Quantitative Morphometric Analysis of a Manganga Basin, Maharashtra, India using Cartosat (DEM) and GIS

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ABSTRACT: Quantitative analysis of the watershed plays an important role for natural resources management, such as soil, water their conservation helps to improve livelihood of peoples of the region. In the presence study an attempt has been made to study morphometry of Manganga basin situated in eastern part of Satara district of Maharashtra, India. Cartosat digital elevation model (DEM) of 32 m resolution and survey of India toposheet no. E43O14, E43J12 and E43P10 of 1:50,000 scale were used to confirm the length and order of the stream to calibrate site specific brake value of flow accumulation in geoprocessing. Results of the analysis reveals that, Manganga basin has 8th order trunk stream and total stream of all orders were found to be 39814, Bifurcation ratio (Rb) varies from 2 to 6.5 and main channel length (CI) 151.35 Km. Areal aspect of the basin showed that area of the basin (A) is 4757 sq.km, Form factor (Rf) 0.31, Drainage density (Dd) 3.55 Km/sq.Km, Length of overland flow (Lg) 0.14 Km and Elongation ratio (Re) 0.26. Relief parameters were showed that total basin relief (H) of Manganga watershed is 749 m, Ruggedness number (Ra) 2.65 and Relief ratio (RhI) 6.02. From the results it is observed that Manganga basin having dendric pattern and affected by erosion which is reflected by drainage density and overland flow length. Basin is highly undulating terrain and needs protection to control deterioration of natural resources such as soil and water.

Keywords: Linear Aspect, Areal Aspect, Relief Aspect, GIS.

INTRODUCTION

Morphometry may be defined as the quantitative measurement and mathematical analysis of the earth's surface, shape and various dimensions of its landforms. The basin scale analysis is important in any hydrological investigation like assessment of surface and groundwater potential and effectively used for their management. Basin scale analysis of morphometric parameters of watershed is very important for watershed planning since it gives an idea about the basin characteristics regarding slope, topography, soil condition, runoff characteristics, surface water potential, etc. (Chandrashekar, et al, 2015. Morphometric analysis of drainage basin consist of linear, areal and relief aspects. The linear aspect includes the analysis of stream order, number of stream, length of stream, etc. The areal aspect includes the study of basin area, basin perimeter, stream frequency, drainage density, etc. The relief aspect includes the analysis of absolute and relative relief ratio, dissection index, average slope, etc. (Abboud, et al, 2017). Stream order, stream number, stream length, mean stream length, stream length ratio, bifurcation ratio, mean bifurcation ratio, drainage density, drainage texture, stream frequency, relief ratio, form factor, elongation ratio, circularity ratio, length of overland flow are the most common morphometric parameters (Rai, et al, 2017, Chandrashekar, et al, 2015, Abboud, et al, 2017, Vittala, et al 2004, Abboud, et al, 2017, Yangchan, et al 2015, Vinutha, et al, 2014). All these parameters of Manganga basin was studied to describe and evaluate their hydrological characteristics by analyzing topographical map and SRTM data using GIS processes.

The study area comes under semi-arid conditions and agriculture is the main occupation of the people living in the area. Production and productivity of the agriculture varies with morphometric characteristics of the watershed. Soil and water are the basic resource for agriculture which availability and condition shows significant effect on the socio-economical status of the region. These resources are under threat at varying rate at different location due to climate change issue. Due to erratic rainfall pattern and uncontrolled abstraction, groundwater levels have declined to deeper levels. Therefore watershed development schemes become important for developing the surface and groundwater resources in these areas. To understand the present status of the soil and water resources of the basin its morphometric analysis is one of the best and most suitable method. To prepare a comprehensive watershed development plan, it becomes necessary to understand the topography, erosion status and drainage pattern of the region using digital elevation data and GIS techniques which is a speedy, precise, fast and inexpensive way for calculating morphometric analysis (Farr and Kobrick, 2000; Smith and Sand well, 2003; Grohmann, 2004; Grohmann et al. 2007). Therefore in the present study an attempt has been made to utilize cartosat DEM data and the interpretative techniques of GIS to find out the relationships between the morphometric parameters and hydrological parameters Manganga river basin using GIS technique.

STUDY AREA

In the present study Manganga river tributary of Bhima river is considered for the morphometric analysis which originates from the hills laying in the eastern part of Satara district at Kulakjai village and flowing through Sangali and Solapur districts and finally meets to Bhima river at Sarkoli village. The latitudinal and longitudinal extent of the Manganga river basin are between 17 27'N to 17 44'N and 74 95'E to75 14'E. The catchment area of the basin is 4757 square km and main channel length of the river is 151.35km. The climatic condition of the district is tropical. The average annual rainfall in the district is about 1094 mm and the average annual temperature is about 24.1C. Agriculture is the major occupation which supports more than 80 per cent peoples living in the basin.

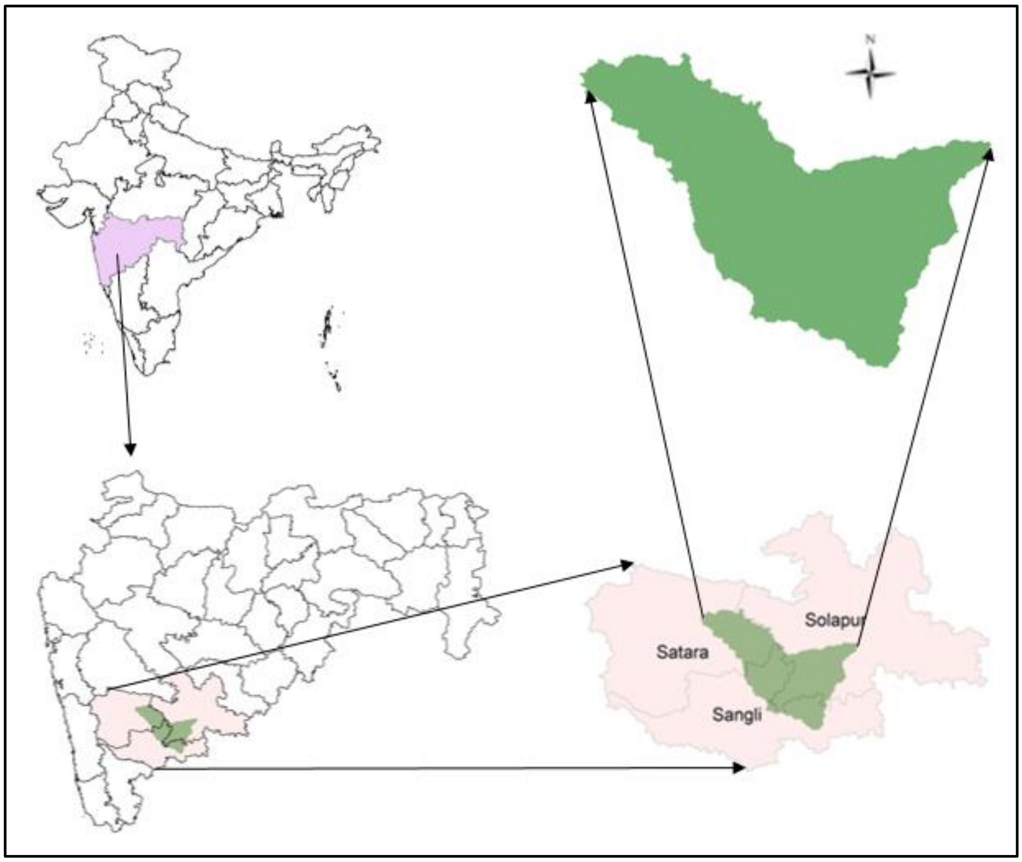

Figure 1. Location Map of study area

METHODOLOGY

ARC GIS 10.3 is used to analysis the basin with the input data such as Cartosat DEM, length of stream is based on the break value which was decided with the help of toposheet the different morphometric characteristics are calculated by the method or formulae developed by different scientists and further used in obtaining all the parameters. Topographical Map: Survey of India Toposheet no. E43O14, E43J12 and E43P10 of 1:50,000 scale were used to calibrate the break value of flow accumulation. Remote sensing data: Cartosat-1:DEM-Version-3RI satellite imagery with 32 m spatial resolution were used as input data.

RESULT AND DISCUSSION

Linear Aspects

Stream Order (Su)

The stream order or water body order is a positive whole number used in geomorphology and hydrology to indicate the level of branching in a river system. The smallest tributaries are referred to as first order stream.

Stream Number (Nu)

The number of stream is also described as total counts of stream segments of different order separately. The number of stream segment decreases with increase in stream order.

Bifurcation Ratio (Rb)

The bifurcation ratio is the ratio of number of the stream segments of given order (Nu) to the number of stream in the next higher order (Nu+1), Horton (1945).

Weighted Mean Bifurcation Ratio (Rbwm)

Weighted mean bifurcation ratio obtained by multiplying the bifurcation ratio for each successive pair of orders by the total numbers of stream involved in the ratio and taking the mean of the sum of these values, Strahler (1953).

Table 1: Stream Order, Stream Number and Bifurcation Ratio of Manganga basin.

Su	Nu	Rb	Nu-r	Rb*Nu-r	Rbwm
I	31512				4.79
II	6576	4.79	138088	182441.52	
III	1334	4.92	7910	38917.2	
IV	305	4.37	1639	7162.43	
V	71	4.29	376	1613.04	
VI	13	5.46	84	458.64	
VII	2	6.5	15	97.5	
VIII	1	2	3	6	
Total	39814	32.33	48115	230696.33	
Mean		4.62			

Stream order (Su), Number of stream (Nu), Bifurcation ratio (Rb), Mean bifurcation ratio (Rbm), Number of stream used in the ratio (Nu-r) and Weighted mean bifurcation ratio (Rbwm).

Stream Length (Lu)

The stream length is measured from source to mouth with the help of ArcGIS 10.3. The total length of stream segments is maximum in first order stream and the length is decreases as the stream order increases

Mean Stream Length (Lum)

Mean Stream length is a dimensional property revealing the characteristic size of components of a drainage network and its contributing watershed surfaces (Strahler, 1964). The mean stream length is defined as the ratio of the total stream length of order to the number of stream.

Stream Length Ratio (Lur)

The stream length ratio can be defined as the ratio of mean stream length of a given order to the mean stream length of next lower order, Horton (1945, p.291).

Table 2: Stream Length and Stream Length Ratio of Manganga Watershed

Su	Lu	Lu/Su	Lur	Lur-r	Lur*Lur-r	Luwm
I	8966	0.28				2.27
II	4000	0.61	2.18	12966	28265.88	
III	1970	1.48	2.43	5970	14507.1	
IV	1082	3.55	2.40	3052	7324.8	
V	541	7.62	2.15	1623	3489.45	
VI	188	14.46	1.90	729	1385.1	
VII	121	60.5	4.18	309	1291.62	
VIII	45	45	0.74	166	122.84	
Total	16913	133.5	15.98	24815	56386.79	
Mean			2.28			

Stream order (Su), Stream length (Lu), Stream length ratio (Lur), Mean stream length ratio (Lurm), Stream length used in the ratio (Lur-r) and Weighed mean stream length ratio (Luwm)

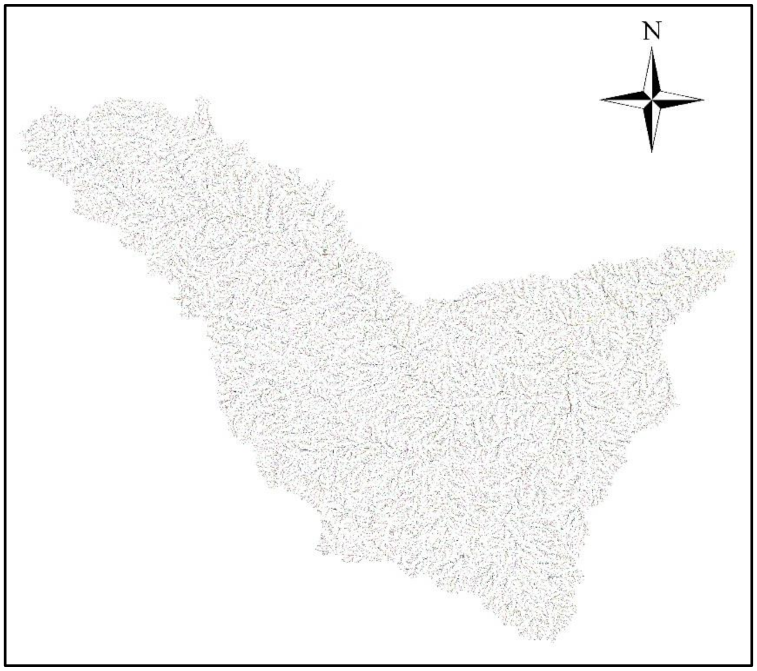

Figure 2. Stream Network of Manganga Basin

Length of Main Channel (CI)

The length along the longest watercourse from the outflow point of designated sun watershed to the upper limit to the watershed boundary.

Channel Index (Ci) and Valley Index (Vi)

The river channel has divided into number of segments as suggested by Muller (1968), and Friend and Sinha (1998) for determination of sinuosity parameter. The measurement of channel length, valley length, and shortest distance between the source, and mouth of the river.

Rho Coefficient (p)

The climatic, geologic, biologic, geomorphologic, and anthropogenic factors determine the changes in this parameter. Rho values of the Manganga watershed is 0.49, (Horton 1945).

Table 3: Linear Aspects of Manganga Basin.

Sr. No	Morphometric parameter	Formula	Reference	Result
1	Stream Order (Su)	Hierarchical Rank	Strahler (1952)	1-8
2	1st Order Stream (Suf)	Suf = N1	Strahler (1952)	31512
3	Stream Number	(Nu) Nu = N1+N2+	Horton	39814

		...Nn	(1945)	
4	Stream Length (Lu) Kms	Lu = L1+L2 ...... Ln	Strahler (1964)	16913
5	Stream Length Ratio (Lur)	see Table 2	Strahler (1964)	2.18-15.98
6	Mean Stream Length Ratio (Lurm)	see Table 2	Horton (1945)	2.28
7	Weighted Mean Stream Length Ratio (Luwm)	see Table 2	Horton (1945)	2.27
8	Bifurcation Ratio (Rb)	see Table1	Strahler (1964)	2-6.5
9	Mean Bifurcation Ratio (Rbm)	see Table1	Strahler (1964)	4.62
10	Weighted Mean Bifurcation Ratio (Rbwm)	see Table1	Strahler (1953)	4.79
11	Main Channel Length (Cl) Kms	GIS Software Analysis	-	151.35
12	Valley Length (Vl) Kms	GIS Software Analysis	-	124.28
13	Minimum Aerial Distance (Adm) Kms	GIS Software Analysis	-	120
14	Channel Index (Ci)	Ci = Cl / Adm (H & TS)	Miller (1968)	1.26
15	Valley Index (Vi)	Vi = Vl / Adm (TS)	Miller (1968)	1.03
16	Rho Coefficient (ρ)	ρ = Lur / Rb	Horton (1945)	0.49

Areal Aspects

Length of the Basin (Lb)

Length of the basin is defined as the length of the line from a basin mouth to a point on the perimeter equidistant from the basin mouth in either direction around the perimeter, Gardiner (1975).

Basin Area (A)

Schumm (1956) an interesting relation between the total watershed areas and the total stream lengths, which are supported by the contributing areas. The author has computed the basin area by using ArcGIS-10.3 software, which is 4757 Sq. Kms (Table 4).

Basin Perimeter (P)

It is measured along the divides between watersheds and may be used as an indicator of watershed size and shape. The author has computed the basin perimeter by using ArcGIS-10.3 software, which is 482 Kms (Table 4).

Length Area Relation (Lar)

Hack (1957) found that for a large number of basins, the stream length and basin area are related by a simple power function as follows: Lar = 225.17

Lemniscate's (K)

Chorely (1957), express the lemniscate's value to determine the slope of the basin. In the formula k = Lb2 / A. Where, Lb is the basin length (Km) and A is the area of the basin (km2). The lemniscate (k) value for the watershed is 3.25 (Table 4).

Form Factor Ratio (Rf)

According to Horton (1932), form factor may be defined as the ratio of basin area to square of the basin length. In the formula Rf =A / Lb2. Where, Lb is the basin length (Km) and A is the area of the basin (km2). The form factor ratio (Rf) value for the watershed is 0.31 (Table 4).

Elongation Ratio (Re)

According to Schumm (1965, p. 612), 'elongation ratio is defined as the ratio of diameter of a circle of the same area as the basin to the maximum basin length. The elongation ratio of watershed is 0.63 (Table 4).

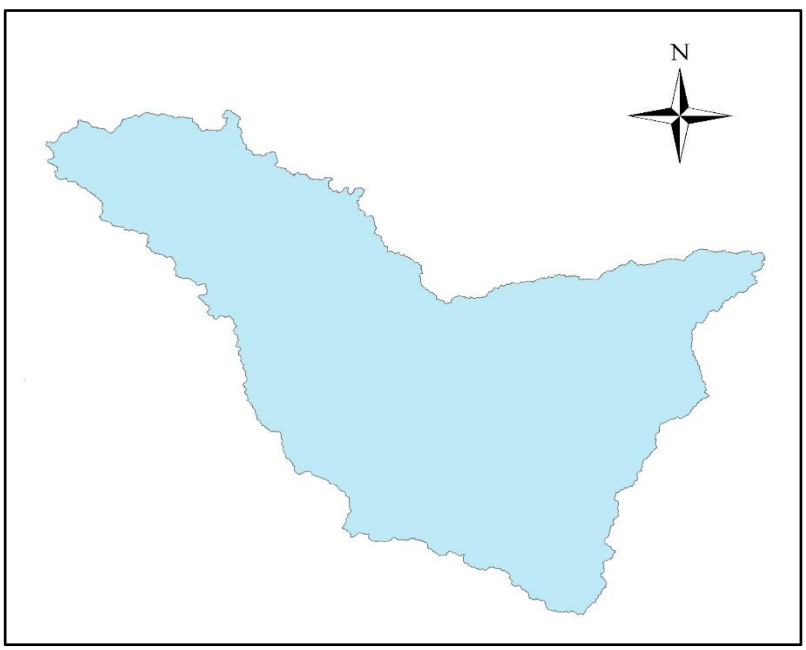

Figure 3. Manganga watershed Area.

Texture Ratio (Rt)

Schumm (1965) the texture ratio is defined as the ratio between the first order streams and perimeter of the basin. In the formula Rt = N1/ P. the texture ratio of the watershed is 65.37 (Table 4).

Circularity Ratio (Rc)

Strahler (1964) Circularity ratio is defined as the ratio of watershed area to the area of a circle having square of the same perimeter as the watershed. The circularity ratio of the watershed is 0.26 (Table 4).

Drainage Texture (Dt)

The drainage texture is defined as the ratio of number of streams to the perimeter of the basin. In the formula Dt = Nu/ P. the drainage texture of the watershed is 82.60 (Table 4).

Compactness Coefficient (Cc)

According to Gravelius (1914), compactness coefficient of a watershed is the ratio of perimeter of watershed to circumference of circular area. The Cc is independent of size of watershed and dependent only on the slope. The compactness coefficient of watershed is 1.98 (Table 4).

Fitness Ratio (Rf)

As per Melton (1957), The fitness ratio is defined as the ratio of main channel length to the length of the watershed perimeter. In the formula Rf = Cl/ P. The fitness ratio of watershed is 0.31 (Table 4).

Wandering Ratio (Rw)

According to Smart & Surkan (1967), wandering ratio is defined as the ratio of the main stream length to the valley length. In the formula Rw = Cl/ Lb. The wandering ratio of watershed is 1.22 (Table 4).

Centre of Gravity of the Watershed (Gc)

It is the length of the channel measured from the outlet of the watershed to a point on the stream nearest to the center of the watershed. Also computed the centre of gravity of the watershed by using ArcGIS-10.3 software, which is a point showing the latitude 17.44N and longitudes 74.95 E (Table 4).

Sinuosity Index (Si)

Sinuosity has been defined as the ratio of channel length to down valley distance. For the measurement of sinuosity index Mueller (1968, p. 374-375) has suggested some important computations that deal various types of sinuosity indices. The hydraulic, topographic, and standard sinuosity index, which are 88.46%, 11.53%, and 1.22, respectively (Table 4).

Stream Frequency (Fs)

Horton (1932, p. 357 and 1945, p. 285) The stream frequency is defined as the ratio of as the number of stream segments per unit area. . In the formula Fs = Nu/A. the stream frequency of the watershed is 8.37 (Table 4).

Drainage Density (Dd)

Horton (1945) The drainage density is defined as the ratio of as the length of stream segments per unit area. . In the formula Dd = Lu/A. the drainage density of the watershed is 3.55 (Table 4).

Constant of Channel Maintenance (C)

Schumm (1956) used the inverse of drainage density or the constant of channel maintenance as a property of landforms. Constant of channel maintenance of the watershed is 0.28 Kms2/Km (Table 4).

Drainage Intensity (Di)

Faniran(1968)The drainage intensity is defined as the ratio of the stream frequency to the drainage density. In the formula Di =Fs/Dd. The drainage intensity of the watershed is 2.36 (Table 4).

Infiltration Number (If)

Faniran(1968) The infiltration number of a watershed is defined as the product of drainage density and stream frequency. In the formula If =Dd*Fs. The infiltration number of the watershed is 29.27 (Table 4).

TABLE 4: Areal Aspects of Manganga Basin

Sr.No	Morphometric parameter	Formula	Reference	Result
1	Length from W's Center to Mouth of W's (Lcm) Kms	GIS Software Analysis		60.31
2	Width of W's at the Center of Mass (Wcm) Kms	GIS Software Analysis	Black (1972)	35.47
3	Basin Length (Lb) Kms	GIS Software Analysis	Black (1972)	124.28
4	Mean Basin Width (Wb)	Wb = A / Lb	Horton (1932)	38.27
5	Basin Area (A) Sq Kms	GIS Software Analysis	Schumm(1956)	4757
6	Basin Perimeter (P) Kms	GIS Software Analysis	Schumm(1956)	482
7	Relative Perimeter (Pr)	Pr = A / P	Schumm(1956)	9.86
8	Length Area Relation (Lar)	Lar = 1.4 * A0.6	Hack (1957)	225.17
9	Lemniscate's (k)	k = Lb2 / A	Chorley (1957)	3.25

10	Form Factor Ratio (Rf)	Ff = A / Lb2	Horton (1932)	0.31
11	Shape Factor Ratio (Rs)	Sf = Lb2 / A	Horton (1956)	3.25
12	Elongation Ratio (Re)	Re = 2 / Lb * (A / π) 0.5	Schumm(1956)	0.63
13	Elipticity Index (Ie)	Ie = π * Vl2 / 4 A		2.55
14	Texture Ratio (Rt)	Rt = N1 / P	Schumm(1965)	65.37
15	Circularity Ratio (Rc)	Rc = 12.57 * (A / P2)	Miller (1953)	0.26
16	Circularity Ration (Rcn)	Rcn = A / P	Strahler (1964)	9.87
17	Drainage Texture (Dt)	Dt = Nu / P	Horton (1945)	82.60
18	Compactness Coefficient (Cc)	Cc = 0.2841 * P / A 0.5	Gravelius (1914)	1.98
19	Fitness Ratio (Rf)	Rf = Cl / P	Melton (1957)	0.31
20	Wandering Ratio (Rw)	Rw = Cl / Lb	Smart & Surkan (1967)	1.22
21	Centre of Gravity of the Watershed (Gc)	GIS Software Analysis	Rao (1998)	74 95’E 17 44’N
22	Hydraulic Sinuosity Index (Hsi) %	Hsi = ((Ci - Vi)/(Ci - 1))*100	Mueller (1968)	88.46
23	Topographic Sinuosity Index (Tsi) %	Tsi = ((Vi - 1)/(Ci-1))*100	Mueller (1968)	11.53
24	Standard Sinuosity Index (Ssi)	Ssi = Ci / Vi	Mueller (1968)	1.22
25	Longest Dimension Parallel to the Principal Drainage Line (Clp) Kms	GIS Software Analysis	-	137.80
26	Stream Frequency (Fs)	Fs = Nu / A	Horton (1932)	8.37
27	Drainage Density (Dd) Km / Kms2	Dd = Lu / A	Horton (1932)	3.55
28	Constant of Channel Maintenance (Kms2 / Km)	C = 1 / Dd	Schumm(1956)	0.28
29	Drainage Intensity (Di)	Di = Fs / Dd	Faniran (1968)	2.36
30	Infiltration Number (If)	If = Fs * Dd	Faniran (1968)	29.71
31	Drainage Pattern (Dp)		Horton (1932)	Dn & Ra
32	Length of Overland Flow (Lg) Kms	Lg = A / 2 * Lu	Horton (1945)	0.14

Relief Aspects

Relief Ratio (Rhl)

The elevation difference between the highest point of a watershed and the lowest point on the valley floor is known as the total relief of the river basin. The relief ratio may be defined as the ratio between the total relief of a basin and the longest dimension of the basin parallel to the main drainage line (Schumm, 1956). The value of relief ratio is 6.02 (Table 6).

Relative Relief (Rhp)

The maximum basin relief was obtained from the highest point on the watershed perimeter to the mouth of the stream, Melton's (1957). Relative relief was calculated using the formula: Rhp = (H*100) / P. The value of relative relief is 155.39 (Table 6).

Absolute Relief (Ra)

The difference in elevation between a given location and sea level.

Channel Gradient (Cg)

The total drops in elevation from the source to the mouth were found out for the Manganga watershed, and horizontal distances were measured along their channel. The also computed the channel gradient of the river basin is 3.46m/kms.

Ruggedness Number (Rn)

Strahler's (1968) Ruggedness number is the product of the basin relief and the drainage density and usefully combines slope steepness with its length. The Manganga watershed has a ruggedness number is 2.65 (Table 6).

Melton Ruggedness Number (MRn)

The melton ruggedness number is a slope index that provides specialized representation of relief ruggedness within the watershed (Melton 1965). Manganga watershed has an MRn is 10.85 (Table 6).

Gradient Ratio (Rg)

Gradient ratio is an indicator of channel slope, which enables assessment of the runoff volume (Sreedevi 2004). The value of Rg is 6.02 (Table 6).

Slope Analysis (Sa)

Rich (1916) Slope map has created by using Surface Analysis Tool in ArcGIS-10.3 & mean slope has computed, which is 0.38' (Table 6).

Average Slope of the Watershed (S)

Wenthworth's (1930) The average slope of the watershed is determined as, S = (Z * (Ctl / H)) / (10 * A). The average slope of the Manganga watershed, which is 0.67% (Table 6).

Mean Slope of Overall Basin (θs)

(Chorley, 1979) Mean slope of overall basin was computed as Ɵs = ∑Ctl * Cin / A. Where Ɵs = Mean slope of overall basin, Ctl = Total length of contour in the watershed, Cin = Contour interval, and A = Area of the watershed. Mean slope of Manganga watershed is 67.85 (Table 6).

Table 5: Hypsometry of the Mnganga Basin

Sr.No.	Altitude Range(m)	Height(m)h	Area(kms2)a	h/H1	a/A2
1	1004	650	0	1	0
2	950-1004	596	8	0.91	0.00168
3	850-1004	496	24	0.76	0.00504
4	750-1004	396	188	0.60	0.03
5	650-1004	296	811	0.45	0.17
6	550-1004	196	2071	0.30	0.43
7	450-1004	96	3919	0.14	0.82

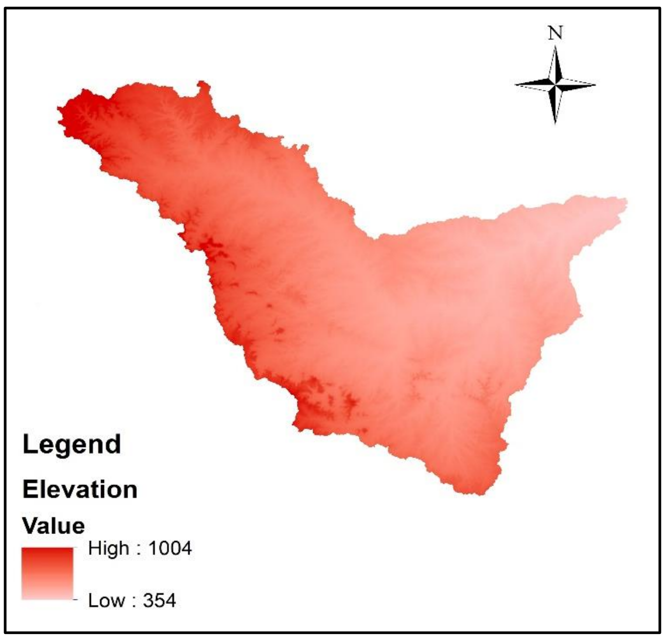

Figure 4. Elevation Model of Manganga Basin

Table 6: Relief Aspects of Manganga Basin.

Sr.No	Morphometric parameter	Formula	Reference	Result
1	Height of Basin Mouth (z) m	GIS Analysis / DEM	-	335
2	Maximum Height of the Basin (Z) m	GIS Analysis / DEM	-	1085

3	Total Basin Relief (H) m	H = Z - z	Strahler (1952)	749
4	Relief Ratio (Rhl)	Rhl = H / Lb	Schumm(1956)	6.02
5	Absolute Relief (Ra) m	GIS Software Analysis		760
6	Relative Relief Ratio (Rhp)	Rhp = H * 100 / P	Melton (1957)	155.39
7	Dissection Index (Dis)	Dis = H / Ra	Singh & Dubey (1994)	0.98
8	Channel Gradient (Cg) m / Kms	Cg = H / {(π/2) * Clp}	Broscoe (1959)	3.46
9	Gradient Ratio (Rg)	Rg = (Z - z) / Lb	Sreedevi (2004)	6.02
10	Watershed Slope (Sw)	Sw = H / Lb		6.02
11	Ruggedness Number (Rn)	Rn = Dd * (H / 1000)	Patton & Baker (1976)	2.65
12	Melton Ruggedness Number (MRn)	MRn = H / A0.5	Melton (1965)	10.85
13	Total Contour Length (Ctl) Kms	GIS Software Analysis	-	32279.09
14	Contour Interval (Cin) m	GIS Software Analysis		10
15	Slope Analysis (Sa)	GIS Analysis / DEM	Rich (1916)	0.38’
16	Average Slope (S) %	S = (Z * (Ctl/H)) / (10 * A)	Wenthworth’s (1930)	0.67
17	Mean Slope of Overall Basin (Θs)	Θs = (Ctl * Cin) /A	Chorley (1979)	67.85
18	Relative Height (h/H)	see Table 4 (h/H)	Strahler (1952)	100-0
19	Relative Area (a/A)	see Table 4 (a/A)	Strahler (1952)	0-100
20	Surface Area of Relief (Rsa) Sq Kms	Composite Profile	Brown (1952)	4757
21	Composite Profile Area (Acp) Sq Kms	Area between the Composite Curve and Horizontal Line	Pareta (2004)	4757

CONCLUSION

Morphometric analysis of Manganga basin showed dendritic and radial patterns with moderate drainage texture. The variation in stream length ratio might be due to slope of basin and topography. The bifurcation ratio of the basin indicates controlled geological structure. The value of form factor indicating elongated basin with lower peak flow of longer duration. The texture ratio and drainage texture showed fine nature of watershed. Length of overland flow revealed low surface peak runoff of the basin. Relief ratio and ruggedness number of the watershed indicate moderate and high relief which cause high erosion. Total 69 morphometric parameters were estimated by using GIS tool and digital data, which helps to understand the condition of the watershed and prioritize it for the development.

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