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WATERSHED DELINEATION AND MORPHOMETRIC ANALYSIS USING REMOTE SENSING AND GIS MAPPING TECHNIQUES IN MUSI RIVER BASIN

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***Abstract*—Remote sensing and geographical information system (RS-GIS) approach is considered to be an effective tool to determine the morphological characteristics and investigating properties of the basin, as they provide a user friendly environment and act as a powerful tool for manipulation and analysis of spatial information. The detailed morphometric analysis coupled with remote sensing and geographical information system techniques can interpret the shape, hydrological parameters and describes the configuration of various land forms, dimensions quantitatively. These morphological investigation is an important prerequisite for the watershed development plan and evaluating the basin hydrology. Musi watershed is stretched between Latitude 17º 58^{1} N to 16º 38^{1} N and Longitude 77º 46^{1} E to 79º 48^{1} E which is one of the tributary of the Krishna river in the deccan plateau and covers distance of 240 km. The present study addressed linear, areal and relief aspects of the watershed. The study deals with the emphasis on the evaluation of morphometric parameters such as Stream length, stream order, bifurcation ratio, drainage density, stream frequency, elongation ratio, circularity ratio, form factor, Length of overland flow, texture ratio, drainage intensity, drainage texture, infiltration number, constant channel maintenance, sinuosity index, basin relief, relief ratio, ruggedness number, shape factor. The morphometric analysis of the basin revealed that musi is sixth-order drainage basin with total of 1270 drainage network, consisting the total length of 4004.90 km and total length of stream is longer for the first order and decreases with increasing stream order. The extracted drainage network exhibits dendritic to sub-dendritic drainage pattern. The mean bifurcation ratio is 1.87 which is lower than the standard range, and it indicates that the basin is flat or rolling drainage basin and drainage pattern is not affected by the geologic structures. Low drainage density is observed which is 0.35 km/km^2. It indicates that basin has highly permeable and thick vegetation cover. Areal aspect of the morphometric analysis of the basin revealed that the basin is slightly potential to flooding, indicating that low peak flows generated from the upland area of the watershed is significantly infiltrated at the gentle slope of downstream part and contributing groundwater potential for longer duration. The main objective of this examination is to figure out different drainage parameters in order to minimize the risk involved inplanning and management of watershed and for better understanding of the drainage basin. Ultimately, the various land use practices can also be well monitored by taking the results into consideration. Further studies with the help of GIS and remote sensing with high-resolution remote sensing data integrating with ground control data in the field are more effective to formulate appropriate type of natural resource management system and to understand the hydrological response of the watershed.**

Keywords—Remote sensing, watershed, Morphometry, Drainage density, Drainage network, Peak flow

I. INTRODUCTION

The constant rise in urbanization and population, are the two main reasons for the diminishing the resources like water and land, because of their overutilization. So, it is absolutely important to conserve these natural resources and application of these resources in an effective way. Among all, watershed is regarded as an ideal unit for planning and management of natural resources. The watershed consist of both natural and social systems, as it is a hydrological, bio-physical and socio-economical unit. Also, it has been used as a widespread development model and an approach to attain food security (German et al. 2007). If adequate conservative measures are undertaken, a watershed harmonizes the use of soil, water and vegetation. This will optimize the productivity with the minimal environment impacts (Alemu and kidane 2014). A well planned watershed practices can overcome poor watershed conditions such as low productive yield, peak runoff, increasing soil erosion and poor infiltration as well as natural threats such as floods and droughts. Hence, watershed management is aimed to enhancing food security and protect the environment (kumar and palanisami 2009) and, there is an instant demand for the assessment of water resources as it is vital for accomplishing sustainability and has been in focus all over the globe.

Therefore, watershed characteristics and the hydrological processes occurred within watershed can be recognized and it will be useful for decision making. The term watershed applies to a naturally formed hydrological unit defined by natural boundaries and characterized by topographical, physical and climatic conditions (Kumar et al. 2012). It is an area which contributes runoff to a common point along a single waterway, and is categorized on the basis of its geographical area (Javed et al. 2009). For watershed planning and management, a proper delineation of it is a prerequisite.

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The most important information of any watershed can be estimated using Morphometric analysis, which accounts for hydro morphological processes of the basin and describes the crucial drainage system quantitatively. So, it has become an important topic to many policy planners and researchers particularly in the field of urban and watershed management. The conventional approach for analyzing the river morphometry is a very complex process which consumes great rime and labor. However, with the advancement of geospatial and computational technologies, more precise assessment can be performed with much easy efforts. GIS offers a flexible environment and a powerful tool for the analysis and manipulation of spatial information, mainly for the future identification and extraction of information for well understanding of watersheds (Rekha et al. 2011).

In case, where topographic maps are not available, satellite terrain data such as digital elevation model (DEM) obtained through the remote sensing technology may be used to identify the morphometric parameters of a watershed. The remote sensing technique is the convenient method for morphometric analysis as the satellite images provide a synoptic view of a wide area. Application of Remote sensing technology along with Geographical information system (GIS) i.e integrating Digital elevation models with Geographic information technology provides continuous data unlike contours in topographic maps(Moore et al. 1991) is used for evaluating various terrain and morphometric characteristics of a drainage basin. It is most effective, time saving, and accurate practice for the morphometric basin analysis (Rai et al, 2014).

The morphometric analysis of watershed is an essential primary step towards the basic understanding of watershed analysis and helpful in an appraisal of water resource potential, flood risk management. A detailed morphometric analysis is needed to prepare a comprehensive watershed development plan to understand the topography, status of erosion and drainage pattern of the region and valuation of the same assist to elaborate an initial hydrological diagnosis to predict the approximate behavior of a watershed if properly coupled with a geological and geomorphological setting (Esper, 2008). Morphometry is the measurement and mathematical evaluation of land surface configuration, shape, dimension and landform processes (Obi Reddy et al. 2002).

The Watershed morphometric analysis typically covers the quantitative aspects and physical characteristics of the watershed. It is a static criteria that do not change easily over a period of time. It computes quantitative attributes of landscapes such as: Linear, Areal and Relief aspects of a watershed, which includes basin area, length, perimeter, stream length, stream order, bifurcation ratio. Mean stream length, drainage density, stream frequency, elongation ratio, circularity ratio, texture ratio and form factor, length of overland flow, drainage intensity, infiltration number, constant channel maintenance, sinuosity index and basin relief, relief ratio, ruggedness number and shape factor. This study could be valuable for researchers for further studies on hydrological and other complex watershed related models and regional planners and overall policy makers for agricultural/water management strategies.

STUDY AREA

The study area Musiriver is the capital of Telangana state. It is situated between 17º 58¹ N to 16º 38¹ N Latitude and 77º 46¹ E to 79º 48¹ E Longitude. The river Musi emerges from Anantagirihills in Vikarabad district located at 661 meters above mean sea level. The river covers distance about 240 km. Musi River one of the tributary of the Krishna river in the Deccan plateau, which extends over 11,270 Sq.km approximately and connects Krishna river at Vadepally, 40 km down from Suryapet in Nalgonda District. Hyderabad stands on the banks of Musiriver, which divides the historic old and new city. HimayatSagar and Osman Sagar dams built on it, which used to act as a source of water for Hyderabad. These reservoirs were constructed after the devastating floods in 1908 during the regime of Mir Osman Ali Khan. Conservation of Musi has assumed relevance only in recent years. Until the 1960s, Musi River was looked at from the point of view of a river flowing through the city of Hyderabad and as a water source in the form of reservoirs built on its tributaries. In general river is common property resource of the people and thus it is the duty of the state and central bodies to protect the water resources.

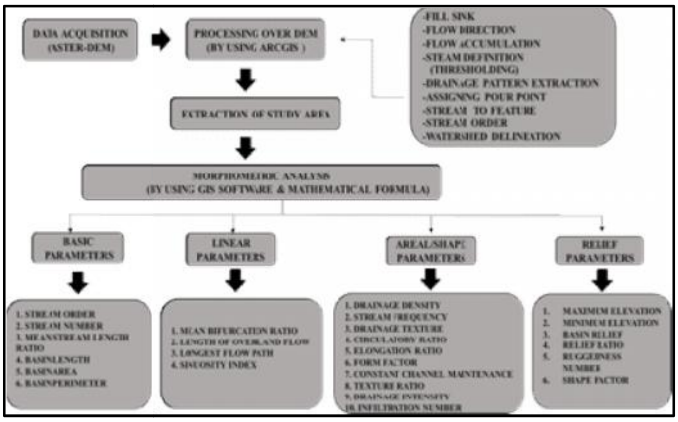

Fig. 1. Location Map of the Study Area

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II. METHODOLOGY

The major objective of the present study is to investigate and identify various drainage parameters to understand the geometry of the study area through the use and application of GIS by basin delineation from the remotely sensed data. The satellite remote sensors give exact and dependable data regarding natural resources, which is prerequisite for proper planning and management of the watershed. The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data with the resolution of 30 m used and processed with ArcGIS 10.4 software to Digital Elevation Model (DEM) for Musi River Basin. The overall methodology used to delineate and generate stream networks is as follows in the Figure 2.

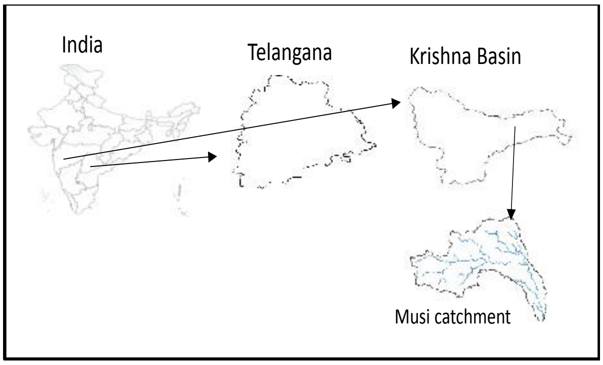

Fig. 2. Methodology of watershed morphometry analysis

PROCESS:

1. Collect and re-projected DEM data to WGS 1984 UTM Zone 44N coordinate system using ArcGIS toolbox.
2. Terrain pre-processing was done to fill the sinks using fill tool under Spatial Analyst tools of Hydrology option.
3. The flow direction and accumulation map of the watershed was created using flow direction and accumulation tools using spatial analyst Hydrology option.
4. Raster calculation operation was carried out using the threshold value of 5000 to produce the stream networks, and watershed outlet point i.epourpoint was selected.
5. The watershed boundary was plotted, and the watershed area, length and order of the streams were calculated. The next step in the process is to Morphometric analysis.
6. The analysis of Morphometric parameters were analyzed and classified into 3 classes associated with their orientation in space. They are Baisc/Linear, Areal/Shape and Relief aspects.

The fundamental basin parameters and Linear Aspect of the basin, namely Stream order, Stream Number, Mean Stream Length, Mean Stream Length Ratio, Bifurcation Ratio and Areal Aspect of the basin, namely Basin area, Basin perimeter, Basin length, Stream Frequency, Drainage Density, Drainage intensity, Drainage Texture, Length of overland flow, Infiltration number, Circulatory Ratio, Elongation Ratio, Form Factor, Constant channel Maintenance and Relief Aspects of the basin, namely Basin relief. Relief Ratio, Ruggedness number, Shape factor.

Stream ordering is usually the initial step to drainage basin analysis. It defines the stream size based on hierarchy of its tributary. For stream ordering, Horton (1932) law slightly modified by Strahler (1952) was used. All the other parameters were computed to analyse the behaviour of the drainage basin based on the formulae shown in the Table I, suggested by Horton (1945), Miller (1953), Schumm (1956), Strahler (1964).

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TABLE I. FORMULAE FOR COMPUTATION OF MORPHOMETRIC PARAMETERS

S.NO	***Morphometric Parameter***	***Formula/Definition***	***References***
1	Stream order (U)	Hierarchical Order	Strahler, 1964
2	Stream Length (Lu)	Length of Stream in Km	Horton, 1945
3	Mean stream Length (Lsm)	Lsm= Lu / Nu Where, Lu = Total stream length of order ‘u Nu = Total no. of stream segments of order ‘u’	Horton, 1945
4	Stream Length Ratio (RL)	RL= Lsm / Lsm-1 Where, Lsm=Mean stream length of a given order ; Lsm-1= Mean stream length of next lower order	Horton, 1945
5	Basin Length (Lb)	Length of the Basin in Km	Schumm, 1956
6	Bifurcation Ratio (RB)	Rb = Nu/ Nu+1 Where, Rb = Bifurcation Ratio ; Nu = No. of stream segments of a given order ; Nu +1= No. of stream segments of next higher order	Schumm,1956
7	Longest Streamflow Path	Length of the longest stream of basin in Km	
8	Drainage Density (Dd)	Dd = Lu/A Where, Dd = Drainage density (1/km) ; Lu = Total stream length of all orders ; A = Area of the basin (km^2)	Horton,1945
9	Sinuosity Index (SI)	SI = Actual path of highest order/Expected straight path of highest order	Schumm,1956
10	Basin Perimeter (P)	P	
12	Basin Area (A)	A	
13	Length of Overland Flow (Lo)	Lo= 1/2Dd Where, Dd = Drainage density	Horton,1945
14	Elongation Ratio (Re)	Re= 1.128*√A/Lb ,Where, A=Area of basin, Lb=Basin	Schumm,1956
15	Circularity Ratio (Rc)	Rc = 4πA/P2, Where A= Area of basin, P= Perimeter of basin	Miller,1953
16	Form Factor (Rf)	Rf=A/$(Lb)^2$, Where, A=Area of basin, Lb=Basin length	Horton,1945
17	Stream Frequency (Fs)	Fs=N/A,Where, L=Total number of streams, A=Area of basin	Horton,1945
18	Drainage Texture (DT)	T= Dd * Fs, Where, Dd = Drainage density, Fs=Stream frequency	Smith,1950
19	Drainage Intensity (Di)	Di= Fs/Dd, where, Fs = Stream Frequency, Dd = Drainage density	
20	Texture Ratio (T)	T = N1/P,Where, N1=Total number of first order stream, P=Perimeter of basin	Horton,1945
21	Infiltration Number (If)	If = Dd × Fs Where, , Dd = Drainage density, Fs=Stream Frequency	Faniran, 1968

S.NO	Morphometric Parameter	Formula/Definition	References
22	Constant channel maintenance(c)	C=1/Dd Where, Dd= Drainage density	Horton, 1945
23	Basin relief (Bh)	Vertical distance between the lowest and highest points of basin	Schumm, 1956
24	Relief Ratio (Rh)	Rh= Bh/Lb WHERE Bh= BASIN RELIEF Lb= LENGTH OF BASIN	Schumm, 1956
25	Ruggedness Number (Rn)	Rn= Bh * Dd WHERE Bh= BASIN RELIEF Dd= DRAINAGE DENSITY	Strahler, 1957
26	Basin shape factor (Rf)	Rf= Lb2/A	Horton, 1935

III. Results and Discussion

A. Watershed Delineation

GIS Hydrology tools were used to delineate the watershed from the 30 m spatial resolution of DEM. The hydrology tools from ARC GIS were used to derive the several data sets, to recondition the DEM through analysis. Then to produce flow direction, flow accumulation, stream order, and to delineate the watershed, Figure 4 illustrates the steps in the watershed delineation and extraction of catchment boundary. Then this data is used to generate the vector representation of the basin and streams network. The pour point is defined using the flow accumulation layer in the contributing watershed. Then sub-watersheds were delineated by pour point using flow direction in the watershed function. As a result, 13 sub-watersheds have been delineated in the study area (Fig. 3) .

B. Morphometric Analysis

The Musi watershed was delineated and geomorphological parameters were analysed using remote sensing and GIS techniques. Different aspects of morphometric parameters were calculated, which are calculated according to their dimensional aspects. Morphometric parameters such as relief, shape, and length also influence basin discharge patterns strongly through their varying effects on lag time (Gregory and Walling, 1973). The details of Linear, Areal and Relief parameters were computed shown in Table II,III, V.

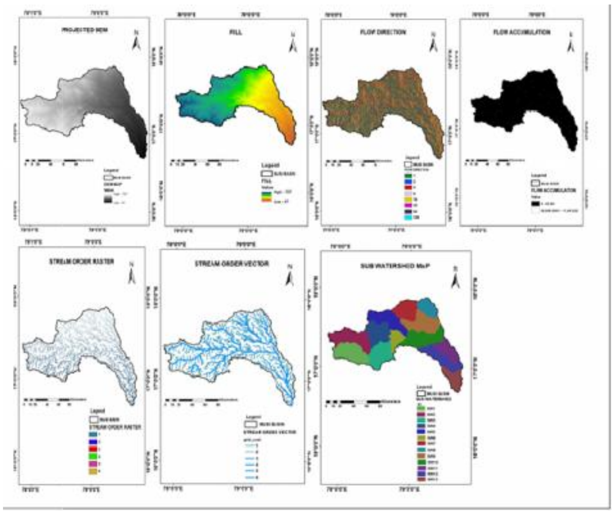

Fig. 3. Watershed Delineation through DEM Data

C. Basic/Linear Morphometric Parameters

The Basic parameters of the study area are Stream order, Stream number, Mean stream length ratio, Basin length, Basin area, Basin perimeter and Linear aspects of drainage refer to the analysis of Bifurcation ratio, Length of overland flow, Longest flow path and sinuosity index. This leads patterns of the drainage network with the topological characteristics of the stream segments and analysis is based on open links of the stream network. Computed parameters results are shown in Table II.

TABLE II. BASIC/LINEAR ASPECTS OF BASIN

S.NO	Linear Aspect		Result
1	Stream order (U)		6th
2.	Stream Number (NU)	1	636
		2	269
		3	183
		4	108
		5	42
		6	32
3.	Total Stream Length (km)	1	2093.15
		2	971.85
		3	481.85
		4	260.35
		5	110.19
		6	88.07
4.	Stream Length Ratio	II/I	1.09
		III/II	0.72
		IV/III	0.91
		V/IV	1.08
		VI/V	1.04
5.	Mean Stream Length Ratio		0.968
6.	Basin Length (Lb)		245.37 km
7.	Basin Area		11326.89 km^2
8.	Basin Perimeter		1118.15 km
9.	Bifurcation Ratio (RB)	I/II	2.36
		II/III	1.46
		III/IV	1.69
		IV/V	2.57
		V/VI	1.31
10.	Mean Bifurcation Ratio (RB)		1.87
11.	Length of Overland Flow (Lo)		1.42 km
12.	Longest Flow Path		287.689 km
13.	Sinuosity Index (SI)		1.17

D. Stream Order (S_o)

Stream Order is the first step of quantitative analysis of the drainage basin. For the analysis Strahler law (1964) has been followed. It is defined as a measure of the position of a stream in the hierarchy of tributaries (Leopold, Wolman, & Miller, 1964). After analysis of the result it was found that the watershed is of the sixth order type. Drainage pattern of the basin was dendritic to sub-dendritic type (Fig 3) that develop where the river channel follows the slope of the terrain.

E. Stream Number (N_u)

The count of stream channels in each order is termed as a stream number. Generally, the number of streams gradually decreases as the stream order increases. The variation in size and order of basin's tributary is largely depends on physiographic and structural condition of the region.

The total number of stream segments 1270 were identified, out of which 636 streams are first order, second, third, fourth, fifth and sixth order were 269, 183, 108, 42 and 32, respectively(TableII).

F. Stream Length (L_u)

Stream length was computed on the basis of law proposed by Horton. Stream length indicates the behaviour of surface runoff, which has significant role in the drainage basin system. Generally, the total length of stream segment is the maximum in first order stream and decreases with an increase in the stream order. The stream with smaller length indicates the larger slopes and finer textures, whereas streams with the longer length is characteristics of area of flatter gradient. The corresponding lengths of the first, second,third, fourth, fifth and sixth order were 2093.15, 971.85, 481.85, 260.35, 110.19 and 88.07 km, respectively.

G. Stream Length Ratio (L_{UR})

Stream length ratio is the ratio of the mean length of one order to the next lower order of the stream segment. Stream length ratio increasing towards higher order of stream. Changes of 'Lur' from one order to another order signifies their late youth stage of geometric development (Singh et al. 2014; Rai et al. 2014). During the study, it is computed that the 'Lur' be between consecutive stream orders of the basin change widely from 0.72 to 1.09 due to variation in gradient and topographical characteristics. This character shows an important relationship with the surface flow discharge and the erosional stage of the basin.

H. Bifurcation Ratio (R_b)

The term bifurcation ratio (Rb) defined as the ratio of the number of streams of any given order to the number of streams in the next higher order in a basin (Schumm 1956). It is related to branching pattern of a drainage network. The bifurcation ratio in present study found to be in the range of 1.31 to 2.57 with the mean bifurcation ratio 1.87. According to Kale and Gupta (2001) Lower bifurcation ratio indicates natural drainage system within a homogeneous rock. Higher bifurcation ratio indicates well- dissected drainage basins with less chances of flood and erosion risk (Horton 1945). The small variations in bifurcation values for different regions is due to geological and lithological development of the drainage basin and lower value of mean bifurcation ratio found in the basin suggesting poor structural disturbance and drainage patterns have not been distorted (Strahler 1964).

I. Length of Overland Flow (L_o)

It is the length of water over the ground before it gets concentrated into certain stream channel. Lo= 1/(2X Dd), where Dd is drainage density is in km/km2. There are three classes of Lo i.e., (<0.2) low value, (0.2-0.3) moderate value, and (>0.3) high value. Low value of Lo indicates high relief, short flow paths, more runoff, and less infiltration which turns vulnerable to the flash flooding. Lo value for the study area is 1.42 km, which indicates gentle slopes and long flow paths, more infiltration, and reduced runoff.

J. Sinuosity Index (SI)

Sinuosity index denotes the degree of deviation of actual path of stream from its expected theoretical straight path. The Si is a substantial quantitative index for studying the significance of drainage in the land forms development and valuable for Hydrologists, Geologists and Geomorphologists. In the study area, Si of the 6th order stream is calculated which is known as the trunk stream segment. For a straight river course this ratio is equal to unity. A ratio varying from 1 to 1.5 defines the river course as sinuous and from 1.5 to 4 as meandering (Miller 1953). The Si value found to be 1.17 which shows that the stream is deflected from it's straight path and follow somewhat transitional course (sinuous).

K. Aerial aspects

Basin area deals with the two-dimensional parameters and it has influence over distribution of numerous morphometric parameters with respect to space like basin shape and area, drainage density, drainage texture, stream frequency, elongation ratio, circularity ratio, and form factor etc., which are presented below in table III.

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TABLE III. AREAL ASPECTS OF BASIN

S.NO	***Areal Aspects***	***Results***
1.	Drainage Density (D_d)	0.35 km/km^2
2.	Stream Frequency (F_s)	0.11 Km^{-2}
3.	Drainage Texture (Dt)	1.13
4.	Circularity Ratio	0.11
5.	Elongation Ratio	0.48
6.	Form Factor	0.18
7.	Constant of Channel Maintenance (C)	2.85
8.	Texture Ratio (T)	0.56 km^{-1}
9.	Drainage Intensity (D_i)	0.31
10.	Infiltration Number (I_f)	0.038

L. Drainage Density (D_d)

The drainage density (D_d) is the total lengths of streams of all orders (km) per drainage area (km^2) in basin area (Horton 1945) and is a key element which provides a numerical measurement of landscape dissection and runoff potential (Chorley 1969). The 'D_d' of the basin is 0.35 km/km^2, indicating low drainage density. It specifies the basin is having a flat terrain composed of permeable subsurface strata and has a characteristic feature of coarse drainage, good vegetation cover, and low relief which results in more infiltration capacity and comparatively are good sites for ground water recharge as compared to high D_d watersheds. The drainage density map for the study area is shown in Fig 4

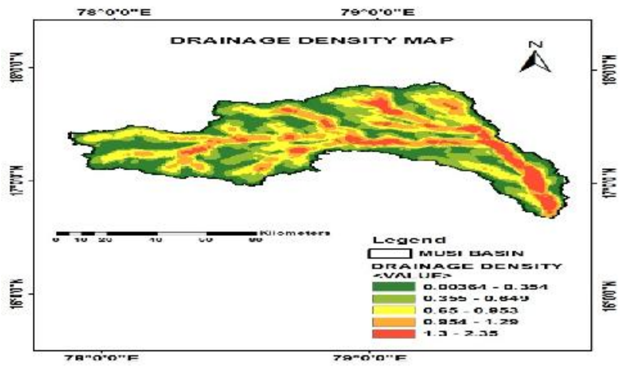

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Fig. 4. Drainage Density Map of the Study Area

M. Stream Frequency (F_s)

The stream frequency is the number of stream segments per unit area (Horton 1932). It is an index of the various landscape evolution stages. Stream frequency value for the present study is 0.11. Reddy et al. (2004) stated that low values of stream frequency indicate presence of a permeable subsurface material and low relief, which implies relatively low run-off.

N. Drainage Texture (D_t)

Drainage density is a measure of relative channel spacing in a fluvial-dissected terrain. The drainage texture depends upon a number of natural factors such as vegetation, climate, rainfall, rock and soil type, relief and infiltration capacity (Smith, 1950). Low drainage density leads to coarse drainage texture while high drainage density leads fine drainage texture, high runoff and erosion potential of the basin area. In the study area drainage texture (D_t) is 1.13. According Table IV classification, the basin has very coarse drainage texture. Hydrologically very coarse texture watersheds have large basin lag time periods followed by coarse, fine, and very fine texture classes. This shows longer duration to peak flow.

TABLE IV. DRAINAGE TEXTURE CLASSIFICATION (SMITH ,1950)

Range	Texture
For 4.0 and below	Coarse
4.0-10.0	Intermediate
>10.0	Fine
>15.0	Very fine (bad land topography)

O. Circularity Ratio (R_c)

Circularity ratio (R_c) is defined as the ratio of basin area to the circle area having the same perimeter as the basin (Strahler 1964; Miller 1953). 'R_c' influenced by the length and frequency of streams, land use/land cover, geological structures, climate, relief and slope of the basin. The R_c< 0.5 represents the basin to be elongated whereas, R_c>0.5 infers for their near circular shapes. The 'R_c' value is found to be 0.11 which is low indicates strongly elongated nature of the basin with the highly permeable homogenous geologic materials, low discharge of runoff. The low, medium and high values of the circulatory ratio are indications of the youth, mature and old stages of the basin. In present case the basin indicates the late youth stage of topography. When the circularity ratio is closer to 1, the basin is more like circle in shape.

P. Elongation Ratio (R_e)

R_e indicates the basin shape. It is the ratio of diameter of a circle of the same area as the basin to the maximum basin length. When the Re value increases, the basin will be more circular and highly susceptible to flooding due to low time of concentration and vice versa. According to pareta and pareta, (2012) Re is circular (0.9-0.10), oval (0.8-0.9), less elongated (0.7-0.8), elongated (0.5-0.7) and more elongated (<0.5). The R_e value of the study area is 0.48 indicating the basin is an elongated and less probable to flooding as well as moderate to slightly steep slope.

Q. Form Factor (R_f)

Form factor is an indicator of degree of erosion, flood formation and transport capacities of sediment load in a basin (Soni, 2016). The value of form factor ranges from 0.10 to 0.80. Lesser the value of form factor, the more elongated will be the drainage basin. The basin with high form factor values >0.80, have high peak flows of shorter duration, whereas, elongated drainage basin with low form factors have a lower peak flow of longer duration. Form factor of 0.18 was obtained for the basin. The lower form factor value suggested elongated basin with flatter peak flows of longer duration which leads to ground water percolation. Flood flows of elongated basin are easier to manage than from the circular shaped basin (Rajora, 1998).

R. Constant Of Channel Maintenance (C)

The reciprocal of the drainage density is constant of channel maintenance (Schumm, 1956) and signifies how much basin surface is required to maintain a unit length of channel. It depends on the rock type, permeability, vegetation cover, climatic regime as well as the duration of erosion. 'C' increases in magnitude as the scale of the land form unit increases. Channel maintenance of the basin is 2.85. The higher 'C' value show a basin with high permeability rocks and vice-versa.

S. Texture Ratio (T)

It is stated that ratio of total number of first stream orders per basin perimeter (Horton, 1945). It depends on the underlying lithology, infiltration capacity, and relief aspect of the basin terrain (Schumm, 1956). The texture ratio in the study area is 0.56 km^{-1}, which indicates medium run-off with long basin lag time.

T. Drainage Intensity (D_i)

Faniran (1968) defined the drainage intensity, as the ratio of the stream frequency to the drainage density. It is an indicative of the effectivity of both drainage density and stream frequency together on the surface denudation. The intensity value for the study area is 0.31

U. Infiltration Number (I_f)

Infiltration number is the product of drainage density and stream frequency. It is inversely proportional to the infiltration capacity of the basin. The higher the infiltration number, the lower will be the infiltration and consequently the higher run-off. IF value in the basin is 0.038, suggesting favourable conditions for infiltration in the basin area.

V. Relief Aspects

Relief Aspects deals with three-dimensional parameters like Basin Relief, Relief Ratio, Ruggedness Number, Shape factor.

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TABLE V. RELIEF ASPECTS OF BASIN

S.NO	***Relief Aspect***	***Results***
1.	Maximum Elevation	594m
2.	Minimum Elevation	419m
3.	Basin Relief (B_h)	175m
4.	Relief Ratio (R_h)	0.71
5.	Ruggedness no (R_n)	0.061
6.	Shape Factor (R_f)	5.31

W. Basin Relief (B_h)

The basin relief is defined as the difference between the highest and lowest point of the basin. BH controls the stream gradient and therefore influences flood patterns and amount of sediment that can be transported (Hadley and Schumm 1961) and important factor in understanding the denudational characteristics of the basin. The maximum height of the basin is 594 m and the lowest is 419 m. Therefore, the relief of the basin is 175 m, showing a moderate slope, low runoff and enhanced infiltration in the basin.

X. Relief Ratio (R_h)

Relief ratio is defined as the basin relief to the horizontal distance along the longest dimension of the basin parallel to the main drainage line (Schumm, 1956). The R_h normally increases with decreasing drainage area, size of the basin (Gottschalk. 1964). It is noticed that the high value of Rh indicates steep slope and high relief. The value of R_h is 0.71 for the study area, the lower values may indicates the presence of basement rocks that are exposed in the form of small ridges and mounds with lower degree of slope (GSI, 1981).

Y. Ruggedness No (R_n)

Ruggedness number is the geometric characteristics of a drainage basin and it is used to measure surface unevenness, flash flood potential and an indicator of the intensity of erosion process (Selvan et al., 2011). Strahler’s (1956) Rn is the product of the basin relief and the drainage. Extremely high value of ruggedness number occur when slopes of the basin is not only steeper but long as well. For the present basin, the ruggedness number obtained is 0.061. The low ruggedness value of basin implies that area is less prone to soil erosion and have intrinsic structural complexity in association with drainage density and relief.

Z. Shape Factor (R_f)

Shape factor (R_f) is the ratio of the square of the length of the basin. R_f of the study region shows the value of 5.31.

IV. SUMMARY & CONCLUSIONS

Morphometric analysis of drainage system in a basin is prerequisite to any hydrological study. Thus, identification of stream network’s behaviour and their interrelation with each other is of great importance in many water resource studies. The study indicates that remotely sensed data (SRTM-DEM) and GIS based approach in evaluation of drainage morphometric characteristics and their influence on soils, landforms and eroded land features at basin level is more suitable than the conventional methods. Different landforms were identified in the watershed based on SRTM (DEM) data with 30 m spatial resolution, and GIS software. The morphometric analyses were carried out through measurement of Basic/linear, areal and relief aspects of the basin parameters, which helps in understanding various terrain parameters such as nature of bedrock, surface runoff, infiltration capacity etc.

The detailed morphometric analysis of Musi river basin has been showedthe following facts:

1. The morphometric analysis of Musi river basin reveals that it is designated as VI^{th} order stream and extracted stream network exhibits dendritic to sub-dendritic drainage pattern.

2. The small variations in bifurcation values for different regions is due to lithological and geological development of the drainage basin and lower value of mean bifurcation ratio is found in the basin suggesting drainage pattern is not much influenced by the geological structures and basin is less affected by structural disturbances.

3. The drainage density values specifies that basin is having a flat terrain composed of permeable subsurface strata and has coarse drainage texture with a good vegetation cover, which shows comparatively are good sites for ground water recharge as compare to high D_d watersheds.

4. Sinuosity Index parameter denotes that stream is deflected from it's straight path and follow somewhat transitional course (sinuous).

5. The elongated shape of the basin indicated by values obtained from elongation ratio, circulatory ratio and form factor. The lower form factor indicates elongated basin with flatter peak flows of longer duration which leads to ground water percolation. Flood flows in such a basin are easily manageable than from the circular shaped basin. In the present case, study reveals that the drainage areas of the basin are passing through late youth stage of the fluvial geomorphic cycle.

6. The low values of drainage density, stream frequency, drainage texture, length of overland flow, texture ratio, relief aspects and infiltration number show that the study area sub surface strata underlain by permeable rocks responsible for low discharge of runoff with longer flow paths and enhanced infiltration.

7. Relief ratio, Ruggedness number measure watershed steepness and can be used to represent intensity of erosion process. In the study area low relief values indicate lower degree of slope and low ruggedness value implies area is less prone to soil erosion.

8. The river basin originates from the steep slope area. Most of the streams occur in comparatively plain lands and the sub-surface strata is permeable. Therefore, the plains are an important locations for constructing an artificial recharge structures for augmenting the groundwater.

The morphometric analysis attempted in this study is helpful in relation to watershed prioritization with respect to the susceptibility to soil erosion and flooding. Further, the results provide useful information for watershed managers to assist in decision making with more informed characteristics of the watershed. In the present scenario where water resources are becoming scarce, this exercise of assigning various attributes to the river basin plays a vital role in watershed development as well as locating sites for watershed harvesting structures. The results can be applied over several regions with similar morphological characteristics.

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