates low rainfall, shallow weathering and low dissection of the valley and it shows low to medium relief aspect during investigation of the basin. This can be visualised using DEM, relief ratio, ruggedness number, and slope maps of the study area. The drainage density was found to be 2.13 km/km^2 which indicate a low class D_d value, thereby indicating a poorly drained watershed with low response to hydrological parameters. The texture ratio of the micro-watershed is 3.52, which indicated coarse texture of drainage basin and the values of Form Factor, Circulatory ratio and Elongation ratio may imply an oval shape of the basin with a slightly elongated main stream. The value for the length of overland flow in this study is 0.23 km which shows moderate infiltration and percolation characteristics of soil.

Keywords: digital elevation model, GIS, remote sensing, watershed morphometric analysis

1. Introduction

Watershed is an area of land where precipitation collects and drains off into a common outlet, such as into a river, bay, or other body of water. The structure and land form of watershed and their associated stream networks are described mainly by their morphometric parameters. Morphometry deals with mathematical measurement of morphometric parameters of drainage basin. In geomorphology, quantitative description and analysis of landforms are practiced(Sukristiyanti et al., 2018). Morphometric analysis generally applied to a particular kind of landform or to drainage basins. Watershed morphometry indices can be used to determine the shape and hydrological properties of a drainage basin. Application of quantitative techniques in morphometric analysis of drainage basins was initially undertaken by(Horton, 1932; Strahler, 1964).Watershed analysis based on morphometric parameters is very important for watershed planning since it gives an idea about the basin characteristics regarding slope, topography, soil condition, runoff characteristics, surface water potential, etc. (Chandrashekar et al., 2015).To prepare a comprehensive watershed development plan, it becomes necessary to understand the permeable nature of subsurface, infiltration and runoff status and drainage pattern of the region morphometric analysis will be carried out (Clarke et al., 1996). Geographical information system (GIS) has emerged as an efficient tool in delineation of watershed and drainage pattern and its planning. GIS and remote sensing techniques can be employed for the identification of morphological features and analyzing properties of basin (Waikar & Nilawar, 2014). The morphometric analysis of watershed aims to know and correlate the aspects of linear, areal, and relief parameters(Abboud & Nofal, 2017). They are stream order, stream number, stream length, mean stream length, stream length ratio, bifurcation ratio, mean bifurcation ratio, drainage density, drainage texture, stream frequency, relief ratio, form factor, elongation ratio, circularity ratio, length of overland flow are the most common morphometric parameters(Horton, 1932).

Investigating morphometry of the Chilenahalli Micro-watershedwhich affects the hydrological process using RS and GIS tool is the objective of this paper. Understanding the drainage basin morphometric parameters play a vital to role in planning and prioritizing the watershed. The present study bridges the connection between surface morphometry and drainage characteristics of a drainage basin to produce effective information as a part of basin management.

2. Materials and methods

2.1 Description of study area

The Chilenahalli Micro-watershedcovers 40.42 km². It is situated in the Doddaballapura taluk, Bangalore rural district, and north-eastern dry zone of Karnataka. Its geographic extent is 13°22' south to 13° 26' north and 77° 21' west to 77° 31' east (Fig. 1). Administratively, it is fully bounded Doddaballapura taluk, the Micro-watershed drains water to Gundamagere Lake situated atSonnenahalli and Gundamagere villages. The climate of the watershed remains pleasant throughout the year. Most of its rainfall occurs in the monsoon season.

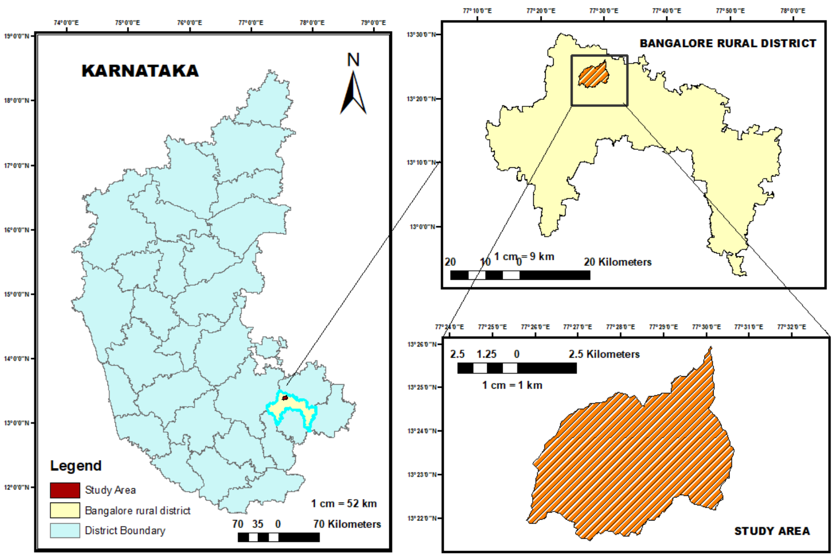


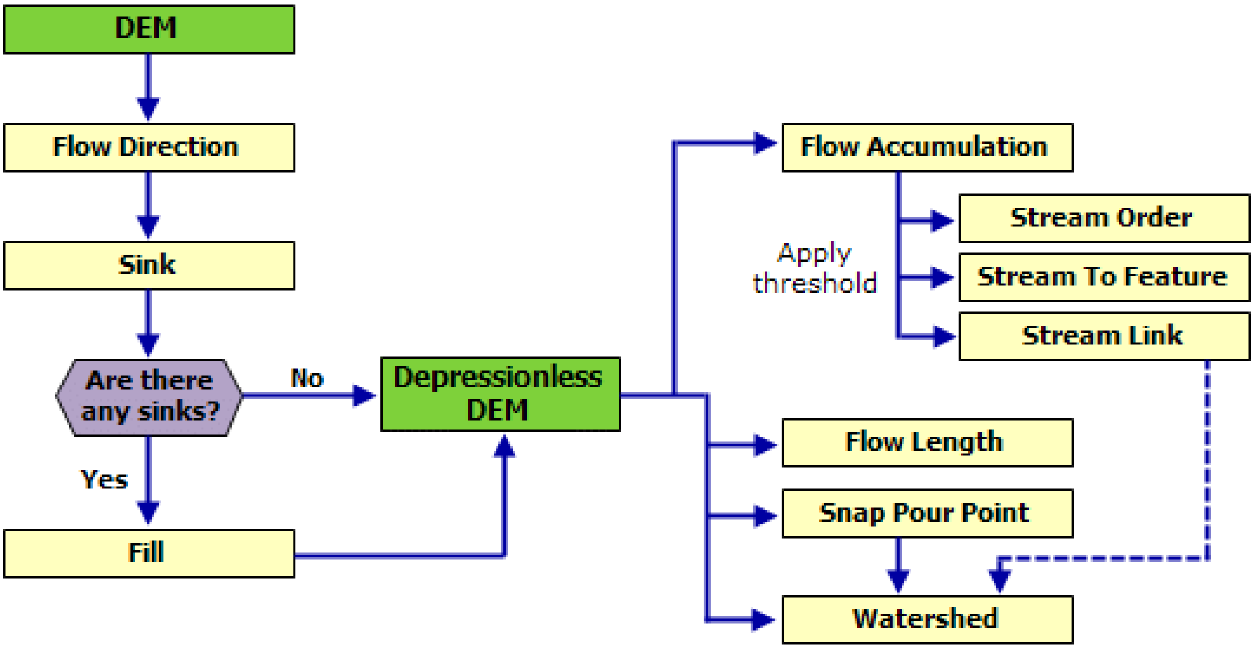
Fig. 1. Location map of the study area

The climate is classified as seasonally dry tropical Savana, this climate includes four main seasons. The watershed has the hottest month in April and coldest in December with temperature fluctuations remarkably stable. It experiences minimum temperature of 15˚C and maximum temperature of 33.6˚C. The watershed has two rainfall seasons i.e. from June to September and October to November with opposite wind regimes and, of average rainfall is 802mm (Koti et al, 2019).

2.2. Methodology

The Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) 30m resolution (**Error! Reference source not found.**) was used to digitize study watershed and generate drainage pattern. The data was downloaded from United States Geological Survey (USGS) website. A number of procedures were used to delineate watershed and generate stream networks. Arc GIS 10.4 software was used to analyze the morphologic characteristics of the basin. The study watershed and stream networks are automatically generated from SRTM digital elevation model using arc toolbox in GIS 10.4. The overall methodology used to delineate watershed and generate stream networks is as follows, which were adopted by Bogale, 2021; Mohd Bukari et al., 2013 and presented in Flowchart below.

1. Collect and re-projected the DEM data of extract Area of Interest (AOI) to UTM zone 43 N coordinate system using ArcGIS under Data management tools of Project raster (Fig. 2).
2. The DEM filled out the pits using fill tool under Spatial Analyst tools of Hydrology option
3. The flow direction and accumulation map of the watershed was created using flow direction and accumulation tools of the same spatial analyst tools of hydrology option
4. Raster calculation operation was carried out using the threshold value of 5000 to generate the stream networks, and correct location of watershed outlet was selected and delineated watershed with district and state boundaries
5. The watershed boundary was plotted, and the area of the watershed, length and order of the streams were calculated using attribute tables of different layers
6. After delineation of the watershed slope map, contour map aspect map, drainage density and drainage pattern maps were generated using SRTM digital elevation model (DEM) and Arc GIS 10.4 software. Different procedures were used in the generation of these maps as stated below
   a) To generate a contour map (**Error! Reference source not found.**), navigate to System Toolboxes > Spatial Analyst Tools > Surface > Contour and select input raster, then output feature location and add contour interval value and Z value, generally kept as 1
   b) The drainage pattern map (Fig.1) is generated using the flow accumulation layer. The raster calculator under Map Algebra of Spatial Analyst Tools was adopted with a threshold value, then the raster file was converted into polyline to find out stream order, number of streams and stream length
   c) Using the drainage pattern map and the Line Density tool, a stream density map (**Error! Reference source not found.**) was generated
   d) An aspect map is generated as follows: navigate to System Toolboxes > Select Spatial Analyst Tools > Surface > Aspect and input and output raster locations (Fig. 2)
   e) To generate a slope map (Fig. 3), navigate to System Toolboxes > Spatial Analyst Tools > Surface > Slope and select the input raster. Then specify the location of the output raster and select the output measurement. A slope map is created from the DEM layer, then reclassified accordingly
7. Finally, Microsoft Excel and the formulas were used to calculate and analyze different morphometric parameters of a watershed.



Flow chart 1. Hydrological watershed delineation

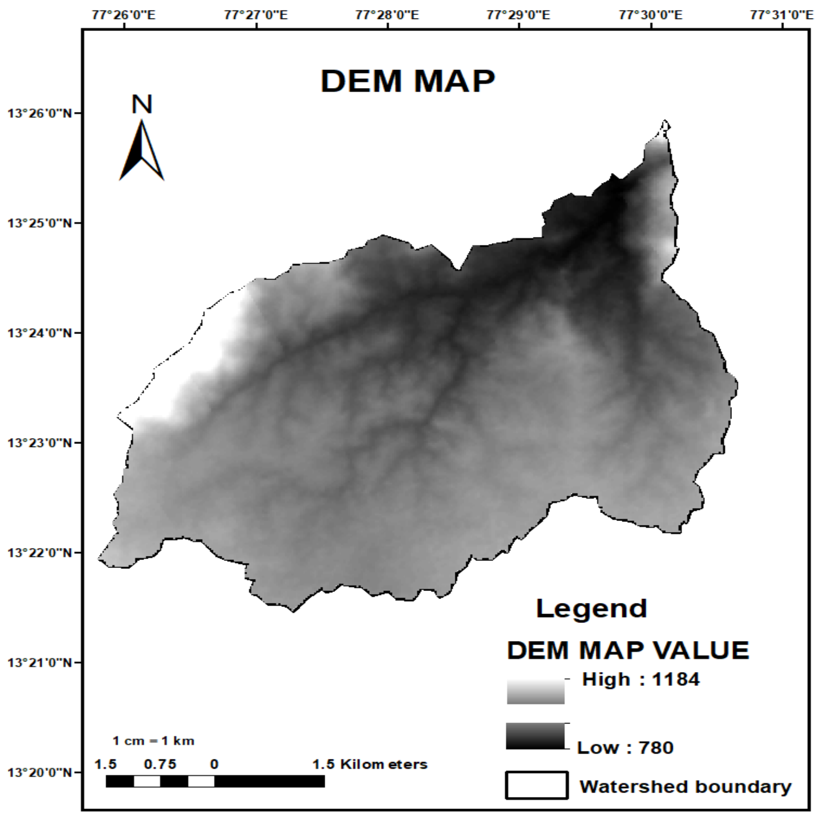


Fig. 2. DEM Map showing elevation values of study area

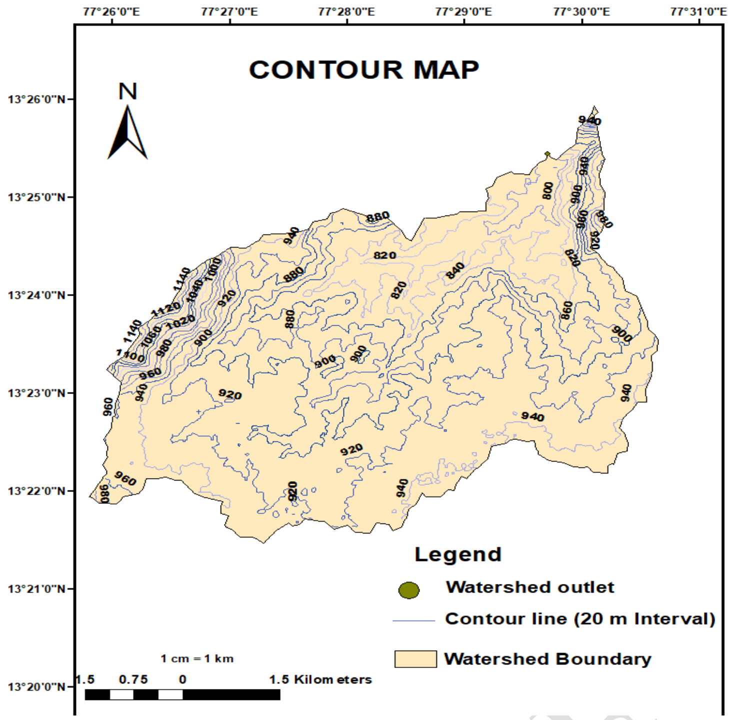


Fig. 3. Contour map of chilenahalli micro-watershed

3. Result and discussion

Morphometric analysis of a Chilenahalli micro-watershed describes the characteristics of the basin based on quantitative evaluation of different parameters, Parameters are discussed according to their dimensional aspects; linear aspects, areal aspects, and relief aspects. The methods of (Horton, 1945), (Strahler, 1964), (Schumm, 1956)are used for linear aspects studies, for areal aspects study usingHorton (1945), (Miller, 1953) and (Schumm, 1956)technique, and the technique applies to relief aspects are (Schumm, 1956). All the above listed morphometric parameters (

) are discussed in the below sections.

3.1 Linear aspects

3.1.1 Stream order (U)

In the present study, ranking of streams has been carried out based on the method proposed by (Strahler,1964). The stream order of the Chilenahalli micro-watershed is classified up to the 4^{th} order.

The observation shows that the micro-watershed has streams where the 1st, 2nd, 3rd, and 4th are 86, 24, 5, and 1 respectively in numbers (Table 2 and Fig.1). The total number of stream segments is 166. The drainage patterns of stream network indicate dendritic type that develops where the river channel follows the slope of the terrain.

Table 1 Method of Calculating Morphometric Parameters of Drainage basin

Morphometric Parameters	Formula/Definition and procedure used	References
	Linear aspects	
Stream order (U)	Hierarchical order	(Strahler, 1952)
Stream Length (L_u)	Length of the stream	(Horton, 1945)
Mean stream length (L_{sm})	**$L_{sm} = L_u/N_u$** Where, L_u= Total stream length of a given order (km), N_u=Number of stream segment.	(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}=The total stream length of its next lower order.	(Horton, 1945)
Bifurcation Ratio (R_b)	**$R_b= (N_u/N_{u+1})$** Where, N_u =Number of stream segments present in the given order N_{u+1}= Number of segments of the next higher order	(Horton, 1945)
	Relief aspects	
Basin relief (B_h)	Basin relief is the difference in elevation between the highest and lowest point of the basin.	(Schumm, 1956)
Relief Ratio (R_h)	**$R_h=B_h/L_b$** Where, B_h=Basin relief, L_b=Basin length	(Schumm, 1956)
Ruggedness Number (R_n)	**$R_n=B_h x D_d$** Where,B_h = Basin relief, D_d=Drainage density	(Schumm, 1956)
	Areal aspects	
Drainage density (D_d)	**$D_d=L/A$** Where, L=Total length of stream, A= Area of basin.	(Horton, 1945)
Stream frequency (Fs)	**Fs=N/A** Where, N=Total number of stream, A=Area of basin	(Horton, 1945)
Texture ratio (T)	**T=N/P** Where, N=Total number of streams, P=Perimeter of basin.	(Horton, 1945)
Form factor (R_f)	**$R_f=A/(L_b)^2$** Where, A=Area of basin, Lb=Basin length	(Horton, 1945)
Circulatory ratio (R_c)	**$Rc=4\pi A/P^2$** Where A= Area of basin,π=3.14, P= Perimeter of basin.	(Miller, 1953)
Elongation ratio (R_e)	**$Re=\sqrt{(Au/\pi)}/ Lb$** Where, A=Area of basin, π=3.14, L_b=Basin length	(Schumm, 1956)
Length of overland flow (Lg)	**$Lg=1/2D_d$** Where, D_d= Drainage density	(Horton, 1945)

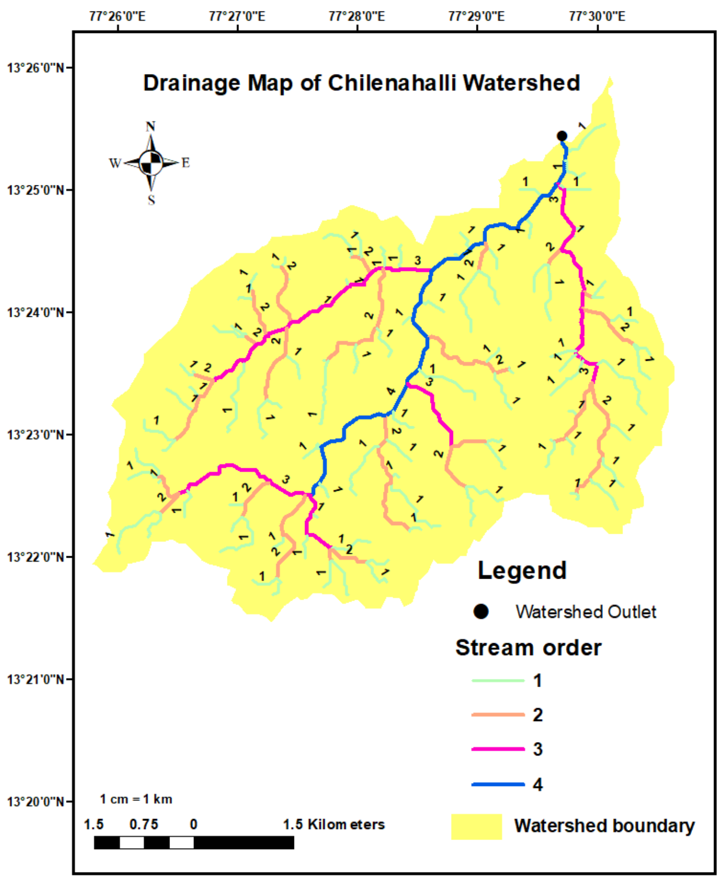


Fig.1. *Drainage Map*

3.1.2 Stream length (L_u)

The stream length was calculated using the GIS-based regulation proposed by(Horton, 1945). The first order stream total length is total 43.26 km,second order has a total length of 21.81km, third order has a total length of 12.89 km, fourth order covers a total length of 8.11 km and the total length of all streams covering all these orders is 86.07 km (Table 2). Therefore, it is observed that the first order stream has the highest total stream length and the number of streams because they are distributed more effectively than the other orders. The first order stream having more or less half of the stream length is ephemeral in dry season and rest of the season, the stream is perennial. The perennial length may decrease further upstream and may be shorter in the dry season with decreasing groundwater recharge (Kaliraj et al., 2015).The observation of stream order verifies the Horton's law of stream number i.e. the number of stream segment of each order forms an inverse geometric sequence with order number.

3.1.3 Mean Stream Length (L_{sm})

The mean stream length (L_{sm}) has been calculated by dividing the total stream length of order by the number of stream. It is a characteristic property related to the drainage network and its associated surfaces (Strahler, 1964).The mean stream length of Chilenahalli micro-watershed is 0.50 km for first order, 0.91 km for second order, 2.58 km for third order and 8.11km for fourth order(Table 2). The mean stream length of stream increases with increase of the order.

3.1.4 Stream Length Ratio (R_L)

Stream length ratio is the ratio of the total stream length of the one order to the next lower order of stream segment.The R_L has an important relationship with the surface flow discharge and erosional stage of the basin (Horton, 1945).The calculated values of the stream length ratio were given in the Table 2. An increasing trend in the stream length ratio from lower order to higher order indicates their mature geomorphic stage(Vinutha & Janardhana, 2014).

Table 2 Results of Linear morphometric parameters

Stream order	Number of stream Nu	Bifurcation ratio	Total length of stream Lu (Km)	Mean stream length (Km)	Stream length ratio (R_L)	Mean of Bifurcation ratio (Rbm)
1	86	3.58	43.26	0.50	-	4.46
2	24	4.80	21.81	0.91	0.50	
3	5	5.00	12.89	2.58	0.59	
4	1	-	8.11	8.11	0.63	

3.1.5 Bifurcation Ratio (R_b)

The bifurcation ratio is expressed as the ratio of the number of stream segments of a given order U to the number of stream segments of the next higher order (U + 1). The ratio is useful to predict various features of a drainage basin (Horton, 1945).It has importance in drainage basin analysis as it is the principal parameter to associate the hydrological character of a basin with the geological structure and climatic conditions (Kabite & Gessesse, 2018). In our studies, as indicated onTable 2, the Bifurcation Ratio (R_b) for streams in Chilenahalli micro-watershed was 3.58, 4.80 and 5.0 for streams with orders of 1, 2 and 3 respectively, while the Mean Bifurcation Ratio (R_{bm}) was found to be 4.46, which indicates low rainfall, shallow weathering and low dissection of the valley of the area under investigation. The values of bifurcation ratio less than 5 suggested that the geological structures do not show any dominant influence on the drainage pattern (Arulbalaji & Gurugnanam, 2017).

3.2 Areal aspects

3.2.1 Drainage Density (D_d)

It is defined as the total length of streams of all orders per drainage area (Horton, 1932).It is also an important parameter which provides the relationship between the form-attributes of the watershed and the processes occurring along stream course. It reflects the land use and affects infiltration and the basin response time between precipitation and discharge rate of the watershed. It also effect the both concentration and amount of flow. High drainage density implies increase in food peaks, whereas there is reduced food levels in low drainage density(Pallard et al., 2009).

In the study area(**Error! Reference source not found.** and Table 3), D_d is 2.13 km/km² which indicates, low class of D_d value shows a poorly drained watershed with a slow response to hydrologic parameters or the basin is a highly permeable subsoil and thick vegetative cover (Abboud & Nofal, 2017; Nag & Chakraborty, 2003).

3.2.2 Stream frequency (F_s)

It is the total number of stream segments per unit area of the basin, Horton in 1932 introduced stream frequency. From Table 3, it is observed that the stream frequency of watershed is 2.87 km^{-2} . The low F_s value of watershed indicates low relief feature, for better results the relative values of $F_s$should be applied.

3.2.3 Texture ratio (T)

The watershed characteristics such as slope, soil type, climate, rainfall, vegetation, and infiltration capacity were greatly influence the drainage texture ratio (Smith, 1950). It is the ratiototal number of stream segments of all orders to perimeter of that area. The texture ratio of the micro-watershed is 3.52, which indicatedcoarse texture of drainage basin (Smith, 1950)

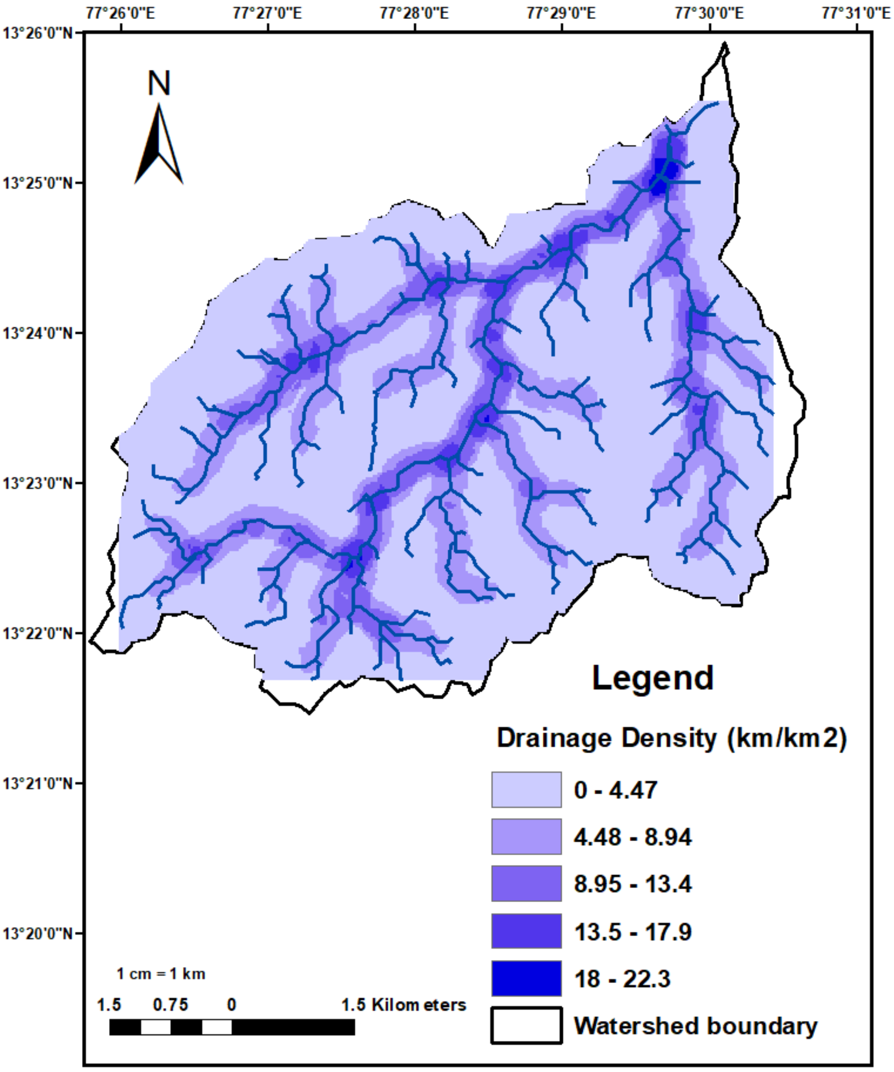


Fig. 5. Line drainage density map of chilenahalli micro-watershed

3.2.4 Form Factor (R_f)

According to (Horton, 1932), the form factor is the ratio of the area of the basin to the square of the basin length. This parameter has been widely used in building correlations with maximum flood-discharge formulas. The form factor value is small for the elongated shape, the runoff duration will be long with low runoff volume, and the contrarily rounded-shape watershed with a high value of form factor experiences a short time of concentration with high runoff volume, and it is highly sensitive to flooding. The value of the form factor should not be more than 0.7854.(Waikar & Nilawar, 2014).The form factor ratio value for this study area is 0.55, which has a medium range value of form factor. Therefore, the basin is slightly elongated in shape with low peak flow and longer duration of flow (Table 3)

3.2.5 Circulatory ratio (R_c)

Circularity ratio is defined as the ratio of watershed area to the area of a circle having the same perimeter as the watershed. It indicates shape of the basin andincrease in the R_c value indicates increase in the food level and susceptibility to food hazards at the outlet of the basin (Miller, 1953).In the present study, the Rc values of micro-watershed was less than 0.5 (from Table 3,0.47) indicating the characteristics of anslightly elongated basin.

3.2.6 Elongation ratio (R_e)

Elongation ratio is defined as the ratio between the diameter of the circle of the same area as the drainage basin and the maximum length of the basin (Schumm, 1956).The elongation ratio values indicate that the areas with higher elongation ratio values have high infiltration capacity and low runoff, and that a circular basin is more efficient in the discharge of runoff than an elongated basin (Singh & Singh, 1997).The Re value of the study area is 0.84 (Table 3). The value is close to 1.0, which implies that it is typical of regions of very low relief and indicates that there are fewer geomorphological controls on stream networks(Magesh et al., 2013; Strahler, 1952). On the basis of the elongation ratio value, the watershed is oval in shape but it is less elongated with reference to the R_f value.

3.2.7 Length of overland flow (L_g)

Length of overland flow is one of the important parameter of a watershed area which affects the physiographic development and hydrologic characteristics of watershed. This concept is similar to surface run-off, but these two are quite different hydrological phenomenon(Karim, 2020).The length of overland flow is calculated as half of the reciprocal of the drainage density, and infiltration (exfiltration) and percolation through the soil affect the value L_g(Schmid, 1997) also.The value for the length of overland flow in this study is 0.23 km which is moderate.

3.3 Relief aspects

3.3.1 Basin relief (B_h)

Basin relief (B_h) is defined as the difference in elevation between the highest and the lowest points of the basin (Schumm, 1956). The basin relief controls the stream gradient and it influences the flow patterns, amount of the sediment transported and geomorphic processes and landform characteristic of the catchment area (Burrough et al., 2015).In the study, basin relief is obtainedas 400 m with the maximum height of the whole basin is 1180 m and the lowest is 720 m. The contour map (**Error! Reference source not found.**) shows contour lines of study area with 20 m contour interval, it is used to study topographic features of drainage basin.

3.3.2 Relief ratio (R_h)

The relief ratio is defined as the ratio between the total relief of a basin and the basin length of the drainage basin (Schumm, 1956).The R_h is inversely varies with drainage area and size of watersheds of a given drainage basin (Gottschalk, 1964). The value of the relief ratio indicate steep slope and high relief and vice-versaand is an indicator of the intensity of erosion process operating on slope of the basin (Schumm, 1956). The value of relief ratio in micro-watershed is 0.05 indicating moderate relief and moderate slope(Table 3).

3.3.3 Ruggedness number (R_n)

The ruggedness number as the product of maximum basin relief and drainage. An extreme high value of ruggedness number occurs when both variables are large and slope is steep (Schumm, 1956).$R_n$values indicate the level of smoothness and roughness of the watershed or surface unevenness (Selvan et al., 2011) and level of soil erosion level in the watershed(Debelo et al., 2017). The ruggedness value watershed is 0.85 (Table 3), which shows the terrain of the basin is moderately rugged. A study by (Kumar & Joshi, 2015)on watershed got Rn value 0.78 and interpreted as the area has steep slope and susceptible for soil erosion. If the watershed is more rugged, high sediment transport will take place, thereby exposing it to soil erosion.

Table 3 Result of morphometric analysis

SL No	Parameter	Value
1	Basin Area $(Km)^2$	40.42
2	Perimeter (km)	32.92
3	Basin order	4
4	Drainage density(D_d) (Km/Km^2)	2.13
5	Stream frequency (F_s) $(Km)^2$	2.87
6	Relief Ratio (R_h)	0.05
7	Texture ratio(T) (Km)	3.52
8	Basin Length(L_b) (Km)	8.59
9	Basin Relief(B_h) (m)	400
10	Ruggedness number (R_n)	0.85
11	Mean Bifurcation ratio (R_b)	4.46
12	Form Factor (R_f)	0.55
13	Circulatory ratio (Rc)	0.47
14	Elongation Ratio (R_e)	0.84
15	Length of overland flow (L_g) (Km)	0.23

3.4 Aspect Map

The aspect map is usually related to the direction of the slope face. It is an important parameter to know the impact of the sun shine on the site of the neighborhood time. Aspect map has an important effects in the distribution of the vegetation form in an area(Maathuis & Wang, 2006). The aspect map derived from SRTM-DEM represents the compass route, 0^0 is north with time; 360^0 issue to the south(**Fig. 2.** Aspect MapFig. 2). The Chilenahalli micro-watershed offers north-west facing slopes and thus these slopes have a higher moisture content and higher vegetation than in the other slope.

3.5 Slope Map

The slope is a measure of changes in surface values at a distance and can be expressed in a percentage. The SRTM-DEM, which is in raster format in the form of grids, represents unique pixel values with common reference. After calculating the slope the maximum difference can be determined, and then the slope values will be reclassified accordingly (Jha et al., 2007; Kudnar & Rajasekhar, 2020).The study area map is grouped into five classes, namely 0-5 (Gently sloping), 5–10 (Sloping), 10–15 (strongly sloping), 15 – 20 (moderately steep) and >20 (Steep)It was observed that a large part of the study area was under gentle slopes and slight slopes, suggesting nearly flat topography of the region. Some parts along the drainage boundary in the north and north-western regions show steep slopes (Fig. 3).

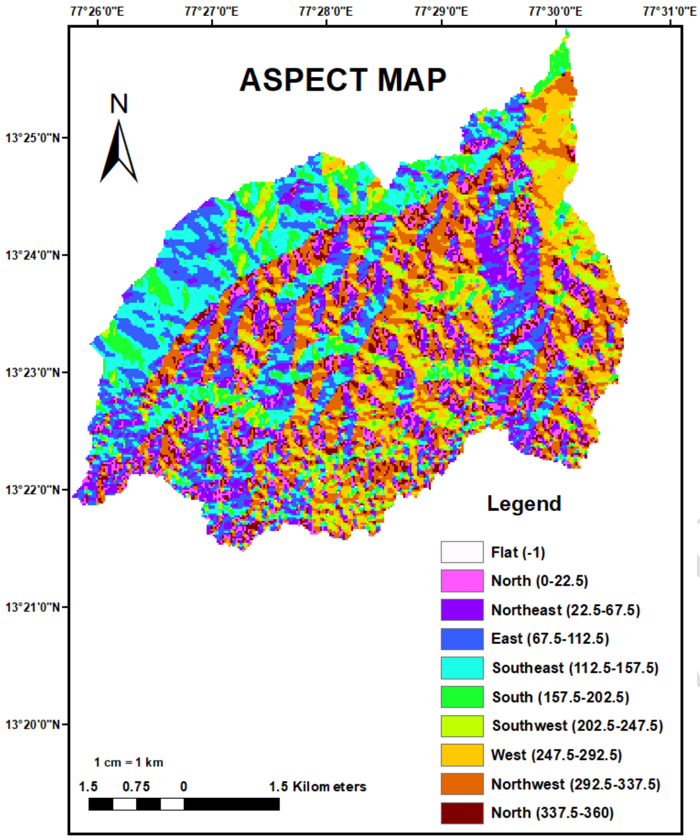


Fig. 2. *Aspect Map of chilenahalli micro-watershed.*

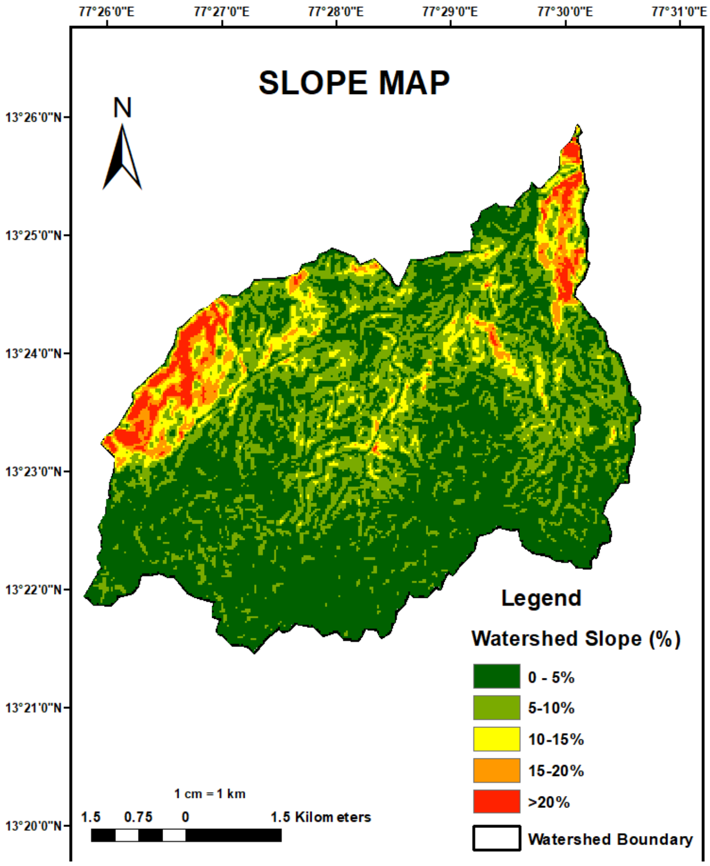


Fig. 3. *Slope Map of chilenahalli micro-watershed.*

4. Conclusion

The morphometric analysis of the Chilenahalli micro-watershed wascarried out using GIS and remote sensing techniques. The measurement of linear, areal, and relief aspects was based on different formulas and the aspect, contour and slope maps were prepared to study topographic features .The study, reveals that Chilenahalli micro-watershed designated as 4^{th} order stream and drainage indicate dendritic pattern with mature geomorphic stage and stream order verifies the Horton's law of stream number. The Mean Bifurcation Ratio (R_{bm}) was found to be 4.46, which indicates low rainfall, shallow weathering and low dissection of the valley of the area under investigation and The relief aspect shows low to medium relief of the basin. This can be visualised using DEM, relief ratio, ruggedness number, and slope maps of the study area. The drainage density was found to be 2.13 km/km^2,which indicates a low class D_d value, thereby indicating a poorly drained watershed with low response to hydrological parameters. The texture ratio of the micro-watershed is 3.52, which indicated coarse texture of drainage basin and the values of Form Factor (Rf), Circulatory ratio (Rc) and Elongation ratio (Re) ratio imply an oval shape of the basin with a slightly elongated main stream. The value for the length of overland flow in this study is 0.23 km which is moderate and shows moderate infiltration and percolation characteristics of soil.

The significance of studying morphometric properties of Chilenahalli micro-watershed help in future watershed management and hazard management studies. This study aims to build relationships between morphometry, sub-surface geology and hydrological characteristics of the watershed and this study provide knowledge and database for strategic planning, prioritization and management of watershed.

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