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Morphometric Analysis to Infer Hydrological Behaviour of ERU Watershed, Western India

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ABSTRACT
The Morphometric characteristics of a Rural Watershed of Eru river of Bhilwara and Bundi district, Rajasthan India, have been studied in the current work. Survey of India toposheets at 1:50,000 scale and SRTM 1 Arc-Second Global DEM data with 30m spatial resolutions were used for the detailed investigation. ArcGIS, Hydrology tool was used to create the watershed boundary, flow accumulation, stream number, stream ordering, and stream length. Thus, the total length of streams throughout the entire watershed was discovered to be 641.5 kilometres, indicating an extensive drainage network. More than 15 morphometric metrics from various perspectives were examined. This research is extremely important for watershed management and rainwater harvesting plans.

KEY WORDS: Morphometric analysis, SRTM 1 Arc-Second Global DEM, Delineation, Watershed

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I. INTRODUCTION

Morphometry is characterized as the estimation of the shape. Morphometric analyses within the field of hydrology were started by R.E. Horton and A.E. Strahler in the 1940s and 1950s. Morphometry may be characterized as the estimation and scientific investigation of the arrangement of the earth's surface and of the shape and measurements of its landforms' (J.I Clarke, 1970). Morphometry consolidates quantitative study about the area, elevation, volume, slope, and other characteristics of the region concerned (Savindra Singh, 1972). A drainage basin is an area of land where water from rain or snow melt sinks downhill into a body of water, such as a river, lake, estuary, wetland, or ocean.

The drainage basin comprises both the streams and rivers that carry the water as well as the land surfaces from which water drains into those channels and is separated from adjoining basins by a drainage boundary. The drainage basin acts like a siphon, collecting all the water within the area covered by the basin and channeling it into a river. Each drainage basin is divided topographically from adjoining basins by a geographical obstacle such as a ridge, hill, or mountain, which is known as a water divide. Morphometric assessment of watershed is the best method to identify the relationship of various characteristics in the area. It is a relative evaluation of different watersheds in various geomorphological and topographical situations. Watershed has surfaced as the basic planning unit of all hydrologic evaluations and projects. The main purpose of this work was to discover complete stream properties from the measurement of various stream traits. Geographical information systems (GIS) with its capacity to gather spatial data from different sources into a unified environment appeared as a significant tool for demarcation of watersheds.

II. REVIEW OF LITERATURE

Pathak and Saikia (2019) analyzed fluvial morphometry of Aie river basin of Bhutan using remote sensing and Geographical Information System by mathematically quantifying the different aspects of the drainage basin, the morphometric parameters used in analysis were linear, areal and relief aspects of the basin. Adhikari Sandeep (2020) studied the morphometric characteristics of Ghatganga basin of Nepal by using Geographical Information System. Different morphometric parameters such as stream length (Lu), bifurcation ratio (Rb), drainage density (D), stream frequency (Fs), texture ratio (T), elongation ratio (Re), circularity ratio (Rc), form factor ratio (Rf), relief ratio (Rh) and river profile have revealed the basin has dendritic pattern of drainage. A Farrukh, M Gowhar and R A Shakil (2013) examined morphometry of Lidder river in the Northwest

Greater Himalayan mountain range and concluded that the hydrological response in the sub watersheds is a direct function of the geomorphology, the topography, and the existing vegetation conditions only.

Srivastava O S, Denis D M and Srivastava S K (2014) investigated the Morphometric characteristic of a Semi Urban watershed, trans Yamuna at Allahabad, Uttar Pradesh. The study was useful for planning rainwater harvesting and watershed management. Sukritstiyanti S, Maria R and Lestiana H (2017) studied watershed based morphometric analysis dealing with the meaning of values of the various morphometric parameters, with adequate contextual information. Harinath V and Raghu V (2013) performed morphometric analysis of Dharurvagu, of Kurnool district, Andhra Pradesh using Arc GIS techniques. Rai P K, Mishra V N and Mohan K (2016) undertook morphometric evaluation of the Son basin using geospatial approach. They extracted data from ASTER DEM and found that the stream order of the basin is predominantly controlled by physiographic and structural conditions. Bera A, Mukhopadhyay B P and Das D (2018) attempted a study to analyze morphometric characteristics of Adula River Basin in Maharashtra using GIS and Remote Sensing technique. Stream networks, different linear, areal, and relief aspects of the basin were analyzed using Arc GIS 10.1 software. Rai P K and others (2019) took geospatial approach for quantitative drainage morphometric analysis of Varuna River basin of Uttar Pradesh. The entire Varuna River was divided into three watersheds and 41 morphometric parameters were taken for study. In the development of morphologic techniques many scholars have contributed not only abroad but also in India.

III. STUDY AREA

Eru River watershed lies in Bhilwara, Chittaurgarh and Bundi district of Rajasthan. It lies in the southernmost part of Bhilwara and Bundi district between $75^{0}11^{l}$ 30 ^{11}E to $75^{0}44^{l}$ E longitudes and 25^{0} N to $25^{0}8^{l}30^{l\,l}$ N latitudes. The watershed is a part of Chambal basin as the Eru river drains into river Chambal just before Jawahar Sagar dam. Eru river rises from Astoli on the *Uparmal* Plateau in Bhilwara district and is bounded by Mukundra hills in the south. The area is rich in red sandstone which is exported to Gulf countries as tiles. Location of the study area is shown in Figure 1.

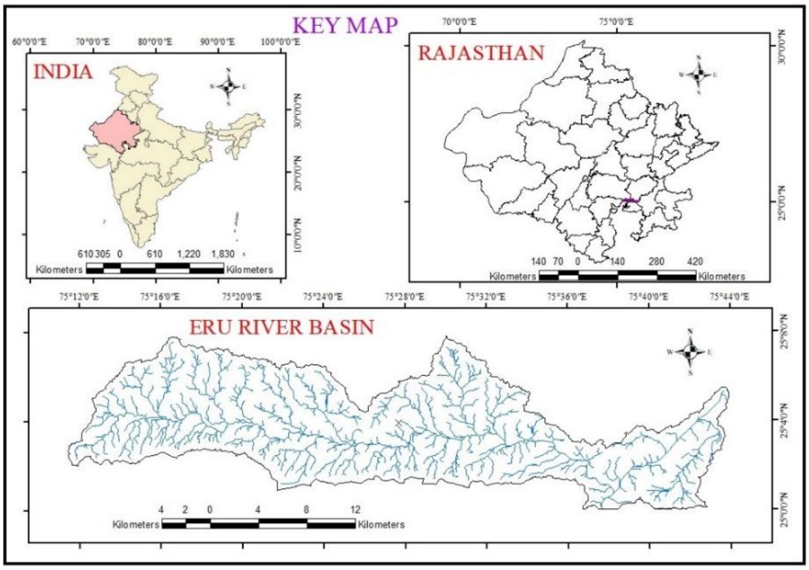

Figure1 Location Map of Eru River Basin

IV. METHODOLOGY

SRTM 1 Arc-Second Global DEM data **(**10m) has been used in this study to extract watershed boundary, drainage network and analysis of morphometric parameters. The extraction of the drainage network of the study area was carried out from SRTM 1 Arc-Second Global satellite imagery-based DEM data, in raster format with a 30m reolution, which was downloaded from US GS Earth explorer. Hydrology tool under Spatial analyst tools of arc tools in ArcGIS 10.4 software was used to extract drainage channels other parameters. Mosaic, DEM fill, slope, flow accumulation, stream order and basin were used to delineate Eru river watershed.

Table 1. Methods of calculating morphometric parameters

Morphometric Parameters	Formula	References	Results
Linear Aspects			
Stream order (U)	Hierarchical order	Strahler,1952	5
Stream Length (Lu)	Length of the stream	Horton, 1945	641.5 km
Mean stream length (Lsm)	Lsm=Lu/Nu; Where, Lu=Mean stream length of a given order (km), Nu=Number of stream segment.	Horton, 1945	0.6 km
Stream length ratio (RL)	RL= Lu / Lu-1 Where, Lu= Total stream length of order (u), Lu-1=The total stream length of its next lower order	Horton, 1945	0.96
Bifurcation Ratio (Rb)	Rb = Nu / Nu+1 Where, Nu=Number of stream segments, present in the given order, Nu+1= Number of segments of the next higher order	Schumm, 1956	1.72
Areal Aspects			
Drainage density (Dd)	Dd=L/A Where, L=Total length of stream, A= Area of basin.	Horton, 1945	1.59 km/km^2
Stream frequency (Fs)	Fs=N/A Where, L=Total number of streams, A=Area of basin	Horton, 1945	2.53 km^{-2}
Texture ratio (T)	T=N1/P Where, N1=Total number of first order stream, P=Perimeter of basin.	Horton, 1945	3.02/km
Form factor (Rf)	$Rf=A/(Lb)^2$ Where, A=Area of basin, Lb=Basin length	Horton, 1945	0.154
Elongation ratio (Re)	$Re=\sqrt{(Au/\pi)}/ Lb$ Where, A=Area of basin, π=3.14, Lb=Basin length	Schumm, 1956	0.004
Circulatory ratio (Rc)	$Rc=4\pi A/P^2$Where A= Area of basin, π=3.14, P= Perimeter of basin.	Miller,1953	0.175
Length of overland flow (Lg)	Lg=1/2Dd Where, Drainage density	Horton, 1945	0.31km
Constant channel maintenance(C)	C=1/Dd Where, Dd= Drainage density	Horton, 1945	0.63km
Relief Aspects			
Total basin relief (H)	H = Highest – Lowest Height	Strahler (1952)	312 meters
Relative relief ratio (Rhp)	H*100/P	Melton (1957)	0.18
Watershed Slope (Sw)	Sw=H/Lb	Sreedevi et al., 2005	0.006
Ruggedness Number (Rn)	Dd*(H/100)	Patton & Baker, 1976	0.49

V. RESULTS AND DISCUSSION

The total watershed area of the Eru is 403.78 sq.kms. The drainage pattern is dendritic pattern, and it depends on the topography, geology, and rainfall conditions of the study area. SRTM 1 Arc-Second Global satellite imagery-based DEM data is used to make slope, aspect, and contour map of the watershed. The morphometric investigation is attained through the calculation of linear, areal, and relief aspects of the study area using ArcGIS 10.4 software.

A. LINEAR ASPECTS

Linear aspects are one-dimensional parameters like Stream Order, Stream Number, Bifurcation Ratio, Stream Length, Sinuosity Index. This shows how the drainage network’s channel patterns correspond to the topological properties of stream segments, and the study is based on the stream network’s open linkages.

Stream Order (U)

It is the first step in morphometric analysis of a watershed. Stream ordering is the determination of the hierarchical position of a stream within a watershed. It is observed that first order stream has maximum frequency followed by second, third and fourth order respectively as shown in table 2. The number of streams steadily decreases with increase in stream order.

Table 2 -Order wise Stream Numbers

Stream order (U)	Stream Number (Nu)	Total Length(km)	Mean Stream Length (Km)	Cumulative Mean Stream Length (Km)
1st	514	336.72	0.66	0.66
2nd	252	162.44	0.64	1.3
3rd	108	57.94	0.54	1.84
4th	57	35.15	0.62	2.46
5th	90	49.25	0.55	3.01

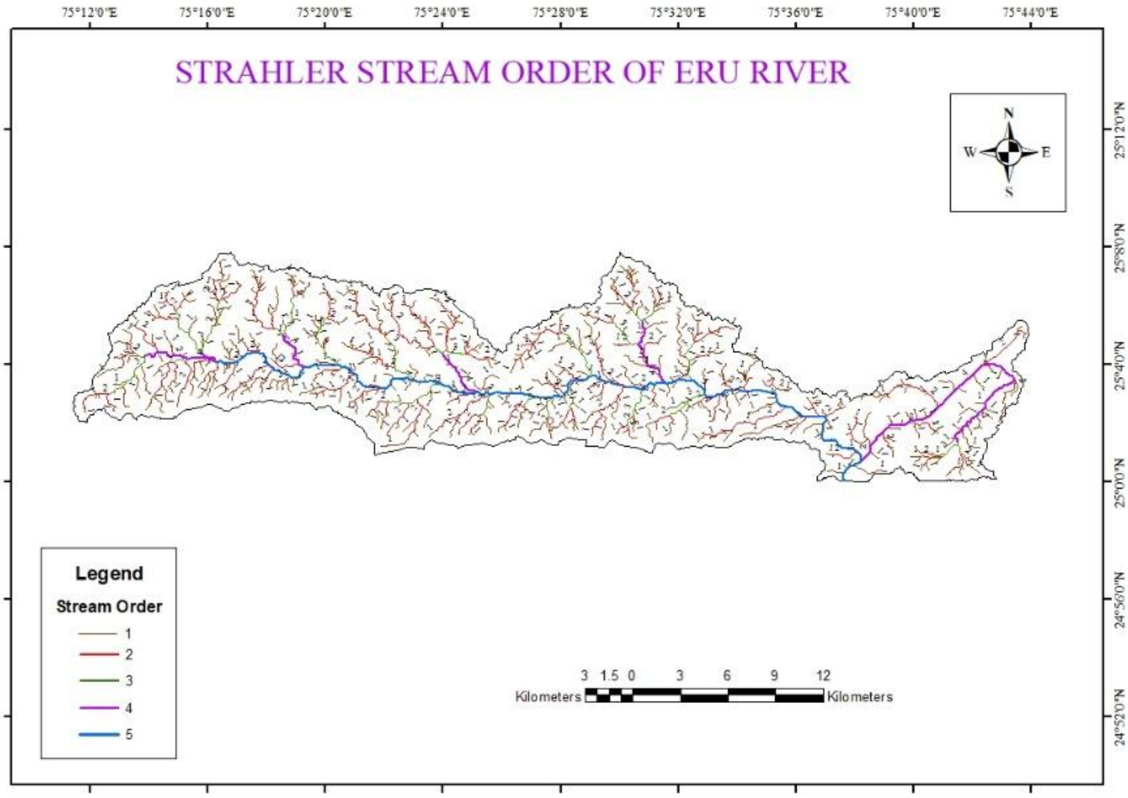

Figure 2 Strahler Stream Order of Eru River

Stream Numbers (Nu)

The number of stream segments in each order is known as stream number. The number of stream segments decreases as the order increases but here the case is different as we see increase in stream numbers. Stream number is directly proportional to size of the contributing watershed, to channel extents. Total 1021 streams were identified of which 514 was found to be of first order, 252 of second order, 108 of third order, 57 were of fourth order and 90 of fifth order. Drainage patterns of stream network analysis have been observed as mainly of dendritic type which indicates that the homogeneity in texture and lack of structural control.

Stream length ratio (RL)

The stream length ratio is defined as the ratio of the mean stream length of a given order to the mean stream length of the next lower order and having an important relationship with the surface flow and discharge and erosion stage of the basin (Horton, 1945). The calculation is shown below:

RL 21= 0.64/0.66 = 0.97
RL 32= 0.54/0.64 = 0.84
RL 43=0.62/0.54 = 1.15
RL 54=0.55/0.62 = 0.89

It is noticed that the RL between successive stream orders of the basin has slight variation due to the difference in degree of slope.

Mean Stream Length (Lsm)

Mean stream length (Lsm) describes the characteristic size of components of a stream network and its contributing surfaces (Strahler, 1964). The mean stream length has been calculated by dividing the mean stream length of given order by the number of stream segment (Table 2). The mean stream length of the study area is 0.66 Km for the first order, 0.64 Km for the second order, 0.54 Km for the third order and 0.62 Km for the fourth order and 0.55 Km for fifth order. Overall mean stream length is 0.60 Km. Mean stream length is directly proportional to the topography and size of the watershed.

Bifurcation Ratio (Rb)

Bifurcation ratio is related to the branching pattern of drainage network and is defined as number of streams of one order to the next higher order which is expressed in terms of the following equation:

Rb = Nu / Nu+1

Where, Nu = stream number

Nu +1 = stream number of higher order

Rb 12 = 2.04

Rb 23 = 2.33

Rb 34 = 1.89

Rb 45 = 0.63, Mean bifurcation ratio is 1.72.

The bifurcation ratio is dimensionless property, and its value generally ranges from 3 to 5. But in certain studies, its value goes to as high as 15 and as low as 1. Low bifurcation ratio value indicates poor structural disturbance and the drainage patterns have not been distorted (Strahler, 1964).

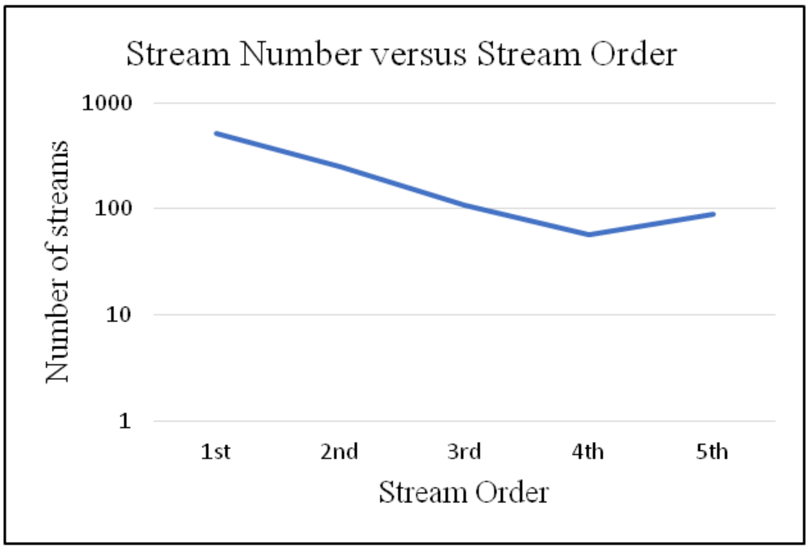

Figure 3 Graph of Stream Number versus Stream Order

B. AREAL ASPECTS

Areal aspects are two-dimensional parameters like basin shape, area, stream frequency, drainage density, drainage texture, elongation ratio, circularity ratio and form factor. The area and perimeter of the watershed are 403.78 sq.km and 170.4 km respectively.

Drainage Density (Dd)

Drainage density refers to total stream lengths per unit area. Drainage density is a significant morphometric parameter that determines the travel time of surface run off reaching the outlet of master stream of a drainage basin and it determines the shape and discharge peak of the basin. The surface run off is accelerated to reach the master stream and its outlet in a basin having high drainage density while surface run off is delayed reaching the mainstream in a basin having low drainage density. It is associated with stream head source area, relief, climate, vegetation, soil, and rock characteristics of the area. Low drainage density is preferential in area of high resistant or highly permeable sub soil materials, under dense vegetation cover and where relief is low. Drainage density in the Eru watershed is 1.59 km/km^2 which is a result of highly resistant or impermeable sub soil material of the area.

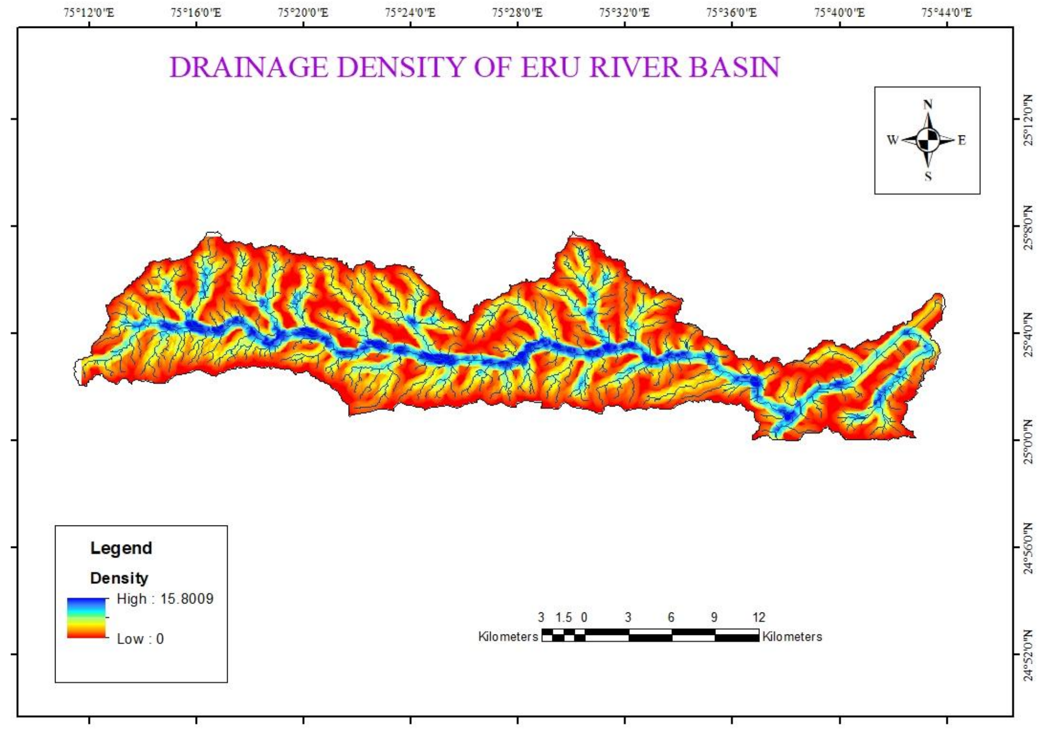

Figure 4 Drainage Density Map of Eru River Basin

Stream Frequency (Fs)

It is the total number of stream segments of all stream orders per unit area (Horton,1932). The stream frequency for the study area is 2.53 per sq. km. The result shows that surface runoff in the area is slow.

Fs= Nu/A

Where, A = Area of the basin (403.78 sq. km)

Nu = Stream number (1021)

It exhibits a positive correlation with drainage density in the watershed indicating an addition in stream population with respect to increase in drainage density. Climatic conditions, vegetation cover, rock and soil types, rainfall concentration, infiltration capacity, relief, run-off intensity, permeability terrain, slope has played an important role in controlling the drainage frequency and density.

Texture ratio (T)

Texture ratio is an important parameter in the drainage morphometric analysis which is depending on the underlying lithology, infiltration capacity, and relief aspect of the terrain (Schumm, 1956). It is calculated by dividing the number of first order streams by perimeter of the watershed. The texture ratio in the study area is 3.02 per km. which implies that texture is very coarse in nature.

Form factor (Rf)

Form factor is a ratio of watershed area to the square of the length of the watershed. Form factor is the numerical index which is commonly used to represent different basin shapes (Horton, 1932). It is expressed as

$Rf = A/L^2$

Where, A = Area of the basin (403.78 sq. km) L^2 = Basin length $(51.22)^2$

The form factor values vary from 0 (in highly elongated shape) to 1 (in perfect circular shape). Value greater than 0.78 indicates the perfectly circular basin, smaller values suggest the elongated form of basin. The value of form factor for the study area is 0.154 indicating that the basin is highly elongated.

Elongation Ratio (Re)

The elongation ratio is the ratio between the diameter of the circle of the same area as the drainage basin and the maximum length of the basin. It is a measure of the shape of the river watershed, and it mainly depends on the climatic and geologic characteristics. Its value varies from 0 (in highly elongated shape) to unity i.e., 1(in the circular shape). The elongation ratio of Eru watershed is 0.004 which indicates watershed to be highly elongated with high relief and steep slope.

Circulatory Ratio (Rc)

Circularity ratio is the ratio between the areas of a watershed to the area of the circle having the same circumference as the perimeter of the watershed and it is a dimensionless property. Its value ranges between 0 to 1 and values close to 1.0 represent the circular shape of the basin with structurally controlled by length and frequency of streams, geological structures, land use/land cover, climate, relief, and slope of the watershed. The circulatory ratio value of the watershed is 0.175 indicating elongated shape, low discharge of runoff, and high permeability of the subsoil conditions (Saikia et al.,2019).

Length of overland flow (Lg)

Length of overland flow is a length of water over the ground before it gets concentrated into certain stream channels. Length of overland flow (Lg) is one of the most vital self-governing variables affecting hydrologic and physiographic development of drainage basin (Horton, 1932). It is inversely proportional to half of reciprocal of drainage density. The high Lg value indicates that the rainwater had to travel a relatively longer distance before getting concentrated into stream channels. The value for the length of overland flow in this study is 0.31 km which shows lower distance runoff in the study area.

Constant channel maintenance (C)

The constant of channel maintenance indicates the relative size of landform units in a drainage basin and has a specific genetic connotation (Strahler, 1957). Schumm (1956) has used the inverse of the drainage density having the dimension of length as a property termed constant of channel maintenance. The constant indicates the number of km of basin surface required to develop and sustain a channel 1km long (Pareta, 2011). Channel maintenance constant of the watershed was calculated as 0.63 km^2/km.

C. RELIEF ASPECTS

Relief aspects of drainage basin relate to the three-dimensional features of the basin involving area, volume, and altitude of vertical dimension of landforms.

Slope

Watershed slope determines the nature and magnitude of infiltration and runoff. Slope analysis is an important factor in morphometric analysis and geomorphological study of Eru watershed. The drainage basin with steep channel gradient and high value of average slope generates more runoff than the drainage basin characterized by gentle slope because surface detention and infiltration of rainwater is discouraged in the basins of comparatively high slope value. The degree of slope in the Eru watershed varies from 0^0 to 55^0 .

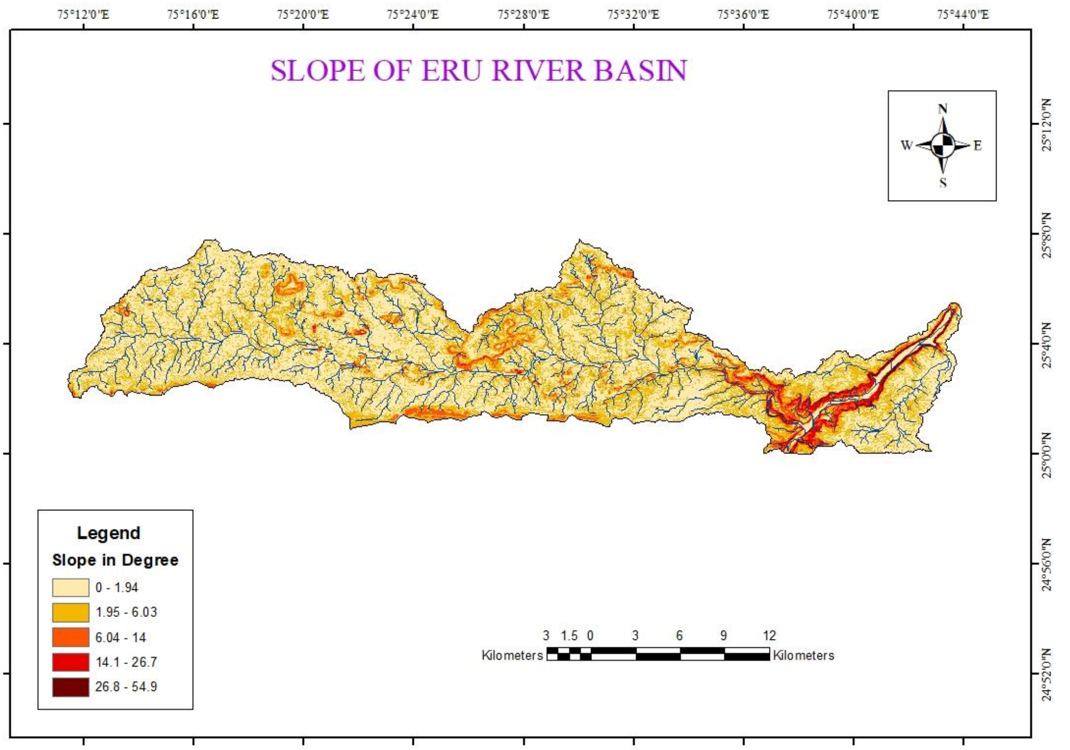

Figure 5 Slope map of Eru River Basin

Ruggedness Number (Rn)

The ruggedness number indicates the structural complexity of the terrain in association with the relief and drainage density. This number is used by the geologists in connection with the morphological studies of terrain and it leads to better understanding of the surface configuration evolving out of complex geomorphic processes. It is the product of maximum basin relief and drainage density, where both parameters are in the same unit. The Rn value for the watershed is 0.49 and the low ruggedness value of watershed implies that area is less prone to soil erosion.

Relative Relief

Relative relief is a vital morphometric variable to assess the morphological characteristics of any topography. It is the difference between the lowest and highest point of the study area. The elevation of watershed is 561m above mean sea level and the lowest relief was 249 m above mean sea level. The overall relief, H calculated for the watershed was 312 m. The high relief value in a region indicates high gravity of water flow, low permeable and high runoff conditions. Melton's (1957) relative relief was also calculated using the formula given as:

$$Rhp = H*100/P$$

Where, P is perimeter in meters. It is 0.18 for the Eru watershed. The low relief indicates a gentle slope, and the area could be basically used for agricultural activities.

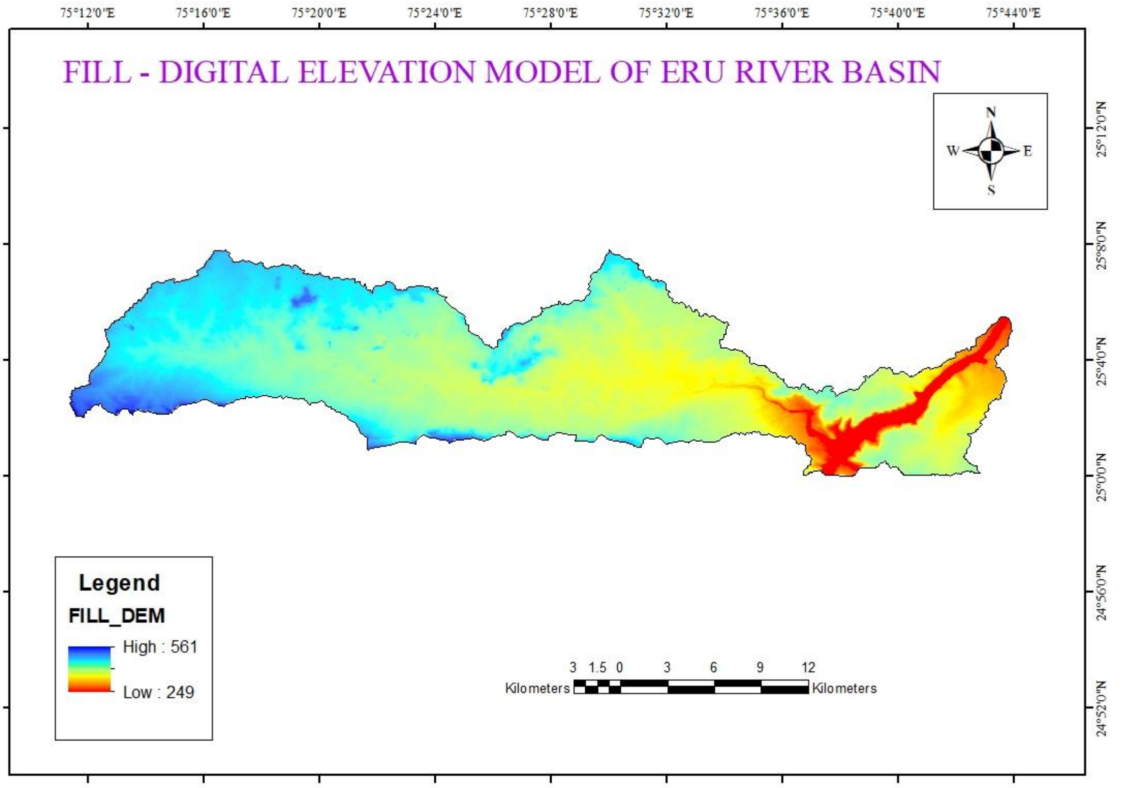

Figure 6 Fill Digital Elevation Model of Eru River Basin

VI. CONCLUSION

Quantitative investigation of morphometric parameters of the watershed is found to be exceptionally valuable within the drainage basin assessment, water preservation and characteristic asset administration at smaller scale level. Morphometric investigation of the study area is characterized by dendritic pattern, lower order streams are in abundance with the highest order being the fifth order. The value of form factor and circulator ratio and elongation ratio indicates the watershed is elongated in shape having low runoff. the study concludes that (DEM) data united with GIS technique is an efficient tool to analyse the morphometric parameters for water resource management at smaller scale of any terrain by planners and decision makers to develop strategy for sustainable watershed development programs. Application of GIS modelling merged with remote sensing has proven to be an efficient tool for geohydrological studies in understanding any terrain parameters.

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