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The approach of geospatial technique in the investigation of morphometric parameters and its impact on hydrological features

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Abstract

The Remote Sensing and GIS becoming an efficient tool for the collection of remotely sensed large areal extent of data in a periodic way. The globally available digital elevation model (DEM) is one of the example of GIS launched by different satellites which acquires terrain elevation data to characterize any size of watershed by estimating morphometric parameters for watershed management. The present study attempted to computation of morphometric parameters of the Western flowing Vashishti river basin in the district of Ratnagiri, M.S. The basin was delineated using AW3D30 DEM in ArcGIS 10.4 software. The study computed 32 categorized morphometric parameters. The drainage area is found 2129.97 km2 comprises 5th order basin. The higher stream number of 316 obtained in 1st order indicates most dominant while lowest 28 stream number in 5th order. In linear aspects, mean bifurcation ratio (1.86) and Mean stream length ratio (0.98) indicates basin is less structurally disturbed and initial stage of geomorphic development. In areal aspects, drainage density (0.536 Km^{-1}) and stream frequency (0.296 Streams/Km2) indicates basin is highly permeable subsurface strata with coarser texture tends to less runoff potential having longer flow path. In areal aspects, Form factor (0.205), Elongation ratio (0.511) and Compactness coefficient (1.755) indicates elongated basin shape, less chances to attains flatter peak in flood hydrograph. In relief aspects, relief ratio (0.012), relative relief (0.425 m/km), ruggedness number (0.66), time of concentration (12 hr 45 min) indicates rolling to gentle slopes, moderate roughness and unevenness, dissected characteristics of the basin with minimum denudation stage and flow takes more travel time. The study concluded that the GIS based morphometric analysis give knowledge of lithology, infiltration capacity and prioritization of watershed very effectively by reducing the time and cost factor important for watershed management.

Keywords: AW3D30 DEM, digital elevation model, morphometric parameters, remote sensing and GIS technology and watershed

1. Introduction

A drainage area is a land that drains the concentrated flow rainfall generating runoff into one location to single outlet point by means of a river's stream network, lake or wetland. The drainage area or watershed is hydrological entity where different kind of sustainable developmental activities can perform in availability of natural resources (Sangma and Guru 2020) [26]. Watershed management is nothing but the study of different watershed characteristics and natural resources within a watershed and makes its uniform distribution for sustainable development by implementing different watershed development projects to improve the watershed's efficiency beneficial for living ecosystems. watershed management has ability to protect the biodiversity and improves erosion control, surface and subsurface recharge, agricultural productivity, flood control, decreases pollutant level in water resources, etc (Kumar and Palanisami 2009) [38].

The watershed management has complex structure of variable characteristics which is not access and apply all at once. The quantitative information of morphometry provides simple, basic and logical approach in watershed management (Umer *et al*. 2015) [33]. The morphometric analysis is very useful where, present limited data, lack of information access and variety of soil (Meshram *et al*. 2020) [19]. The morphometric parameters categorized into different aspects according to physiological characteristics. The morphometric analysis provides information of terrain features, basin geometry like size, shape, landforms feature a hydrological process which helps in basin characterization (Strahler 1964) [30]. The morphometric parameters provide comprehensive relationship of peak runoff, lag time, sedimentation risks and soil erosion (Gajbhiye and Sharma 2017) [9]. The watershed's hydrological response from morphometry is used in sediment transport and flood modeling (Arulbalaji and Gurugnanam 2017) [3].

The acquisition of watershed's morphometric parameters by traditional survey method is not easy due to numerous problems like huge area of land, irregular topographic features, time and cost factor (Meshram *et al*. 2020) [19]. The question arises which technique will suitable to acquire this huge data while conserving time and cost factor. Over the past two decades, the largely deriving technique of Remote Sensing and GIS to acquire remotely sensed data like terrain elevation data by Digital Elevation Model, and land cover data by Landsat satellites etc., The GIS proved to be a feasible application in the evaluation of the hydrological response behaviour of any drainage basin (Rai *et al*. 2017). GIS-based drainage morphometric analysis is not only faster but also efficient in computation for analyzing basin characteristics, and watershed prioritization studies (Yadav *et al*. 2014) [36].

2. Materials and Methods

2.1 Study area

The study area Vashishti basin located in the Ratnagiri district of Maharashtra state in India (Fig. 1). It is one of the largest river basin in Konkan coast of M.S. contributing an area of 2238 km^2. The basin is stretched between 17° 31' and 17° 35' N longitude and 73° 42' and 73° 7'E latitude with an altitude between -17 m to 1219 m above MSL. The Shiv Nadi (left bank), Jagbudi and Kodjai (right bank) are the main tributaries that drains water to basin. The study area comes under Humid to Semi-arid Very High Rainfall Zone with Lateritic Soils as per Agriculture Department, Govt. of M.S. The average annual rainfall is 3391mm and temperature variation ranges from 12 °C to 39° from winter to summer. The study area covered about 85% hilly land surface. The basin eastern portion made of Basalt rock (8 to 10m) and western portion made of Lateritic Plateau (6 to 60m) shows basin starts from rocky portion to clay texture towards outlet. The land use/land cover analysis of the study area, 39 % is under forest, 52 % land under scrub/shrub, and very less 2.1 % comes under agricultural land (Anonymous, 2019) [2].

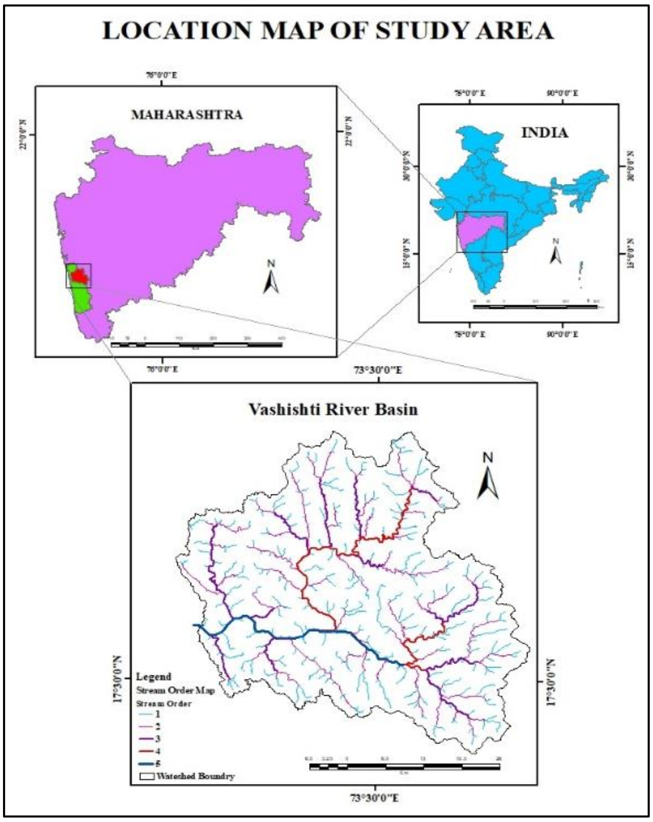

Fig 1: Study area map Vashishti river basin

2.2 Data used and Methods

The integrated remoted sensing and GIS approach used to analyze the morphometric parameters of the basin. The study area delineated or drainage network extraction using Alos World 3D (AW3D30) 30m resolution-based DEM in ArcGIS 10.4 software by procedure discussed below Fig. 2.

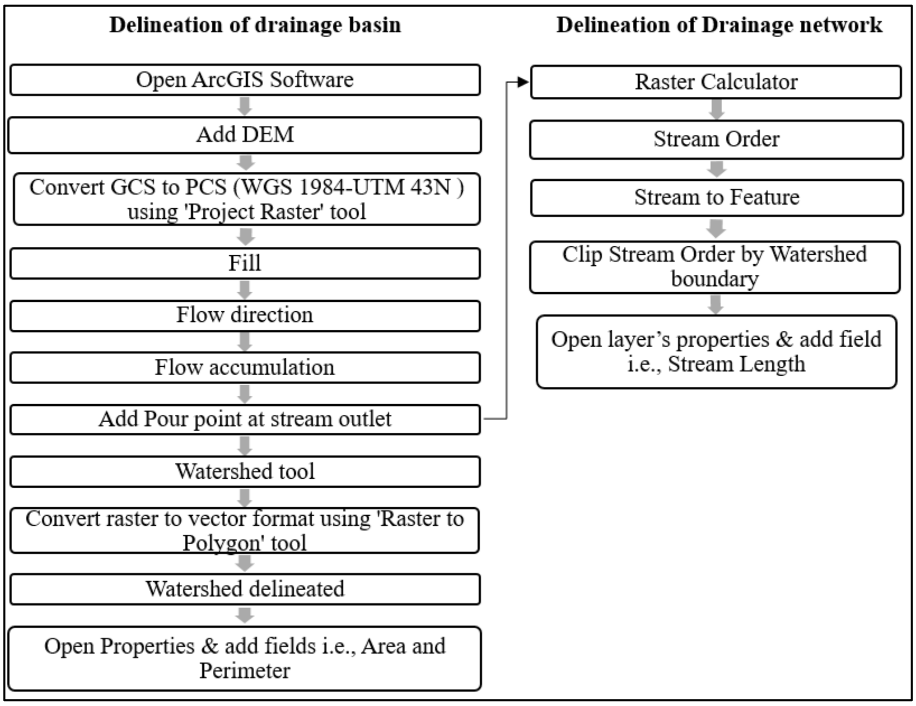

Fig 2: Watershed delineation and stream network extraction process using ArcGIS 10.4

The stream ordering is done using modified Horton's law stated by Strahler (1952) [31]. The fundamental parameters like basin area, perimeter and stream order wise stream number and length were recorded after watershed delineation. The other linear, areal, shape and relief attributes are computed to analyze the complete hydrological behaviour of the drainage basin based on the different formulas suggested various researchers given in Table 1.

Table 1: Formulas for different morphometric parameters:

No.	Parameter	Symbol	Formula	Units	References
A. Basic morphometric parameters					
1	Basin area	A	ArcGIS Software	km^2	
2	Perimeter	P	ArcGIS Software	m	
4	Max. Elevation	H_{max}	ArcGIS Software	m	
5	Min. Elevation	H_{min}	ArcGIS Software	m	
6.	Basin Length	L_b	$Lb = 1.312 \times A^{0.568}$	m	Nookaratnam (2005) [22]
B. Linear Morphometric parameters					
7.	Stream order	μ	Hierarchical rank	Unitless	Strahler (1957, 1964) [29, 30]
8.	Number of streams	N_μ	Total number of stream segments of the order "μ"	Unitless	Strahler (1957) [29]
9.	Stream length	L_u	$L_u = L_{u1} + L_{u2} + \ldots + L_{un}$	m	Horton (1945) [12]
10.	Mean stream length	L_u	$- \ L_u = \frac{L_\mu}{N_\mu}$	m	Strahler (1964) [30]
11.	Stream length ratio	R_l	$R_l = \frac{L_u}{L_{\mu-1}}$	Unitless	Horton (1945) [12]
12.	Bifurcation ratio	R_b	$R_b = \frac{N_u}{N_{u+1}}$	Unitless	Schumm (1956) [27]
13.	Mean bifurcation ratio	R_{bm}	R_{bm} = average R_b of all orders	Unitless	Strahler (1957) [29]
C. Areal morphometric parameters					
14.	Drainage density	D_d	$D_d = \frac{L_\mu}{A}$	km/km^2	Horton (1945) [12]
15.	Stream frequency	F_s	$F_s = \frac{N_\mu}{A}$	Km^{-2}	Horton (1945) [12]
16.	Drainage Intensity	D_i	$D_i = \frac{F_s}{D_d}$	Km^{-1}	Faniran (1968) [37]
17	Drainage texture	T	$T = \frac{N_u}{P}$	Km^{-1}	Horton (1945) [12], Smith (1950) [28]
18.	Length of overland flow	L_g	$L_g = \frac{1}{D_d} \times 2$	km	Horton (1945) [12]
D. Basin shape parameters					
19.	Form factor	F_f	$F_f = \frac{A}{Lb^2}$	Unitless	Horton (1945) [12]
20.	Elongation ratio	R_e	$R_e = 2 \times \frac{\sqrt{A/\pi}}{L_b}$	Unitless	Schumm (1956) [27]
21.	Circulatory ratio	R_c	$R_c = 4\pi \frac{A}{P^2}$	Unitless	Strahler (1957) [29]
22.	Shape index	S_w	$S_w = \frac{Lb^2}{A}$	Unitless	Horton (1945) [12]
E. Relief morphometric parameters					
23.	Relief	R	$R = H_{max} - H_{min}$	m	Hadley & Schumm (1961) [10]
24.	Relative relief	R_{hp}	$R_{hp} = R \times \frac{100}{P}$	Unitless	Melton (1957) [17]
25.	Relief ratio	R_r	$R_r = \frac{R}{L_b}$	Unitless	Schumm (1956) [27]
26.	Ruggedness number	R_n	$Rn = R \times D_d$	Unitless	Strahler (1957) [29]
27.	Melton ruggedness number	MR_n	$MR_n = R/\sqrt{A}$	Unitless	Melton (1965) [18]
28.	Time of concentrations	T_c	$Tc = 0.01947 \times Lb^{0.77} \times (\frac{R}{Lb})^{-0.385}$	Hrs.	Kirpich (1940) [15]
29.	Constant of channel maintenance	C	$C = \frac{1}{D_d}$	km^2/km	Schumn (1956) [27]
30.	Texture ratio	R_t	$T = N_1 \times \frac{1}{P}$	Unitless	Ozdemir and Bird (2009) [23]
31.	Time to Recession	N	$N = 0.84A^{0.2}$	Days	Mustafa & Yusuf, (2012) [20]
32	Compactness coefficient	C_c	$C_c = 0.2821 \times \frac{P}{A^2}$	Unitless	Horton (1945) [12]
33	Basin Infiltration Number	I_F	$If = D_d \times F_s$	km^{-3}	Pareta & Pareta, (2011) [25], Faniran (1968) [37]

34	Dissection index	DI	$DI = \frac{R}{H_{max}}$	Unitless	Nir (1957) [21]

3. Result and Discussion

The stream network generation from AW3D30 DEM using ‘Spatial Analyst’ and ‘Hydrology’ toolbox in ArcGIS 10.4. The aspect wise morphometric parameters of the Vashishti basin analyzed, which results summarised in Table 4.

3.1 Basic Aspects of Drainage Basin

Basic aspects of the basin are closely related to the size and shape of basin are analysed. It includes analysis of area (A), perimeter (P), and Basin length (L_b) calculated DEM dataset.

3.1.1 Watershed Area (A)

It is the total area of the projected horizontal surface enclosed under the ridgeline of watershed. It computes after delineation of drainage basin. It significantly affects directly on streamflow as size of watershed increases. The basin area is obtained 2129.97 Km^2.

3.1.2 Watershed Perimeter (P)

It is length of the entire delineated vectorised boundary or ridgeline of watershed. The shape and size of the ridgeline of basin extracted from DEM generates due to changes in highest to lowest elevation. The perimeter is obtained 287.12 Km.

3.1.3 Length of Basin (L_b)

It is the extended linear dimension of the basin collateral to the principal drainage line which travels the largest quantity of stream flow (Schumm 1956) [27]. The basin length of study basin is obtained 101.965 Km.

3.2 Linear Aspects of Drainage Basin

Linear parameters of the basin are closely related to the stream network where the topological features of the stream segments are analysed. It includes analysis of stream orders, stream number (Nu) stream length (L_u), mean stream length (L_{um}), stream length ratio (R_L), and bifurcation ratio (R_b).

3.2.1 Stream Order (u)

Stream ordering is the initial step of drainage pattern analysis. Its categorization can be done based on number and junction of tributary. It is not only indexing or ordering but also understanding to know the size of watershed, degree of stream branching and quantity of stream flow will generate from any particular stream network. The stream ordering concept was firstly initiated by Horton (1945) [12], but Strahler (1952) [31] presented the popularly known stream segment method with some changes which are followed in that study. According to Strahler (1964) [30], the smallest unbranched tributaries start from watershed ridgeline, numbered as 1st order. The 2nd order stream appears where two 1st-order streams connect. A 3rd-order stream appears when two 2nd-order streams connect and so on in that manner main channel discharges a large quantity of water indicated as the highest order stream of a drainage basin. In the present study, the highest stream order is obtained 5.

3.2.2 Stream Number (Nu)

It is the number of total stream segments of individual stream order which forms branches like tree root structure. Horton (1945) [12] stated that the inverse geometric sequence forms between the order-wise number of stream segments with order number. The maximum numbers of first-order streams indicate a higher amount infiltration rate, permeability, maximum time of concentration, and erosive topography (Biswas 2016) [4]. In the present study, the log of the stream numbers of individual order is plotted against the stream order, and it found an inverse geometric sequence that showed a linear relationship that indicates uniform lithology shown in Fig. 3. The order-wise different stream number is 316 for the Ist order, 169 for IInd order, 71 for IIIrd order, 47 for IVth order and 28 for Vth order. From the results, it reveals that the number of streams decreases as stream order increases which reflect the quantity of surface runoff stream flow capacity due to structural and geomorphological features of the basin.

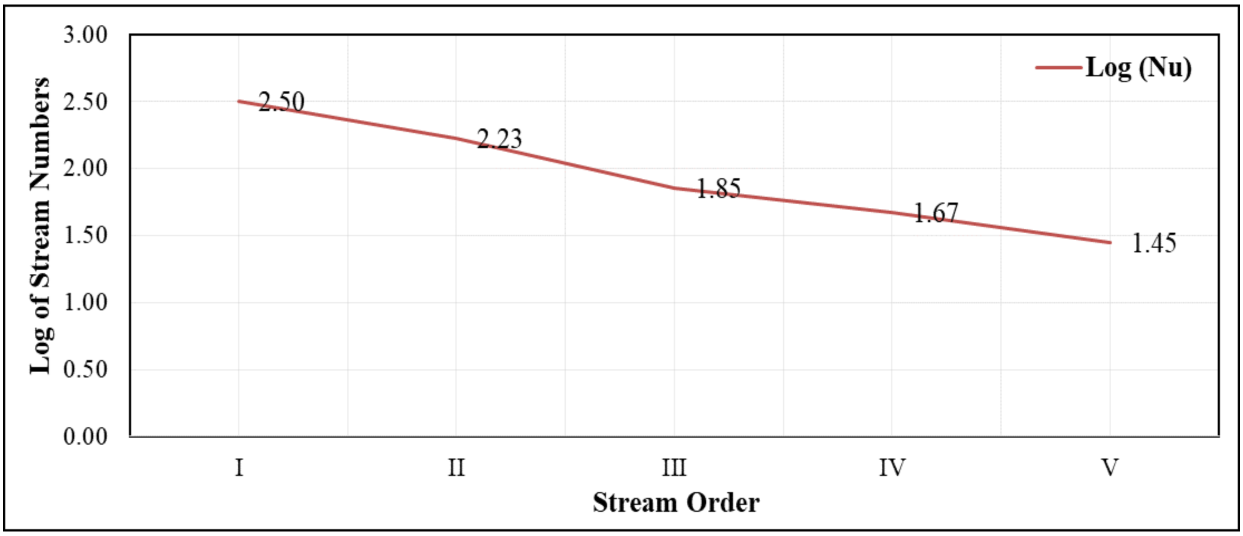

Fig 3: Stream Order *Vs* Log (*N_u*)

3.2.3 Stream Length (Lu)

It is the total length of stream number of individual stream order. The highest stream length was obtained in first order and it going to decrease with order number increases which occurs due to topographic changes from steep slope with hard strata to flat slope with finer texture (Horton 1945, Strahler 1964) [12, 30]. Sreedevi *et al.* 2005 [39] observed that high value of stream length in mountain–plain land than in plateau–plain land of the river basin. In the present study, the total stream length is obtained 1140.79 Km with order-wise stream lengths being 555.7 Km of Ist order, 310.8 Km of IInd order, 146.3 Km of IIIrd order, 83.5 Km of IVth order and 44.4 Km of Vth order. The highest stream length is obtained from Ist order streams which reveal that the maximum study area comes under a hydrologically high rainfall zone and presence of uneven topography. The results also show that stream length decreases as stream order increases.

3.2.4 Mean Stream Length (L_{um})

It is calculated by dividing the total stream length (L_u) of individual order 'u' by total number of streams of that order (N_u). The order-wise mean stream length is obtained 1.76 Km in Ist order, 1.84 Km in IInd order, 2.06 Km in IIIrd order, 1.78 Km in IVth order and 1.59 Km in Vth order given in Table 2. The results, shows higher value found in IIIrd and IIrd order streams.

Table 2: Stream order wise stream number and stream length

Stream Order	Stream Number	Stream Length	Mean Stream Length
I	316	555.72	1.76
II	169	310.83	1.84
III	71	146.33	2.06
IV	47	83.53	1.78
V	28	44.39	1.59
Total	631	1140.80	
Mean		228.16	1.81

3.2.5 Stream Length Ratio (R_L)

It is the ratio between total stream length of one order to the total stream length of its previous order. It shows relationship between basin surface water flow as discharge and stage of erosion. The mean stream length ratio is obtained 0.98 with order wise variation of 1.05 of II/I, 1.12 of III/II, 0.86 of IV/III and 0.89 of V/ IV, which shows inverse proportion obtained between stream lengths and stream order given in Table 3. From overall results, stream length ratio obtained from different DEM denoted that the area is under initial stage of geomorphic development and high capability of frequent changes in future. This is also indicated non-uniform hydrological behaviour.

3.2.6 Bifurcation Ratio (R_b)

It is the ratio between total numbers of streams in a one order (Nu) to the number of next higher order (Nu + 1) (Schumm 1956) [27]. It can be measures surface water potential and hydrographs of a watershed (Jain *et al*. 2000) [13]. It varies between 1 to 10, normally in range of 3 to 5 (Strahler 1964) [30]. In present study, the mean bifurcation ratio is obtained 1.87 varying in range of 1.87 of I/II order, 2.38 of II/III order, 1.51 of III/IV order and 1.68 of IV/V order given in Table 3. The R_b between 2nd and 3rd order streams may be considerably higher than the R_b in other sequence due to active ravines and gullies (Verstappen 1983). R_{bm} does not remain constant from order to order because there are variations in basin geometry and its lithology. The overall results, the lower value Rb indicates basin has less structurally disturbed without any distortion in drainage network with low flood potentiality (Suji *et al*. 2015) [32], Which also indicates delayed or late hydrograph peak and basin has less or negligible structural control on the drainage development for this basin.

Table 3: Stream order wise bifurcation ratio and stream length ratio

Stream Order	Bifurcation Ratio	Stream Length Ratio
I-II	1.87	1.05
II-III	2.38	1.12
III-IV	1.51	0.86
IV-V	1.68	0.89
Mean	1.86	0.98

3.3 Areal Aspects of Drainage Network

In that, the study gives the description of arrangement of areal element like Drainage Density (D_d), Drainage Intensity, Drainage texture, Stream frequency (F_s), Length of overland flow were computed and the results have been given in Table 4.4.

3.3.1 Drainage density (D_d)

It is ratio of the total stream length to the area of the basin (Horton 1932) [11]. Drainage density is having direct inverse relationship with infiltration capacity, permeability and vegetative cover Horton 1945 [12], Strahler 1956 [27]. Strahler (1957) [29] categorised D_d indifferent ranges like course (< 5 km^{-1}), medium (5.00 to 13.7 km^{-1}, fine (13.7 to 155.3 km^{-1}), and ultra-fine (> 155 km^{-1}). The lower D_d results in the areas have permeable subsoil or highly resistant, dense vegetative cover, low relief and runoff, whereas higher D_d value have a more streams number results in gives rapid stream response (Chorley 1969) [6]. In present study, the value of drainage density is obtained 0.536 km/km^2, which indicates course drainage density, infiltration characteristics, highly permeable resistant subsurface strata tend to lower runoff and with denser vegetation. These features suggest that basin is highly suitable for groundwater recharge.

3.3.2 Drainage texture (T)

It is the ratio between total stream number of all orders and perimeter of that area (Horton 1945) [12]. It is critical factor which affects infiltration capacity (Horton 1945) [12], however Smith (1950) [28] suggested drainage texture depends on various physical factors like rainfall, type of soil, vegetative cover and relief. They categorised drainage texture values in the five groups, very fine (> 8), fine (6–8), moderate (4–6), coarse (2–4), and very coarse (< 2). The drainage texture was found 2.20 Km^{-1}, which indicates coarser drainage texture implies the watershed has larger basin lag periods than the fine textured basins. From the values, the study area has very coarse to course drainage texture having larger basin lag period.

3.3.3 Stream frequency (F_s)

It is the ratio between total number of streams of all orders and unit area of the watershed. It gives drainage basin response to runoff processes. It has inverse relationship with mean annual rainfall and Infiltration whereas direct related to runoff and degree of dissection (Pankaj and Kumar 2009). The results comparing with other study of Das *et al*. (2016), the value of S_f is obtained 0.296 streams per Km^2. The lower value of S_f indicates because large extent of area under low slope in plateau with poor drainage network tends to more infiltration and less runoff.

3.3.4 Drainage intensity (D_i)

It is the ratio of stream frequency to the drainage density of basin. (Faniran 1968) [37]. The lower value of stream frequency (F_s) and drainage intensity (Id) shows ultimately lower values of drainage intensity (D_i) (Faniran 1968) [37]. The drainage density is obtained 0.55 km/km^2, which lower value indicates that the surface runoff is not remove quickly and good capability of absorbing water into soil which helps in groundwater recharge from the river basin there is also reduction of flood risk.

3.3.5 Length of overland flow (L_g)

It is equal to half of the drainage density (D_d) which describes the length of surface runoff flow over ground before it becomes accumulated in definite stream line channel. It estimates of erodibility, infiltration capacity of subsoil which significantly effects on development of watershed (Sahu *et al.* 2016) [40]. Chandrashekar *et al.* 2015 [5] suggested the different ranges of L_g with indications such as value <0.2 km indicates short flow length due to a steep slope and low infiltration causes more runoff from the catchment; If the L_g f value between 0.2 to 0.3 km, indicates moderate condition; If the L_g value >0.3 km, indicates longer flow path due to low slope and high infiltration causes low runoff from the catchment. In present study, the value of overland flow is obtained 0.934 Km, which indicates relatively longer L_g due to more infiltration and relatively permeable nature of river basin and catchment showed low response to runoff.

3.4 Shape Aspects of Drainage Basin

This refers to the analysis of Form factor (F_f), Elongation ratio (R_e), Circulatory ratio (R_c) and Shape index (S_w) It describes the shape of basin which may be elongated to circular character tends to changes in quantity of runoff generation

3.4.1 Form factor (F_f)

Form factor is defined as the ratio between area of watershed to the square of basin length. The F_f value affects stream flow because it depends on basin shape. A lower value indicates an elongated shape of basin whereas higher value for a circular shape of basin which is responsible for maximum peak flow with short time period (Horton 1932) [11]. In present study, The value of form factor was obtained 0.205, which indicates elongated basin shape and less possibility to attains flatter peak flow in flood hydrograph at basin outlet if a heavy rainfall event is done.

3.4.2 Elongation ratio (R_e)

Elongation ratio is defined as the ratio of diameter of circle of same area as the watershed to the basin length. The R_e always vary in range of 0 for highly elongated shape to 1 for circular shape of basin (Strahler 1964). These values categorised in different groups as 0.9 to 1 for circular, 0.8 to 0.9 for oval, 0.7 to 0.8 for less elongated, 0.5 to 0.6 for elongated and <0.5 for more elongated (Biswas *et al.* 2016) [4]. The elongation ratio of the study area is found 0.511, which indicates elongated shape of basin and falls in category of low relief.

3.4.3 Circulatory ratio (R_c)

It is the ratio of the area of basin to the area of the circle having the same circumference as the basin perimeter. The value of the R_c always varies between 0 (in line) to 1 (in a circle) (Chougale and Jagdish 2017) [7]. The value of R_c of the study area is obtained 0.32. R_c depends on various factors like stream length and its frequency, relief, geology and climate. The results indicated the basin is elongated shape having pervious strata, low relief and younger stage of basin.

3.4.4 Compactness coefficient (C_c)

It is the ratio of basin perimeter to the circumference of identical circular area. The value C_c varies with ≥1, in which value 1 indicates that basin has perfectly circular shape and greater value indicate more deviation from the circular shape of basin (Horton 1945) [12]. It is a dependent of slope of basin not on size of basin. In the present study, the value obtained 1.755, which indicates elongated shape of basin and reduce the chances of flood higher time of concentration.

3.4.5 Shape factor (S_w)

It is the proportion of the square of basin length to the basin area (Horton 1945) [12]. The shape factor or index effects on many factors in that significantly affects on-stream flow, sediment yield along flow path (Sangma and Guru, 2020) [26]. The value of the shape factor for the study area found 4.88 which shows elongated basin shape having moderate or less susceptible to erosion.

3.5 Relief Aspects of Drainage Basin

This refers to the analysis of basin relief (R), Relative Relief (R_{hp}), Relief ratio (R_r), Infiltration Number (IF), Channel of Constant Maintenance (C), Ruggedness number (R_n), Melton Ruggedness number (MR_n), Time of Concentration (T_c), Time of Recession, Dissection index (D_i). The character relates to the distribution of slope of the basin depends on the contour distribution within it.

3.5.1 Basin relief (R)

Basin relief is the elevation difference exist between maximum (H) and minimum (h) points in a basin. It is major factor which decides their topographic features at that site. In the present study, the maximum relief of the basin obtained from AW3D30 DEM is 1236 m. The higher value of basin relief shows very sensitive to gravity of flow and infiltration rate. The study area has major portion covered with flat topography than hilly topography.

3.5.2 Relief ratio (R_r)

It is defined as the proportion between the total basin relief (H) to the maximum basin length parallel to the main drainage line (L). The value of R_r changes with inverse proportion of basin area and size (Adhikary and Dash 2018) [1]. It gives idea about overall slope steepness, erosion susceptibility on watershed slopes (Schumm 1956) [27]. In this study, the value of relief ratio is obtained 0.012, which value indicates that the presence of rolling and gentle slopes in the basin tends to the least intensity of erosion susceptibility in the basin, suggestive study of Kasi *et al.*, (2020) [14] The relief ratio helps to get better picture of relief parameters than total relief.

3.5.3 Relative relief (R_{hp})

It is the ratio between basin relief and the perimeter of basin. It is directly related to erosion intensity and its susceptibility (Melton 1957) [17]. In this study, the value of relative relief is obtained 0.425 m/km. From suggestive study of Tarte and Kumar (2020) the obtained value indicates Low R_{hp} which represents gentle topography with low erosion susceptibility.

3.5.4 Ruggedness number (R_n)

Ruggedness number is multiplication of basin relief (R) and drainage density (D_d). It measures surface roughness and unevenness or structural complexity of the basin (Strahler 1957) [29]. The five classes of morphology were done as R_n <

0.1 shows smooth morphology; 0.1 to 0.4 shows slight morphology, 0.4 to 0.7 shows moderate morphology, 0.7 to 1.0 shows sharp morphology, >1.0 shows extreme morphology (Yahya *et al*. (2015) [41]. For the study area, the value of ruggedness number is found 0.66. In classified groups, value of R_n follows moderate morphological characteristics having moderate roughness and unevenness also there is moderate risk of flood hazard and soil mass movement

3.5.5 Melton Ruggedness Number (MR_n)

It is the ratio of basin relief to the square root of area of basin. It measures the elevation differences exist in basin to its basin area. Melton 1965 [18] categorised the basin in two classes like one is water flood basin and other one is debris flood basins. Thereafter, Wilford *et al*. (2004) decided the range of MR_n, if the value of MR_n is <0.3 then basin comes under water flood basin and if value of MR_n >0.6 then the basin comes under debris flood basins. In present study the value of MR_n is obtained 0.03, indicates basin comes under flood flow basin.

3.5.6 Texture ratio (R_t)

It is ratio of stream number of 1st order stream to the basin perimeter. It is very important in the basin morphometric analysis, which depends on the infiltration capacity of at present lithology and terrain relief. The categorisation of Rt values in different groups such as <4.0 shows coarse texture; 4.0 to 10.0 shows moderate texture; >10.0, has fine texture and so on (Smith 1950) [28]. In present study, the texture ratio value is obtained 1.10, which indicates a course drainage texture.

3.5.7 Constant of channel maintenance (C)

It is the inverse of drainage density (D_d), which measures the unit channel length of drainage basin area is needed to maintain. Kumar *et al*., 2010 [16] suggested the value of C <1 shows the drainage basin network facing structural disturbance, less pervious strata, steep to more steep slopes and maximum surface runoff, whereas the high value shows basin under less structural disturbances and low runoff value. In present study, the value of constant of channel maintenance is obtained from 1.86 km^2/km, which indicates basin has permeable strata with low runoff possibility and mature to the old stage of basin.

3.5.8 Infiltration number (IF)

It is obtained by the multiplication of drainage density (D_d) and stream frequency (S_f). It has inverse relationship with infiltration rate and surface runoff (Faniran 1968) [37]. The value of infiltration number is found 0.16 Km^{-3}, this lower value indicates the basin has more permeable, high infiltration rate, and low amount of runoff and less flooding chances from basin.

3.5.9 Dissection index (DI)

It is the ratio between relative relief (R_r) to the maximum elevation (H). It measures degree of erosion undergone in basin. The value of DI varies between 0 to 1, in which ‘0’ indicates vertical dissection is absent with stage of maximum denudation and ‘1’ indicates vertical basin area with stage of minimum denudation. The DI value of Vashishti river basin is obtained 1.013, the index value indicates dissected characteristics of the basin with minimum denudation stage of geomorphic development and minimum denudation stage. It is also indicating further potentiality of erosion but actually, this is not occurring in whole basin and is found in mountainous occupied area of first order streams.

3.5.10 Time of concentration (T_c) and Time of recession (N)

It is defined as the time period required for a drop of water travel from the most hydrologically remote point on ridgeline in the watershed to the collection point or outlet. T_c value indicates the more length of time will gain to travel from the remotest point of the basin to its collection point or outlet. It depends on many factors like topographic features like relief, soil type, vegetation, SWC structures installed or not etc. In present study, the value of T_c was obtained 12 hr 45 min 8 sec, the value of T_c indicates required more to travel due to large area and various topographic features. The value of time of recession is obtained 3 days 21 hr for flood water to recede after peak.

Table 4: Results of drainage basin morphometric parameters.

Sr. No.	Parameter	Symbol	Units	Results
Basin basic parameters				
1	Watershed area	A	km^2	2129.97
2	Perimeter	P	km	287.13
3	Max. Elevation	H_{max}	m	1219
4	Min. Elevation	H_{min}	m	-17
5	Basin length	Lb	km	101.96
Basin Linear parameters				
6	Stream order	µ	Unitless	1 to 5
7	Number of streams	N_μ	Unitless	631
8	Stream length	L_u	km	1140.79
9	Mean stream length	L_{um}	km	1.81
10	Stream length ratio	R_L	Unitless	0.86 to 1.12
11	Mean Stream length ratio	R_{Lm}	Unitless	0.98
12	Bifurcation ratio	R_b	Unitless	1.5 to 2.4
13	Mean bifurcation ratio	R_{bm}	Unitless	1.86
Basin areal parameters				
14	Drainage density	D_d	km/km^2	0.54
15	Drainage texture	T	Km^{-1}	2.20
16	Stream frequency	F_s	Km^{-2}	0.30
17	Drainage Intensity	Di	Km^{-1}	0.55
18	Length of overland flow	L_g	km	0.93

Basin shape parameters				
19	Form factor	F_f	Unitless	0.20
20	Elongation ratio	R_e	Unitless	0.51
21	Circulatory ratio	R_c	Unitless	0.32
22	Compactness coefficient	C_c	Unitless	1.75
23	Shape index	S_w	Unitless	4.88
Basin Relief parameters				
24	Relief	R	m	1236
25	Relative relief	R_{hp}	Unitless	0.43
26	Relief ratio	R_r	Unitless	0.012
27	Ruggedness number	Rn	Unitless	0.66
28	Melton ruggedness number	MR_n	Unitless	0.027
29	Texture ratio	Rt	Unitless	1.10
30	Constant of channel maintenance	C	km^2/km	1.87
31	Basin Infiltration Number	IF	km−3	0.16
32	Dissection index	DI	Unitless	1.01
33	Time of concentrations	T_c	Minutes	12 hr 45 min
34	Time of Recession	N	Days	3 days 21hr

4. Conclusions

The quantitative morphometric parameters data important for watershed management to understand the hydrological behavior. The remote sensing and GIS database overcome the problem of studying various hydrological features by conventional methods. The study area, Vashishti basin delineated by using the AW3D30 DEM dataset which has given better results in past studies. The study area covered 2129.97 km^2 comprising a 5th-order basin shows dendritic drainage pattern. In morphometric analysis, the linear aspects shows basin has less structurally disturbed and initial stage of geomorphic development. The areal aspects indicated basin is a highly permeable resistant subsurface strata with coarser drainage texture and less runoff potential due to the large area having low slope and longer flow path. The shape aspects show elongated basin shape which has less possibility to attains flatter peak flow and reduce chances of flood. The relief aspects indicated rolling to gentle slopes, moderate roughness, dissected characteristics of the basin with min. denudation stage and stream flow take more travel time due to large area and topographic features. Remote Sensing and GIS technique reduces time and cost factor and gives clear picture of hydrological behavior with problems in natural resource stability. The GIS based morphometric analysis reduces the time and cost factor for watershed management as compare to conventional methods. The morphometric parameters give knowledge of lithology, surface condition, infiltration capacity and prioritize the watershed very effectively.

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