ISSN (online): 2349-784X

Morphometric Analysis And Prioritization of Sub-Watersheds of Barna Watersheds, Raisen District, Madhya Pradesh, India using Remote Sensing and GIS Techniques

D. K. Umak
M. P. Council of Science and Technology, Bhopal

Dr. V. L. Punwatkar
Govt, MVM, Bhopal

Dr. V.K. Parasher
Govt. Holkar Science College, Indore

Abstract

In this study, Morphometric analysis and prioritization of the five sub-watersheds of Barna watersheds located in Raisen district of Madhya Pradesh, India is carried out using remote sensing and GIS techniques. The Morphometric parameters considered for analysis are Stream length, bifurcation ratio, drainage density, stream frequency, and texture ratio, Length of overland flow, form factor, circulatory ratio, elongation ratio, and compactness ratio. The Barna watershed has little Parallel & Radial drainage pattern but mainly dendritic drainage pattern. The maximum value of bifurcation ratio is 3.000 for the sub-watershed No. 5D4A2b. The bifurcation ratio among all the sub-watersheds is ranging between 1.795 to 3.000, which indicates Lower R_b values are the characteristics of structurally less disturbed watershed without any distortion in drainage pattern. The sub-watershed No. 5D4A2b has the maximum value of circulatory ratio 0.4108, maximum value of elongation ratio 0.6257 and maximum value of form factor 0.3073. The form factor values are in range of 0.2662 to 0.3073 which indicates 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. The compound parameters values are calculated and prioritization ranks for all five sub-watersheds is carried out. The sub-watershed with the lowest compound factor is given the highest priority. The sub-watershed No. 5D4A2b has a minimum compound factor of 2.4 is likely to be subjected to maximum soil erosion, hence it should provided with immediate soil conservation measures.
Keywords: Morphometric, Remote sensing, GIS, prioritization

I. INTRODUCTION

"A watershed can be defined as an Independent unit it is a drainage basin or catchments area of a particular stream or river at any particular point".

A watershed, also called a drainage basin or catchment area, is defined as an area in which all water flowing into it goes to a common outlet. People and livestock are the integral part of watershed and their activities affect the productive status of watersheds and vice versa. From the hydrological point of view, the different phases of hydrological cycle in a watershed are dependent on the various natural features and human activities. Watershed is not simply the hydrological unit but also socio- political-ecological entity which plays crucial role in determining food, social, and economical security and provides life support services to rural people (Wani et al.2008). Hence watershed is an ideal unit for management and sustainable development of its natural resources..

Due to rain and wind action our land is subjected to soil erosion and degradation which ultimately results in change in river morphology, reservoir sedimentation and reduction in storage capacity ,poor crop yield , floods and more. Integrated use of remote sensing and GIS techniques can be used in soil erosion assessment and watershed prioritization studies. The input parameters required for soil erosion modeling can be generated by remote sensing (for example, land use map of a watershed).Geographical information system helps in creation of a database for the watershed which is very much useful for carrying out spatial analysis thereby helping the decision maker in framing appropriate measures for critically affected areas.

Morphometric analysis is a significant tool for prioritization of sub-watersheds even without considering the soil map (Biswas et al., 1999). Morphometric analysis require measurement of the linear feature, gradient of a channel network, and contouring ground slopes of the drainage basin .Many works have been reported on the Morphometric analysis using remote sensing and GIS techniques . Shrimali et al (2001) presented a case study of the 42 sq. km sukhana lake catchment in the shiwalik hills for the for the delineation and prioritization of soil erosion areas by using remote sensing and GIS techniques. Srinivasa et al. (2004) has used remote sensing and GIS techniques in Morphometric analysis of sub-watersheds of pawagada areas, Tumkur district, Karnataka .Chopra et al. 92005)carried out Morphometric analysis of Bhagra –Phungotri and Hara maja sub-watershed of Gurdaspur district, Punjab . Khan et al. (2001) used remote sensing and GIS techniques for watershed Prioritization in the Guhiya basin, India. Nookaratnam et al. (2005) carried out study on check dam positioning by prioritization of micro-watersheds using the sediment yield index (SYI) model and Morphometric analysis using remote sensing and GIS. Prioritization of Mohr watershed, lying between Sabarkantha and Kheda district, Gujarat has been carried out by Thakkar and Dhiman (2007). By prioritization of watersheds, one can conclude which watershed can lead higher amount of discharge due to excessive amount of rainfall.

II. STUDY AREA

The study area Barna, watershed is is lying in the central and southern part of the Raisen district and falling in survey of India Toposheets no's 55E/12, 55E/15, 55E/16, 55I/3, 55I/4, 55F/9, 55F/13, and 55J/1.The area lies between the latitude 22^{0} 54' 00" to 23^{0} 18' 00 North and the longitude 77^{0} 43' 00" to 78^{0} 06' 00"East and, covering an area of about 1129 sq. km. The Barna River is a tributary of Narmada River and Barna dam is built across Barna River, which is located 2.5 km .N-W of Barikhurd village of Tehsil Bari district, Raisen. The total number of settlements lying in Barna watershed is 116.

A. *Data and Methodology*

Survey of India Toposheets No's 55E/12, 55E/15, 55E/16, 55I/3, 55I/4, 55F/9, 55F/13, and 55J/1 were used for delineating watershed boundary of Barna watershed and Indian Remote Sensing LISS III-P6 digital Satellite data of the year 2009-2010 for three seasons (January, April and October) were used for preparing thematic maps using Arc GIS 9.3 & 10.1 Software. Thematic maps like Drainage (Map no.1) and water bodies (Map no.2) are prepared by using survey of India toposheets & updated with the satellite data of IRS P6 LISS-III data of January, April and October 2005 &2006.

All India soil and Land use survey, Govt. of India New Delhi has published a watershed Atlas of India on 1:1 million scale, have and demarcated the whole country into following hydrologic unit at different stages.

- Water Resource Regions - 6
- Basins - 35
- Catchments - 112
- Sub Catchment - 500
- Watershed - 3237

The watershed map of Barna watershed is prepared by using above mentioned, All India soil and Land use survey watershed Atlas. According to watershed Atlas, The Barna watersheds are falling in Region 5 and in Basin D i. e. Narmada Basin. The Narmada Basin has total 6 catchments, 18 sub-catchments and 129 watersheds. Thus the Barna watersheds is falling in Region 5 and in Basin D i. e. Narmada Basin in catchments No 4, i.e. Tawa confluence to Marble rock RB Narmada, sub catchments A i. e. Tawa confluence to Hiren RB –Narmada, and in watershed No's 2 & 3. Thus the study area Barna is falling in watershed No's 5D4A2 and 5D4A3 as shown in (map no 3) & Barna watershed No's 5D4A2 and 5D4A3 with Barna Reservoir and drainage has shown in (map no 5). The watershed no 5D4A2 is again divided in to two sub-watersheds i.e. 5D4A2a and 5D4A2b & the watershed no 5D4A3 is also divided into three sub-watershed i.e. 5D4A3a, 5D4A3b & 5D4A3c. All these five sub-watersheds 5D4A2a, 5D4A2b, 5D4A3a, 5D4A3b & 5D4A3c of Barna have shown in (map no 4). All the five Sub –watersheds 5D4A2a, 5D4A2b, 5D4A3a, 5D4A3b & 5D4A3c of Barna with Drainage & Barna Reservoir has shown in (map no 6).

B. *Morphometric Analysis and Prioritization*

1) *Basic Parameters*

a) Area (A) and perimeter (P)

The drainage area (A) is the single most important watershed characteristics for hydrologic design and reflect the volume of water that can be generated from rain fall. Present result shows that sub-watershed no 5D4A3b covers the maximum area of 310.054 km^2, while watershed no 5D4A2b has minimum area of 107.826 km^2. The basin perimeter (p) can be represented as length of the line that defines the surface divide of the basin. Perimeters of sub- watersheds are shown in Table No 3; maximum and minimum values in sub-watershed no's are same as the area parameter.

b) Total length of streams (L)

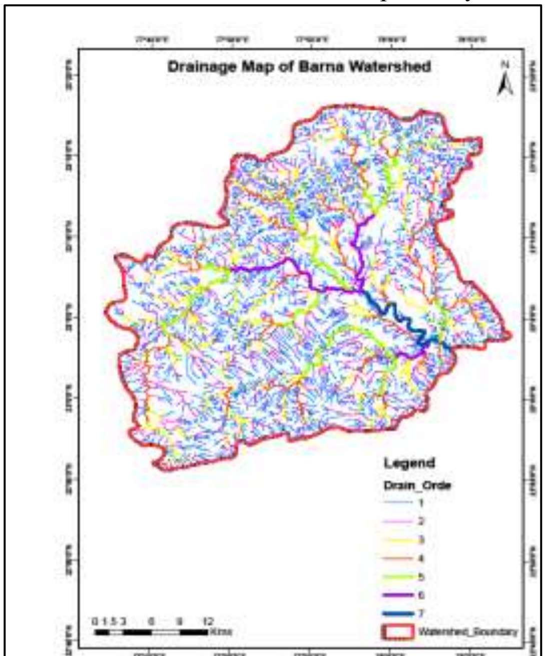
Addition of the length of all streams, in a particular order, defines total stream length. The numbers of streams of various orders in a sub-watershed were counted and their length measured, Shown in Table no. 3. These results help us to find drainage density. The number of streams of various orders in a sub-watershed is counted and their length is measured from head to mouth with the help of GIS software. The stream length (L) has been calculated using Horton's Law (1945) for all the sub-watersheds. The total length of stream segment is maximum in the first order and it decreases as the stream order increases. Sub-watershed namely, 5D4A2a, 5D4A2b, 5D4A3a 5D4A3b, and 5D4A3c in Table no 3 showing the length of streams, in a particular order. The sub-watershed no. 5D4A3b showing the maximum total stream length 637.075 km., While sub-watershed no. 5D4A2b, showing the minimum total stream length 269.807 km.

c) Stream Order (u)

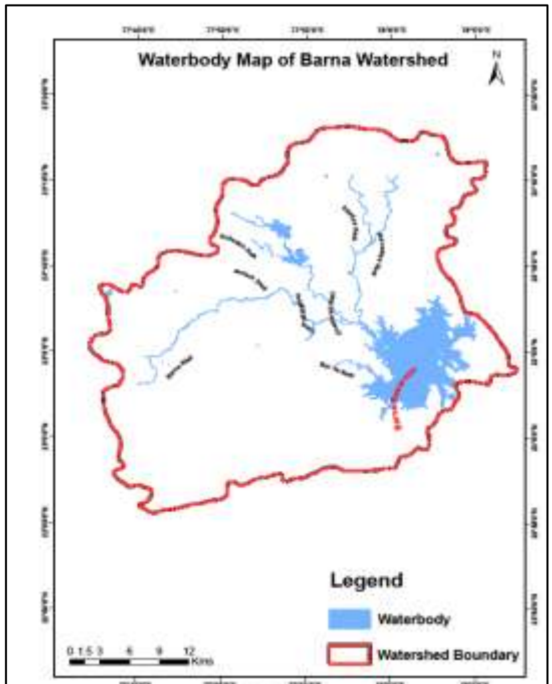
The concept of stream order was introduced by Horton (1945) and Strahlar (1964) to describe the basin in quantitative terms. This concept is applied with the linear dimension of the stream length. The first order stream has no tributary and its flow depends entirely on the surface overland flow to it. Likewise the second- order stream is formed by the junction of two first -order stream and as such has higher surface flow and the third- order stream receives flows from two second - order streams. This supplemented the study of stream order of the watershed. The sub-watershed no 5D4A3b having stream no, 1090 out of which 533 are having stream order I. (Table no2). In sub-watershed no's 5D4A2b & 5D4A3c none is having stream order VII (shown in Table no 2).

d) Basin Length (L_b)

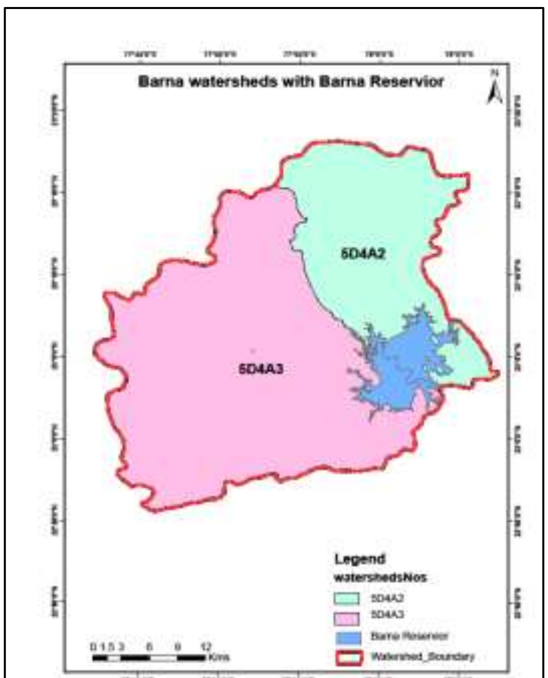
The basin length (L_b) is one of the watershed characteristics of interest and is important in hydrologic computations and increases as the drainages increases and vice versa. Basin length is usually defined as the distance measured along the main channel from the watershed outlet to the basin divide. 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 principal flow path. Basin length is the basic input parameter to count the major shape parameters. In the result, basin length varies between 18.729 km and 34.124 km. For sub-watershed no's 5D4A2b and 5D4A3b respectively, showed in Table no 3..



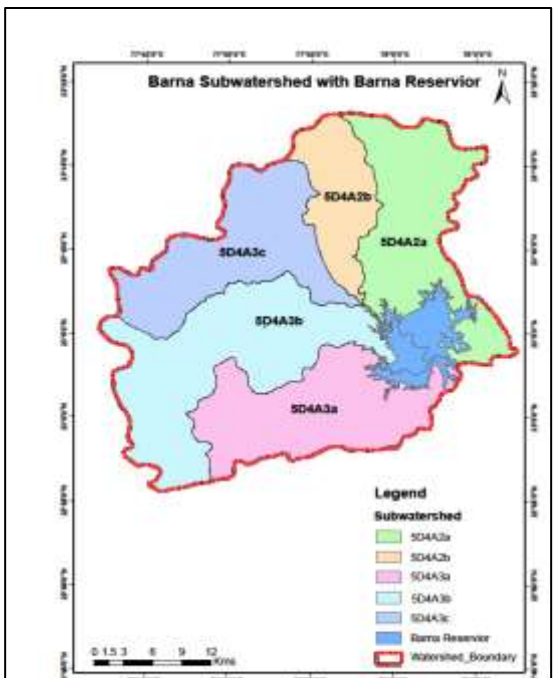
Map No 1



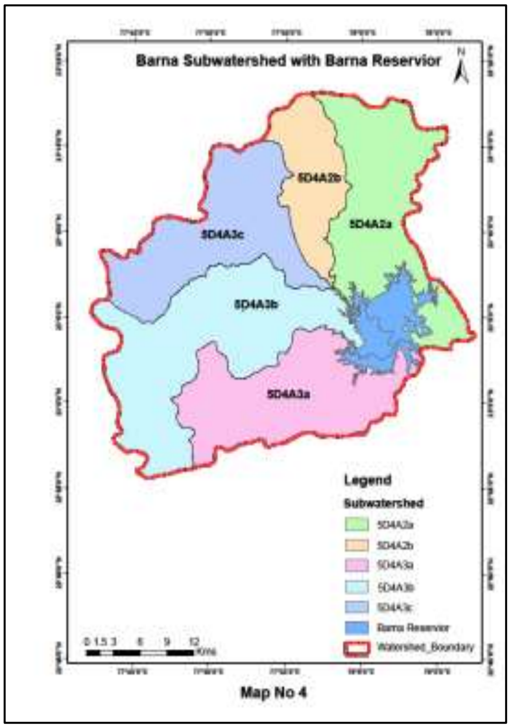
Map No 2

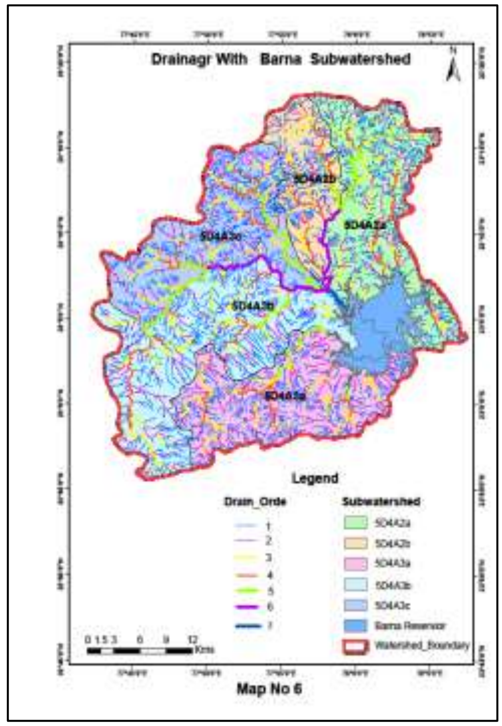


Map No 3



Map No 4





C. *Linear Parameters;*

1) Bifurcation Ration (R_b)

It is ratio of the number of streams of a given order to the number of streams of the next higher order (Schumn1956).Lower R_b values are the characteristics of structurally less disturbed watershed without any distortion in drainage pattern (Nag 1998). Table no 4 shows that bifurcation ratios (R_b) of sub-watershed no, 5D4A3c has the least bifurcation ratio of 1.795 and sub-watershed no 5D4A2b has maximum bifurcation ratio of 3.000.

2) Drainage Density (D_d)

It is the ratio of the total length of streams with in a watershed to the total area of the watershed; thus D_d has units of the reciprocal of length (I/L). A high value of drainage density would indicate a relatively high density of stream s and thus a rapid storm response, values of D_d are shown in Table no 4. It is defined as the length of drainage per unit area. It is an inverse function of permeability and therefore is an important factor in run off studies. The term was first introduced by Horton (1932) and is determined by dividing the total length of streams with in drainage basin by the drainage area. A high drainage density reflects a highly dissected drainage basin with a relatively rapid hydrologic response to rainfall events, while a low drainage density means a poorly drained basin with a slow hydrologic response (Melton 1957; Gupta and Srivastava 2010). The drainage density can be defined as (Edet et al. 1998):

Table - 1
Formula for computation of Morphometric Parameters

	Morphometric Parameters	*Formula/Definition*	*Reference*
BASIC	*Area of the Basin*	*A = Area of the Basin in* km^2	*Nookaratnam et al (2005)*
	Perimeter of Basin	*P = Perimeter in km*	*Nookaratnam et al (2005)*
LINEAR	*Total No. of Streams*	*N = No. of Streams*	*Nookaratnam et al (2005)*
	Total No. of first order Stream	N_1 = *Total no. of first order streams.*	
	Stream order (u)	*Hierarchical order*	*Strahler,1964*
	Basin Length (L_b)	$L_b = 1.312 * A^{0.568}$ *Where,* L_b *=Length of Basin (km)* *A= Area of Basin* (km^2)	*Nookaratnam et al (2005)*
	Stream Length (L)	*Length of the stream*	*Horton, 1945*
	Bifurcation Ratio (R_b)	$R_b = Nu / Nu+1$. *Where,* *Where,* R_b *= Bifurcation Ratio* *Nu =Total Number of stream segment of order u.* *Nu+1 = Number of segments of the next higher order*	*Schuman ,1956*
	Mean Bifurcation ratio (R_{bm})	R_{bm} *=Average of bifurcation ratio of all orders*	*Strahler,1964*

AERIAL (SHAPE)	*Drainage density (D_d)*	$D_d = L_u/A$ Where, Where, D_d = Drainage density Lu = Total stream length of all order A = Area of the basin (km^2)	*Horton, 1945*
	Stream frequency (F_u)	$F_u = N_u/A$ Where, Where, N_u = Total number of stream of all order. A = Area of basin (km^2)	*Hortan, 1945*
	Texture ratio (T)	$T = N_u/P$ Where, N_u = Total number of streams of all order P = Perimeter of basin (km)	*Horton , 1945*
	Length of overland flow (L_O)	$L_O = ½ D_d$ Where, L_O = Length of over land flow. D = Drainage density	
	Form factor (R_f)	$R_f = A/L_b^2$ Where, R_f = Form factor A = Area of basin (km^2) L_b^2 = Square of the Basin length	*Horton, 1945*
	Shape factor (B_S)	Where , $B_S = L_b^2/A$, B_S = Shape factor A = Area of basin (km^2), L_b^2 = Square of the Basin length	*Nookaratnam et al (2005)*
	Elongation ratio (R_e)	$R_e = (2/L_b) \times (A/\pi)^{0.5}$ Where , R_e = Elongation ratio L_b = Length of basin (km) A = Area of basin $(km)^2$	*Schumn,1956*
	Compactness Constant(C_c)	$C_c = 0.2821\ P/A^{0.5}$ where, C_c = Compactness Ratio A = Area of basin$(km)^2$ P = Perimeter of the basin(km)	*Horton, 1945*
	Circulatory ratio (R_c)	Where, R_c = Circulatory ratio $R_c = 4\pi A/P^{2}$, A = Area of basin , π=3.14, P = Perimeter of basin. (km)	*Miller,1953*

The drainage density indicated that out of five sub- watersheds four sub- watersheds 5D4A2b, 5D4A3c, 5D4A3a, & 5D4A3b are under moderate drainage density category with an average value of 2-4 (km/km^2), except one sub-watershed no.5D4A2a was found under low drainage density category (o-2 km/km^2). This analysis suggested that the most of the sub-watersheds showed moderately drained basin with a moderate hydrologic response. The one sub- watershed was found to be associated with low drainage density reflects a low dissected drainage basin with a relatively slow hydrologic response to rainfall events.

3) 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 run-off value and increases in stream population with respect to drainage density .The value of stream frequency ranges from 3.515 to 4.732 for sub-watershed no's 5D4A3b and 5D4A3c respectively, as shown in table no 4.

4) Texture Ratio (T)

The texture ratio can be defined as the ratio of total no o0f streams of first order to the perimeter of the basin. The values texture ratio ranges from 4.025 to 6.400. These values of run -off show the high run-off, as shown in table no 4.

5) Length of Overland flow (L_o)

It is the length of water over the ground before it gets concentrated into definite stream channel is and is equal to half of drainage density (Horton, 1945). Length of overland flows relates inversely to the average channel slopes. The values of overland flows range from 0.975 to 1.251, as shown in table no 4.

D. Shape Parameters

Shape parameters include form factor, shape factor, elongation ratio, and Circulatory ratio.

1) 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 (Hortan, 1945). The value of form factor would always be less than 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 factor have peak flow of shorter duration , whereas , elongated mini-watershed with low form factors have lower peak flow with longer duration. In the present case the value of form factor is varied between 0.2662 for sub-watershed 5D4A3b and 0.3073 for sub- watershed 5D4A2b as Shown in table no 5. This value indicates 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.

2) Shape factor ((B_S)

The Shape factor can be defined as the ratio of the square of the basin length to the area of the basin (Horton, 1945). And is in inverse proportion with form factor (R_f), Shape factor lies between 3.253 to 3.755 in present work, which indicates the elongated shape of basin.

3) Elongation ratio (Re)

Elongation ratio is defined as the ratio between the diameters of the circle of the same area as that of the drainage basin to the maximum length of the basin (schumn, 1956). A Circular basin is more efficient in run-off discharge than an elongated basin.(Singh and Singh 1997).The value of elongation ratio is varied between 0.6 and 1.0 are the typical region 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 the elongation ratio indicates that particular mini watershed is more elongated than other. The elongation ratio 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 this study in Table no 5, these values are less than o.7 and hence the basin is elongated in shape.

4) 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 Gravelius Index (GI0). This factor is indirectly related with the elongation of the basin and less erosion, while higher values indicate the less elongation and high erosion. In this study, highest value is 2.120 while the lowest value is 1.559 Shown in table no. 5.

5) Circularity Ratio (R_c)

It is a ratio of basin area (A)of circle having the same circumference as the perimeter as basin (Miller 1953)It is affected by the length and frequency of streams ,geological structure ,land use/land cover ,climate, relief, and slope of the basin .If the circularity in the main basin is minimum ,it shows that the basin is less circular , hence the discharge will be slow as compared to the other and so possibility of erosion will be less . In present study, maximum value is for sub-watershed no. 5D4A2b, which is 0.4108 and minimum value is for sub-watershed no 5D4A3b which is 0.2221 as shown in table no.5.

6) Compounding Factor and Prioritized Ranking

Compound factor is calculated by summing all the ranks of linear parameters as well as shape parameters and then dividing by number of, parameters. From the group of these sub-watersheds highest rank was assigned to the sub- watershed having the lowest compound factor and so on. Depending upon the value of compound factor, Prioritized ranking to each sub- watersheds is assigned as shown in (Map No 7). For the sub- watershed no 5D4A2b is given Prioritized rank 1 with least compound factor 2.4.and is followed by sub-watershed no 5D4A3a is given Prioritized rank 2 with compound factor 2.7, it is followed by sub-watershed no 5D4A3c is given Prioritized rank 3 with compound factor 2.9.The Values of compound factor and Prioritized rank are shown in table no 6. The sub- watershed no 5D4A2b with compound factor 2.4. Receives the highest priority (one) with the next in the priority list is sub-watershed no 5D4A3a with compound factor 2.7. Highest priority indicates the greater degree of erosion in the particular sub-watershed and it becomes potential sub-watershed for applying soil conservative measure .The final prioritized map of the study area is shown in (Map No7). The soil conservation measures can be first be applied to Sub-watershed no 5D4A2b and then to the other Sub-watershed depending upon their priority.

Table – 2
Stream Analysis of Barna Sub-Watersheds

S. No	Sub-watershed No's	Stream order	I	II	III	IV	V	VI	VII	Total
1	5D4A2a	No of Streams	532	281	128	47	17	9	9	1023
		Stream Length	278.544	112.753	53.840	24.662	9.888	11.993	17.607	509.289
2	5D4A2b	No of Streams	276	138	76	45	5	10	0	550
		Stream Length	146.808	52.651	29.504	25.085	3.691	12.066	0	269.807
3	5D4A3a	No of Streams	569	291	114	49	40	9	4	1076
		Stream Length	328.20	119.702	52.215	21.559	19.444	5.496	3.307	549.925
4	5D4A3b	No of Streams	533	266	149	60	43	32	7	1090
		Stream Length	330.928	136.956	75.760	29.562	23.833	17.648	14.386	637.075
5	5D4A3c	No of Streams	499	258	117	56	56	32	0	1018
		Stream Length	263.123	111.550	58.772	27.008	32.523	17.714	0	519.693

Table - 3
Basic Parameters of Barna Sub-Watersheds

S.No.	Watershed no's	Area (A) Km^2	Perimeter (p) km.	Total length of stream (L, kms.) of all orders	Total streams of all order(N)	No of Ist order streams	Basin Length (Lb) $Lb=1.312*A^{0.568}$
1	5D4A2a	261.104	101.450	509.289	1023	532	30.951
2	5D4A2b	107.826	57.413	269.807	550	276	18.729
3	5D4A3a	235.097	88.893	549.925	1076	569	29.161
4	5D4A3b	310.054	132.395	637.075	1090	533	34.124
5	5D4A3c	215.096	90.962	519.693	1018	499	27.724

Table - 4
Linear Parameters of Barna Sub-Watersheds

S.No.	Sub-watershed No's	Bifurcation Ratio (R_b)	Drainage density (D_d)	Stream frequency (F_u)	Texture ratio (T)	Length of overland flow (L_O)
1	5D4A2a	2.077	1.950	3.917	5.243	0.975
2	5D4A2b	3.000	2.502	5.100	5.474	1.251
3	5D4A3a	2.458	2.339	4.559	6.400	1.169
4	5D4A3b	2.280	2.054	3.515	4.025	1.027
5	5D4A3c	1.795	2.416	4.732	5.485	1.208

Table – 5
Shape Parameters of Barna Sub-Watersheds

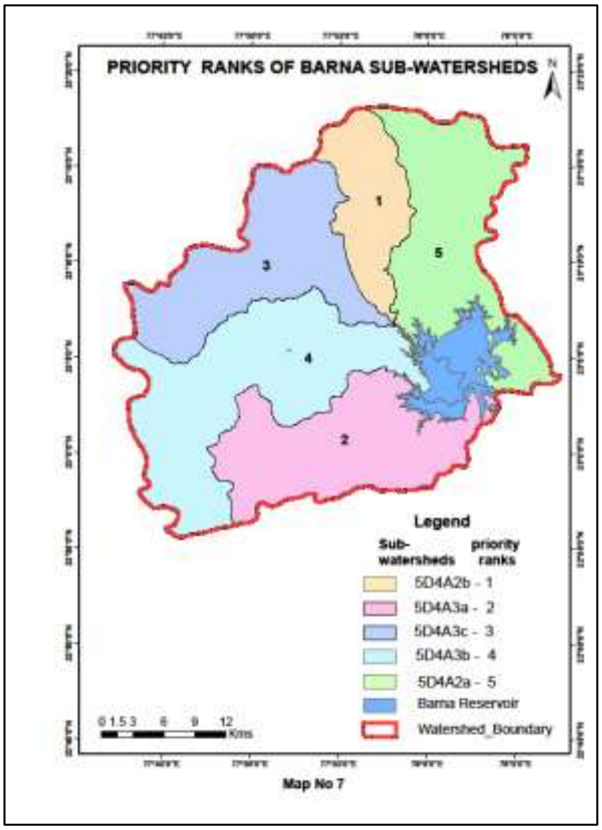
S.No.	Sub-watershed No's	Form factor (R_f)	Shape factor (B_S)	Elongation ratio (R_e)	Compactness Constant(C_c)	Circulatory ratio (R_c)
1	5D4A2a	0.2725	3.668	0.5892	1.770	0.3186
2	5D4A2b	0.3073	3.253	0.6257	1.559	0.4108
3	5D4A3a	0.2764	3.617	0.5934	1.634	0.3736
4	5D4A3b	0.2662	3.755	0.5824	2.120	0.2221
5	5D4A3c	0.2798	3.573	0.5970	1.749	0.3265

III. CONCLUSIONS

The present study demonstrates the usefulness of GIS for Morphometric analysis and prioritization of the sub-watersheds of Barna watersheds of Raisen district of Madhya Pradesh. Further, the remote sensing techniques have been found to be suitable for the preparation of updated drainage map in a timely and cost effective manner and should be preferred in soil erosion studies for deriving input data. Results of Morphometric analysis shows that sub-watershed no. 5D4A2b and 5D4A3a are possibly having high erosion & the control measures are required in these sub-watersheds to preserve the land from further erosion.

Table - 6
Calculation of compound factor and prioritized Ranks

S.No	sub-watershed no's	Linear -factor					Shape - factor					Compound factor	Final prioritize ranks
		Bifurcation Ratio (R_b)	Drainage density (D_d)	Stream frequency (F_u)	Texture ratio (T)	Length of overland flow (L_O)	Form factor (R_f)	Shape factor (B_S)	Elongation ratio (R_e)	Compactness Constant(C_c)	Circulatory ratio (R_c)		
1	5D4A2a	4	5	4	4	5	2	4	2	4	2	3.6	5
2	5D4A2b	1	1	1	3	1	5	1	5	1	5	2.4	1
3	5D4A3a	2	3	3	1	3	3	3	3	2	4	2.7	2
4	5D4A3b	3	4	5	5	4	1	5	1	5	1	3.4	4
5	5D4A3c	5	2	2	2	2	4	2	4	3	3	2.9	3



REFERENCES

[1] Chopra, R, Dhiman, R., & Sharma, P. K. (2005), Morphometric analysis of sub-watersheds in Gurdaspur district, Punjab using remote sensing and GIS Technique. Journal of Indian Society of Remote Sensing. 33(4), 531-539.
[2] Gupta, M & Srivastava, P.K.(2010) , Integrating GIS and Remote Sensing For Identification of ground water potential zones in the hilly terrain of Pavagarh, Gujarat India. Water International, 35,233-245.
[3] Horton, R.E. (1932). Drainage basin characteristic, Transaction American Geophysical Union, 13, 350-361.
[4] Horton, R.E. (1945). Erosional development of streams and their drainage basins; hydro physical approach to Quantitative morphology, Geological society of America bulletin .56, 275-370.
[5] Miller, V. C. (1953). A quantitative geomorphic study of drainage basin characteristic in the clinch mountain area, Virginia and Tennessee, proj. NR. Tech.Rep.3Columbia University, Department of Geology, ONR, New York, pp 389-402.
[6] Nag S. K.(1998) , Morphometric analysis using remote sensing techniques in the Chaka Sub – basin ,Purulia district , West Bengal , Journal of Indian Society of Remote Sensing. 26(1-2),69-76
[7] Nookaratnam, K Srivastava. Y. K. Venkateshswarao. V. Amminedu. E. and Murthy .K.S.R.(2005) check dam positioning by prioritization of micro-watershed using SYI model and Morphometric analysis – Remote sensing and GIS perspective Journal of Indian Society of Remote Sensing. 33(4), 531-539.
[8] Sigh , J.P. Singh, D, & Litoria ,P.K.(20090, Selection of suitable site foe eater harvesting structure in Soankhad watershed Punjab, using Remote Sensing and Geographical Information system (RS and GIS) approach – A case study , Journal of Indian Society of Remote Sensing. 37, 21-35.
[9] Strahlar, A. N. (1964).Quantitative geomorphology of drainage basins and channel networks, section 4-ii. In V.T. chow(Ed).Handbook of Applied Hydrology (PP.04-39)-New York: McGraw-Hill.
[10] Thakkar, A. K. & Dhiman, S. D. (2007). Morphometric analysis and prioritization of mini watershed s in Mohr watersheds, Gujarat using remote sensing and GIS techniques, Journal of Indian Society of Remote Sensing. 33(1); 25-38.
[11] Watershed Atlas of India (on 1: 1 Million Scale), Government of India, Published by The Chief Soil Survey Officer, All India Soil & Land use Survey I.A.R.I. Campus New Delhi on September1990.