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Morphometric Analysis of Karkala Micro Watershed, Karkala Taluk Udupi District, Karnataka India

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***Abstract:** An integrated assessment of morphometric parameters has been conducted in this study with an objective of to develop the watershed and manage the available water resources in a hard rock terrain area at Karkala Taluk, Karnataka. According to the analysis of the Karkala micro-watershed, which is classified as closed basin with third-order dendritic drainage pattern, the watershed has a dense canopy of vegetation, a low relief, minute runoff, and a high infiltration rate. Drainage patterns are not greatly affected by geological structures. The basin's elongated shape is supported by the form factor, circulation ratio, and elongation ratio numbers. The Karkala micro-watershed's longitudinal profile exhibits a sharp gradient in the initial stages that has been progressively flattening as the river has weakened. Hypsometric integral found for the Karkala micro watershed is 0.5, showing the maturity stage of the basin. Low values for drainage density and texture, stream frequency, and infiltration number suggest that permeable rocks are underling and this controls the runoff in study area. Therefore, the integrated results of the morphometric assessment at the micro watershed level would be helpful for developing and managing water resources as well as for water harvesting.*

***Keywords:** Hypsometric Analysis; Hard Rock; Morphometry; Watershed Management; Karkala; Karnataka.*

I. INTRODUCTION

The only supply of water in the hard rock terrain region of Karkala is groundwater. Karkala has its heaviest rainfall during the SW monsoon, although the hot summer water crisis is a severe issue for residents due to the geology of the area. In a hard rock terrain area, a sustainable water resource development and management through a watershed analysis becoming more interesting and in demand. For a sustainable water resources, the quality and quantity of groundwater is more essential. Assessment of drainage pattern and their quantitative morphometric parameters decide the geohydrological nature of basin. A drainage basin is a catchment zone that a water system drains, allowing all flow to escape in that area through a single outlet [3].

Morphometric analysis of a drainage basin, is the best way to gather all the information regarding the hydrological performance, such as slope, infiltration rate, drainage density, runoff, soil erosion, sediment transport, geology and landform development. Additionally, comparing the evaluation of several drainage basins in various geological and climatic environments and grasping the relationships between various components of the basin's drainage pattern [4]. Since the study area entirely depends on precipitation, identifying the zones of groundwater potential is more essential for a sustainable resource management [1], [2]. Based on a literature review, Horton (1932, 1945) [4], [5] discussed the importance of the quantitative geomorphological study in water resource management studies. Later, Strahler, (1957, 1964) [6], [7] and other geomorphologists expanded the study with watershed morphometry approaches. Earlier morphometric analysis was carried out through topographical maps and fieldwork. Recently using remote sensing data in GIS environment made the task much easier for the researchers. Integrated approach along with high-resolution digital elevation maps (DEM) were used for the extraction of drainage networks in watershed study. Due to its faster, reliable, relevant and affordable feature received increased attention in watershed study method [8]. Shuttle Radar Topographic Mission (SRTM) DEM and CARTOSAT DEM [9], [10] were used by most of the researchers for acquiring the morphometric parameters. Avinash et al., (2011) [11] expressed that morphometric analysis is an important tool for evaluating and interpreting the hydrological behaviour as well as understanding the evolutionary changes in geomorphology. Watershed morphometric parameters namely bifurcation ratio, drainage density, stream frequency, stream length, circulatory ratio, elongation ratio etc. were extracted. The Kusre, (2013) [12] suggested that hypsometric analysis is useful in planning engineering project in a watershed where the information regarding the actual runoff and sediment yield is lacking.

II. STUDY AREA

Karkala micro watershed lies between geographical extents of North latitudes 13º11´30´´ to 13º14´0´´ and East longitudes 74º57´30´´ to 75º00´30´´ which covers 10 km2 area found in the Karkala Taluk of the Udupi district of Karnataka State (Fig.1). The Karkala micro watershed is a sub-basin of the Swarna river falling in the western flank of Western Ghats draining.

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Karnataka's typical Kanara pediplain surfaces of Coastal Landform Terrain. The average annual precipitation of Karkala is around 400 mm and the rainy season lasts roughly four months from June to September (SW-monsoon). Normal annual precipitation estimated for last thirty years for Karkala is 4626 mm. The mean temperature of 26 to 29 °C and relative humidity levels between 74 and 91, the study region has a tropical humid climate.

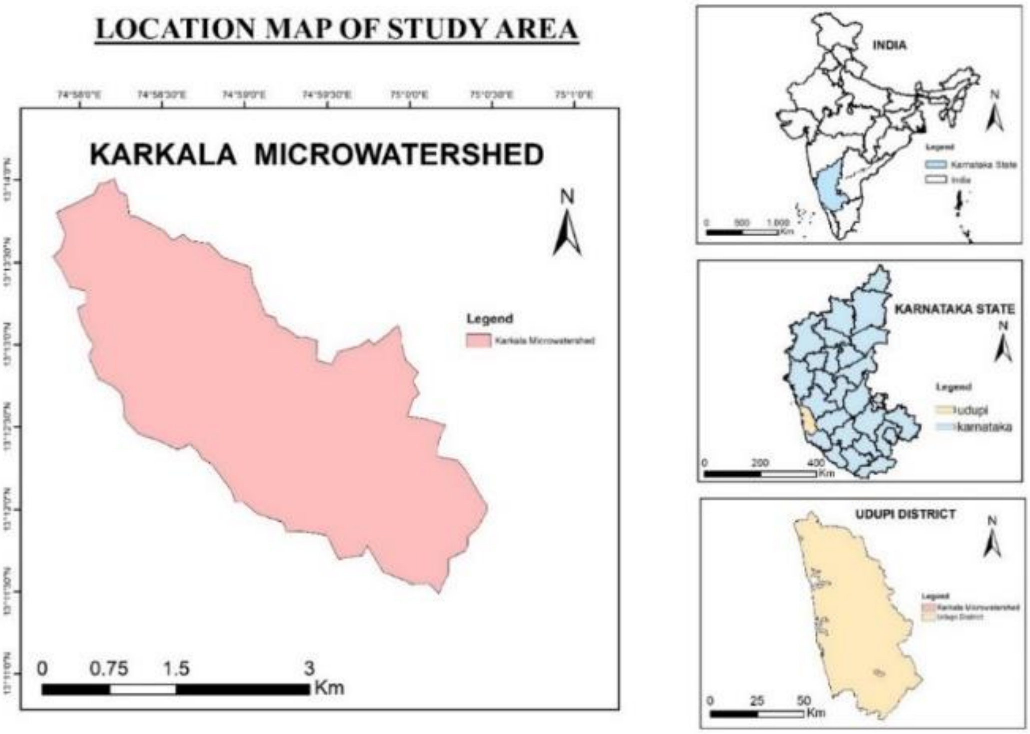

Fig.1 Location map

Geology and geomorphology have major role in the existence of groundwater especially in the hard rock terrain. The geology of Karnataka is restricted to the two oldest eras namely Archean and Proterozoic (Geological Survey of India, 1981). One of the world's oldest Pre-Cambrian terrains is the Karnataka Craton, which is found in the western section of Southern Peninsular India. Its geological history is restricted to the Archaean and Proterozoic eras. The Peninsular Gneissic Complex's primary rock unit, granite, is abundantly exposed in the region. Granite gneiss is distinguished by such a collection of gneisses and granites that differ in composition and texture. The particular type of South Kanara granite is called porphyritic biotite granite.

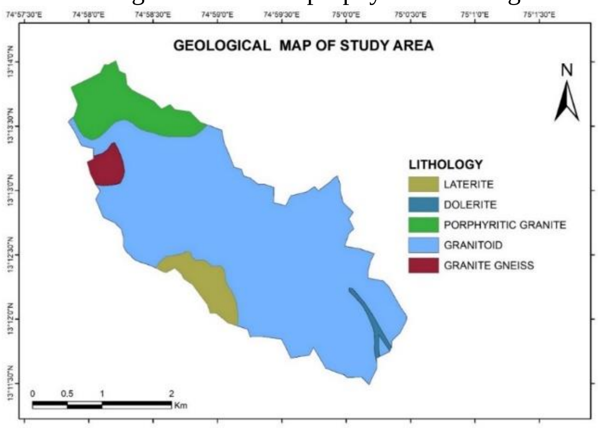

Fig.2 Geological map of Karkala Micro watershed

Figure 2 represent the geological map of the study area and the rocks were identified as laterites, dolerite dykes, porphyritic granites, granitoid and granite gneiss. These rocks belong to different periods of geological history from Archean to the recent age. Lateritic soils have been noted at places capping mainly over the gneisses. The thicknesses of the soils vary from place to place from less than one meter to as much as five meters [13]. Highly elevated area is Parpale gudde, where the bare hilltop is exposed to intense subaerial weathering and leaching. Due to this process laterite capping is found on the peninsular gneissic complex. Most of the plains are occupied by the soils that originated from the granites and gneisses. Using ArcGIS 10.3.1, the geological map was digitally generated from GSI (1:50,000 scale).

III. METHODOLOGY

For better understanding the hydrologic behaviour of the Karkala micro-watershed, the entire watershed is evaluated for morphometric analysis [5], [14] and [15].

A. Data Collection

Remotely sensed satellite imagery is acquired from the USGS website in order to complete the current study. A field visit was chosen in order to conduct the geomorphological and geological examination. The hydrological network (drainage pattern) was extracted from the SRTM DEM (30 m resolution). Figure 3 shows the different steps used in methodology. Karkala micro watershed is digitized from the SRTM DEM. ArcGIS 10.3.1 geoprocessing tools were used for the morphometric parameters analysis and different aspects such as Basic, Linear, Areal and Relief were estimated and results were obtained.

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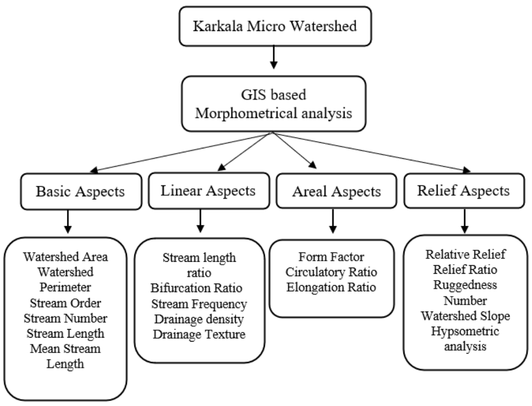

Fig. 3 Methodology adopted for the study

IV. RESULT AND DISCUSSION

A. Basic Aspects

i. Watershed area (A), Perimeter (P), length (L) and Width (W): The basic characteristics of watershed namely basin area, perimeter, basin length and width, stream order, stream length and stream number were measured in the GIS environment. The watershed area (A) of Karkala micro watershed is 9.66 sq. km with perimeter (P) of 16.71 km. The maximum length (L) and width (W) are 5.91 km and 2.58 km respectively. Figure 4 illustrate the drainage pattern within the watershed and it is drained by third order stream with dendritic drainage pattern which indicates the erosional streams with homogenic texture and not disturbed by structural control [16].

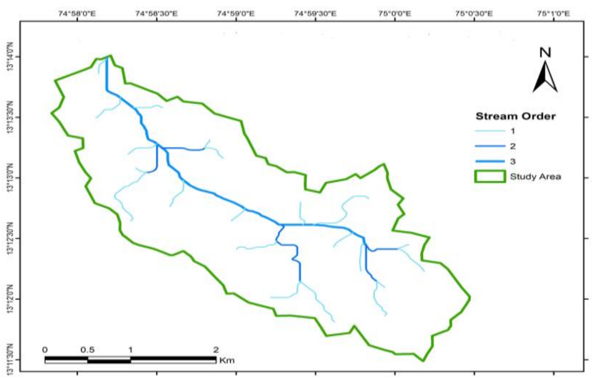

Fig.4 Drainage network of Karkala Micro watershed

ii. Stream order (U): Strahler's (1952) [15] approach to the direction of flow and flow accumulation has been applied. The first-order streams exhibit the maximum frequency, which drops when the stream order is raised. In Table I, explain the stream order (U) and number of streams (N) of respective orders. The estimated value of Lsm, RL and Rb for the study area also shown in the table.

Table I Estimated values of linear aspects

Stream order (U)	*Nu*	*Lu (km)*	*Lsm= Lu/Nu*	*RL*	*Rb*
1	21	8.9	0.42		4.2
2	5	3.2	0.63	0.36	5
3	1	4.6	4.65	1.47	
Total	27	16.7			
Mean			5.7	RLm = 0.91	Rbm = 4.6

iii. Stream length (Lu) and Stream number (Nu): The length and number of streams are calculated by the drainage threshold value defined during the retrieval of the drainage pattern from the DEM. Stream length has great significance in geo-hydrological study and it influences the surface runoff features [1]. The third order Karkala micro watershed identified with total 27 stream segments (Nu) and the total length of stream (Lu) is 16.7 km. Percentage contribution for length of stream, 1st order is 81.5%, 2nd order is 11% and 3rd order is 7.5% given in Table 1. Generally, streams number decreases with the increasing order of the stream [10]. Figure 5 illustrates the link between the number of streams and stream order and confirming Horton's (1932) "Law of stream numbers".

iv. Average stream length (Lsm): As shown in Table 1, the fraction of the Lsm rises with the increasing order of streams. The Lsm for the 1st order is 0.42 km, 2nd order is 0.63 km and 3rd order is 4.65 km. The correlation between mean stream length and stream order was plotted (Fig. 6) and the results support Horton's (1932) "Law of stream length" by demonstrating an approximative direct geometric relationship between the two. The physiographic and structural characteristics of the area have a major role in the watershed's size and order difference [17].

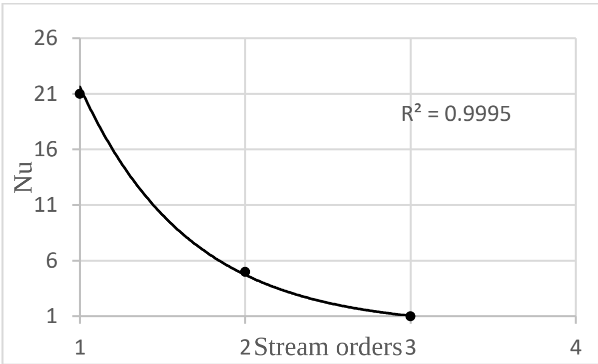

Fig. 5 Geometric connection of stream orders and number of streams.

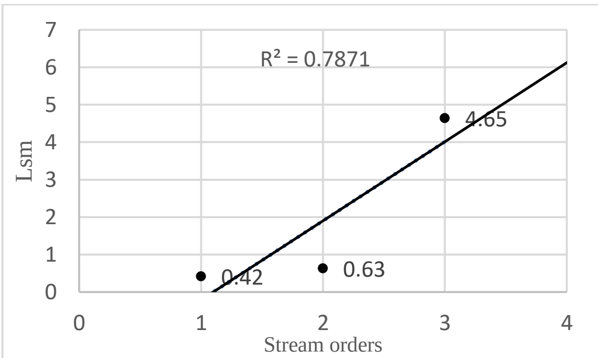

Fig. 6 Geometric connection of stream orders and Lsm

B. Linear Aspects

The following linear characteristics of the drainage basin were determined using common formulae: stream length ratio (RL), bifurcation ratio (Rb), stream frequency (Sf), drainage density (Dd) and drainage texture (Dt) (Table II).

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Table II Morphological parameters and equations

Sl. No.	*Aspects*	*Formulae*	*References*	*Study area (KMW)*
A	**Basic Aspects**			
i	Watershed area (A), Perimeter (P), length (L) and Width (W)	-	Horton (1945)	A= 09.66 km^2 P= 16.71 km L= 05.91 km W= 02.58 km
ii	Stream order (U)	Hierarchical rank	Strahler (1952)	1, 2, 3
iii	Stream length (Lu) and Number (Nu)	Length of the stream	Horton (1945)	Lu =16.7 km, Nu = 27
iv	Mean stream length (Lsm)	Lsm = Lu/Nu	Strahler (1964)	5.70
B	**Linear Aspects**			
v	Stream length ratio (RLm)	RL = Lu/(Lu-1)	Horton (1945)	0.91
vi	Bifurcation ration (Rbm)	Rb = Nu/Nu + 1	Horton (1945)	4.6
vii	Stream frequency (Sf)	Sf =Nu/A	Horton (1945)	02.79
viii	Drainage density (Dd)	Dd =∑Lu / A	Horton (1945)	01.73
ix	Drainage texture (Dt)	Dt=Dd x Sf	Smith (1950)	04.84
C	**Areal Aspects**			
x	Form factor (Ff)	Ff =A/L^2	Horton (1945)	00.28
xi	Elongation ratio (Re)	$Re = \left(\frac{2}{L}\right)\left(\frac{A}{\pi}\right)^{0.5}$	Schumm (1956)	00.52
xii	Circularity ratio (Rc)	Rc =4 $\pi A/P^2$	Strahler (1964)	00.43
D	**Relief Aspects**			
	Maximum elevation (H)			225 m
	Minimum elevation (h)			61 m
xiii	Basin Relief (R)	R= H- h	Schumm (1956)	164 m
xiv	Relief ratio (Rr)	Rr =R/L	Schumm (1956)	0.04 m
xv	Relative relief (Rhp)	Rhp=R/P	Melton (1957)	0.0135 m
xvi	Ruggedness number (Rn)	Rn= R*Dd/1000	Strahler (1958)	0.284km/km^2
xvii	Slope Analysis	ArcGIS analysis		
xviii	Hypsometric integral (HI)	$= \frac{Elev\ mean - Elev\ min}{Elev\ max - Elev\ min}$	Pike & Wilson (1971)	0.5

v. Stream length ratio (RL): RL value can well explain about the permeability capacity of underneath rock strata [18]. The estimated RL ratio for 1st to 2nd order are 0.36 and 2nd to 3rd order are 1.47, respectively (Table II). The terrain, gradient and advanced stage in geomorphic development could significantly contributing to the variation in RL values [19].

vi. Bifurcation ratio (Rb): The number of streams of a particular order (Nu) to its next higher order (Nu+1) is referred to as the bifurcation ratio (Rb) [5]. Strahler (1964) states that drainage patterns are not disrupted by geologic structures when the value of Rb is between 3 and 5. However, drainage patterns are controlled by structures when the value of Rb is greater than 5. The drainage network is not impacted by geological structures, as per the Rb value for the Karkala micro watershed, which ranges from 4.2 to 5.8. The mean bifurcation ratio (Rbm) is 4.6. The shape of the basin can also be assessed from the bifurcation ratio, a high Rb value indicates an elongated basin, while a low Rb value indicates a circular basin. The high Rb value illustrates the elongated character of the Karkala micro watershed [20].

vii. Stream frequency (Sf): Stream frequency is regulated by rainfall, permeability, infiltration capacity, relief, and drainage density of the basin. A poor drainage network is represented by a lower Sf value, in such cases infiltration capacity and groundwater potentials are very less [21]. While in plateau regions, the limited porosity and reduced surface flow diminish the Sf value, high rainfall and slope enhance stream frequency. The Karkala micro-watershed has a stream frequency of 2.79 km^2, a moderate value that highlights the area's low elevation and highly permeable geology.

viii. The Drainage density (Dd): The drainage density (Dd): The drainage density expresses how closely spaced the stream channels are within the drainage basin and offers information on the landform [22]. Karkala Micro Watershed's drainage density value is 1.73 km/km^2 (Table II) and it represents (Fig. 7) the strong infiltration capacity, dense plant cover, low relief, minimal runoff and highly permeable subsurface material in the study area [23], [24] and [25]. The infiltration number is 4.83, result of multiplying the drainage density by the stream frequency (Sf) and this suggests greater infiltration and decreased runoff [26].

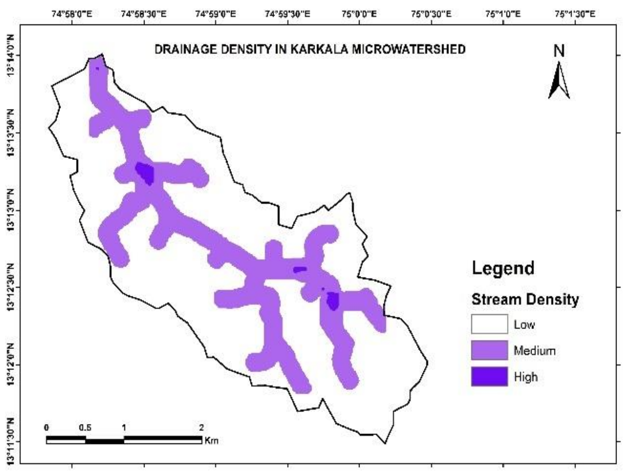

Fig. 7 Drainage density map of study area

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ix. Drainage texture (Dt): One of the key factors in geomorphological study and it reveals the actual spacing of drainage systems. Infiltration capacity affects drainage texture and its values rely on the geological setting, infiltration rate and relief characteristics of the catchment. According to Smith (1950), there are 5 distinct drainage density textures: very coarse (2), coarse (2–4), intermediate (4–6), fine (6–8) and very fine (>8) [26]. From Table II, the drainage texture is 4.84 in study area shows coarse to moderate texture.

C. Areal aspects

Shape parameters for the drainage basin, particularly form factor (Ff), elongation ratio (Re) and circularity ratio (Rc), were computed using formulas that are commonplace (Table II).

x. Form factor (Ff): Horton (1945) suggested this method to forecast the flow rate of a basin within a specified area. A smaller form factor number implies that the basin is elongated. The estimated number of Ff is 0.28 (Table II), indicating a very long basin with flatter peak flows that last for a longer time.

xi. Elongation ratio (Re): The Re value normally varies from 0.6 to 1.0 and is related to a wide range of geology and climatic conditions. The studied area's elongation ratio is 0.52 (Table II), which indicates a less elongated watershed**.**

xii. Circularity ratio (Rc): This was first defined by Strahler (1964) as the ratio of the basin's surface area to the surface area of a circle with the same diameter as the basin's perimeter. The circularity ratio and elongation ratio are related metrics [25]. Naturally, all basins have a tendency to take on an extended shape as they mature. The obtained value for the study area is 0.43 the (Table II), which indicates that the basin has an elongated shape.

D. Relief Aspects

Basin relief (R), Relief ratio (Rr), Relative relief (Rhp), Ruggedness number (Rn) and hypsometric integral analysis are among the relief-related three-dimensional characteristics.

xiii. Basin relief (R): The elevation difference between the basin's highest and lowest points is known as the "basin relief" (R) [27]. All landforms, especially drainage patterns, surface and subsurface water flow, intensity of erosion and permeability of a basin, are a reflection of basin relief [3]. Understanding the denudational characteristics of the basin rests on the relief of the basin. Figure 8 shows the DEM map of the study area where the highest elevation and lowest elevation is 225 m and 61 m respectively and the estimated basin relief is 164 m (Table II). The high relief value denotes situations with heavy runoff, low infiltration and gravity-driven water flow. The basin relief always regulates the stream gradient, which affects the flood patterns and the amount of transportable silt.

xiv. Relief Ratio (Rr): The study area comes under a low relief plain, is an extended basin with significant overland flow and has reached the maximum denudation phases of geomorphic evolution, as evidenced by the estimated Rr value of 0.038 (Table II) [4]. The distinguishing property of pediplains and valleys is the low relief ratio number [1]. Mountain regions normally have higher Rr values than flat river basins [28].

xv. Ruggedness Number (Rn): The study area ruggedness number is 0.284 km/km^2 which corresponds to an averagely sloped basin (Table II). Because of the area's key structural complexity with respect to relief, drainage density and its low roughness value, it is less likely to experience soil erosion [17]. Extremely high values of the roughness number indicate a long, steep slope, whereas low values indicate a gradual slope of the basin.

xvi Slope analysis: The contour (Fig. 9), aspect (Fig. 10) and slope (Fig. 11) map were acquired from the SRTM DEM at 30 m resolution. The contour map with 10 m intervals provides insight into the inclination of drainage basin and interpret the characteristics of the land surface [29]. At the southwest corner of the watershed, the contours have been found to be closely spaced and as one moves down the watershed, the distance between each subsequent contour increases (Fig. 9).

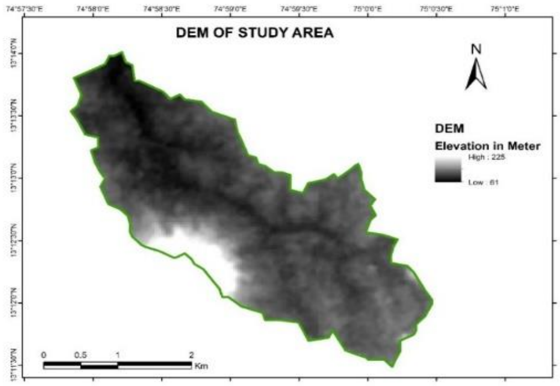

Fig. 8 DEM map of study area

The term "aspect" often refers to the direction that a mountain slope faces. Because the sun's rays are in the west during the hottest part of the day, in the afternoon, a west-facing hillside will generally be warmer than a covered east-facing slope. This determines how vegetation and biological diversity are distributed in the research region [22].

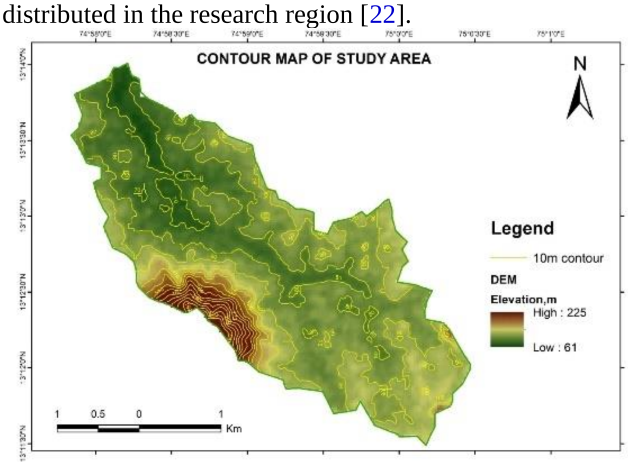

Fig. 9 Relief map of study area

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Analysis of slope has a major role in the geomorphological studies. It influences the watershed characteristics, the rainfall circulation and land utilization [25]. The infiltration rate, flow velocity, runoff and sediment transportation were regulated by slope. Based on the slope map (Fig.11) Karkala watershed slope ranges from 0° to 24°. Low runoff, minimal erosion and high recharge potential are provided by lower slope angle [17].

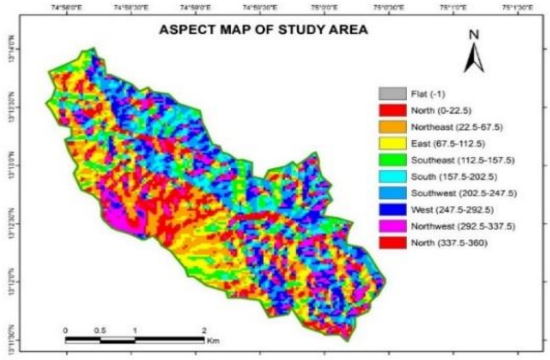

Fig. 10 Aspect map of study area

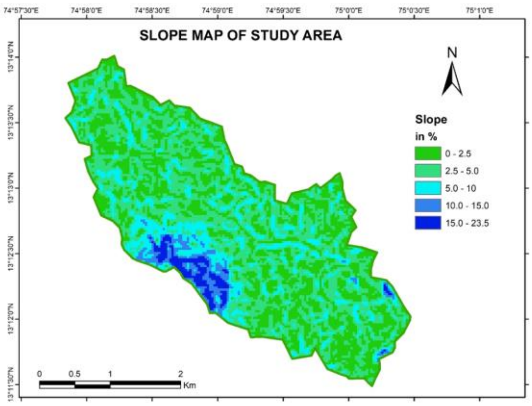

Fig.11 Slope map of study area

xvii. Hypsometric curve and Hypsometric Integral analysis: The hypsometric curves and hypsometric integral (HI) values reveal important details regarding the geological evolution of the area. The hypsometric curve is generated by plotting the relative heights (h/H) and areas (a/A). The ratio of the area above a specific contour to the entire watershed surrounding the outlet yields the relative area. The height of a specific contour (h) from the base plane to the maximum basin elevation (H) is used to compute the relative elevation [12]. The hypsometric integral is obtained by integrating the hypsometric curve. A mathematical formula for calculating the elevation-relief ratio E was proposed by Pike and Wilson in 1971 [29].

$$E = \frac{Elev\ mean - Elev\ min}{Elev\ max - Elev\ min}$$

Where, E is the elevation-relief ratio similar to the hypsometric integral (HI). *Elev mean* is the weighted mean elevation of the watershed; *Elev min.* and Elev *max*. are the minimum and maximum elevations. The hypsometric integral is represented in percentage units [29]. Three threshold values were proposed by Strahler, (1952) for hypsometric integrals (HI) such as in equilibrium (youthful) state (HI $\geq$ 0.6); equilibrium state (0.35 $\leq$ HI <0.6) and monadnock state (HI < 0.35). A hypsometric analysis was performed in order to draw the hypsometric curve (Fig.12) and the cumulative percentage of surface areas to elevation points were calculated in a GIS environment (Fig.13). The HI value for the Karkala micro watershed is 0.5 and it reflect the equilibrium state of Karkala micro watershed in the erosional cycle [30].

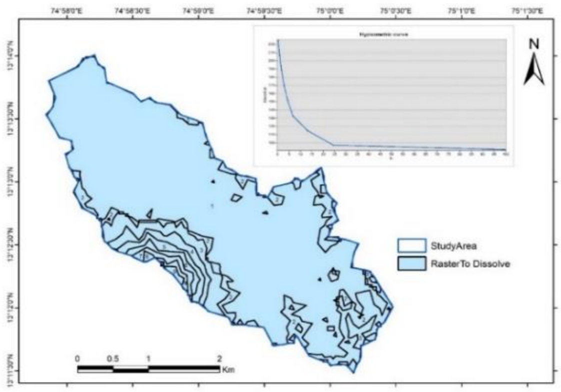

Fig. 12 Hypsometric analysis of study area

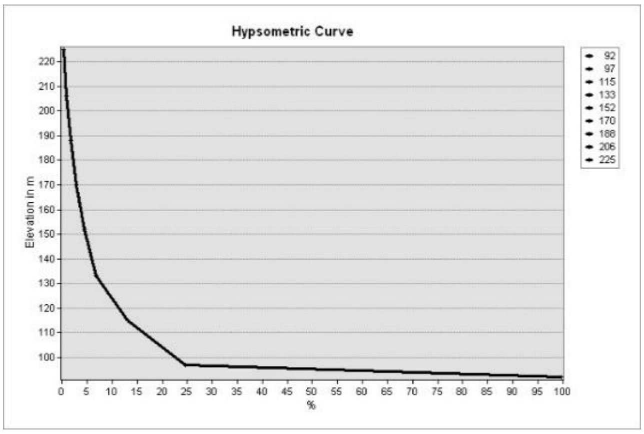

Fig. 13 Hypsometric curve of study area

E. Land use and Land cover

Land is one of the most important natural resources. Land resource management and development is based on the spatial pattern of land use/land cover and their temporal changes in the pattern [26]. Environmental parameters such as climate, geology, geomorphology, soil cover, vegetation and occurrence of water influences the changes in land use/land cover pattern.

Table III LU/LC classes of study area

Sl. No.	*LU/LC class*	*Area (Sq. Km)*	*Percentage (%)*
1	Forest	3.008	31.14
2	Agriculture	3.7617	38.94
3	Waterbody	0.0646	0.67
4	Barren land	1.811	18.75
5	Built-up	1.0148	10.51

Information regarding the existing environmental conditions is necessary for a watershed management and developmental studies. Five classes are listed in the Level 1 LU/LC classification: forest, agriculture, water bodies, barren land and built-up zones (Fig.14). In Table III, the LU/LC analysis is discussed in detail and Fig. 15 illustrates a pie diagram for the graphical representation.

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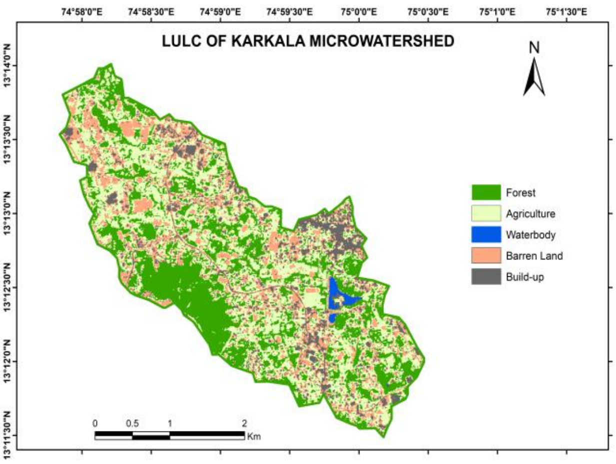

Fig.14 LULC map of study area

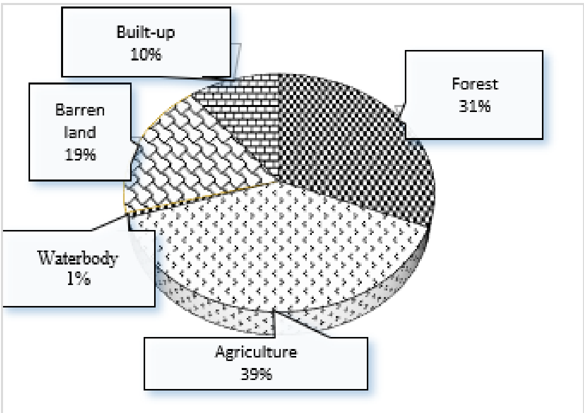

Fig.15 Pie diagram of LU/LC

V. CONCLUSION

Assessment based on morphometric parameters of Karkala micro-watershed of Udupi District of Karnataka reveals the hydro geomorphological conditions where the geology is consists of hard rock types date from the age Archaean to Recent. The watershed is composed of highly permeable subsurface material, low relief, low runoff, high infiltration capacity with dense vegetation cover. A closed third-order basin with a dendritic drainage pattern and the drainage patterns are not much influenced by geological structures. The elongated shape of the basin supported by the form factor, circulation ratio and elongation ratio values. The longitudinal profile represents a high gradient at the origin, but it gradually flattens out as the river erodes towards its base level, according to the hypsometric integral assessment, which reveals the basin's stage of maturity.

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