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Morphometric and Land use Analysis for Watershed Prioritization in Gujarat State, India

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Abstract— In the present study, an attempt has been made to evaluate morphometric parameters derived from Indian Remote Sensing Satellite (IRS) Cartosat-1 DEM-10 m data and LISS-IV data covering Viswamitre watershed in Vadodara and Panchmahals districts in Gujarat State. The Morphometric parameters like stream length, bifurcation ratio, drainage density, stream frequency, texture ratio, form factor, circularity ratio and compactness coefficient and elongation ratio are considered for prioritization of all the mini-watersheds in the study area. The land-use map of the study area was generated using the IRS LISS-IV digital data and used as one of the input for prioritization of the mini-watersheds.

The mini-watersheds were prioritized based on the composite ranking of the parameters considered for morphometric analysis. The highest value of the linear parameter was ranked 1, the second highest value ranked 2, and so on. On the contrary, the shape parameters have converse relation with linear parameters, which means lower their value, more is the erodability. Thus the lowest value of the shape parameter was rated as rank 1 and the second lowest as rank 2, and so on. Compound factor was then computed by summing all the ranks of liner parameters as well as shape parameters and then dividing by number of parameters. From the group of these mini-watersheds, highest prioritized rank was assigned to the mini-watershed having the lowest compound factor and so on.

Viswamitre Watershed consists of 9 mini-watersheds out of which mini-watershed no.9, is conferred uppermost priority based on the compound factors computed based on various morphometric parameters. The results indicate that the analysis of various morphometric parameters derived from IRS LISS-IV and Cartosat-1 DEM 10 m digital data in GIS environment, can be effectively used for prioritization of watersheds, soil and water conservation and natural resources management at the watershed level.

Index Terms—Morphometric analysis, Indian Remote Sensing Satellite (IRS), Cartosat-1 DEM-10 m, Stream order, Drainage density, Land use classification, Watershed Prioritization,

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1 INTRODUCTION

Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms (Agarwal, 1998; Obi Reddy et al., 2002). Prioritization and management of any watershed depends upon its accurate delineation and plays an important role in the determination of stream flow. Watershed, the drainage basin or catchment area of river, is geo-hydrological unit which drains runoff into small rivulets. Watershed management is a significant constituent for sustainable improvement of natural resources and is the process of formulation carrying out a course of action that involves modification in the natural system of watershed to achieve specified objectives (Johnson et al., 2002). It further implies appropriate use of land and water resources of a watershed for optimum production with minimum hazard to natural resources (Osborne and Wiley 1988; Kessler et al., 1992). For conserving soil and water, water harvesting structure is being an imperative component of watershed development.

Remote Sensing (RS) along with Geographical Information System (GIS) technologies have been successfully used to derive considerable accurate representation of various watershed delineation features (Ozdemir and Bird, 2009). GIS techniques characterized by very high accuracy of mapping and measurement prove to be a competent tool in morphometric analysis. Drainage density and stream frequency are the most useful criterion for the morphometric classification of drainage basins which certainly control the runoff pattern, sediment yield and other hydrological parameters of the drainage basin.

In India drainage and morphometric characteristics of many river basins have been studied using conventional methods (Krishanmurthy et al., 1996). GIS helps to create database for the watershed which is very much useful for carrying out spatial analysis thereby helping the decision makers in framing appropriate measures for critically affected areas (Thakkar and Dhiman, 2007). It is an effective tool not only for collection, storage, management and retrieval of a multitude of spatial and non-spatial data, but also for spatial analysis and integration of these data to derive useful outputs and modelling (Gupta and Srivastava 2010; P. K. Srivastava et al. 2010; Mukherjee et al. 2009; P. Srivastava et al. 2011). Ahmed et al., 2010, carried out the evaluation of morphometric parameters derived from ASTER and SRTM DEM for proper planning and management of Sub-watershed basin in Kranataka state. In present study, an attempt has been made to evaluate morphometric parameters derived from Indian Remote Sensing satellite Cartosat-2 DEM-10 m data covering Viswamitre mini-watershed in Vadodara and Panchmahals districts in Gujarat State.

2. Study Area

The study area comprises of Viswamitre watershed which falls under the Mahi river basin in Vadodara and Panchmahals districts of Gujarat State. This watershed comprises of 9-mini-watersheds which cover a total area of about 1185 km². The location map of the study area is given in Figure-1. There are 9-mini-watersheds in the Viswamitre watershed. The Indian Remote Sensing Satellite (IRS) LISS-IV data along with mini-watershed boundary is shown in Figure-2.

Figure-1: Location map of the Viswamitre watershed in Gujarat State

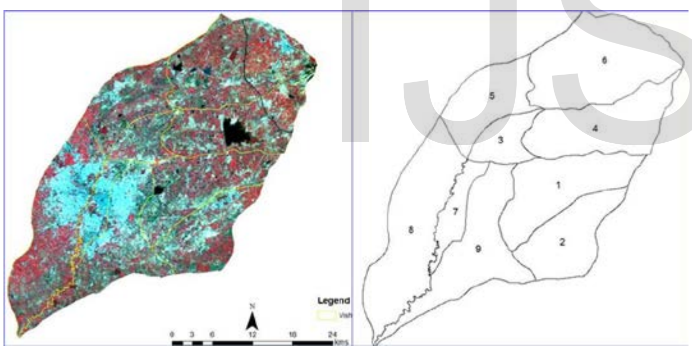

Figure-2: IRS LISS-IV data covering Viswamitre watershed along with mini-watershed boundaries

3. Materials and Method

3.1 Morphometric Analysis

The methodology flow chart of morphometric analysis is given in **Figure-3**. The IRS LISS-IV digital data was analyzed using the ground truth information and land use map of the study area indicating cropped land, waste land, forest land etc. in the Viswamitre watershed was generated **(Figure-4).** Cartosat-1 stereo-data was used to generate 10 m spatial resolution Digital elevation Model (DEM) covering the study area, delineation of drainage, and watershed boundary. The Digital elevation Model (DEM) of the Viswamitre watershed is given in **Figure-5**.

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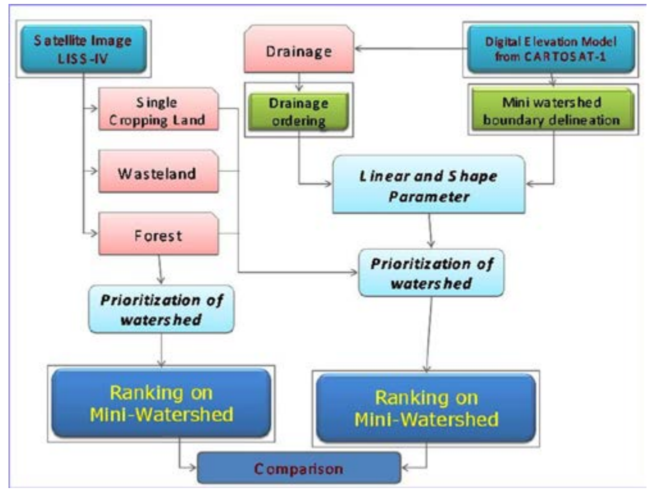
Figure-3: Methodology flow chart of Morphometric analysis



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4. Results and Discussion

The morphometric parameters were categorized into three categories namely, basic parameters, derived parameters and shape parameters. The basic parameters include area, perimeter, basin length, stream order, stream length, maximum and minimum heights and slope. The derived parameters are bifurcation ratio, stream length ratio and drainage density. The shape parameters are elongation ratio, circulatory index and form factor (Ahmed et al., 2010). The drainage network of the watershed and stream ordering was analyzed as per Horton (1945), Strahler (1964), Schumn (1956), Nookartnam et al., (2005), Thakkar and Dhiman (2007) and Miller (1953). The details of various formulae used in this study are given in Table-1.

4.1 Basic Parameters

The morphometric analysis of Viswamitre watershed was carried out using the parameters given in Table-1. Basic parameters include watershed area, perimeter, stream length, stream order and basin length.

i. Perimeter (P) and Area (A)

Mini-watershed delineated layer is used to obtain basic morphometric parameters such as area (A), perimeter (P), length (L), number of streams (N). Basin length (Lb) was calculated from stream length, while the bifurcation ratio (Rb) was calculated from the number of streams. Other linear and shape morphometric parameters were calculated using the equations

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as given in Table-1. Liner parameters have a direct relationship with erodability, higher the value more is the erodability (Nookaratnam et al., 2005). The perimeter (P) is the total length of the drainage basin boundary. The perimeter of the Vishwamitre watershed is 558.8 km. The basin perimeter (P) can be represented as length of the line that defines the surface divide of the basin. Perimeters of mini-watersheds are shown in Table-3. The result shows that mini-watershed number 6 covers the maximum area of 215.7 km² while watershed number 7 has minimum area of 44.8 km².

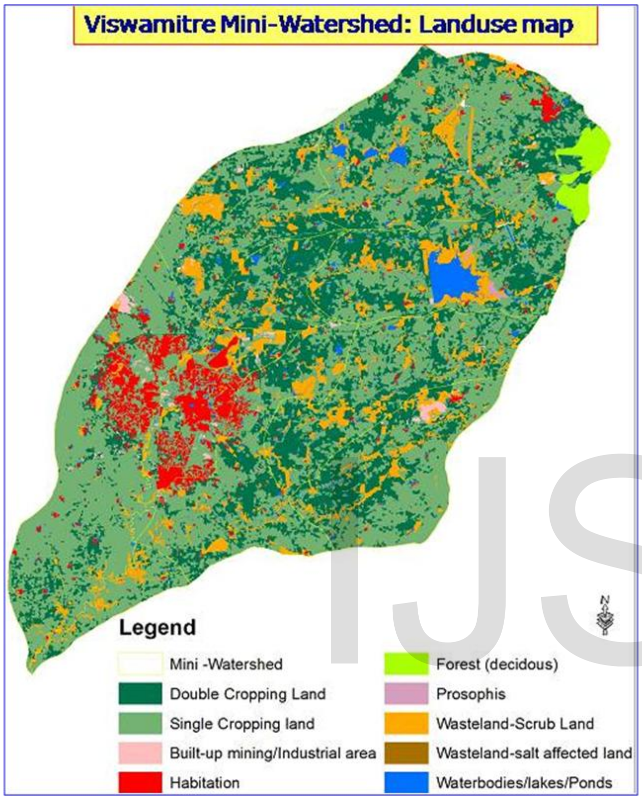

Figure-4: Land use map of the Viswamitre watershed in Gujarat State

ii. Stream Order (u)

To describe the basins in quantitative terms, concept of stream order was introduced by Horton, (1945) and Strahler, (1964). This concept is applied with the linear dimension of the stream length. The first order stream has no tributary and its flow depends entirely on the surface overland flow to it. Likewise the second-order stream is formed by the junction of two first-order streams and as such has higher surface flow and the third-order stream receives flow from two second-order streams.

This supplemented the study of stream order of the watershed. Among 9 watersheds, mini-watershed numbers 9, 1, 6, 8 and 4 are the watersheds having 415, 208, 193, 188 and 177 streams respectively as shown in **Table-2**. In watersheds no. 9 out of 415 streams, 328 have stream order I, whereas 21 have stream order V. The drainage order map of the Viswamitre watershed is given in Figure-6.

Morphometric Parameters	Formula	Reference
Total Stream Order (u)	$\sum Nu$ (Hierarchical rank)	Strahler (1964)
Basin Length (L_b)	$Lb = 1.312 \times A^{0.568}$ Where: L_b = Length of Basin (km) A = Area of Basin (km^2)	Nookaratnam *et al.* (2005)
Total Stream Length (L) Bifurcation Ratio (R_b)	$\sum Lu$ Length of the stream $R_b = N_u/N_u+1$ Where, R_b = Bifurcation Ratio N_u = Total number of stream segment of order 'u' N_u+1 = Number of segment of next higher order	Horton (1945) Schumn (1956)
Drainage Density (D_d)	$D_d = L_u/A$ Where, D_d = Drainage density L_u = Total stream length of all order A = Area of the basin	Horton (1945)
Stream Frequency (Fu)	$Fu = Nu/A$ Where, Fu = Total number of streams of all order A = Area of the Basin (km2)	Horton (1945)
Texture Ratio (T)	$T = Nu/P$ Where, Nu = Total number of streams of all orders P = Perimeter (km)	Horton (1945)
Length of Overland Flow (Lo) Form Factor (Rf)	$Lo = ½ Dd$ Where, Lo = Length of the Overland Flow D = Drainage density $Rf = A/Lb2$ Where, Rf = Form Factor A = Area of the basin (km2) Lb2 = Square of the basin length	Horton (1945) Horton (1945)
Shape Factor (Bs)	$Rf = Lb2/A$ Where, Bs = Shape Factor A = Area of the basin (km2) Lb2 = Square of the basin length	Nookaratnam et al. (2005)
Elongation Ratio (Re)	$Re = (2/Lb) \times (A/\pi)$ ½ Where, Re = Elongation Ratio Lb = Length of basin (km) A = Area of the basin (km2)	Schumn (1956)
Compactness Constant (Cc)	$Cc = 0.2821P/A0.5$ Where, Cc = Compactness Constant A = Area of the basin (km2) P = Perimeter of the basin (km)	Horton (1945)
Circularity Ratio (Rc)	$Rc = 4\pi A/P2$ Where, Rc = Circularity Ratio A = Area of the basin (km2) P = Perimeter (km)	Miller (1953)

Table-1: Formulae used to compute Morphometric parameters and their references

Table-2: Sream order and number of streams in Viswamitre

Watershed No.	I-order	II-order	III-order	IV-order	V-order	Total No. of streams
1	110	46	32	20		208
2	46	15	17	1		79
3	39	14	6	12		71
4	97	42	28	10		177
5	51	9	10	25		95
6	109	62	16	6		193
7	48	5	2			55
8	148	33	7			188
9	328	61	23	3	21	415

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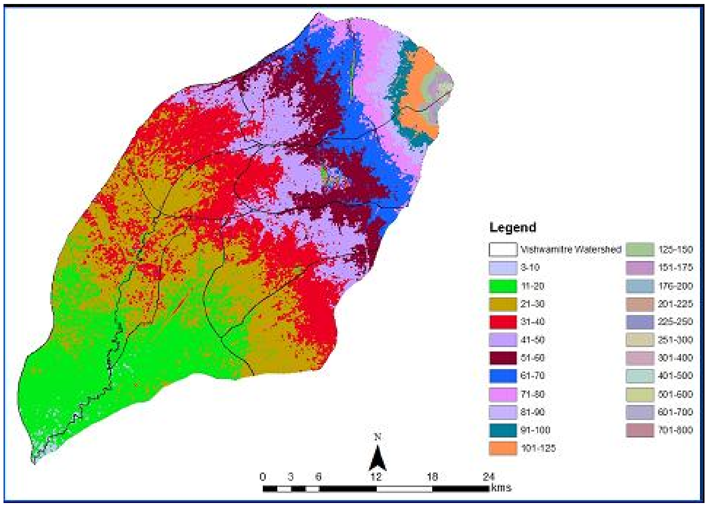

Figure-5: Digital Elevation Model (DEM) of the Viswamitre watershed

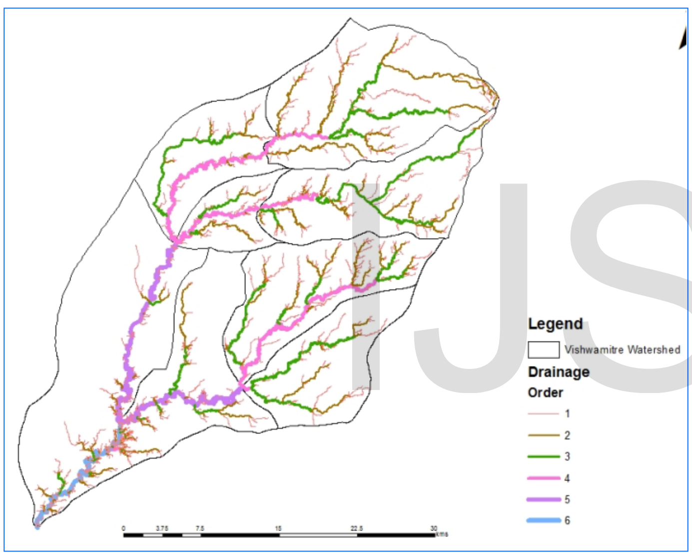

Figure-6: Drainage order map of the Viswamitre watershed

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iii. Total Length of Stream (L)

Stream length is the addition of all streams lengths in a particular order. The numbers of streams of various orders in a mini-watershed were counted and their lengths measured, which help us to find the drainage density, the results are tabulated in Table 3.

iv. Basin Length (L_b)

The basin length (L_b) is one of the watershed characteristics of interest and is important in hydrologic computations and increases as the drainages increases and vice versa. Basin length is usually defined as the distance measured along the main channel from the watershed outlet to the basin divide. Since the channel does not extend to the basin-divide, it is necessary to extend a line from the end of the channel to the basin-divide following a path where the greatest volume of water would travel. Thus, the length is measured along the principal flow path. Basin length is the basic input parameter to count the major shape parameters. The results of basin length analysis show that it varies between 11.4 km (mini-watershed no. 7) and 27.3 km (mini-watershed no. 8) in the Viswamitre watershed (Table 3).

v. Linear Parameters

Linear parameters include bifurcation ratio, drainage density, stream frequency, texture ratio and length of overland flow.

vi. Bifurcation ratio (R_b)

It is the ratio of the number of streams of a given order to the number of streams of the next higher order (Schumn, 1956). Lower R_b values are the characteristics of structurally less disturbed watersheds without any distortion in drainage pattern (Nag, 1998). Table 3 shows that in bifurcation ratios (R_b) of Viswamitre watershed, watershed no. 6 has the least bifurcation ratio of 1.8 and no. 5 has maximum ratio of 5.7.

vii. Drainage Density (D_d)

It is the ratio of the total length of streams within a watershed to the total area of the watershed; thus D_d has units of the reciprocal of length (1/L). A high value of the drainage density would indicate a relatively high density of streams and thus a rapid storm response, values of D_d are as shown in Table 3. Mini-watershed no. 9 has the highest drainage density whereas min-watershed no. 2 has the lowest drainage density in the Viswamitre watershed.

viii. Stream Frequency (F_u)

Stream frequency/channel frequency (F_u) is the total number of stream segments of all order per unit area (Horton, 1932). Low value of stream frequency indicates low runoff value and increase in stream population with respect to drainage density. The value of stream frequency ranges from 0.71to 2.61, as shown in Table 3.

ix. Texture ratio (T)

The texture ratio can be defined as the ratio of total number of streams of first order to the perimeter of the basin. The value of the texture ratio ranges from 1.0 to 4.6 as shown in Table 3.

x. Length of overland flow (L_o)

It is the length of water over the ground before it gets concentrated into definite stream channels and is equal to half of drainage density (Horton, 1945). Length of overland flow relates inversely to the average channel slope. Table-3 indicates the length of overland flow for various mini-watersheds in the Viswamitre watershed.

xi Shape Parameters

Shape parameters include form factor, shape factor, elongation ratio, compactness ratio and circulatory ratio.

xii Form factor (R_f)

The form factor can be defined as the ratio of the area of the basin to square of the basin length (Horton, 1945). The value of the form factor would always be less then 0.7854 (for a perfectly circular basin) (Chopra et al., 2005). Smaller the value of form factor, the basin will be more elongated. The basin with high form factors have peak flow of shorter duration, whereas, elongated mini watershed with low form factors have lower peak flow with longer duration. In the Viswamitre watershed, value of form factor is 0.28 for watershed no.8 which is minimum and 0.35 for watershed no.7 which is the maximum as shown in Table-3. These values indicate the elongated shape of the basin and having flatter peak flow for longer duration, which helps to manage the flood easily than those of the circular basin.

xiii. Shape Factor (B_s)

The shape factor can be defined as the ratio of the square of the basin length to area of the basin (Horton, 1945) and is in inverse proportion with form factor (R_f). Shape factor lies between 2.9 to 3.6 in the Viswamitre watershed, which indicates the elongated shapes of basin.

xiv. Elongation Ratio (R_e)

It is the ratio between the diameters of the circle of the same area as that of the drainage basin the maximum length of the basin. A circular basin is more efficient in runoff discharge than an elongated basin (Singh and Singh, 1997). The value of elongated ratio is varied between 0.6 and 1.0 are the typical regions of very low relief, whereas value ranged between 0.6 and 0.8 are associated with high relief and steep ground slope (Strahler, 1964). The lower value of the elongation ratio indicates that particular mini watershed is more elongate than others. The elongation value can be grouped into three categories, namely circular basin (R_e>0.9), Oval basin (R_e: 0.9-0.8), Less elongated basin (R_e <0.7). In the Viswamitre watershed (Table 3), these values are less than 0.7 and hence the mini-watersheds are elongated in shape.

xv. Compactness Coefficient (C_c)

It can be represented as basin perimeter divided by the circumference of a circle to the same area of the basin and also known as the Gravelius Index (GI). This factor is indirectly related with the elongation of the basin area. Lower values of this parameter indicate more elongation of the basin and less erosion, while higher values indicate less elongation and high erosion. In the Viswamitre watershed, highest value is 2.3 while the lowest is 1.2 as shown in **Table-3**, which indicates that mini-watershed no. 7 is more elongated as compared to mini-watershed no. 6.

xvi. Circulatory Ratio (R_c)

It is a ratio of basin area (A) to the area of circle having the same circumference as the perimeter as basin (Miller, 1953). It is affected by the length and frequency of the streams, geological structures, land use/ land cover, climate, relief and slope of the basin. If the circularity in the main basin is the minimum, it shows that the basin is less circular hence the discharge will be slow as compared to the others and so possibility of erosion will be less. In the Viswamitre watershed, maximum value of circularity ratio is for watershed no. 6, which is 0.7 and minimum value is for watershed no. 7, which is 0.2.

4.2 Ranking of the Parameters

The highest value of the linear parameter was ranked 1, the second highest value ranked 2, and so on. On the contrary, the shape parameters have converse relation with linear parameters, which means lower their value, more is the erodability. Thus the lowest value of the shape parameter was rated as rank 1 and the second lowest as rank 2, and so on. Compound factor was then computed by summing all the ranks of liner parameters as well as shape parameters and then dividing by number of parameters as shown in Table 4. From the group of these mini-watersheds, highest prioritized rank was assigned to the mini-watershed having the lowest compound factor and so on.

4.3 Compound Factor and Ranking

Compound factor is computed by summing all the ranks of liner parameters as well as shape parameters and then dividing by number of parameters. From the group of these mini-watersheds, highest rank was assigned to the mini watershed having the lowest compound factor and so on. Depending upon the value of compound factor, ranking to each mini watershed is assigned. In the Viswamitre watershed, mini-watersheds no. 9 is given rank 1 with least compound factor value of 3.1 and it is followed by watersheds no. 1 and 3, as second and third. The values of compound factor and respective rank of all mini-watersheds are shown in Table-4. The ranking of the mini-watersheds using the compound factors computed using land-use alone and ranking by land-use and morphometric analysis is given in Figure-7.

5. CONCLUSIONS

Systematic analysis of morphometric parameters within the watershed using Remote Sensing and GIS can provide significant information for understanding basin characteristics as well prioritization of mini-watersheds. This helps for sustainable development of watershed, based on suitable soil and water conservation measures. In this study watershed prioritization based on analysis of morphometric parameters derived from Indian Remote Sensing Satellite (IRS) CARTOSAT-1 DEM-10 m data and LISS-IV data was carried out in the Viswamitre watershed in Vadodara and Panchmahals districts of Gujarat State. The GIS based approach facilitates analysis of different morphometric parameters and to explore the relationship between drainage morphometry and properties of

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land forms, soil and eroded lands. The results indicate that the analysis of various morphometric parameters in GIS environment can be effectively used for prioritization of watersheds, soil and water conservation and natural resources management at the watershed level.

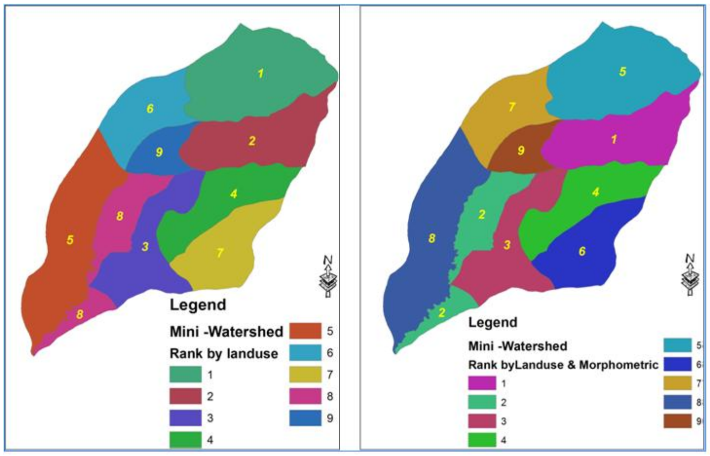

Figure-7: Ranking of mini-watersheds using Land-use and Morphometric Analysis

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Table-3: Results of computation of various Morphometric parameters in Viswamitre Watershed

Mini-Watershed No.	Area Km^2	Perimeter km	Length Km	N	N1	L_b	R_b	D_d	F_u	T	L_0	R_f	B_s	R_e	C_c	R_c	Agri %	Wasteland %	Forest %
1	142.23	59.22	181.08	208	110	21.92	2.39	1.27	1.46	3.51	0.73	0.30	3.38	0.61	1.40	0.51	36.77	12.64	0.00
2	111.17	48.34	85.46	79	46	19.06	3.07	0.77	0.71	1.63	0.36	0.31	3.27	0.62	1.29	0.60	32.15	10.44	0.00
3	49.63	35.43	64.22	71	39	12.05	2.79	1.29	1.43	2.00	0.72	0.34	2.93	0.66	1.41	0.50	53.54	12.16	0.00
4	151.04	61.81	149.02	177	97	22.68	2.31	0.99	1.17	2.86	0.59	0.29	3.41	0.61	1.41	0.50	34.93	13.77	5.14
5	102.47	48.87	90.20	95	51	18.20	5.67	0.88	0.93	1.94	0.46	0.31	3.23	0.63	1.36	0.54	37.21	13.45	0.00
6	215.68	61.71	197.37	193	109	27.77	1.76	0.92	0.89	3.13	0.45	0.28	3.57	0.60	1.18	0.71	30.51	10.53	3.40
7	44.82	55.58	23.93	55	48	11.38	9.60	0.53	1.23	0.99	0.61	0.35	2.89	0.66	2.33	0.18	7.36	8.55	0.00
8	209.18	96.90	76.38	188	148	27.29	4.48	0.37	0.90	1.94	0.45	0.28	3.56	0.60	1.88	0.28	12.59	3.47	0.00
9	158.77	90.99	176.15	415	328	23.33	5.38	1.11	2.61	4.56	1.31	0.29	3.43	0.61	2.03	0.24	24.96	9.84	0.00

Table-4: Computation of Compound Factor and Prioritized Ranks

Mini-Watershed No	R_b	D_d	F_u	T	L_o	R_f	B_s	R_e	C_c	R_c	Agri. %	Waste-land %	Forest %	Compound Factor	Prioritized Rank
1	7	2	2	2	2	5	5	5	4	6	3	7		3.8	2
2	5	9	9	8	9	6	4	6	2	8	5	4		5.8	9
3	6	3	3	5	3	8	2	8	5	5	1	6		4.2	3
4	8	5	5	4	5	4	6	4	6	4	4	9	2	5.1	7
5	2	6	6	6	6	7	3	7	3	7	2	8		4.8	6
6	9	8	8	3	8	1	9	1	1	9	6	5	1	5.3	8
7	1	4	4	9	4	9	1	9	9	1	9	2		4.8	4
8	4	7	7	7	7	2	8	2	7	3	8	1		4.8	5
9	3	1	1	1	1	3	7	3	8	2	7	3		3.1	1

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