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Remote sensing and GIS based characterization of Ranikere catchment using morphometric analysis

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Abstract: Watershed delineation plays an important role in hydrologic analysis. Digital Elevation Model (DEM) data is used to analyze watershed characteristics. Using GIS, it is possible to automatically extract drainage networks and to delineate watershed boundary. Watershed management includes creating and implementing plans, projects, and programs to enhance and sustain water resources (Pandurang D. Jankar et al, 2013. An attempt has been made to delineate Ranikere catchment area and analyze the morphometric patterns of this catchment and also the significance of these parameters are discussed in this article.

Key Words: Morphology, Remote sensing, GIS, Digital Elevation Model (DEM)

Introduction: Groundwater is the purest water which meets the supply of domestic need, irrigation, industrial usage and other developmental activities (Abdo Wudad et al, 2021). Rainwater is a scarce and critical resource in recent decade to support livelihood, food, agriculture, and horticulture (Mr. Vishal P. Kumbhar et al, 2013). Groundwater conditions at a given place are unique and not uniform (Ganesh K.M et al 2018).). For proper planning of agriculture, forestry and regional planning, it is very necessary to understand the water flow direction and factors affecting the water flow.

Land use practice and elevation parameters affects the majority of ground water resource in an area as over-exploitation of ground water has been directly influencing the change of climate and creating disturbed spikes in water cycle. The need of recharge and saving the ground water hits the peak in recent era. This is one field where an effective human involvement can make a big positive difference. In recent years Geoinformatics and remote sensing-based case studies have gained much value because of its dynamic data handling and detailed information insights. GIS and Remote sensing techniques allows to perform groundwater potential zone categorization in an effective and efficient manner. An attempt has been made to deep dive on watershed applications in delineating Ranikere catchment zone and to analyze geomorphological parameters.

Study area: The present study area lies in semi – arid region in Karnataka state. Ranikatte catchment is shared between Challakere and Chitradurga taluk as shown in figure1. This study area covers an area of 1045 Sq Km. Chitradurga district is considered as one of the drought prone district in Karnataka. Arid and semi – arid regions are diverse in terms of soil, lithology, rainfall, water table and Land use/Land cover distribution. Chitradurga district covers an area of 8388 sq. kms and comprises six taluks as shown in Figure 1. This district receives low to moderate rainfall and listed under drought prone districts in the state. Normal annual rainfall ranges from 668mm in Holalkere taluk in western part to 457mm in Chellakere taluk, in the northeastern part. Geographically major portion of the district falls under Krishna basin and is drained by Vedavathi River. This study is immediately required to balance the water distribution within the catchment and to plan necessary recharge structures required at suitable sites.

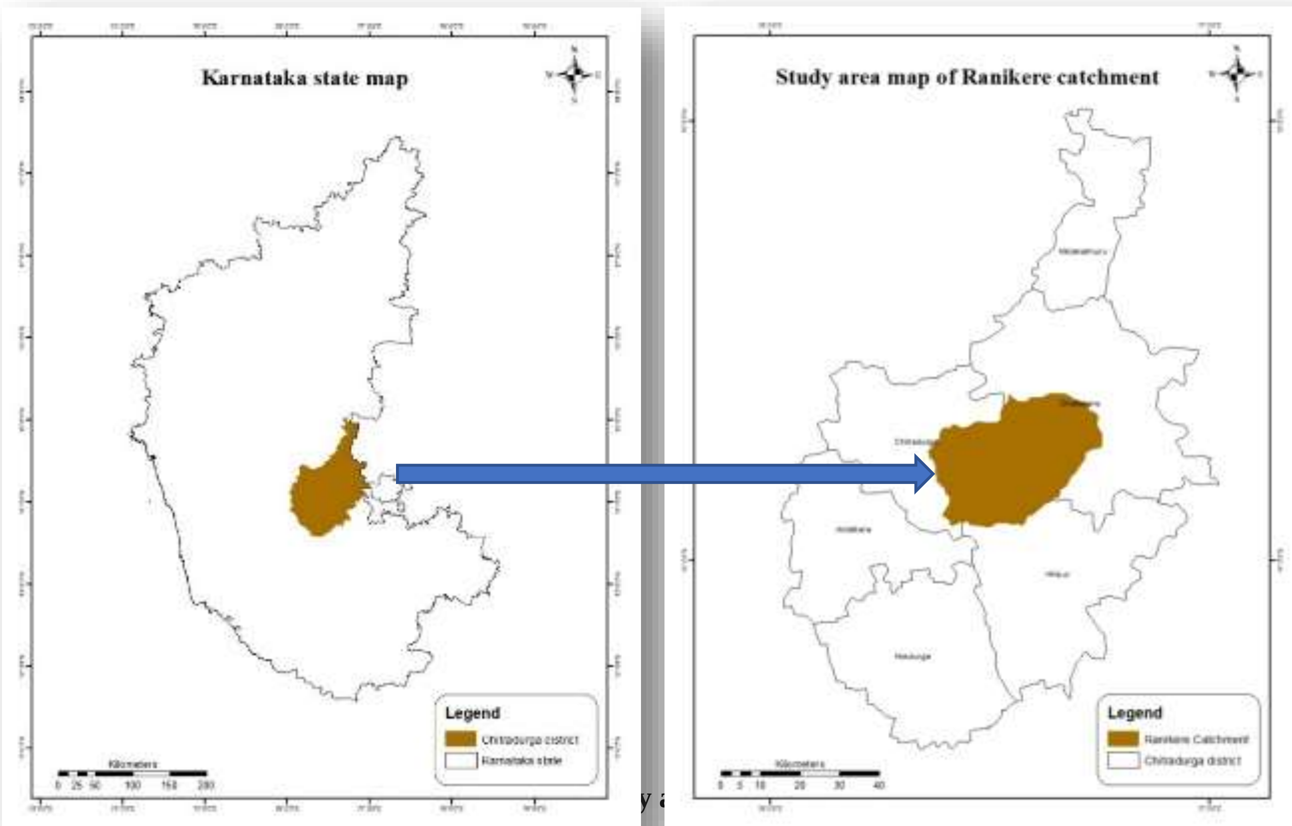

Figure 1: Map showing study area of Ranikere catchment

Data used: Digital Elevation Model is a digital model or 3D representation of terrain surface. It represents land surface elevation with respect to a fixed point. CartoSat DEM was downloaded from Bhuvan portal (https://bhuvan-app3.nrsc.gov.in/data/download/index.php) and processed in ArcGIS 10.1 to analyze hydrological regime. Cartosat – I is launched by ISRO on 5th May 2005 (Gajalakshmi K. and Anantharama V., 2015). It serves sterio data for entire India. DEM data is generated with the help of digital photogrammetric techniques. CartoSat DEM is best fit for the analysis of contour generation, soil erosion studies, drainage network analysis, land slide analysis, river and flood analysis, surface run-off estimates and watershed planning (D. Giribabu et al, 2017).

Methodology: GIS technology helps to automatically extract watershed and drainage features. Huge amount of water resource data can be processed within a short duration using geospatial approaches. GIS provides various set of tools to improve efficiency and effectiveness for geographic and non-geographic data (Vassilos A. Tsihrintzis, 1996). Hydrology tools allows to model the waterflow across a surface. ArcGIS is an efficient tool in analyzing the hydrologic properties. Following analysis were performed using the "Hydrology tools" in ArcGIS.

Result and Discussions:

Fill:

Fill performs the filling of sinks in a grid. Fill averages the value of elevation and shows the flow direction. Sinks and peaks are usual errors occurred mainly based on data resolution or sometimes levelling or rounding up of elevation to the nearest integer value. All these sinks should be filled before delineation of streams, watershed, and basins.

The process is set in such a way that it iterates until all sinks within the given limit (z value) are filled. Once the sinks are filled, we can extract the boundaries of filled area. This process can also use to remove the peaks in the data which are usually cells with greater elevation than expected. Figure 3.1 represents the filled data of Cartosat DEM.

Ranikere catchment follows the slope from West to east. Eastern part of Ranikere catchment is the low lying area. Figure 3.1 represents the filled DEM with dark tone pixels as low elevation terrain and light tone pixels as high elevation land.

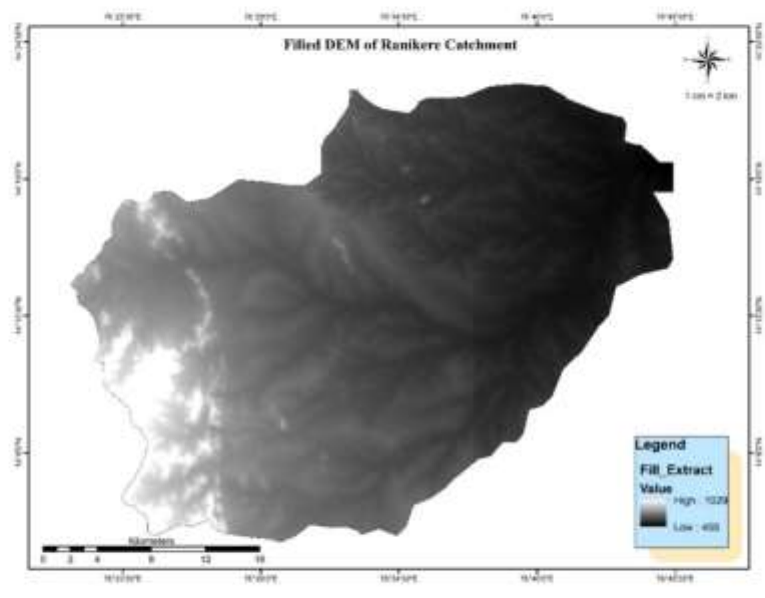

Figure 3.1: Filled DEM of Ranikere catchment

Flow accumulation:

Flow accumulation calculates the drainage flow into each cell. After filling the sinks now, the region is free of errors like sinks and peaks and now whatever water flows inside the area or region will distribute without getting stored. In flow accumulation we will generate a raster which represent the water accumulation scenario inside the given area. This is main step to identify and extract the drainage network.

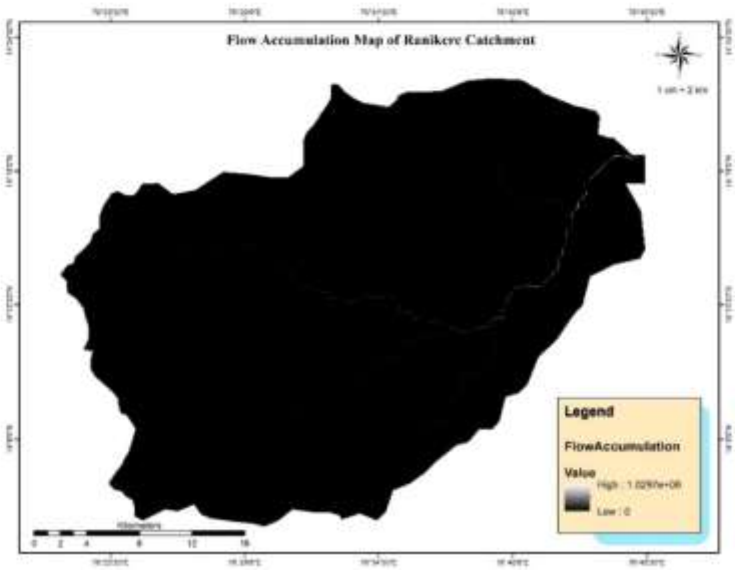

Figure 3.2: Flow accumulation of Ranikere catchment

A best example to explain flow accumulation is calculation of amount of rain fallen in each watershed and this example is a scenario where the scenario of pure runoff and no infiltration or evaporation of water. The result of this method will be used to create stream network by giving threshold which is based on cell of high accumulated flow. Flow accumulation of Ranikere catchment is from west to east. All the water source in Ranikere catchment ends in Ranikere tank. Flow accumulation of Ranikere catchment is shown in Figure 3.2.

Flow direction:

Flow direction performs the flow direction from each cell to its neighbor downslope. One of the main reasons to derive hydrologic characteristics of a surface is the ability to identify the flow of water from one pixel to other in the raster. This function takes surface as input and creates an image in which the flow from each pixel to its steepest downslope neighbor found. This process sometimes fails to operate effectively on flat areas (pixel with equal elevation) where flow routing does not exist.

Figure 3.3: Flow direction of Ranikere catchment

There were several algorithms in recent times which happens to extract flow direction from the flat surfaces taking surface characteristics. Figure 3.3 represents the flow direction map of Ranikere catchment. Flow direction of Ranikere catchment is shown in 8 category of slope directions. The deepest slope direction is recorded with blue color.

Raster calculated stream features:

Raster calculator is a tool in ArcGIS. It helps us to create algebraic expressions to validate the statements. The main feature we need to extract watershed is the drainage system and which is vector layer. To create this, we use both flow accumulation and flow direction raster by applying a threshold value to select pixels with high accumulated value. These high accumulated cells can be mentioned as mouth of watershed or sub watershed from which water flow will start to the downfall.

Figure 3.4: Raster calculated map of Ranikere catchment

The resulting raster image of streams is converted to vector for further analysis. Figure 3.4 represents the drainage map of Ranikere catchment, which is an output raster from raster calculation process. The resulting drainage map of Ranikere catchment is shown above with streams directing from higher elevation terrain to lower elevation terrain.

Drainage map:

The result of previous process holds a weightage based on amount of water accumulated and direction of water flow. In the final drainage system, we can identify the drainage orders which also gives us the idea of water holding capacity of the watershed. This is the scenario-based approach under terms and conditions of sink, runoff concepts. The calculated length of each order stream is represented in Table 3.1 and Figure 3.3a as shown below.

Stream order	Extent in Kms	Stream Numbers
1st order stream	488.846	522
2nd order stream	259.963	91
3rd order stream	135.027	24
4th order stream	35.045	5
5th order stream	1.037	1

Table 3.1: Stream order details of Ranikere catchment

1st order stream in Ranikere occupies a greater extent with 522 number of total streams. This signifies the surface runoff in high in this catchment. There is a very much need of infiltration of groundwater in this catchment. For this purpose, watershed harvesting structures and rainwater harvesting measures should be very immediately required in this zone.

Figure 3.3a represents proportionate decrease in stream order extent. 5th order stream accounts only 1 kilo meter area in Ranikere catchment. As the catchment contains stream order up to 5th, it is essential to recharge the groundwater by following measures to hold surface runoff of rainwater. This study recommends to adopt the rainwater harvesting measures and watershed harvesting structure applications to sustainably develop water resource.

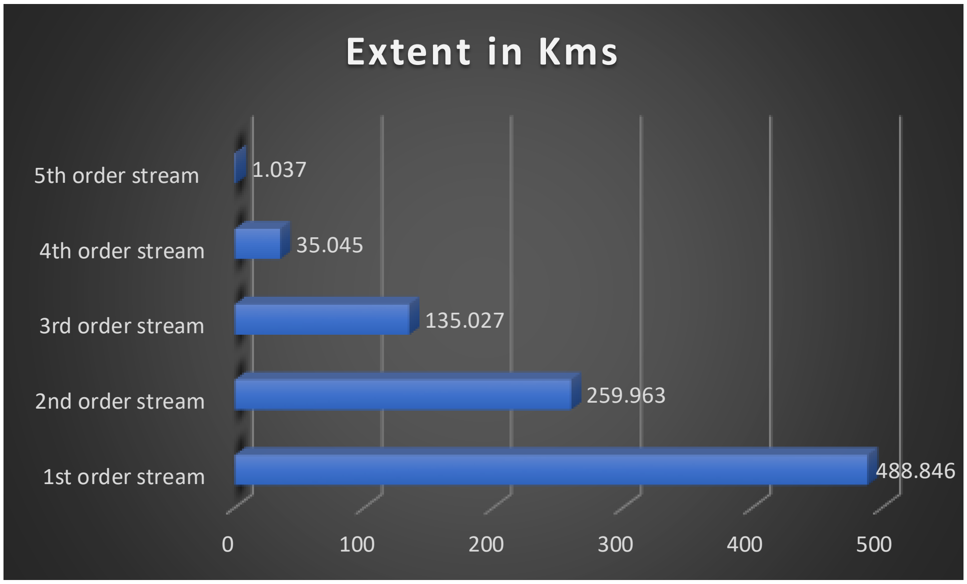

Figure 3.3a Stream order and distribution

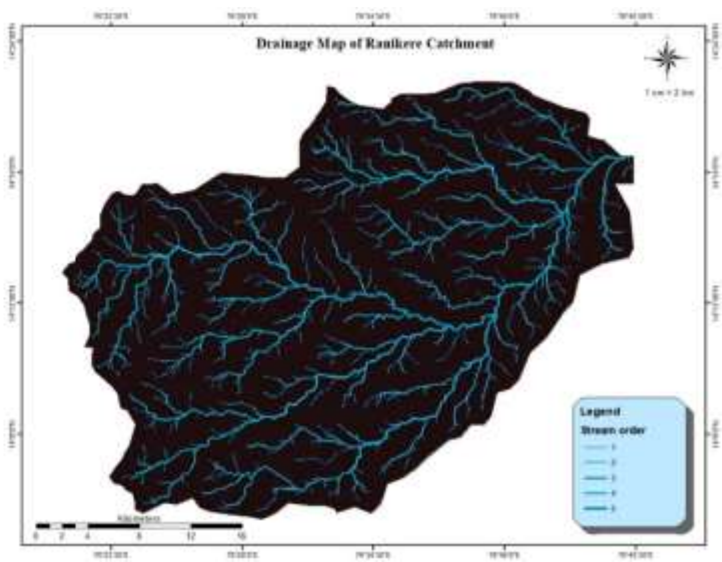

Figure 3.4: Drainage map of Ranikere catchment

The drainage map of Ranikere catchment was extracted and the stream order in this area ranges from first order to fifth order stream. Stream order map is shown in Figure 3.4, and analyzes the runoff of water from mouth to tail and capacity of watershed to withhold the water from rainfall. These studies play a massive role in understanding the floods or draught cases.

Morphometric analysis

Morphometric analysis is a quantitative and mathematical analysis of landforms (Daniel Asfaw and Getachew Workineh, 2019). It depicts the relation between terrain characteristics and geohydrologic conditions. Using morphometric analysis, it is possible to estimate surface runoff, infiltration, erosion, and rate of sediment transport.

An attempt is made to understand the relation between Ranikere catchment with the terrain characteristics. Selected morphometric linear parameters were analyzed and detailed below.

Drainage Density:

Drainage density is defined as the total length of all streams in a catchment to the total area of the catchment. It depicts the poorness or richness of a catchment to drain by streams. Drainage density depends on factors like lithological porosity and soil permeability. Areas with value of High drainage density indicate low water potentiality as the runoff contributes major in such a region. It indicates mountainous reliefs with sparse vegetation. The areas of high drainage density values are not suitable for groundwater development.

The total length of all stream order in Ranikere catchment is 999.788 Kms. The area of Ranikere catchment is 963.942 Sq Kms. Drainage density value of the Ranikere catchment is found to be 1.0371 km/km^2. As the drainage density is almost equal to 1 km/km^2 (Low value). this catchment is highly permeable landscape with minimum surface runoff. The formulae to calculate the drainage density is listed below.

$$\mathbf{Dd = Lu/A}$$

$$Dd = 999.788/963.942$$

$$Dd = 1.0371\ km/km2$$

Where, Dd indicates Drainage density

Lu indicates total length of all streams

and A indicates area of the catchment

Drainage Frequency:

Drainage frequency majorly depends on the lithology prevailing in the area. It reflects the drainage network texture and is directly related to permeability, relief of litho-units and infiltration capacity. High frequency value depicts greater surface runoff, impermeable subsurface material, steep slope, and sparse vegetation.

The total number of streams in Ranikere catchment is 643. The area of Ranikere catchment is 963.942 Sq Kms. The drainage frequency value of Ranikere catchment is found to be 0.667. As the drainage frequency value is 0.667 Km^{-2} (Low value), it indicate that this catchment consists of permeable subsurface lithology and allows much infiltration of rainwater whereby, it decreases the surface runoff. Drainage frequency formulae is listed below.

$$\mathbf{Fd = SNu/A}$$

$$Fd = 643/963.942$$

$$Fd = 0.667\ Km^{-2}$$

Where, Fd represents Drainage frequency

SNu represents total number of streams within the catchment

and A represents area of the catchment.

Drainage Texture:

Drainage texture is referred as the relative spacing between drainage per unit length in a square grid. The drainage texture of the streams is found to be 0.6917. As the drainage texture is 0.6917 (Low value), this catchment represents young topography with low relief and less surface runoff. The formulae to calculate drainage texture is listed below.

T = Dd*Fd

T = 1.0371 *0.667

T = 0.6917

Where, T represents Drainage texture

Dd represents Drainage density

and Fd represents Drainage frequency

Elongation ratio:

Elongation ratio is the significant index to analyzing basin shape. Re is defined as the ratio of diameter of a circle of the same area as the drainage catchment to the maximum length of the catchment It provides an idea of hydrological character of a catchment. The elongation ratio of the catchment is found to be 0.4347. As the Re value is 0.4347, it indicates a flat terrain with normal vegetation which is responsible for higher infiltration rate. The formulae used to calculate elongation ratio is mentioned below.

Re = D/L

Re = 47.63*109.57

Re = 0.4347

Where, Re represents Elongation ratio

D represents diameter of the catchment

And L represents longest length in the catchment

Form factor:

Form factor is referred to the ratio of catchment area to the square of the watershed length. Low Ft value resembles less side flow for shorter duration and high main flow for longer duration. The form factor for this catchment is found to be 0.4419 Km2/Km. As the Ff value is 0.4419 Km2/Km, it indicates lower peak flows of long term duration. Form factor formulae is listed below.

$$\mathbf{Ff = A/L^2}$$

$$Ff = 963.942/(20.6389)^2$$

Ff = 0.4419 Km2/Km

Where, Ff represents Form factor

A represents area of the catchment

And L represents catchment length

Constant of channel maintenance:

Constant of channel maintenance decreases with decrease in erodibility. Greater value of C depicts much area is required to produce surface flow. Lower value of C depicts less chances of infiltration or percolation and allows much surface runoff. C is the reciprocal of drainage density. The constant of channel is found to be 0.9641 km2/km. As the C value is 0.9641, it represents the catchment with high infiltration, much vegetation cover and week rock types with porosity. The formulae used to calculate C is described below.

C = A/Lu

C = 963.942/999.788

C = 0.9641 km2/km

Where, C represents constant of channel maintenance

A represents Area of the catchment

And Lu represents length of all streams

Conclusion

Groundwater is the major source in Ranikere catchment. GIS software allows us to process large amount of satellite data in user-friendly way. Hydrologic analysis in semi-arid climatic condition is immediate and very necessary for watershed planning and sustainable usage. Morphometric analysis play a significant role in understanding geo-hydrologic characteristics. An attempt is made to calculate morphometric parameters which account basin drainage network, drainage texture, geometry, and relief characteristics together with hydrological characteristics. The results showed higher porosity, lower surface runoff and weaker lithological formations with porosity. The results indicated higher infiltration of groundwater and lower amount of surface runoff. The watershed prioritization and sustainable approach is very necessary as this area is not covering much with 4th order and 5th order streams (as shown in Table 3.1). Hence recharge harvesting structures and artificial zones should be given high priority to reduce the surface runoff of rainwater. Rainwater infiltration should be the primary approach to develop groundwater resource in Ranikere catchment.

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