GIS Based Quantitative Morphometric Analysis of Warna Watershed, Maharashtra India

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ABSTRACT - Watershed management has gained importance for natural resources management, such as soil, water their conservation and improvement in the livelihood of the peoples in the region. Morphometric analysis has been commonly applied to prioritization of watersheds development work to conserve maximum possible soil and water in the basin. In the present study an attempt has been made to study morphometric evaluation of Warna basin of Maharashtra, India. Warna watershed is situated in the southern part of the Maharashtra. Morphometric parameters were calculated using geoprocessing techniques in GIS. In the present study Cartosat digital elevation model of 32 m resolution and Toposheet were used. Survey of India 1:50,000 scale Toposheet no. E43U1, E43U5 and E43U9 were used to confirm the length and order of the stream to calibrate break value of flow accumulation. Results of the analysis reveals that, Warna basin has trunk stream of 8^{th} order, total streams of all orders were found to be 20325, Bifurcation Ratio (Rb) varies from 2 to 10.3 and main channel length 140.73 km. Areal aspect of the basin showed that area of the basin is 2082.95 sq.km, form factor (Rf) 0.108, drainage density 3.70 km/sq.km, length of overland flow (Lg) 0.135 km and elongation ratio (Re) 0.37. Relief parameters were revealed that total basin relief (H) of Warna watershed is 572 m, Ruggedness number (Rn) 2.11 and Relief ratio (Rhl) 4.13. From the results it is observed that Warna basin having dendric drainage 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: Morphometric analysis, Linear Aspect, Areal Aspect, Relief Aspect.

INTRODUCTION

The concept of watershed Management recognizes the inter relationship between land use, soil and water and the linkage between upland and downstream areas (Tideman, 1996). Soil and water conservation are key issues in watershed management in India behind demarcating the priority watershed. In developing countries watershed projects which focus on water harvesting and soil conservation typically state three objectives, firstly, to conserve and strengthen the natural resource base; secondly, to make natural resource based activities like agriculture more productive and finally to support rural livelihood to alleviate poverty (Chauhan, 2010;Gupta and Arora, 2010; Arora and Gupta, 2014) Morphometric analysis gives basic character of geometrical and mechanical aspects of river basin, These are helpful to understanding the hydrology basins. The hydrology physiography characteristics of a drainage basin such as shape, size, drainage density, drainage area etc. There are morphometric parameters they are classified into i.e. Linear, Areal and Relief. It helps to assess and evaluate erosion risk, soil and water conservation strategies, ground water potential and other environmental factors. The role of rock types and geologic structures in the development of stream network can be better understood by studying the nature and type of drainage pattern and by a quantitative morphometric analysis. To evaluate the morphometric analysis using Geographical Information Systems (GIS) was attempted by several researchers (Srinivasa *et al.*, 2004; Markose *et al.*, 2014; Das, 2014; Kaliraj *et al.*, 2015; Gajbhiye, 2015; Sahu *et al.*, 2016; Pande and Moharir, 2017; Rai *et al.*, 2017; Chandniha and Kansal, 2017).

Some of the climatic parameters such as rainfall, humidity, temperature and wind speed affect morphometric characteristics of the watershed. Geology, relief and climate are the primary determinants of a running water ecosystem functioning at the basin scale (John Wilson et al. 2012). Climatic change which is one of the major issue in front of every sector and agriculture activities are also not isolated from it. It likely to be affected on the drainage pattern and ultimately fresh water availability in the watershed. To avoid these adverse effect of the climate change on the agriculture field watershed is the primary entity to plan geohydrologic development of the watershed. Before planning any watershed development work needs to evaluate the watershed morphometric aspects to prioritization of the development work in the basin. Thus, detailed study of morphometric analysis of a Warna basin help in understanding the influence of drainage morphometry on landforms and their characteristics.

Study area

The warna river is Flows in between Sangli and Kolhapur district in state of Maharashtra in India, it is important tributary of Krishna river. The area of Basin of warna river is 2082.95 Sq. Kms & topographical co-ordinate location latitude 16° 54’40’’ N and 74 °6’36’’ E longitudes. Located at an elevation of 540meters above sea level, The river originates from the Kutch on the famous stone of Sakshadri near Patpangauage plateau in Sahyadri. The Path of flowing first flows from north-west to south-west and then towards east, the warna river meets to the Krishna river is in the north-east of sangli city found in Haripur in the high altitude area,In around the watershed area having different types of soils, river sides soil are more fertile, the crops like rice, jowar, sugarcane, and groundnut are taken in area of warna river. Due to this river many Kolhapuri dams and some minor irrigation projects have been completed also the village like warnanagar have been developed in that area

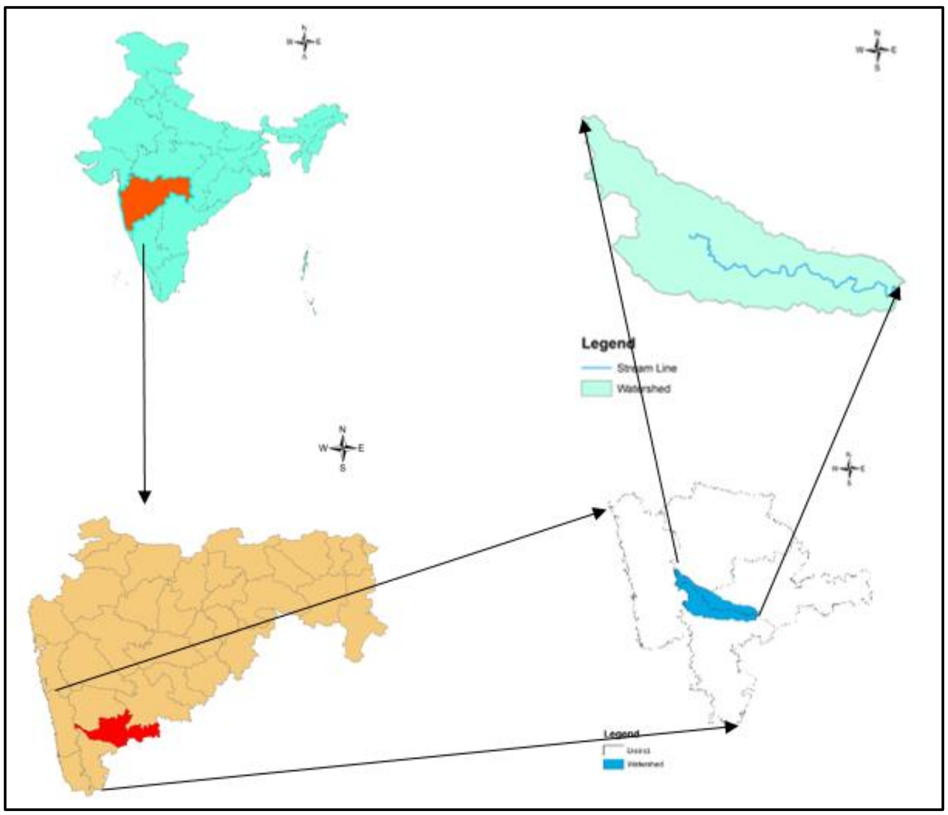

Figure 1. Location map of Warna basin

MATERIALS AND METHODOLOGY

Survey of India (SOI) Toposheets (E43U1, E43U5, E43U9) on 1:50,000 Scale and Cartosat digital elevation model data have been used. SOI topographic map was Georeferenced using WGS 1984 datum, Universal Transverse Mercator (UTM) zone 43N projection in ArcGIS 10.3. The warna watershed was delineated and drainage network was extracted using 32m x 32 m resolution DEM in conjunction with SOI Toposheet. Quantitative analysis has been done based on CARTOSAT (DEM). For entire analysis of drainage morphometry having all tributaries of different extents and patterns were digitized from survey of India toposheets. Based on the data we prepared the slope and topographic elevation maps with contours for the watershed.

Input morphometric maps have been prepared by using GIS Platform Arc GIS 10.3. The methodologies adopted for the computation of selected morphometric parameters are given in Table 1.

RESULT AND DISCUSSION

Linear parameters

Stream order (U): Stream order is a measure of the relative size of streams. The variation in order and size of the tributary basins are largely due to physiographic and structural conditions of the region. Application of this ordering procedure through GIS shows that the drainage network of the study area is of a 8^{th} order trunk strem.

Stream Number: the total number of streams gradually decreases as the stream order increases with the application of GIS, the number of streams of each order and the total number of streams were computed.

Table 1: Stream Order, Streams Number, and Bifurcation Ratios of Warna Watershed

Su	Nu	Rb	Nu-r	Rb*Nu-r	Rbwm
I	13221	2.097	19525	40943.925	4.244
II	6304	10.300	6916	71234.8	
III	612	4.107	761	3125.427	
IV	149	4.806	180	865.08	
V	31	6.200	36	223.2	
VI	5	2.5	7	17.5	
VII	2	2	3	6	
VIII	1				
Total			27428	116415.932	
Mean					

Stream Length: The stream lengths for all sub-basins of various orders have been measured on digitized map with the help of GIS. the total stream length of each order (Lu) is computed, Whereas total stream length is 7709.71 kms

Mean stream length (Lsm): The mean stream length is a dimensional property, revealing the characteristic size of the components of a drainage network and its contributing basin surface (Strahler 1964). Stream order-wise mean length in each watershed was obtained by dividing the total length of streams of a particular order by the total number of stream segments of the order. In general, it is observed that the mean stream length increases with the stream order.

Stream Length Ratio (RL): Ratio of the mean length of a stream of a given order to the mean length of the next lower order stream in the same basin.

Table 2: Stream Length, and Stream Length Ratio of Warna Watershed

Su	Lu	Lu/Su	Lur	Lur-r	Lur*Lur-r	Luwm
I	4147.151	0.313	2.1384	6086.491	13015.35	2.1909
II	1939.340	0.307	2.1969	2822.082	6199.831	
III	882.742	1.442	2.2184	1280.656	2841.007	
IV	397.914	2.670	2.541	554.502	1408.989	
V	156.588	5.051	4.534	191.118	866.529	
VI	34.530	6.906	0.466	108.626	50.619	
VII	74.096	37.048	0.957	151.446	144.933	
VIII	77.350	77.350				
Total	7709.71			11194.921	24527.258	
Mean						

Bifurcation ratio (Rb): bifurcation ratio, which is defined as the ratio of the. Number of stream branches of a given order to the number of stream branches of the next higher order. The bifurcation ratio will not be exactly the same from one order to the next order because of the possibility of the changes in the watershed geometry and lithology but will tend to be consistent throughout the series.

Channel Index & Valley Index: The river channel has divided into number of segments as suggested by Muller (1968). The measurement of channel length, valley length, and shortest distance between the source, and mouth of the river i.e. air lengths are used for calculation of Channel index, and valley index.

Basin length

Basin length is the longest length of the basin, from the catchment to the point of confluence (Gregory and Walling 1973) and this measure is essential to estimate the shape, and also the relative relief of the watersheds, whereas basin length is 138.25kms.

Table 3. Linear Aspect of Warna Watershed

Sr. No.	Morphometric Parameter	Formula	Reference	Result
A	**Drainage Network**			
1	Stream Order (Su)	Hierarchical Rank	Strahler (1952)	8
2	1st Order Stream (Suf)	Suf = N1	Strahler (1952)	13221
3	Stream Number (Nu)	Nu = N1+N2+ …Nn	Horton (1945)	20325
4	Stream Length (Lu) Kms	Lu = L1+L2 …… Ln	Strahler (1964)	7709.71
5	Stream Length Ratio (Lur)	see Table 2	Strahler (1964)	15.0517
6	Mean Stream Length Ratio (Lurm)	see Table 2	Horton (1945)	2.150
7	Weighted Mean Stream Length Ratio (Luwm)	see Table 2	Horton (1945)	2.1909
8	Bifurcation Ratio (Rb)	see Table 1	Strahler (1964)	2-10.300
9	Mean Bifurcation Ratio (Rbm)	see Table 1	Strahler (1964)	4.57
10	Weighted Mean Bifurcation Ratio (Rbwm)	see Table 1	Strahler (1953)	4.244
11	Main Channel Length (Cl) Kms	GIS Software Analysis	-	140.737
12	Valley Length (Vl) Kms	GIS Software Analysis	-	138.25
13	Minimum Aerial Distance (Adm) Kms	GIS Software Analysis	-	94.847
14	Channel Index (Ci)	Ci = Cl / Adm (H & TS)	Miller (1968)	1.483
15	Valley Index (Vi)	Vi = Vl / Adm (TS)	Miller (1968)	1.45
16	Rho Coefficient (ρ)	ρ = Lur / Rb	Horton (1945)	3.29
B	**Basin Geometry**			
17	Length from W's Center to Mouth of W's (Lcm) Kms	GIS Software Analysis	Black (1972)	76.02
18	Width of W's at the Center of Mass (Wcm) Kms	GIS Software Analysis	Black (1972)	10.48
19	Basin Length (Lb) Kms	GIS Software Analysis	Schumm(1956)	138.25
20	Mean Basin Width (Wb)	Wb = A / Lb	Horton (1932)	15.066

Aerial aspects

Form Factor: It is defined as the ratio of the area of the basin to the square of the length of the basin, and according to Horton (1932), the value of 'F' varies from 0 (for basins with highly elongated shape) to 1 (for a basin with perfect circular shape).

Texture Ratio (Rt): 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 38.49

Drainage texture (T): According to Smith (1950), drainage texture (T) is a product of stream frequency and drainage density. The 'T' depends on underlying lithology, infiltration capacity and relief aspect of the terrain. The drainage texture of the Warna basin is 59.177.

Drainage density (Dd): Drainage density is the total length of all the streams and rivers in a drainage basin divided by the total area of the drainage basin. It is a measure of how well or how poorly a watershed rock type affect the runoff in a watershed is drained by stream channels. It is equal to the reciprocal of the constant of channel maintenance and equal to the reciprocal of two times the length of overland flow. Drainage density depends upon both climate and physical characteristics of the drainage basin.

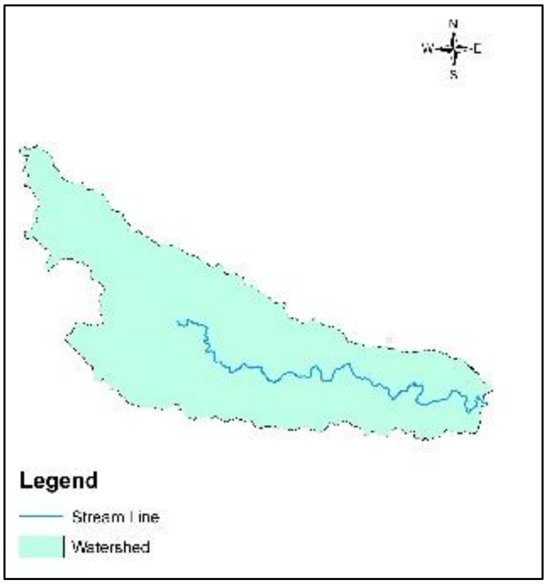

Figure 2. Area of the Warna Watershed

Drainage Intensity (Di): Faniran (1968) defines the drainage intensity, as the ratio of the stream frequency to the drainage density. This study shows a low drainage intensity of 2.635 for the watershed, This low value of drainage intensity implies that drainage density and stream frequency have little effect (if any) on the extent to which the surface has been lowered by agents of denudation.

Stream Frequency (Fs): A measure of topographic texture expressed as the ratio of the number of streams in a drainage basin to the area of the basin. Also known as channel frequency.

Texture Ratio (T): Texture ratio is one of the most important factors in the drainage morphometric analysis, which depends on the underlying lithology infiltration capacity, and relief aspect of the terrain.

Circulatory ratio (Rc): Miller (1953) defined circularity ratio (Rc) as the ratio of the area of a basin to the area of a circle having the same circumference as the perimeter of the basin. The low, medium and high values of the circulatory ratio are indications of the youth mature and old stages of the life cycle of the tributary basins. Warna basin is in the youth stage of its development with a circulatory ratio of 0.221. The result showed that the study area has Rc value <0.5, indicating elongated shape.

Elongation Ratio (Re): Elongation ratio (Re) is defined as the ratio of diameter of a circle having the same area as of the basin and maximum basin length (Schumm 1956). It is a measure of the shape of the river basin and it depends on the climatic and geologic types. The Re value of Warna basin is 0.37, which indicates moderate relief with steep slope and elongated in shape.

Compactness Coefficient (Cc): According to Gravelius (1914), compactness coefficient of a watershed is the ratio of perimeter of watershed to circumference of circular area, which equals area of the watershed. The Cc is independent of size of watershed and dependent only on the slope.

Table 4. Areal aspect of Warna Basin

C	Aerial aspects	Formula	Reference	Result
1	Basin Area (A) Sq Kms	GIS Software Analysis	Schumm(1956)	2082.95
2	Basin Perimeter (P) Kms	GIS Software Analysis	Schumm(1956)	343.46

3	Relative Perimeter (Pr)	Pr = A / P	Schumm(1956)	6.064
4	Length Area Relation (Lar)	Lar = 1.4 * $A^{0.6}$	Hack (1957)	137.19
5	Lemniscate's (k)	k = Lb^2 / A	Chorley (1957)	9.17
6	Form Factor Ratio (Rf)	Ff = A / Lb^2	Horton (1932)	0.108
7	Shape Factor Ratio (Rs)	Sf = Lb^2 / A	Horton (1956)	9.17
8	Elongation Ratio (Re)	Re = 2 / Lb * $(A / \pi)^{0.5}$	Schumm(1956)	0.37
9	Elipticity Index (Ie)	Ie = π * Vl^2 / 4 A		7.20
10	Texture Ratio (Rt)	Rt = N1 / P	Schumm(1965)	38.49
11	Circularity Ratio (Rc)	Rc = 12.57 * (A / P^2)	Miller (1953)	0.221
12	Circularity Ration (Rcn)	Rcn = A / P	Strahler (1964)	6.06
13	Drainage Texture (Dt)	Dt = Nu / P	Horton (1945)	59.177
14	Compactness Coefficient (Cc)	Cc = 0.2841 * P / A 0.5	Gravelius (1914)	2.138
15	Fitness Ratio (Rf)	Rf = Cl / P	Melton (1957)	0.409
16	Wandering Ratio (Rw)	Rw = Cl / Lb	Smart & Surkan (1967)	1.01
17	Watershed Eccentricity (τ)	$\tau = [(\lvert Lcm^2 - Wcm^2 \rvert)]^{0.5} / Wcm$	Black (1972)	7.18
18	Centre of Gravity of the Watershed (Gc)	GIS Software Analysis	Rao (1998)	74.069 E 16.96 N
19	Hydraulic Sinuosity Index (Hsi) %	Hsi = ((Ci - Vi)/(Ci - 1))*100	Mueller (1968)	6.83
20	Topographic Sinuosity Index (Tsi) %	Tsi = ((Vi - 1)/(Ci - 1))*100	Mueller (1968)	93.16
21	Standard Sinuosity Index (Ssi)	Ssi = Ci / Vi	Mueller (1968)	1.022
22	Longest Dimension Parallel to the Principal Drainage Line (Clp) Kms	GIS Software Analysis	-	131.25
	Drainage Texture Analysis			
23	Stream Frequency (Fs)	Fs = Nu / A	Horton (1932)	9.75
24	Drainage Density (Dd) Km / Kms^2	Dd = Lu / A	Horton (1932)	3.70
25	Constant of Channel Maintenance (Kms^2 / Km)	C = 1 / Dd	Schumm(1956)	0.270
26	Drainage Intensity (Di)	Di = Fs / Dd	Faniran (1968)	2.635
27	Infiltration Number (If)	If = Fs * Dd	Faniran (1968)	36.075
28	Drainage Pattern (Dp)		Horton (1932)	Dn & Ra
29	Length of Overland Flow (Lg) Kms	Lg = A / 2 * Lu	Horton (1945)	0.135

Relief parameter

Total Basin relief (H): Total basin relief is the difference in elevation between the highest point on the source and the mouth of the river in a basin

Relief ratio (Rh): It is the ratio between the total relief of the basin and its longest dimension parallel to the principal drainage line.

Ruggedness number (Rn): (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.

Gradient Ratio (Rg): Gradient ratio is an indicator of channel slope, which enables assessment of the runoff volume (Sreedevi, 2004). Watershed has an Rg of 4.15, which reflects the mountainous nature of the terrain.

Slope Analysis (Sa): slope analysis is an important parameter in geomorphic studies. Slope plays a very significant role in determining infiltration vs. runoff relation. Infiltration is inversely related to slope i.e. gentler is the slope, higher is infiltration and less is runoff and vice-versa.

Table 5: Hypsometric Data of Hypsometric Integrals

S. No.	Altitude Range (m)	Height (m) h	Area (Kms^2) a	h / H[1]	a / A^2
1	1031	585	0	1	0
2	985-1031	446	5	0.92	2.40
3	885-1031	346	62	0.75	0.029
4	785-1031	246	235	0.57	0.112
5	685-1031	146	423	0.40	0.203
6	585-1031	46	703	0.23	0.337
7	446-1031	0	2082.95	0	1

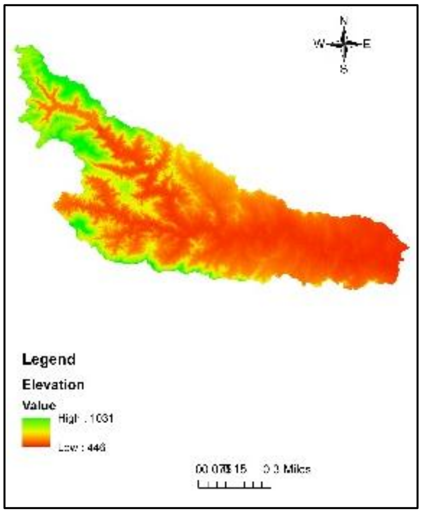

Figure 3. Digital elevation model

Table 6. Relief Aspect of Warna Basin

C	Relief Characterizes	Formula	Reference	Result
1	Height of Basin Mouth (z) m	GIS Analysis / DEM	-	459
2	Maximum Height of the Basin (Z) m	GIS Analysis / DEM	-	1031
3	Total Basin Relief (H) m	H = Z - z	Strahler (1952)	572
4	Relief Ratio (Rhl)	Rhl = H / Lb	Schumm(1956)	4.13
5	Absolute Relief (Ra) m	GIS Software Analysis		585
6	Relative Relief Ratio (Rhp)	Rhp = H * 100 / P	Melton (1957)	166.54
7	Dissection Index (Dis)	Dis = H / Ra	Singh & Dubey (1994)	0.97
8	Channel Gradient (Cg) m / Kms	Cg = H / {(π/2) * Clp}	Broscoe (1959)	2.77
9	Gradient Ratio (Rg)	Rg = (Z - z) / Lb	Sreedevi (2004)	4.15
10	Watershed Slope (Sw)	Sw = H / Lb		4.13

11	Ruggedness Number (Rn)	Rn = Dd * (H / 1000)	Patton & Baker (1976)	2.11
12	Melton Ruggedness Number (MRn)	MRn = H / $A^{0.5}$	Melton (1965)	12.53
13	Total Contour Length (Ctl) Kms	GIS Software Analysis	-	301079.88
14	Contour Interval (Cin) m	GIS Software Analysis	-	10
15	Average Slope in Degree	GIS Analysis / DEM	Rich (1916)	0.026
16	Average Slope (S) %	S = (Z * (Ctl/H)) / (10 * A)	Wenthworth's (1930)	2.60
17	Mean Slope of Overall Basin (ϴs)	ϴs = (Ctl * Cin) / A	Chorley (1979)	1.44
18	Relative Height (h/H)	see Table 4 (h/H)	Strahler (1952)	1-0
19	Relative Area (a/A)	see Table 4 (a/A)	Strahler (1952)	0-1

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CONCLUSION

The prioritizing of river basin based on the linear, areal and relief aspects. The total length of stream segments is maximum in first order streams and decreases as the stream order increases. The few parameter values are considered here those are as a elongation ratio was 0.37 which defines that the watershed is strongly elongated, The development of stream segments in the basin area is more or less affected by rainfall. The morphometric analysis of this basin area is very useful for rainwater harvesting and watershed management plans. Hence from this study it can be concluded that DEM and Arc GIS 10.3 are very essential tools for characterized by very high accuracy in mapping so it is useful and valuable tool for Morphometric analysis.

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