Environment Conservation Journal 24 (1):71-81, 2023

Journal homepage:https://www.environcj.in/

Environment Conservation Journal

ISSN 0972-3099 (Print) 2278-5124 (Online)

The study of morphological characteristics for best management practices over the Halayapura micro-watershed of Karnataka, India, using remote sensing and geospatial techniques

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ARTICLE INFO

Received : 17 February 2022
Revised : 03 June 2022
Accepted : 11 June 2022

Available online: 08.01.2023

Key Words:
DEM
Drainage pattern
Halayapura micro-watershed
Morphometric parameters
RS and GIS

ABSTRACT

The morphometric analysis was carried out on the Halayapura micro-watershed in Karnataka, India. Using ArcGIS 10.2.2 and applying the DEM model, the micro-watershed was subjected to quantitative investigation to determine the channel network involved and understand geo-hydrological behavior. In addition, remote sensing and geospatial techniques were used to study the micro-watershed drainage analysis and its associated parameters, such as stream order, stream length, stream frequency, drainage density, texture ratio, form factor, circulatory ratio, elongation ratio, bifurcation ratio, and compactness coefficient for the micro watershed, were evaluated. According to the findings, the stream order ranges from I to IV, with 97 streams in the micro-watershed. Streams of 72, 19, 5, and 1 are found in the I, II III, and IV order, respectively. The bifurcation values range from 3.78 to 5.00, with the average weight around 3.14. The elongation ratio and farm factor are 0.77 and 0.46, respectively. The drainage density of the micro watershed is 5.20 km/km^2. The form factor, circularity, and elongation ratio contribute to a basin with an elongated shape through decreased flood proneness, erosion, and sediment transport capacity. The results of the micro-watershed morphometric assessment are critical for evaluating and managing water resources and selecting a recharge structure for future water management in the study region.

Introduction

In today's developing world, urbanization, industrialization, and population expansion are inevitable. As a result, depleting resources such as land and water are growing increasingly scarce at an ever-increasing rate. To meet the demands for these resources, the most beneficial and time-efficient utilization is essential for long-term growth. More than half of all water sources are derived from precipitation, infiltrating soil and groundwater when it approaches the Earth's surface and flows into torrents and tributaries when it reaches the surface. The amount of water permeation is controlled by various factors, including geographic location, soil type, and the region's geologic management (Gunjan *et al.,* 2020). Therefore, morphometric drainage analysis is critical for efficient watershed planning because it gives information about the basin characteristics like the slope, topography, soil conditions, runoff, and surface water potential (Prakash *et al.,* 2019). The field of morphometry is studying both the Earth's surface layout and the overall form and size of landforms. Many attributes such as vegetation, sediment, structural elements, geology, and

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Doi:https://doi.org/10.36953/ECJ.11062273

geomorphology all play a significant role in drainage systems developed over time and space. Morphometric analysis is essential in this context and maybe helps with several aspects of hydrology, such as groundwater and basins management, potential groundwater assessment, and insight into the environment.

Estimating surface runoff in a watershed could help prioritize, morphometrically assess, and predicting key micro-basins for conservative measures (Roohi *et al.,* 2020; Ghosh and Saha, 2019). At the watershed scale, the rainfall-runoff transformation process is a highly complex event; however, morphological features can be linked to a watershed's hydrological behavior and ability to produce runoff (Kumar *et al.,* 2018; Aher *et al.,* 2014). Some researchers have recently conducted drainage morphometry investigations using remote sensing technology to identify and characterize seasonal variations in the drainage basin. It also helps to comprehend groundwater potentialities, and resolves flood proneness issues (Angillieri, 2008; Kadam *et al.,* 2017; Rai *et al.,* 2017; Magesh *et al.,* 2013, 2011; Chopra *et al.,* 2005; Pankaj and Kumar, 2009). In addition, numerous studies on watershed management have been conducted, all of which used morphometry analysis as the only foundation for micro-watershed characterization for natural resources management and planning processes (Rajasekhar *et al.,* 2018; Vijith and Satheesh, 2006; Thomas *et al.,* 2010).

For morphometric analysis, Geographic Information Systems (GIS) and Remote Sensing (RS) approaches using satellite images were employed as a very convenient tool during present days in identifying the basin or sub-basin of the drainage systems (Panda *et al.,* 2019; Magesh *et al.,* 2013; Ratnam *et al.,* 2005). The most prevalent technique used in drainage basin studies involves the use of Digital Elevation Models (DEM) and Shuttle Radar Topography Missions (SRTM) (Sujatha *et al.,* 2015; Nag and Chakraborty, 2003). In addition, RS methods that employ satellite imaging and topographical maps have been used to identify morphometric parameters, such as drainage form, stream order, bifurcation ratio, drainage, and density (Zolekar and Bhagat, 2015; Mesa, 2006).

The GIS and RS techniques were used for the study enhancement to predict the drainage's attributes. When combined with previous research, the study gives critical information on researchers, decision-makers, and local communities; it contributes to micro-watershed research in integrated program design and implementation and the scaling up of effective management techniques. It also benefits academics working on related research subjects in other fields. Therefore, in the current study, efforts were made to use geo-processing tools such as the ArcGIS 10.2.2 software to investigate the various morphometric parameters of micro-watershed to plan and manage natural resources in sustainable development properly.

Material and Methods

Study area:

The study was conducted in the Halayapura micro-watershed, situated in Tumkur district of Karnataka state, India, and it has a total area of 503 hectares that falls between 77.05º05'20" to 77.07º07'20" E longitude and 13.08º30" to 13.10º10' N latitude in (Fig. 1). A micro-watershed is a portion of the Hosalaya sub-watershed located at an elevation of 845 m above mean sea level (MSL). In this micro-watershed, the annual average rainfall is 750 mm, and most of the rain received comes from the southwest monsoon (June to October). The temperature fluctuates between about 18°C (64°F) in the winter to about 37°C (99°F) in the summer. The most widely cultivated crops are coconut, areca nut, banana, mango, sorghum, ragi, jower, groundnut, and pulses are grown in the Kharif season. A micro-watershed is composed of five textural groups (loamy sand, sandy loam, sandy clay loam, sandy clay, and clay). Among these, the central part of a micro-watershed is 41.23 % sandy loam (207 ha) and 29.91 % loamy sand soils (152 ha) of the total area. (Fig. 2) show the spatial distribution of a different textural class of soil present in the Halayapura micro-watershed.

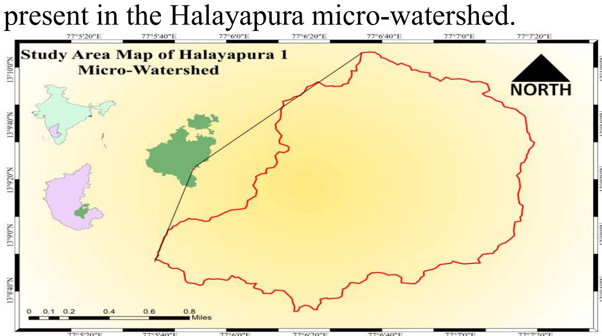

Figure1: Location map of the Halayapura micro-watershed, Tumkur district of Karnataka state, India.

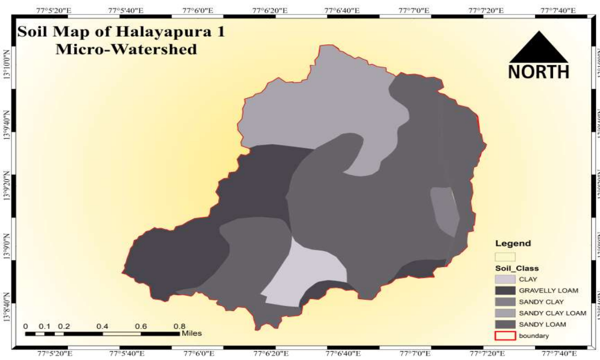

Figure 2: Soil textural map of the Halayapura micro-watershed.

Methodology:

A micro-watershed was generated using sophisticated space-borne thermal emission. A reflection radiometer (30m) resolution digital elevation model (ASTER-DEM) was utilized to create drainage networks and mark off essential areas to comprehend the hydrological and morphological features of micro-watershed using ArcGIS 10.2.2 software. A micro-watershed consisting of primary characteristics, such as the linear aspect (stream order, bifurcation ratio, mean bifurcation ratio, stream length, mean stream length, stream length ratio), the areal aspect (stream frequency, drainage density, texture ratio, form factor, circularity ratio, elongation ratio), and the relief aspect (stream frequency, drainage density, texture ratio, form factor, circularity ratio, elongation ratio) (relative relief, relief ratio, dissection index, ruggedness index). Remote sensing and GIS have successfully analyzed several morphometric characteristics (Singh *et al.,* 2013). Soil loss is proportional to linear parameters like bifurcation ratio, stream frequency, texture ratio, drainage density, length of overland flow, and relief ratio, and inversely proportional to shape parameters like form factor, compactness coefficient, circulatory ratio, and elongation ratio in a watershed (Sangma and Guru, 2020). The methodology's flow chart is shown in the diagram below (Fig. 3).

Morphometric Analysis of a micro-watershed

A combination of geoprocessing techniques available in Arc GIS 10.2.2 was used to extract and calculate the different drainage spatial distribution (linear, areal, and relief). First, the drainage network was created using Strahler's formula, which identifies portions with no tributaries as a 1st order stream. When two 1st order streams come together, they generate a 2nd-order stream and

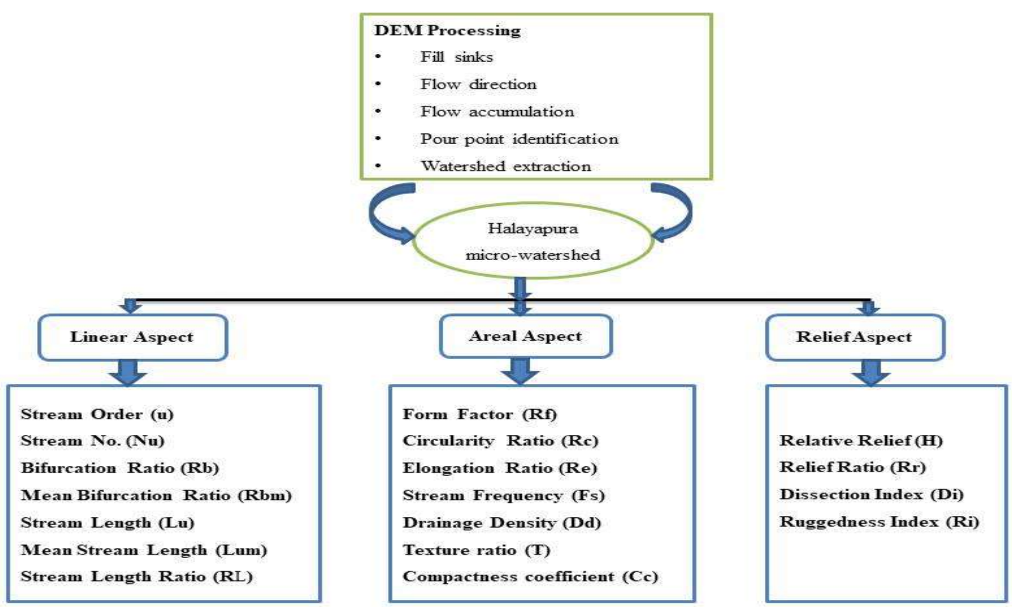

Figure 3: Flow diagram showing an approach for conducting morphometric investigation of the Halayapura micro-watershed

Table 1: Methods of calculating morphometric parameters

SN	Morphometric Characteristics	Formulae	References
1	Stream pattern (u)	Hierarchical order	Strahler (1957)
2	Stream Quantity (N_u)	Nu = amount of streams of a specific order 'u.'	Strahler (1964)
4	Mean stream length (L_u)	$L_{sm}= L_u/N_u$; L_u= average duration of a channel in a specific sequence (km), N_u= the overall the number of segmented channels.	Horton (1945)
5	Maximum length of the watershed (L_b)	The distance from the outlet of the basin from the farthest location.	Horton (1945)
6	Watershed perimeter (P_r)	The whole length of the outer catchment demarcation is manually calculated using a planimeter.	Horton (1945)
7	Stream length ratio (R_L)	$R_L= L_u/L_{u-1}$ L_u= Total stream duration of order (u), L_{u-1}=The total stream duration of its next lower rank.	Horton (1945)
8	Bifurcation ratio (R_b)	$R_b = N_u/N_{u+1}$ $R_b = N_u / N_{u+1}$ N_u= Number of stream order included in the specific order, N_{u+1}= Number of higher-order attributes in the sequence.	Schumm (1956).
9	Form factor (R_f)	$R_f = A/L^2_b$, A= basin area, L_b=length of the basin	Horton (1945)
10	Elongation ratio (R_e)	$R_e = 2/L_b\frac{\sqrt{A}}{\pi}$ A= watershed area, L_b=length of the watershed.	Strahler (1964)
11	Circulatory ratio (R_c)	$R_c = 12.57\ A/P^2r$ A= watershed area, P_r= Perimeter of the watershed.	Strahler (1964).
12	Drainage density (D_d)	$D_d = Lu/A$ L=ttotal length of the stream, A= The basin area	Horton (1945)
13	Stream frequency (F_s)	$F_s = Nu/A$ Nu= Total number of streams, A= The basin area	Horton (1945)
14	Texture ratio (T)	$T = N_1/P_r$ N_1=Total number of the first-order stream, P_r=Perimeter of the basin.	Horton (1945)
15	Maximum watershed relief (H)	$H = R - r$ R = highest relief, r = lowest relief	Schumm (1956)
16	Compactness coefficient (R_c)	$Cc = 0.2821\ P/A^{0.5}$ P= watershed perimeter, A= equivalent a circular area circumference of the watershed	Horton (1945)
17	Ruggedness number (Rn)	$Rn = Bh \times Dd$ Where, Bh =Basin relief; Dd=Drainage density	Schumm (1956)
18	Time of concentration (Tc)	$Tc = 0.0078L^{0.77}\ S^{-0.385}$	Salimi et al. 2017

continue further on. Then, the standard formula in (Table 1) was used to calculate various aspects of drainage morphometry such as bifurcation ratio (R_b), mean bifurcation ratio (R_{bm}), mean stream length (L_{um}), stream length ratio (R_L), form factor (R_f), circularity ratio (R_c), stream frequency (F_s), drainage density (D_d), dissection index (Di), and ruggedness index (Ri), Time of concentration (Tc). The slope characteristics were also determined using Arc GIS 10.2.2 spatial analysis tool.

Results and Discussion

Morphometric studies:

The morphometric drainage characteristics will help understand the micro watersheds' hydrological and morphological features (Thomas *et al.,* 2010). Addressing the structural controls of a micro-watershed is also a very beneficial (Patel *et al.,* 2013). Basin characteristics also influence the hydro-sedimentary flow regimes (Singh *et al.,* 2020). The study aimed to understand better hydrological and morphological processes using several morphometric parameters in the Halayapura micro-watershed. Fig. 4 and Fig. 5 show the features such as the stream order and elevation of a micro-watershed. In addition, table 2 and Table 3 show the detailed morphometric study of parameters corresponding to u, N_u, L_u, L_b, D_d, F_s, R_c, R_b, R_{bm}, L_{um}, R_L, R_f, and R_i, were analyzed. Also, overland flow length, area, perimeter, the difference in elevation, length of basin, total relief, the number of streams, and full stream length for a micro-watershed were determined.

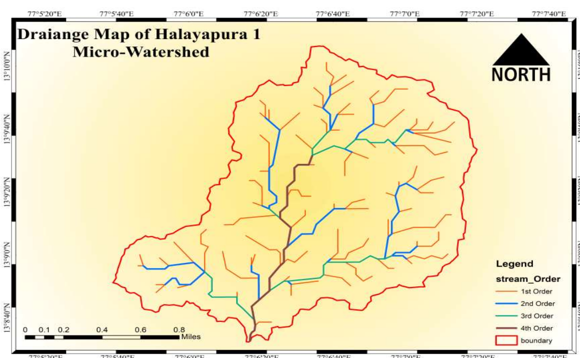

Figure 4: The stream order map for the Halayapura micro-watershed.

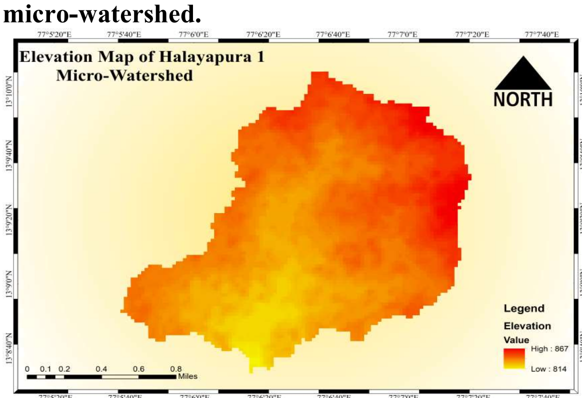

Figure 5: The digital elevation model of the Halayapura micro-watershed.

Stream Order (u):

Stream ordering refers to the process of determining a stream's hierarchical position within a drainage basin (Strahler 1964). Next, the most of the water is discharged, and the most of the water is released. Finally, the most of the water is removed from the critical channel through which the most of the water is released, recognized as the drainage basin's highest order stream. This stream order is determined by the basin's form, size, and terrain features (Srinivasa vittala *et al.,* 2014). The stream pattern is essential in determining the number of exciting drainage morphometric characteristics investigated in this research. It has also been used to determine the maximum stream order within a micro-watershed. From a micro-watershed in our research, the region is identified using the highest stream order, i.e., the trunk stream, wherein all the discharge of a micro-watershed reaches its outflow. The observation made from Fig. 4 and Table 2 depicts that the Halayapura micro-watershed has up to IV order tributaries, with the I, II, III, and IV; streams are 72, 19, 5, and 1, respectively. The highest order of stream segments is the main's channel. Because of the geomorphology of a micro-watershed, all discharges, runoff, and sediments migrate and increase from upstream to downstream (Gaikwad and Bhagat, 2018). Fig. 6 show the logarithmic and arithmetic scales in the Y-axis and X-axis; the connection produces a negative linear pattern.

Table 2: Stream length measurement for the Halayapura micro-watershed.

Stream Order	Stream Number	Cumulative Stream Length (km)	Mean Stream Length (km)	Stream Length Ratio
I	72	14.71	0.2	-
II	19	5.79	0.3	0.66
III	5	3.37	0.67	0.45
IV	1	2.14	2.14	0.31

Stream Length (L_u):

The L_u is estimated using the law anticipated by Horton (1945). The stream length denotes each step involved in the growth of the stream section (Rai *et al.,* 2017), and the overall size of streams is often the most significant in the I order, and Lu decreases as stream order rises. Shorter stream lengths are found in areas with steeper the slopes and more delicate textures, while longer stream lengths are located on lower the slopes and coarser textures (Strahler, 1964). The determined L_u order of the Halayapura micro-watershed is 1st (14.71 km), 2nd (5.79 km), 3rd (3.37 km), and 4th (2.14 km) (Table 2). Fig. 7 show the positive relationship between stream order and length. The line grows geometrically when drawn in arithmetic scale and logarithmic scale at X and Y-axis, respectively.

Table 3. Morphometric analysis results for the Halayapura micro-watershed

SN	Morphometric Parameters	Calculated value
1	Micro-watershed Area	5 km^2
2	Micro-watershed Perimeter	11.13 km
3	Micro-watershed rank	4 th
4	Micro-watershed Length (Lb)	3.27 km
5	Mean Bifurcation ratio (Rb)	3.14
6	Stream frequency (Fs)	19.2
7	Drainage density (Dd)	5.20 km/km^2
8	Micro-watershed relief	0.01
9	Relative ratio	0.004
11	Texture ratio(T)	6.46
12	Ruggedness number (Rn)	0.28
13	Form Factor (Rf)	0.46
14	Circulatory ratio (Rc)	0.50
15	Elongation ratio (Re)	0.77
16	Length of overland flow (Lg)	0.096 km
17	Ellipticity ratio	1.68
18	Drainage texture	8.61 km^{-1}
19	Average micro-watershed width	1.57 km
20	Maximum micro-watershed relief	55 (m)
21	Compactness coefficient	0.63
22	Shape factor	2.14
23	Time of concentration (Tc)	7.58 min

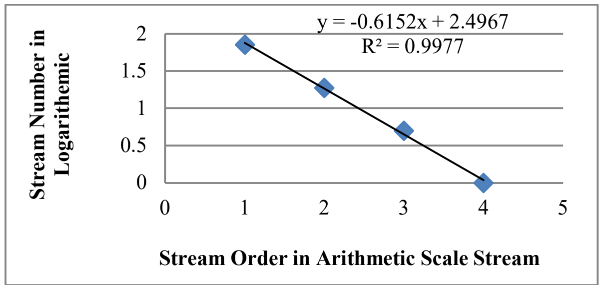

Figure 6: Plot between stream numbers versus stream order.

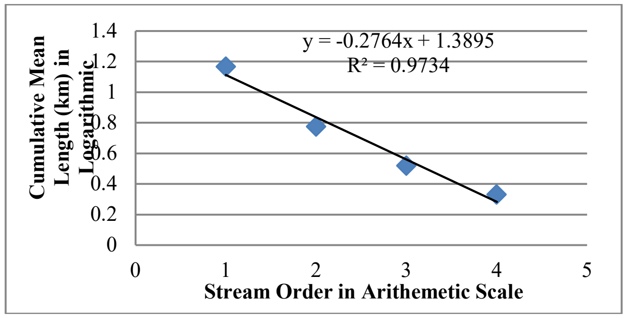

Figure 7: Plot demonstrating the relationship between stream order and cumulative mean length of streams

Bifurcation Ratio (R_b):

A measure of the relationship between the number of streams in a particular order (Nu) and the number of net higher-order streams (Nu+1) is named as bifurcation ratio (Schumm, 1956). The mean R_b of the entire basin is 3.14, as shown in (Table 3). Rai *et al.,* 2017, reported that an R_b between 3 and 5 indicates a natural the drainage systems inside a homogeneous rock. A micro-watersheds that have flat or rolling micro-watersheds will have a lower R_b. On the other hand, higher R_b implies that the drainage pattern is well controlled structurally, and the drainage basins are well dissected. The greater the R_b, the lower the probability of floods (Eze and Efiong, 2010). The obtained results depict a natural the drainage systems having a dendritic pattern inside a homogeneous rock.

The drainage Density (D_d):

According to the study conducted by Horton (1945), the total length of streams presents per unit area is referred to as the drainage density (km/km²). The closeness of channel spacing determines the D_d of a micro-watershed. The low D_d suggests that the basin has an extremely permeable subsurface and heavy vegetation cover (Nag and Chakraborty, 2003). At the same time, high the drainage density contributes to the weak or impermeable underlying material, scarce vegetation, and hilly topography. Weather patterns, precipitation, vegetation, geology, soil properties, infiltration rate, and phase of development contribute to the drainage texture, which is a measure of the channel spacing in a topography (Smith, 1950). D_d contributes 5.21 km/km2 in the selected to the study region, suggesting an intermediate the drainage pattern to a very strongly sloping terrain with various species covering, as shown in Table 3.

Stream Frequency (F_s):

The number of streams presents per unit area is considered as stream frequency (Horton, 1945). The stream frequency correlates positively with the drainage density showing a rise in stream population because of increasing the drainage density. The weather patterns, natural vegetation, bedrock and soil characteristics, rainfall amount, hydraulic conductivity, elevation, discharge concentration, porosity, geography, and gradient all play a significant role in determining the drainage frequency along with density. The Fs for a micro-watershed is 19.2, shown in (Table 3). The runoff will be quicker in basins at higher the drainage density and stream frequency; this may be cause many flooding chances (Solanke *et al.,* 2001).

Circulatory Ratio (R_c):

The basin area calculated is divided by the circle's circumference, which will have the same circumference as the basin's perimeter (Miller, 1953). When the fundamental shape is a perfect circle, the ratio equals one; while the basin shape is considerably elongated, indicates the percentage varies from 0.4 to 0.5 and the presence of highly permeable homogenous geologic materials. The calculated R_c may be influenced by the stream frequency, the slope, geologic structure of the relief, climate changes, and land use/land cover of the basin. As shown in Table 3, R_c value of a micro-watershed was found to be 0.5, suggesting an elongated form, modest runoff discharge, and permeability of the subsurface condition is high. Its intense, intermediate, and high values depict the tributary basins in their youth, maturity, and old age phases of their life cycle (Bisen and Kudnan, 2013).

Form Factor (R_f):

The flow intensity in a specific region is represented by the form factor (Horton, 1932). The form factor obtained is always smaller than 0.754, and the weight indicates perfectly a circular watershed (Rekha *et al.,* 2011; Gajbhiye *et al.,* 2014). The lower the value of shape factor, the longer the basin is, whereas, higher values match to a circular basin. Peak flows in basins having a high shape are more substantial, and last for a shorter time, while peak flows in elongated watersheds with low shape are flatter and last longer. Table 3 show that the R_f value for the study region is 0.46, indicating that the basin is a circular rather than elongated.

Elongation Ratio (R_e):

The maximum length of a micro-watershed basin is plotted in ArcGIS software 10.2.2, as shown in (Fig. 8) and (Table 3). Over a broad range of climatic and geologic types, Schumm's ratio exhibits values in the range of 0.6 and 1.0. The various elongation ratio indexes are classed as round, oval, less elongated, and more elongated, with values ranging from 0.9-0.10, 0.8-0.9, 0.7-0.8, 0.5-0.7, and 0.5-0.7, respectively. It is reported that the discharge of runoff is less efficient in an elongated basin compared to the circular basin (Singh and Singh, 1997). For high relief locations, the value varies in the range 0.6 to 0.8, whereas values near to 1.0 indicate shallow relief with a circular shape (Magesh *et al.,* 2013; Chopra *et al.,* 2005; Gajbhiyem *et al.,* 2014). The selected region has a R_e of 0.77, which indicates that it is less elongated, having a steep to severe the slope with a high relief.

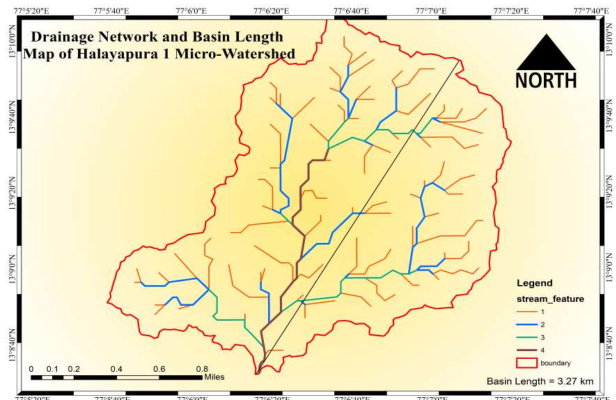

Figure 8: The basin's geometry of the Halayapura micro-watershed.

Texture Ratio (T):

The texture ratio is an essential component in the drainage morphometric analysis, since it depends on the underlying geology, infiltration rate, and relief aspect of the terrain (Schumm, 1956). The textural ratio is well defined as the proportion of I order streams to that of basin perimeter. Table 3 show that the texture ratio in the studied region is around 6.46 km^{-1}.

Relief Ratio (R_r):

R_r values over a certain threshold indicate a steep the slope with a high relief. In steeper basins, runoff is often quicker, resulting in more peaked basin discharges and increased erosive force (Palaka and Sankar, 2016; Pankaj and Kumar, 2009).

The R_r value in a micro-watershed is 0.01, indicating that values are low (0.1), implying a moderate the slope. The results are also graphically viewed and computed using a topographical map of 1:50,000 on Google Earth.

Length of Overland Flow (L_g):

The L_g is well defined as the water across the ground, before being concentrated into the mains stream, and it mainly influences the drainage basin's hydrological and physiographical progression (Horton, 1945). L_g will significantly affect when modified by soil infiltration or percolation, varying in place and time (Schmid, 1997). The higher Lg value implies that precipitation has to travel a considerable distance before condensing into stream channels (Chitra *et al.,* 2011). The overland flow length in this research area is around 0.09 km, indicating that significant structural disturbance, poor permeability, steep to extremely steep slopes, and more surface runoff will have a higher impact.

Slope

The slope in the watershed is the angular inclinations of the terrain between the peaks of the hill and valley bottoms, which is a significant morphometric attribute in studying the drainage basin landforms. Many variables contribute to its occurrence, which includes the structure of geological, absolute or relative reliefs, temperature, plant cover, and the drainage texture (Yadav *et al.,* 2014; Thakkar and Dhiman, 2007). The Halayapura micro-average watershed's the slope ranges from 0 to 14.5 percent (Fig. 9). Nearly level slope (0-1 percent), extremely gentle slope (1-3 percent), gentle slope (3-5 percent), moderate slope (5-8.5 percent), and strong slope (5-8.5 percent) are the five slope categories that vary by area (8.5-16.5 percent).

Compactness Coefficient (R_c)

A complete circle-shaped basin has an R_c of one. For a square basin, the value may be rise to 1.128, and in the case of a very long bay, it may be exceed3 (Singh *et al.,* 2013). According to Ratnam et al. (2005) and Pankaj and Kumar, (2009), the basin with a circular shape is the most detrimental because it yields the smallest concentration-time for peak flow in the basin. The C_c is unaffected by the size of the watershed and is solely influenced by the slope. (Table 3) show that the R_c for the Halayapura micro watershed is around 0.6 and indicating less influence of flood within a short duration (Table 3).

Conclusion

A micro-watershed is a significant geomorphological unit that shows topography and hydrological harmony. The Halayapura micro watershed morphometric analysis was mapped and measured with great accuracy using GIS technology. According to the research, the micro watershed has a well-developed drainage network

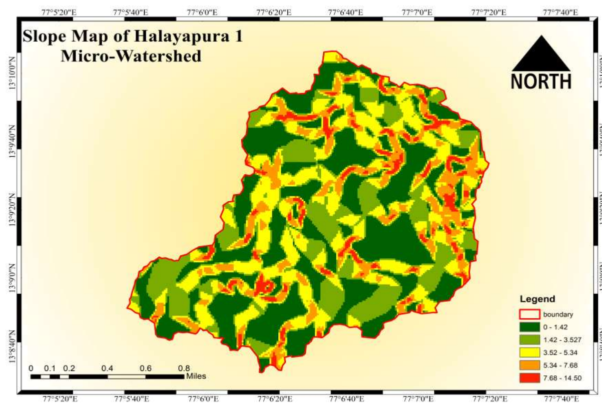

Figure 9: The slope of the Halayapura micro-watershed.

and a mature geomorphic stage. The D_d number denotes terrain with a moderate the slope, minimal to dense vegetation, a higher infiltration rate, and medium surface runoff. The micro watershed form was lengthened, making it less prone to flooding, erosion, and sediment transfer. The assessment of linear, areal, and relief characteristics using a DEM derived from contour and site altitude is extremely valuable for determining a specific micro-watershed area's physical and climatic features. The length of an overland flow indicates that the soil has good infiltration and percolation qualities. The drainage basin is less elongated, resulting in shorter-duration peak flows and shorter-distance outflow. As a result, GIS is a valuable and efficient tool for computing and analyzing the basin's many morphometric parameters.

Acknowledgement

The first author gratefully acknowledges the research fellowship received from the UGC- Post Graduate Scholarship for Professional course, New Delhi, Grant No: F./2016-17/PGSPROF-2016-17-KAR-50144 carrying out research work. The authors also wish to thank Sujala-III project UAS, GKVK, Bengaluru, and KSRSAC faculty members for providing the facilities for experimenting.

Conflict of interest

The authors declare that they have no conflict of interest.

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