Quantitative Morphometric Analysis of Panchganga Basin using GIS

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ABSTRACT - *Morphometric analysis of the basin is important for any hydrological investigation and provide basis to work out a comprehensive development plan for optimum use of natural resources of the basin. The linking of the hydrogeological and geomorphological parameters with the hydrological characteristics of the basin provides a simple way to understand the hydrologic behavior of the basin using recent and reliable GIS technology. In the present study Panchganga river basin of Maharashtra, India was considered for the morphometric evaluation. Panchganga watershed was evaluated under linear, areal and relief aspects using Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) and ArcGIS 10.3. Results were revealed that Panchganga watershed has 8th order trunk stream, total 25043 stream of all order, stream length of all order stream 7201 km and mean bifurcation ratio 4.67. Areal aspect showed that basin area 2582.79 Km^2, Circulatory ratio 0.21, form factor 0.14, elongation ratio 0.435 and drainage density 2.78. Relief aspect of the Panchganga watershed revealed that relief ratio 3.78, absolute relief 508, ruggedness number 1.38 and channel gradient 2.54. From results it is observed that Panchganga watershed has dendric drainage pattern, highly eroded and elongated in shape. It also showed immediate need of the development to conserve natural resources of the basin which would sustainably support livelihood of the people living in the basin.*

Keywords: *Morphometric analysis, GIS, Linear aspect, Areal aspect, Relief aspect.*

INTRODUCTION

A watershed is a primary hydrological unit, which is demarcated by various linear areal and topographic features that relate the movement and occurrence of water resource in the basin. Morphometric analysis of the watershed is the mathematical analysis of the land surface configuration parameters relating to shape, size, landforms dimension etc. (Clarke, 1996). The morphometric analysis of a particular drainage basin is important for hydrological investigation like assessment of surface and groundwater and its management, (Sarma et al.,2013). The linear, aerial and relief aspects of watershed can be the relics to the researchers and planners to characterize the watershed and prioritize the developmental works for proper utilization of natural resource of any watershed. The development of a drainage system over space and time is influenced by several variables such as geology, structural components, geomorphology, soil and vegetation of an area through which it flows. The surface runoff and flow intensity of the drainage system can be estimated using the geomorphic features associated with morphometric parameters (Ozdemir and Bird 2009). Hydrologic and geomorphic processes occur within the watershed and morphometric characterization at the watershed scale reveals information regarding formation and development of land surface processes. Various hydrological phenomena are correlated with the physiographic characteristics of a drainage basin such as size, shape, slope of the drainage area, drainage density, size and length of the contributories, etc. (Pande and Moharir,2015). These parameters describe the basin geometry quantitatively and evaluate the geology, geomorphology, slope, rock hardness and other structural controls of drainage basin (Strahler, 1964). Therefore, it showed important for hydrological investigations of watershed for better management (Magesh et al., 2011). All these parameters were calculated more reliably and conveniently with fast emerging spatial information technology. The morphometric analysis of the drainage basin is aimed to acquire accurate data of measurable features of stream network of the drainage basin. Keeping these things in mind an attempt has been made to assess and evaluate various morphometric parameters of Panchganga watershed of Kolhapur district using GIS technique where the linear, areal and relief aspect were estimated.

Study Area

The watershed area of Panchganga river is 2582.797 Sq Kms. The Panchganga river originates from Prayag Sangam located near the Chikhlali village, Tal- Karveer, Dist- Kolhapur (16.44 N latitude & 74.10 E longitudes). The

Panchganga is formed, by four streams, the Kasari, the Kumbhi, the Tulsi and the Bhogawati. From Kolhapur Panchganga flows east about 30 miles till it fall into the Krishna at Kurundwad. Total length of the river is 80.7 Kms long. In the present study outlet was selected at Kurundwad just before it joins Krishna river. Watershed is highly populated and agriculture is the main profession of more than 70 per cent population living in the basin.

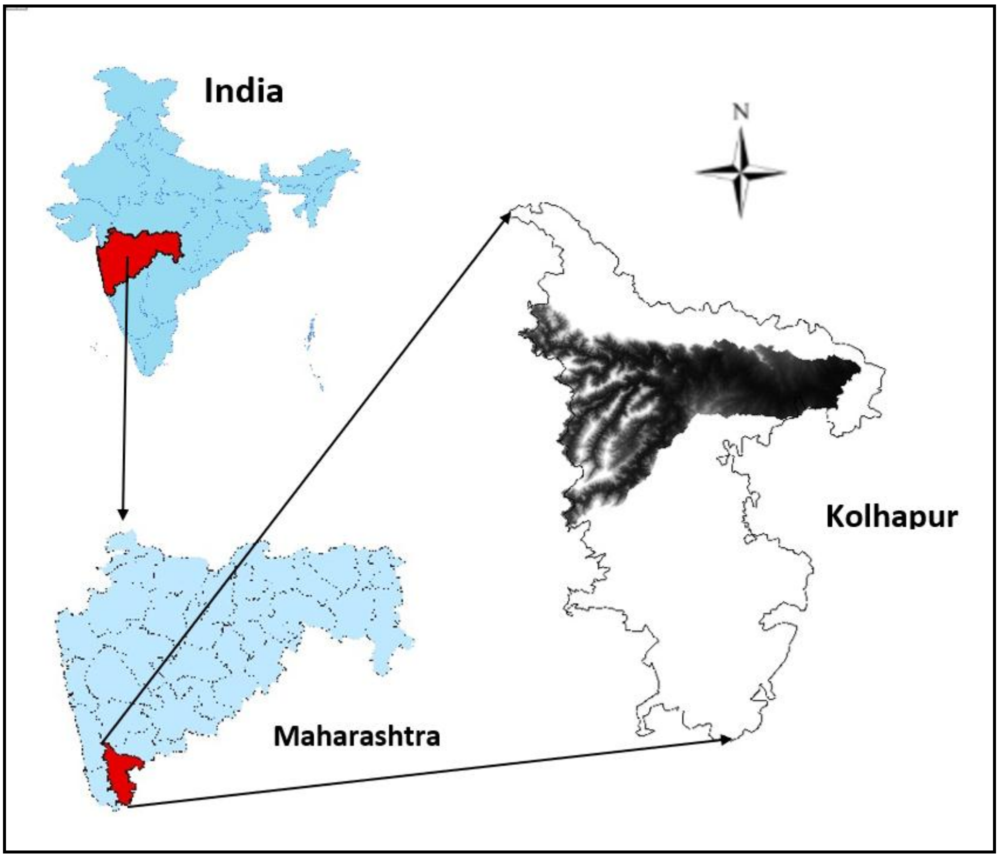


Figure 1. Location Map of Panchganga watershed

MATERIALS AND METHODOLOGY

Survey of India (SOI) toposheets no. E43U101, E43U11, E43U51, E43U61, 47L_21) having 1:50,000 scale and STRM Digital Elevation Model data of 30 m X 30 m resolution have been used for extraction of stream network and various parameters using various GIS tools. The data were project in SOI topographic map was used to confirm the break value of the flow accumulation and generated stream network was calibrated for length and order. The extracted basin and stream networks are projected to the regional projection (WGS-1984, UTM zone 43 N). Input morphometric maps have been prepared by using GIS Platform Arc GIS 10.3.

RESULT AND DISCUSSION

Morphometric Analysis

The morphometric analysis of the Panchganga watershed was carried out by using SRTM-DEM of 30m x 30m spatial resolution and Survey of India topographical maps No E43U101, E43U11, E43U51, E43U61, 47L_21 of 1:50,000 scale. The lengths of the streams, areas of the watershed were measured by using ArcGIS-10.3 software, and stream ordering has been generated using Strahler (1953) system, and Arc Hydro tool in ArcGIS-10.3 software. The linear aspects were studied using the methods of Horton (1945), Strahler (1953), Chorley (1957), the areal aspects using those of Schumm (1956), Strahler (1956, 1968), Miller (1953), and Horton (1932), and the relief aspects employing the techniques of Horton (1945), Broscoe (1959), Melton (1957), Schumm (1954), Strahler (1952), and Pareta (2004). The average slope analysis of the watershed area was done using the Wentworth (1930) method. The Drainage density and frequency distribution analysis of the watershed area were done using the spatial analyst tool in ArcGIS-10.3 software.

Drainage Network

Stream Order (Su)
Stream ordering is a method of assigning a numeric order to links in a stream network. This order is a method for identifying and classifying types of streams based on their number of tributaries. i.e. It is a measure of relative size of streams (Strahler 1957 and Shreve 1966).

Stream Number (Nu)
Stream number is a numerical measure of streams based on hierarchy of tributaries. These numbers were first developed in hydrology by Robert E. Horton (1945) and Arthur Newell Strahler (1952, 1957).

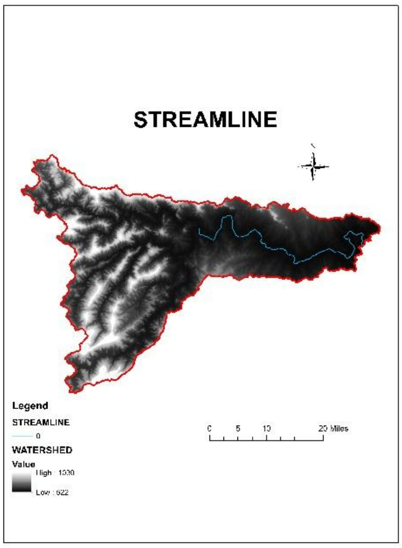
Stream Length (Lu)
The total stream lengths of the Panchganga watershed have various orders, which have computed with the help of topographical sheets and ArcGIS software. The stream length (Lu) has been computed based on the law proposed by Horton. Stream length is one of the most significant hydrological features of the basin as it reveals surface runoff characteristics. gradient. Generally, the total length of stream segments is maximum in first order stream and decreases as stream order increases. The numbers of streams are of various orders in a watershed are counted and their lengths from mouth to drainage divide are measured with the help of GIS software. The total stream length is observed 7201kms in the watershed.

Mean Stream Length (Lum)
The mean stream length is a characteristic property related to the drainage network and its associated surfaces (Strahler, 1964). The mean stream length (Lsm) has been calculated by dividing the total stream length of order by the number of streams. The mean stream length of stream increases with increase of the order.

Table:1 Stream Order, Streams Number, and Bifurcation Ratios in Panchganga Watershed

Su	Nu	Rb	Nu-r	Rb*Nu-r	Rbwm
I	16286				
II	7693	2.116	23979	50739.564	
III	845	9.104	8538	77729.952	
IV	173	4.884	1018	4971.912	3.9866
V	38	4.552	211	960.472	
VI	5	7.6	43	326.8	
VII	2	2.5	7	9.5	
VIII	1	2	3	6	
Total	25043	32.75	33799	1347442	
Mean		4.679			

Stream Length Ratio (Lurm)
The stream length ratio can be defined as the ratio of the mean stream length of a given order to the mean stream length of next lower order and has an important relationship with surface flow and discharge (Horton,1945). The Lurm values between streams of different order in the basin reveal that there are variations in slope and topography. (Table 2)



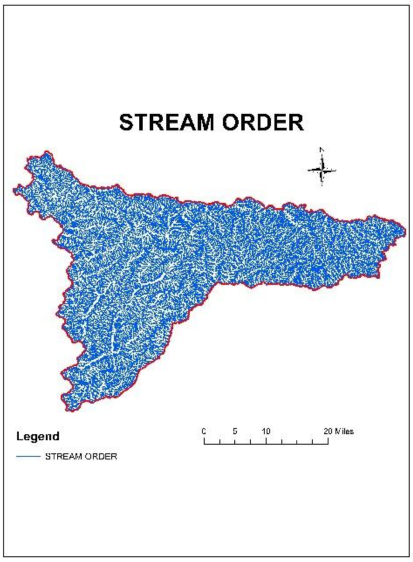


Fig No. 2 Stream Line **Fig No.3** Stream Order

Bifurcation Ratio (Rb)

Bifurcation ratio (Rb) may be defined as the ratio of the number of stream segments of given order to the number of segments of the next higher order (Schumn 1956). Horton (1945) considered the bifurcation ratio as an index of relief and dissections. Strahler (1957) demonstrated that the bifurcation ratio shows a small range of variation for different regions or different environmental conditions, except where the geology dominates. It is observed that Rb is not the same from one order to its next order. In the study area mean Rb varies from 2 to 9.10; the mean Rb of the entire basin is 4.67.(Table 1)

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 streams involved in the ratio and taking the mean of the sum of these values (Strahler 1953). In the study area Rbwm of the entire watershed is 3.9866 (Table 1).

Table: - 2 Stream Length, and Stream Length Ratio of Panchganga Watershed

Su	Lu	Lu/Nu	Lur	Lur-r	Lur*Lur-r	Lurm
I	2884	0.1770				
II	2287	0.2972	1.261	5171	6520.631	
III	1128	1.334	2.027	3415	6922.205	
IV	417	2.410	2.705	1545	4179.225	1.88
V	191	5.026	2.183	608	1327.264	
VI	193	38.6	0.989	384	379.776	
VII	19	9.5	10.157	212	2153.284	
VIII	82	82	0.231	101	23.331	
Total	7201		19.553	11436	21505.716	
Mean			2.79			

Length of Main Channel (Cl)

This is the length along the longest watercourse from the outflow point of designated sun watershed to the upper limit to the watershed boundary. The main channel length by using ArcGIS-10 software, which is 133.89 Kms, (Table 4)

Channel Index (Ci) & Valley Index (Vi)
The measurement of channel length, valley length, and shortest distance between the source, and mouth of the river (Adm) i.e. air lengths are used for calculation of Channel index, and valley index (Table 4).

Rho Coefficient (ρ)
Rho coefficient is the ratio between the stream length ratio (RL) and the bifurcation ratio (Rb). The computed value of Rho coefficient for the study area is 0.596. It is an important parameter that determines the relationship between the drainage density and the physiographic development of the basin, and allows the evaluation of the storage capacity of the drainage network.

Basin Geometry

Length of the Basin (Lb)
Horton defined basin length as the straight-line distance from a basin mouth to the point on the water divide intersected by the projection of the direction of the line through the source of the main stream, parallel to the principal drainage line. The length of the Panchganga basin is arrived as 131.71km. (Table 4)

Basin Area (A)
The area of the watershed is another important parameter like the length of the stream drainage. Schumm (1956) established 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 software, which is 2582.79 sq Kms (Table 4).

Basin Perimeter (P)
Basin perimeter is the outer boundary of the watershed that enclosed its area. It is measured along the divides between watershed and may be used as an indicator of watershed size and shape. The author has computed the basin perimeter by using ArcGIS-10 software, which is 385.23 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: $Lar = 1.4 * A^{0.6}$

Lemniscate's (k)
Chorely (1957), express the lemniscate's value to determine the slope of the basin. In the formula k = Lb2 / 4 * 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 6.71 (Table 4).

Form Factor (Ff)
Form factor ratio (Rf) predicts the flow intensity of a basin of a defined area. The Rf of a drainage basin is expressed as the ratio between the area of the basin (A) and the square of the basin length (Lb^2).

Elongation Ratio (Re)
Elongation ratio (Re) is the ratio between the diameter of a circle of the same area as the basin (A) and basin length (Lb). The elongation ratio of the study area is found to be 0.435 which shows that the basin is elongated but with moderate to low relief.

Texture Ratio (Rt)
According to Schumm (1965), texture ratio is an important factor in the drainage morphometric analysis which is depending on the underlying infiltration capacity and relief aspect of the terrain. The texture ratio is expressed as the ratio between the first order streams and perimeter of the basin (Rt = Nl / P) and it depends on the underlying lithology, infiltration capacity and relief aspects of the terrain. In the present study, the texture ratio of the watershed is 42.27 and categorized as moderate in nature, (Table 4).

Circularity Ratio (Rc)

Circularity Ratio is the ratio of the area of a basin to the area of circle having the same circumference as the perimeter of the basin (Miller, 1953). It is influenced by the length and frequency of streams, geological structures, land use/ land cover, climate and slope of the basin. The Rc value of basin is 0.21 and it indicating the basin is characterized by moderate to low relief and drainage system seems to be less influenced by structural disturbances.

Drainage Texture (Dt)

Drainage texture is one of the important concepts of geomorphology which means that the relative spacing of drainage lines. Drainage texture is on the underlying lithology, infiltration capacity and relief aspect of the terrain. Dt is total number of stream segments of all orders per perimeter of that area (Horton, 1945).

Compactness Coefficient (Cc)

Compactness coefficient of a watershed is the ratio of perimeter of watershed to circumference of circular area, which equals the area of the watershed (Gravelius 1914). The Cc is independent of size of watershed and dependent only on the slope. The author has computed the compactness coefficient of Panchganga watershed, which is 2.15, (Table 4).

Fitness Ratio (Rf)

The ratio of main channel length to the length of the watershed perimeter is fitness ratio, which is a measure of topographic fitness (Melton 1957). The fitness ratio for Panchganga watershed is 0.347. (Table 4).

Wandering Ratio (Rw)

Wandering ratio is defined as the ratio of the mainstream length to the valley length. Valley length is the straight-line distance between outlet of the basin and the farthest point on the ridge (Smart & Surkan 1967). In the present study, the wandering ratio of the watershed is 1.01, (Table 4).

Watershed Eccentricity (τ)

Black (1972) has given the expression for watershed eccentricity, which is: $\tau = [(|Lcm^2 - Wcm^2|)]^{0.5} / Wcm$ Where: τ = Watershed eccentricity, a dimensionless factor, Lcm = Straight length from the watershed mouth to the center of mass of the watershed, and Wcm = Width of the watershed at the center of mass and perpendicular to Lcm. The watershed eccentricity, which is 5.42 (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. The center of gravity of the watershed by using ArcGIS-10.3 software, which is a point showing the latitude 16.65 N, and longitudes 74.10 E (Table 4).

Sinuosity Index (Si)

Sinuosity has been defined as the ratio of channel length to down valley distance. In general, its value varies from 1 to 4 or more. Rivers having a sinuosity of 1.5 are called sinuous, and above 1.5 are called meandering (Wolman and Miller, 1964, p. 281). For the measurement of sinuosity index Mueller (1968, p. 374-375) has suggested some important computations that deal various types of sinuosity indices. He also defines two main types i.e., topographic and hydraulic sinuosity index concerned with the flow of natural stream courses and with the development of flood plains respectively. The hydraulic, topographic, and standard sinuosity index, are 6.04%, 93.95%, and 1.01 respectively, (Table 4).

Drainage Texture Analysis

Stream Frequency (Fs)

The drainage frequency introduced by Horton (1932, p. 357 and 1945, p. 285) means stream frequency (or channel frequency) Fs as the number of stream segments per unit area. In the present study, the stream frequency of Panchganga watershed is 9.69, (Table 4).

Drainage Density (Dd)

Horton (1932), introduced the drainage density (Dd) is an important indicator of the linear scale of land form elements in stream eroded topography. It is the ratio of total channel segment length cumulated for all order within a basin to the basin area, which is expressed in terms of Km/Km^2.The drainage density, indicates the closeness of spacing of channels, thus providing a quantitative measure of the average length of stream channel for the whole basin. It has been observed from drainage density measurement made over a wide range of geologic and climatic type that a low drainage density is more likely to occur in region and highly resistant of highly permeable subsoil material under dense vegetative cover and where relief is low. High drainage density is the resultant of weak or impermeable subsurface material, sparse vegetation and mountainous relief. Low drainage density leads to coarse drainage texture while high drainage density leads to fine drainage texture (Strahler, 1964). The drainage density (Dd) of study area is 2.78 Km/Km^2 indicate moderate drainage densities (Table 4). The moderate drainage density indicates the basin is moderate permeable sub-soil and thick vegetative cover (Nag 1998).

Constant of Channel Maintenance (1/D)

Schumm (1956) used the inverse of drainage density or the constant of channel maintenance as a property of landforms. The constant indicates the number of Kms2 of basin surface required to develop and sustain a channel 1 Km long. The constant of channel maintenance indicates the relative size of landform units in a drainage basin and has a specific genetic connotation (Strahler, 1957). Channel maintenance constant of the watershed is 0.358 Kms^2/Km (Table 4).

Drainage Intensity (Di)

The drainage intensity is defined as the ratio of the stream frequency to the drainage density (Faniran 1968). This study shows a drainage intensity of 3.48 for the watershed, (Table 4).

Infiltration Number (If)

The infiltration number of a watershed is defined as the product of drainage density and stream frequency and given an idea about the infiltration characteristics of the watershed. The higher the infiltration number, the lower will be the infiltration and the higher ran-off (Table 4).

Length of Overland Flow (Lg)

Horton (1945) used this term to refer to the length of the run of the rainwater on the ground surface before it is localized into definite channels. Since this length of overland flow, at an average, is about half the distance between the stream channels, Horton, for the sake of convenience, had taken it to be roughly equal to half the reciprocal of the drainage density. In this study, the length of overland flow of the Panchganga watershed is 0.179 Kms, (Table 4), which shows low surface runoff of the study area.

Relief Characterizes

Relief Ratio (Rhl)

The relief ratio, (Rh) is ratio of maximum relief to horizontal distance along the longest dimension of the basin parallel to the principal drainage line (Schumm, 1956). The Rh normally increases with decreasing drainage area and size of watersheds of a given drainage basin (Gottschalk, 1964). Relief ratio measures the overall steepness of a drainage basin and is an indicator of the intensity of erosion process operating on slope of the basin (Schumm, 1956). The value of Rh in basin is 3.78 indicating moderate relief and moderate slope.

Relative Relief (Rhp)

This term was given by Melton (1957). In the present study area, it is obtained by visual analysis of the digital elevation model prepared from SRTM data. The relative relief of watershed is 129.53.

Absolute Relief (Ra)

The difference in elevation between a given location and sea level. The absolute relief of watershed is 508.

Channel Gradient (Cg)

The total drops in elevation from the source to the mouth were found out for the Panchganga watershed, and horizontal distances were measured along their channels. The gradient was found 2.54 m / Kms.

Ruggedness Number (Rn)

It is the product of maximum basin relief (H) and drainage density (Dd), where both parameters are in the same unit. An extreme high value of ruggedness number occurs when both variables are large and slope is steep (Strahler, 1956). The value of ruggedness number in present basin is 1.38. (Schumm, 1956).

Melton Ruggedness Number (MRn)

The MRn is a slope index that provides specialized representation of relief ruggedness within the watershed (Melton 1965). Panchganga watershed has an MRn of 9.81 (Table 4).

Dissection Index (Dis)

Dissection index is a parameter implying the degree of dissection or vertical erosion and expounds the stages of terrain or landscape development in any given physiographic region or watershed (Singh and Dubey 1994). On average, the values of Dis vary between '0' (complete absence of vertical dissection/erosion and hence dominance of flat surface) and '1' (in exceptional cases, vertical cliffs, it may be at vertical escarpment of hill slope or at seashore). Dis value of Panchganga watershed is 0.98 (Table 4), which indicate the watershed is a moderate dissected.

Gradient Ratio (Rg)

Gradient ratio is an indicator of channel slope, which enables assessment of the runoff volume (Sreedevi, 2004). Watershed has a Rg of 3.78 (Table 4).

Average Slope of the Watershed (S)

Erodibility of a watershed can be studied and can be compared from its average slope (Wenthworth's 1930). More the percentage of slopes more are its erosion, if all other things are kept constant. The average slope of the watershed is determined as, S = (Z *(Ctl / H)) / (10 * A). The average slope of the Panchganga watershed is 2.62%, (Table 4).

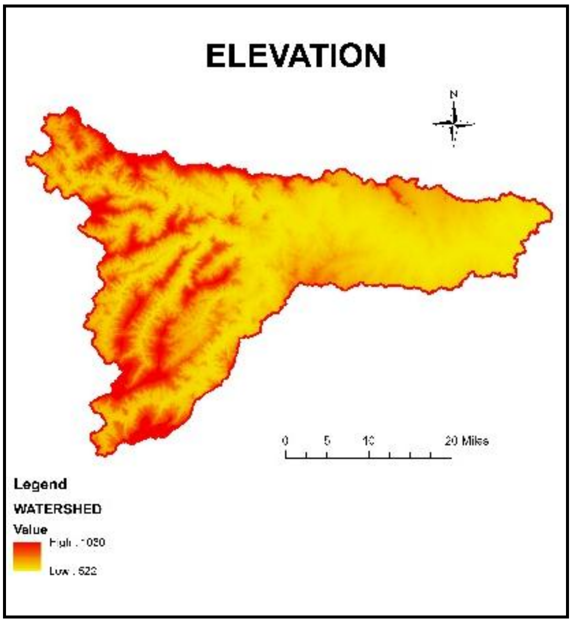


Fig No.4 Digital elevation model of Panchganga watershed

Hypsometric Analysis (Hs)

Langbein et al (1947) appear to have been the first to use such a line of study to collect hydrologic data. However, again Strahler (1952) popularized it in his excellent paper. According to Strahler (1952) topography produced by stream channel erosion and associated processes of weathering mass-movement, and sheet runoff is extremely complex.

Table 3: Hypsometric Data of Hypsometric Integrals of Panchaganga Watershed

Sr.No.	Altitude Range(m)	Height(m)h	Area(kms^2)	h/H[1]	a/A[2]
1	1000-1030	508	2.607	1.000	0.001
2	900-1000	378	60.742	0.744	0.023
3	800-900	278	167.552	0.547	0.064
4	700-800	178	291.197	0.350	0.112
5	600-700	78	703.265	0.153	0.272
6	522	0	2583	0.000	1.000

Table 4: Morphometric Analysis of Panchganga Watershed - Comparative Characteristics

Sr.No	Morphometric parameter	Formula	Reference	Result
A	**Linear Aspect**			
1	Stream Order (Nu)	Hierarchical Rank	Strahler (1952)	1 to 8
2	1st Order Stream (Suf)	Suf = N1	Strahler (1952)	16286
3	Stream Number	(Nu) Nu = N1+N2+ …Nn	Horton (1945)	25043
4	Stream Length (Lu) Kms	Lu = L1+L2 …… Ln	Strahler (1964)	7201
5	Stream Length Ratio (Lur)	see Table 2	Strahler (1964)	0.231-10.157
6	Mean Stream Length Ratio (Lurm)	see Table 2	Horton (1945)	2.79
7	Weighted Mean Stream Length Ratio (Luwm)	see Table 2	Horton (1945)	1.88
8	Bifurcation Ratio (Rb)	see Table1	Strahler (1964)	2-9.10
9	Mean Bifurcation Ratio (Rbm)	see Table1	Strahler (1964)	4.679
10	Weighted Mean Bifurcation Ratio (Rbwm)	see Table1	Strahler (1953)	3.9866
11	Main Channel Length (Cl) Kms	GIS Software Analysis	-	133.89
12	Valley Length (Vl) Kms	GIS Software Analysis	-	131.71
13	Minimum Aerial Distance (Adm) Kms	GIS Software Analysis	-	98.14
14	Channel Index (Ci)	Ci = Cl / Adm (H & TS)	Miller (1968)	1.364
15	Valley Index (Vi)	Vi = Vl / Adm (TS)	Miller (1968)	1.342
16	Rho Coefficient (ρ)	ρ = Lur / Rb	Horton (1945)	0.596
B	**Basin Geometry**			
17	Length from W's Center to Mouth of W's (Lcm) Kms	GIS Software Analysis		96.88
18	Width of W's at the	GIS Software Analysis	Black (1972)	17.39

	Center of Mass (Wcm) Kms			
19	Basin Length (Lb) Kms	GIS Software Analysis	Black (1972)	131.71
20	Mean Basin Width (Wb)	Wb = A / Lb	Horton (1932)	19.60
21	Basin Area (A) Sq Kms	GIS Software Analysis	Schumm (1956)	2582.797
22	Basin Perimeter (P) Kms	GIS Software Analysis	Schumm (1956)	385.23
23	Relative Perimeter (Pr)	Pr = A / P	Schumm (1956)	6.70
24	Length Area Relation (Lar)	$Lar = 1.4 * A^{0.6}$	Hack (1957)	156.09
25	Lemniscate's (k)	$k = Lb^2 / A$	Chorley (1957)	6.71
26	Form Factor Ratio (Rf)	$Ff = A / Lb^2$	Horton (1932)	0.14
27	Shape Factor Ratio (Rs)	$Sf = Lb^2 / A$	Horton (1956)	6.71
28	Elongation Ratio (Re)	$Re = 2 / Lb * (A / \pi)^{0.5}$	Schumm (1956)	0.435
29	Elipticity Index (Ie)	$Ie = \pi * Vl^2 / 4 A$		5.27
30	Texture Ratio (Rt)	Rt = N1 / P	Schumm (1965)	42.27
31	Circularity Ratio (Rc)	$Rc = 12.57 * (A / P^2)$	Miller (1953)	0.21
32	Circularity Ration (Rcn)	Rcn = A / P	Strahler (1964)	6.70
33	Drainage Texture (Dt)	Dt = Nu / P	Horton (1945)	65.007
34	Compactness Coefficient (Cc)	$Cc = 0.2841 * P / A^{0.5}$	Gravelius (1914)	2.15
35	Fitness Ratio (Rf)	Rf = Cl / P	Melton (1957)	0.347
36	Wandering Ratio (Rw)	Rw = Cl / Lb	Smart & Surkan (1967)	1.01
37	Watershed Eccentricity (τ)	$\tau = [(\lvert Lcm^2 Wcm^2 \rvert)]^{0.5}/Wcm$	Black (1972)	5.48
38	Centre of Gravity of the Watershed (Gc)	GIS Software Analysis	Rao (1998)	74.10 E 16.65 N
39	Hydraulic Sinuosity Index (Hsi) %	Hsi = ((Ci - Vi)/ (Ci - 1)) *100	Mueller (1968)	6.04
40	Topographic Sinuosity Index (Tsi) %	Tsi = ((Vi - 1)/ (Ci- 1)) *100	Mueller (1968)	93.95
41	Standard Sinuosity Index (Ssi)	Ssi = Ci / Vi	Mueller (1968)	1.01
42	Longest Dimension Parallel to the Principal Drainage Line (Clp) Kms	GIS Software Analysis	-	125.13
C	**Drainage Texture Analysis**			
43	Stream Frequency (Fs)	Fs = Nu / A	Horton (1932)	9.69
44	Drainage Density (Dd) Km / Kms²	Dd = Lu / A	Horton (1932)	2.78
45	Constant of Channel Maintenance (Kms² / Km)	C = 1 / Dd	Schumm (1956)	0.358
46	Drainage Intensity (Di)	Di = Fs / Dd	Faniran (1968)	3.48
47	Infiltration Number (If)	If = Fs * Dd	Faniran (1968)	26.93
48	Drainage Pattern (Dp)		Horton (1932)	Dn & Ra
49	Length of Overland	Lg = A / 2 * Lu	Horton (1945)	0.179

	Flow (Lg) Kms			
D	**Relief Characterizes**			
50	Height of Basin Mouth (z) m	GIS Analysis / DEM	-	531
51	Maximum Height of the Basin (Z) m	GIS Analysis / DEM	-	1030
52	Total Basin Relief (H) m	H = Z - z	Strahler (1952)	499
53	Relief Ratio (Rhl)	Rhl = H / Lb	Schumm (1956)	3.78
54	Absolute Relief (Ra) m	GIS Software Analysis		508
55	Relative Relief Ratio (Rhp)	Rhp = H * 100 / P	Melton (1957)	129.53
56	Dissection Index (Dis)	Dis = H / Ra	Singh & Dubey (1994)	0.98
57	Channel Gradient (Cg) m / Kms	Cg = H / {(π/2) * Clp}	Broscoe (1959)	2.45
58	Gradient Ratio (Rg)	Rg = (Z - z) / Lb	Sreedevi (2004)	3.78
59	Watershed Slope (Sw)	Sw = H / Lb		3.78
60	Ruggedness Number (Rn)	Rn = Dd * (H / 1000)	Patton & Baker (1976)	1.38
61	Melton Ruggedness Number (MRn)	MRn = H / $A^{0.5}$	Melton (1965)	9.81
62	Total Contour Length (Ctl) Kms	GIS Software Analysis		32805.14
63	Contour Interval (Cin) m	GIS Software Analysis		10
64	Average Slope in degree	GIS Analysis / DEM	Rich (1916)	0.018
65	Average Slope (S) %	S = (Z * (Ctl/H)) / (10 * A)	Wenthworth's (1930)	1.88
66	Mean Slope of Overall Basin (ϴs)	ϴs = (Ctl * Cin) /A	Chorley (1979)	0.12
67	Relative Height (h/H)	see Table 4 (h/H)	Strahler (1952)	1 to 0
68	Relative Area (a/A)	see Table 4 (a/A)	Strahler (1952)	0 to 1
69	Surface Area of Relief (Rsa) Sq Kms	Composite Profile	Brown (1952)	2583
70	Composite Profile Area (Acp) Sq Kms	Area between the Composite Curve and Horizontal Line	Pareta (2004)	2583

CONCLUSION

The study reveals that remotely sensed data (SRTM-DEM) and GIS based approach in evaluation of drainage morphometric parameters and their influence on landforms, soils and eroded land characteristics at river basin level is more appropriate than the conventional methods. The watershed shows a stream of order VIII and a maximum number of first order streams. The stream length ratio is greater than 1. This indicates severe erosion problems in the watershed. Panchaganga watershed is elongated in shape and identified by a moderate value of drainage density (Dd), texture ratio (Dt), stream frequency (Fs), relief ratio (Rh), and low values of elongation ratio (Re), circularity ratio (Rc), form factor (Rf), length of overland flow (Lg), and bifurcation ratio (Rb). The relation among the morphometric parameters can assist in a watershed planning and development even though it is not supported by a good understanding of morphology of a study area.

Acknowledgement

We extend our gratitude to Dr. Budhajirao Mulik College of Agricultural Engineering and Technology Mandki-Palvan, Chiplun, Maharashtra for providing opportunity to prepare this research work. We are also thankful to JD INFOTECH, Aurangabad, Maharashtra for providing technical assistance during INPLANT Training Program. We are also thankful to Dr. Sahebrao Jedhe for the motivation of this work.

REFERENCES

Alexander, P.O (1979), "Age and Duration of Deccan Volcanism: K. Ar. Evidence", Deccan Volcanism Geological Society of India, Memoir No. 3, Bangalore, pp 244-257.

Broscoe, A.J (1959), "Quantitative Analysis of Longitudinal Stream Profiles of Small Watersheds", Project N. 389-042, Tech. Bep. 18, Geology Department, Columbian University, ONR, Geography Branch, New York.

Calef, W. C (1950), "Form and Process, Cambridge University Press", London, pp 473.

Chorley, R.J (1972), "Spatial Analysis in Geomorphology", Mathuen and Co. Ltd., London.

Chorley, R.L (1967), "Models in Geomorphology", in R.J. Chorley and P. Haggett (eds.), Models in Geography, London, pp 59-96.

Dury, G.H (1952), "Methods of Cartographical Analysis in Geomorphological Research", Silver Jubilee Volume, Indian Geographical Society, Madras, pp 136-139.

Faniran, A (1968), "The Index of Drainage Intensity - A Provisional New Drainage Factor", *Australian Journal of Science*, 31, pp 328-330.

Gold, D. P (1980), "Structural Geology", Chapter 14 in Remote Sensing in Geology, edit by Siegal, B. S. and Gillespie, A. R., John Wiley, New York, pp 410-483.

Gregory, K.J. & Walling, D.E (1968), "The Variation of Drainage Density within a Catchment", *International Association of Scientific Hydrology* - Bulletin, 13, pp 61-68.

Horton, R.E (1932), "Drainage Basin Characteristics", Transactions, American Geophysical Union, 13, pp 350-61.

Horton, R.E (1945), "Erosional Development of Streams and their Drainage Basins", *Bulletin of the Geological Society of America,* 56, pp-275-370.

King, C.A.M (1966), "Techniques in Geomorphology", Edward Arnold, (Publishers) Ltd. London, pp 319-321.

Pareta, K (2003), "Morphometric Analysis of Dhasan River Basin, India", Uttar Bharat Bhoogol Patrika, Gorakhpur, 39, pp 15-35.

Pareta, K (2004), "Hydro-Geomorphology of Sagar District (M.P.): A Study through Remote Sensing Technique", Proceeding in XIX M. P. Young Scientist Congress, Madhya Pradesh Council of Science & Technology (MAPCOST), Bhopal.

Pareta, K (2005), "Rainfall-Runoff Modelling, Soil Erosion Modelling, Water Balance Calculation, and Morphometric Analysis of Molali Watershed, Sagar, Madhya Pradesh using GIS and Remote Sensing Techniques", Proceeding in 25th International Cartographic Congress, INCA.

Pareta, K (2011), "Geo-Environmental and Geo-Hydrological Study of Rajghat Dam, Sagar (Madhya Pradesh) using Remote Sensing Techniques", *International Journal of Scientific & Engineering Research,* 2(8) (ISSN 2229-5518), pp 1-8.

Pareta, K. and Koshta, Upasana (2009), "Soil Erosion Modeling using Remote Sensing and GIS: A Case Study of Mohand Watershed, Haridwar", *Madhya Bharti Journal*, Dr. Hari Singh Gour University, Sagar (M.P.), 55, pp 23-33.

Richards, K.S. Arnett, R.R. and Ellis, J (1985), "Geomorphology and Soils", George Allen and Unwin, London, pp 441.

Scheidegger, A.E (1965), "The Algebra of Stream Order Number", U.S. Geological Survey Professional Paper, 525B, B1, pp 87-89.

Schumm, S.A (1954), "The relation of Drainage Basin Relief to Sediment Loss", International Association of Scientific Hydrology, 36, pp 216-219.

Schumm, S.A (1956), "Evolution of Drainage Systems & Slopes in Badlands at Perth Anboy, New Jersey", Bulletin of the Geological Society of America, 67, pp 597-646.

Schumm, S.A (1963), "Sinuosity of Alluvial Rivers on the Great Plains", Bulletin of the Geological Society of America, 74, pp 1089-1100.

Shreve, R.L (1966), "Statistical Law of Stream Numbers", *Journal of Geology*, 74, pp17-37.

Smith, G.H (1939), "The Morphometry of Ohio: The Average Slope of the Land (abstract)", Annals of the Association of American Geographers, 29, pp 94.

Strahler, A.N (1952), "Hypsometric Analysis of Erosional Topography", *Bulletin of the Geological Society of America*, 63, pp 1117-42.

Strahler, A.N (1956), "Quantitative Slope Analysis", Bulletin of the Geological Society of America, 67, pp 571-596.

Strahler, A.N (1964), "Quantitative Geomorphology of Drainage Basin and Channel Network", Handbook of Applied Hydrology, pp 39-76.

Thornbury, W.D (1954), "Principles of Geomorphology", John Wiley and Sons, London.

Wentworth, C.K (1930), "A Simplified Method of Determining the Average Slope of Land Surfaces", *American Journal of Science*, 21, pp 184-194.

West, W.D. and Choubey, V.D (1964), "The Geomorphology of the Country around Sagar and Katangi (M.P.)", *Journal of Geological Society of India*, 5, pp 41-55.

Woldenberg, N.J (1967), "Geography & Properties of Surface", Handward Paper in Theoretical Geography, 1 pp 95-189.

Young, A (1972), "Slope", Oliver & Boyd, Edinburgh, pp 5.

Zwnnitz, E.R (1932) "Drainage Pattern and their Significance", *Journal of Geology*, XL(6), pp 498-521.