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Morphometric analysis of mansi-wakal river basin of western India, using remote sensing and GIS techniques

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Abstract **:** The study area of wakal river basin covers 1914.32 km^2 and divided in to 7 sub-basins range from 203.46 to 360.22 km^2 for the analysis. The drainage network of 7 sub-basins were delineated using remote sensing data (LISS III) on 1:50,000 scale and SOI toposheets were used as reference. The morphometric parameters were computed using ArcInfo and ArcView softwares. The drainage pattern of the study area is dendritic to sub-dendritic with stream orders of sub-basins ranging from VI to VII orders and lower streams order mostly dominated in the basin. The stream length ratios are changing haphazardly at sub-basin indicating differences in slope and topographic conditions. The values of mean bifurcation ratio ranging from 3.12 to 4.56 indicate that all the sub-basins fall under normal basin category. Drainage density varies between 3.08 to 4.20 km/km^2 has a mountainous relief and fine drainage texture. The values of form factor and circulatory ratio of sub-basins indicate that they are sub-circular and elongated in shape. Elongation ratio indicates that the sub-basins in a region of strong relief and steep ground slopes. The values of length of overland flow of the basin indicate that the areas associated with more run-off and less infiltration. The ruggedness number of the basins indicates that the area is extremely rugged with high relief and high stream density. Hence, it is concluded that remote sensing and GIS techniques proved a competent tool in morphometric analysis.

Key words **:** Morphometric analysis, Mansi-wakal river basin, Remote sensing, GIS techniques

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Morphometric analysis of a watershed provides a quantitative description of the drainage system, which is an important aspect of the characterization of watersheds (Strahler, 1964). Morphometric analysis requires measurement of linear features, aerial aspects, gradient of channel network and contributing ground slopes of the drainage basin. Identification of drainage networks within basins or sub basins can be achieved using traditional methods such as field observations and topographic maps or alternatively with advanced methods using remote sensing and GIS. In traditional methods, it is difficult to examine all drainage networks from field observations due to their extent throughout rough terrain and/or vast areas. Drainage characteristics of many river basins and sub basins in different parts of the globe have been studied using conventional methods (Horton, 1945; Strahler, 1952, 1957, 1964; Morisawa, 1959; Krishnamurthy *et al.*, 1996). Morphometric analysis using remote sensing technique has emerged as a powerful tool in recent years. Remote sensing has the ability of obtaining synoptic view of the large area at one time and very useful in analysing the drainage morphometry. In India, some of the recent studies on morphometric analysis using remote sensing technique were carried out by Kumar *et al.* (2000), Vittala *et al.* (2004) and Chopra *et al.* (2005). More recently, Sharma *et al.* (2010) have carried out morphometric analysis of sub-watersheds of Uttala river, which is a tributary of Son river in central India. Evaluation of morphometric parameters necessitates the analysis of various drainage parameters such as ordering of the various streams, measurement of basin area and perimeter, length of drainage channels, drainage density (D_d), stream frequency (F_s), bifurcation ratio (R_b), basin relief (H) and Ruggedness number (R_N). The main objective of this study is using remote sensing and GIS technology to compute various parameters of morphometric characteristics of the basin.

Study area:

In this study, the mansi-wakal river basin was divided into seven sub-basins. Mansi-wakal river basin lies on the western part of India between the latitudes of 24^{0}8'49.41" to 24^{0}46'34.65" N and the longitudes of 73^{0}6'23.41" to 73^{0}35'54.18" E and spread across the state of Rajasthan and Gujarat. The total length of the basin is 71.22 km, whereas the maximum width is 41.01 km. The total catchments area of the basin is 1914.32 km^2 in which 98 per cent of the total area falls in the Udaipur district of Rajasthan. The area is characterized by sub-humid climate with an average annual rainfall of 630 mm. The main tributaries of mansi-wakal river are mansi and pamri rivers. The general topography of the area is hilly and undulating. Most of the cultivated lands are located in the valleys. Surface drainage of the area is generally good due to slight undulations in the topography. The location map of the mansi-wakal river basin is shown in Fig. A.

Fig. A : Location map of Mansi-wakal river basin

■ METHODOLOGY

In the present study, the map showing drainage details were prepared from digital data of LISS III and extracted by digitizing boundary of the basin from the geometrically rectified toposheet (Fig. B). The figure also shows digitized stream network. The drainage pattern for delineated seven sub-basins of mansi-wakal river was exported to ARC/INFO software for morphometric analysis. The parameters computed in the present study including stream order, stream length, stream frequency, bifurcation ratio, drainage density, stream frequency, form factor, circulatory ratio, elongation ratio, relief ratio and ruggedness number by standard methods and formulae as given in Table A. The input parameters for the present study such as area, perimeter, elevation, stream length etc. were obtained from digitized coverage of drainage network map in GIS environment.

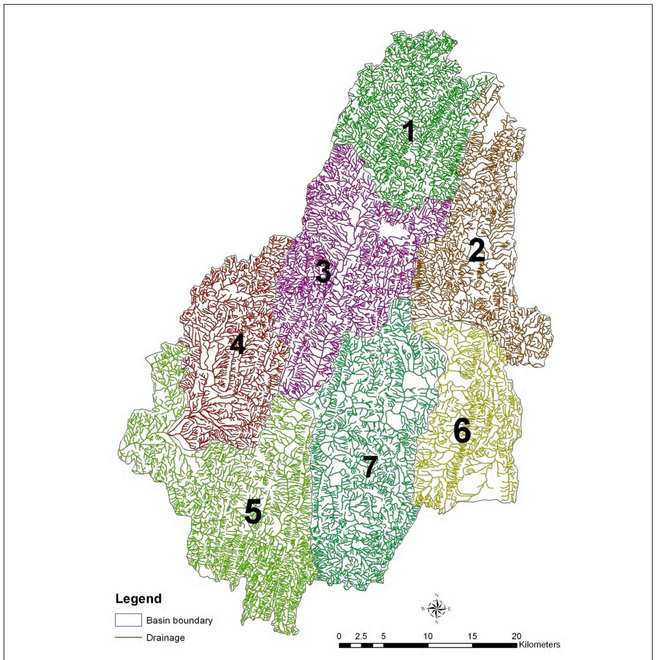

Fig. B : Drainage map of Mansi-wakal river basin

Table A : Formula for computation of morphometric parameters

Morphometric parameters	Formula	Reference
Stream order (u)	Hierarchical rank	Strahler (1964)
Stream length (L_u)	Length of stream	Horton (1945)
Mean stream length (L_{sm})	$L_{sm} = L_u / N_u$	Strahler (1964)
Bifurcation ratio (R_b)	$R_b = N_u / N_{u+1}$	Schumn (1956)
Mean bifurcation ratio (R_{bm})	R_{bm}=Average of bifurcation ratio of all orders	Strahler (1964)
Drainage density (D_d)	$D_d = L_u / A$	Horton (1945)
Stream frequency (F_s)	$F_s = \Sigma N_u / A$	Horton (1945)
Form factor (R_f)	$R_f = A / L_b^{\ 2}$	Horton (1945)
Circularity ratio (R_c)	$R_c = 4 \pi A / P^2$	Miller (1953)
Elongation ratio (R_e)	$R_e = (2 / L_b) * (A/\pi)^{0.5}$	Schumn (1956)
Length of overland flow (Lg)	Lg=I/D*2	Horton (1945)
Constant Charmel Maintenance (C)	C=-I/D	Schumn (1956)
Relief ratio (R_r)	R_r = H/Lb	Schumn (1956)
Ruggedness number (R_N)	R_N = H x Dd	Strahler (1958)

Index of notation:
L_u = Total stream length of order u
N_u = Total number of stream segments of order u
N_{u+1} = Number of stream segment of next higher order u+1
ΣN_u = Total number of stream of all order.
L_b = Length of basin (km) H = Maximum basin relief
A = Area of basin (km^2) P = Perimeter of basin (km)

■ RESULTS AND DISCUSSION

The total drainage area of mansi-wakal river basin is 1914.32 km^2 and it is divided into 7 sub-basins for the analysis. The drainage map of mansi-wakal river basin is shown in Fig. B. The drainage pattern of the basin ranges from dendritic to subdendritic at higher elevations and parallel to sub- parallel in the lower elevations. The drainage characteristics of the seven sub-basins of the study area were determined and are summarized in Tables 1, 2, 3 and 4.

Linear aspects:

The linear aspects of the basin such as stream order (N_u), stream length (L_u) and bifurcation ratio (R_b) were determined and results have been given in Table 1. In the present study ranking of streams was carried out based on the method proposed by Strahler (1964). Out of these seven sub-basins, sub-basin No. 1, 2, 3 and 4 were sixth order basin whereas sub-basin No. 5, 6 and 7 were of seventh order basin. Table also show that the maximum stream frequency in case of first order streams and there was a decrease in stream frequency as the stream order increases. The order wise total number of stream segment is known as the stream number. Horton's (1945) laws of stream numbers states that the number of stream segments of each order form an inverse geometric sequence with plotted against order, most drainage networks show a linear relationship, with small deviation from a straight line. The plotting of logarithm of number of streams against stream order is given in Fig. 1 according to the law proposed by Horton gives a straight line. This means that the number of streams usually decreases in geometric progression as the stream order increases.

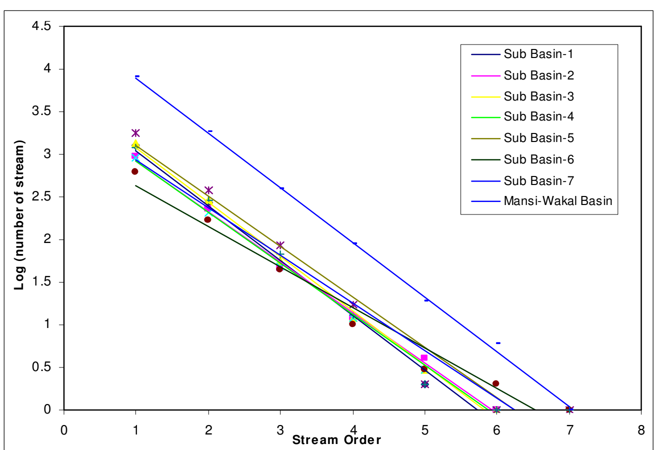

Fig. 1 : Relationship between log (number of stream) and stream order

The stream lengths for all sub-basins of various orders were measured on digitized map with the help of GIS. The

Table 1 : Linear aspects of mansi wakal river sub basins

Basin/ Sub basin	Area (km^2)	Perimeter (km)	Stream number of different orders 1	2	3	4	5	6	7	Total	Order wise total stream length(km) 1	2	3	4	5	6	7	Total
Sub basin 1	232.87	80.91	1260	269	51	12	2	1		1595	643.7	167.2	84.6	39.2	42.2	.03		976.9
Sub basin 2	248.05	101.83	943	229	45	12	4	1		1234	526.5	157.4	80.5	33.6	45.8	5.8		849.6
Sub basin 3	302.41	95.16	1351	290	56	12	3	1		1713	732.1	218.1	94.8	56.5	21.7	29.8		1153.0
Sub basin 4	224.43	81.32	923	209	48	12	3	1		1196	473.9	154.7	99.6	36.1	22.7	5.5		792.5
Sub basin 5	360.22	135.94	1786	381	85	17	2	1	1	2273	881.8	234.4	126.4	62.9	20.5	.3	46.5	1372.8
Sub basin 6	203.46	74.48	617	166	44	10	3	2	1	843	380.7	117.0	66.5	19.7	29.8	13.1	.09	626.9
Sub basin 7	342.88	95.64	1202	289	67	13	2	1	1	1575	694.5	197.0	121.9	46.7	25.4	29.3	32.6	1147.4
Mansi wakal river basin	1914.32	256.70	8082	1833	396	88	19	6	1	10425	4333.1	1245.9	674.2	294.7	208.1	83.9	79.2	6919.1

Table 2 : Linear aspects of mansi wakal river sub basins

Basin/ Sub basin	Average stream length (km) 1	2	3	4	5	6	7	Total	Stream length ratio(RL) 2/1	3/2	4/3	5/4	6/5	7/6	Mean RL	Bifurcation ratio(Rb) Rb 1	Rb 2	Rb 3	Rb 4	Rb 5	Rb 6	Mean Rb
Sub basin 1	0.5	0.6	1.7	3.3	21.1	0.03		27.2	1.2	2.8	1.9	6.4	.001		2.5	4.7	5.3	4.3	6.0	2.0		4.4
Sub basin 2	0.6	0.7	1.8	2.8	11.4	5.8		23.1	1.2	2.6	1.6	4.1	0.5		2.0	4.1	5.1	3.8	3.0	4.0		4.0
Sub basin 3	0.5	0.8	1.7	4.7	7.2	29.8		44.7	1.6	2.1	2.8	1.5	4.1		2.42	4.7	5.2	4.7	4.0	3.0		4.3
Sub basin 4	0.5	0.7	2.1	3.0	7.6	5.5		19.4	1.4	3.0	1.4	2.5	0.7		1.8	4.4	4.4	4.0	4.0	3.0		4.0
Sub basin 5	0.5	0.6	1.5	3.7	10.3	0.3	46.5	63.4	1.2	2.5	2.5	2.8	0.03	155	27.3	4.7	4.5	5.0	8.5	2.0	1.0	4.3
Sub basin 6	0.6	0.7	1.5	2.0	9.9	6.6	0.09	21.4	1.2	2.1	1.3	5.0	0.7	0.01	1.7	3.7	3.8	4.4	3.3	1.5	2.0	3.1
Sub basin 7	0.6	0.7	1.8	3.6	12.7	29.3	32.6	81.3	1.2	2.6	2.0	3.5	2.3	1.1	2.1	4.2	4.3	5.2	6.5	2.0	1.0	3.9
Mansi wakal river basin	0.5	0.7	1.7	3.3	11.0	14.0	79.2	110.4	1.4	2.4	1.9	3.3	1.3	5.7	2.7	4.4	4.6	4.5	4.6	3.2	6.0	4.6

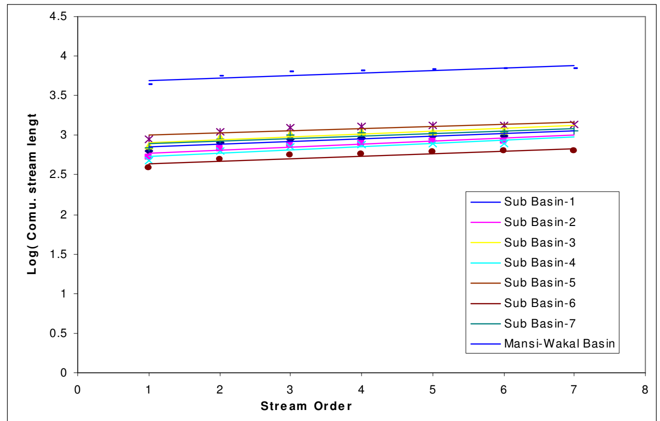

Fig. 2 : Relationship between log (comu.stream length) and stream order

total length of stream segments is maximum in first order streams and decreases as the stream order increases. The total stream length of the mansi-wakal river basin is 6919.1 km and that of the seven sub-basins are 976.9, 849.6, 1153.0, 792.5, 1372.8, 629.9, and 1147.4 km, respectively (Table 1). The stream length ratios (R_L) are changing haphazardly at the basin and sub-basins level. The values of the stream length ratio (R_L) vary from 0.01 to 155 for sub-basins, while it ranges from 1.3 to 5.7 for the whole mansi-wakal river basin (Table 1). It is noticed that the R_L between successive stream orders of the basin vary due to differences in slope and topographic conditions (Sreedevi *et al*., 2005). The stream length ratio (R_L) has an important relationship with the surface flow discharge and erosional stage of the basin.

In the present study, it was observed that the plot of logarithm of the cumulative stream length as ordinate vs. stream order as abscissa was almost a straight line fit. The straight-line fit indicates that the ratio between cumulative length and order is constant throughout the successive orders of a basin (Fig.4).

The mean bifurcation ratio values range between 3.12 and 4.56 for the basins of the study area indicating that all the basins are falling under normal basin category (Strahler, 1957). The bifurcation ratio is also an indicative tool of the shape of the basin. Elongated basins have low R_b value, while circular basins have high R_b value (Morisawa, 1985). In this study area, the higher values of R_b indicated a strong structural control in the drainage pattern whereas the lower values indicated that the sub-basins were less affected by structural disturbances (Stahler, 1964; Vittala *et al*., 2004 and Chopra *et al*., 2005).

Aerial aspects:

The aerial aspects of the basin like drainage density (D), stream frequency (F_s) elongation ratio (R_e), circularity ratio

(R_c), form factor (R_f), were calculated and results have been presented in Table 3. The drainage density in the whole basin and sub-basins of the study area showed variation from 3.08 to 4.20 km per km^2 suggesting high drainage density. It indicates that the region is composed of weak or impermeable subsurface materials, sparse vegetation, mountainous relief and fine drainage texture (Reddy *et al.*, 2004). The stream frequency (F_s) mainly depends on the lithology of the basin and reflects the texture of the drainage network. The stream frequency (Fs) values of the basin and sub-basins of the study area are varying from 4.14 to 6.85. It is also seen that the drainage density values of the sub-basins exhibits positive correlation with the stream frequency, suggesting that there is an increase in stream population with respect to increasing drainage density. Generally, high value of stream frequency (F_s) is related to impermeable sub-surface material, sparse vegetation, high relief conditions and low infiltration capacity (Reddy *et al.*, 2004).

Form factor (F_f) proposed by Horton (1945) to predict the flow intensity of basin of a defined area. The index of F_f shows the inverse relationship with the square of the axial length and a direct relationship with peck discharge. The value of form factor would always be greater than 0.78 for a perfectly circular basin. Smaller the value of form factor, more elongated will be the basin. Form factor (F_f) values of whole basin and sub-basins of the study area varied from 0.23 to 0.54 indicating that they were sub-circular and elongated in shape. The elongated basin with low form factor indicates that the basin will have a flatter peak of flow for longer duration. Flood flows of such elongated basins are easier to manage than of the circular basin (Nautiyal, 1994).

The circularity ratio (R_c) is affected by the lithological character of the basin. Its values approaching one indicates that the basin shapes are like circular and as a result, it gets scope for uniform infiltration and takes long time to reach excess water at basin outlet, which further depends on the prevalent geology, slope and land cover. The ratio is more influenced by length, frequency (F_s) and gradient of various orders rather than slope conditions and drainage pattern of the basin. The R_c of the whole basin and sub- basins of the study area varied from 0.24 to 0.47 is a significant ratio, which indicates the dentritic stage of a basin.

The elongation ratio (R_e) is a very significant index in the analysis of basin shape, which helps to give an idea about the hydrological character of a drainage basin. Elongation ratio (R_e) for the study area varied from 0.54 to 0.83 as shown in Table 3. The value near 1 was typical of regions of very low relief, whereas values in the range of 0.6–0.8 were generally associated with strong relief and steep ground slopes (Strahler, 1968).

Schumm (1956) used the inverse of drainage density as a property known as the constant of channel maintenance (C). It is the area of basin surface needed to sustain a unit length of stream channel and is depends on the rock type, permeability, climatic regime, vegetation cover as well as duration of erosion. In areas of close dissection, its value will be very low. The value of constant channel maintenance (C) of the study area varied from 0.24 to 0.32 indicating that these basin and sub-basins were under the influence of high structural disturbance, low permeability, steeps to very steep slopes and high surface runoff.

The length of overland flow (Lg) is the length of water over the ground before it gets concentrated into definite stream channels. It is approximately equals to half of the reciprocal of drainage density (Horton, 1945). This factor relates inversely to the average slope of the channel and is synonymous with the length of the sheet flow to the large degree. The length of overland flow (Lg) is one of the most important independent variables, affecting both the hydrological and physiographical development of the drainage basins (Horton, 1945). The computed value of L_g for all sub-basins and basin varied from 0.12 to 0.16 km2/km. The low Lg values of basin and sub-basins indicated to short flow paths, with steep ground slopes, reflecting the areas associated with more run-off and less infiltration.

Table 3 : Aerial aspects of mansi-wakal river sub-basins

Basin/ Sub-basin	Form factor	Shape factor	Circulatory ratio	Elongattion ratio	Drainage density	Stream frequency	Constant of channel maintenance	Length of overland flow
Sub-basin-1	0.54	1.87	0.45	0.83	4.20	6.85	0.24	0.12
Sub-basin-2	0.23	4.35	0.30	0.54	3.42	4.97	0.29	0.15
Sub-basin-3	0.35	2.86	0.42	0.66	3.81	5.66	0.26	0.13
Sub-basin-4	0.31	3.27	0.43	0.62	3.53	5.33	0.28	0.14
Sub-basin-5	0.38	2.64	0.24	0.69	3.81	6.31	0.26	0.13
Sub-basin-6	0.48	2.08	0.46	0.78	3.08	4.14	0.32	0.16
Sub-basin-7	0.32	3.13	0.47	0.64	3.35	4.50	0.30	0.15
Mansi-wakal river basin	0.38	2.65	0.37	0.69	3.61	5.45	0.28	0.14

Table 4 : Relief aspects of mansi-wakal river sub-basins

Basin/ Sub-basin	Elevation in meter		Relief (m)	Relief ratio	Ruggedness number
	Max.	Min.			
Sub-basin-1	1060.0	560.0	500.0	0.024	2.10
Sub-basin-2	1001.0	555.0	446.0	0.014	1.53
Sub-basin-3	1042.0	427.5	614.5	0.021	2.34
Sub-basin-4	1037.0	285.0	752.0	0.028	2.65
Sub-basin-5	858.0	275.0	583.0	0.019	2.22
Sub-basin-6	1015.0	533.0	482.0	0.023	1.48
Sub-basin-7	1001.0	433.0	568.0	0.017	1.90
Mansi-wakal river basin	1060.0	275.0	785.0	0.011	2.83

Relief aspects:

The relief parameters include basin relief (B_h) and ruggedness number (R_N). Relief aspect of the watersheds plays an important role in drainage development, surface and sub-surface water flow, permeability, landform development and associated features of the terrain. Relief is the maximum vertical distance between the lowest and the highest points of a basin. The maximum height of the mansi-wakal basin is 1060 m and the lowest is 275 m. Therefore, the relief of the mansi-wakal basin is 785m.The relief of sub–basins of the study area is varied from 446m to 752m. The high relief value indicates the gravity of water flow, low infiltration and high runoff conditions of the study area. Relief ratio has direct relationship between the relief and channel gradient. The relief ratio normally increases with decreasing drainage area and size of the watersheds of a given drainage basin. The relief ratio of the mansi-wakal river basin is 0.011, while that of the seven sub-basins varied from 0.014 to 0.028. The relief ratios of the basin as well as the sub-basins of the study area were low which are characteristic features of less resistant rocks of the area (Sreedevi, 1999).

Ruggedness number, R_N is the product of relief and drainage density in order to define the slope steepness and length. It is a dimensionless term and indicates the structural complexity of the terrain. The mansi-wakal river basin displays the ruggedness number as 2.83 and indicate that the area is extremely rugged with high relief and high stream density. The ruggedness number of sub–basins varied from 1.48 to 2.65 as given in Table 4.

Conclusion:

The quantitative analysis of morphometric parameters is found to be immense utility in river basin evaluation, watershed prioritization for soil and water conservation, and natural resources management at micro level. The mansi-wakal river basin has seventh order basin. The maximum stream frequency is found in first order stream and there is decrease as the stream order increases. The total stream length of study area is 6919.1 km. The mean bifurcation ratio of the study area varied from 3.12 to 4.56 indicating that all the basins are falling under normal basin category. The high drainage density of the study area indicates that the region is composed of weak or impermeable subsurface materials, sparse vegetation, mountainous relief and fine drainage texture. Form factor (F_f) values of basins of the study area indicate that they are sub-circular and elongated in shape. The high relief value of the mansi-wakal river basin is 785 m. indicates the gravity of water flow, low infiltration and high runoff conditions of the study area. The ruggedness number of study area is 2.83, indicate that the area is extremely rugged with high relief and high stream density hence more run-off and less infiltration.

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