Morphometric Analysis for Prioritization of Sub-Watersheds of Jamuna River Watershed, Assam, India Using Remote Sensing and GIS Technique

Himadree Borah* and Dr. Sujit Deka**

** Research Scholar, Department of Geography, Gauhati University, Guwahati, Assam, India*
himadreeborah91@gmail.com

*** Professor, Department of Geography, Bodoland University, Kokrajhar, Assam, India*
sujitdeka@gmail.com

Abstract

Watershed prioritization has gained immense importance in the context of conservation and management of land and water resources for sustainable development. Morphometric analysis helps to decipher watershed and sub-watersheds characteristics such as topography, slope, soil condition, drainage, surface runoff, rainfall and water potential. Therefore, morphometric analysis is commonly applied for prioritizing watersheds and sub-watersheds. The present study makes an attempt to prioritize sub-watersheds based on analysis of morphometric parameters using remote sensing and GIS technique in Jamuna river watershed, Assam. Linear, relief and shape aspects of morphometric parameters have been determined in all the sub-watershed of Jamuna river. The prioritization of sub-watersheds is done by assigning ranks to the individual indicators of each parameters and a Compound value (Cp) is calculated. Watersheds with highest Cp value are determined as having a low priority while those with lowest Cp value have high priority. Based on the morphometric analysis, the sub-watersheds have been categorized into high, medium and low priority zones for conservation and management of land and water resources. Thus, SW1, SW9, SW10, SW13, and SW14 fall in high priority zone, SW3, SW4, SW6 and SW11 under medium priority and SW2, SW5, SW7, SW8 and SW12 in low priority zone.

Keywords*: Jamuna watershed, Morphometric analysis, Prioritization, Resource management, Remote sensing and GIS*

I. INTRODUCTION

Availability of land and water resources is decreasing day by day due to ever increasing biotic pressure. So conservation and management of these resources is of prime importance. In recent years, watershed is considered to be an ideal spatial hydrological unit and efforts are made for conservation and management of resources on watershed basis. The geomorphological characteristics of a watershed are very useful in developing different models to solve various hydrological problems of watershed in the absence of adequate data (Gajbhiye et al., 2014).

Morphometric analysis deal with measurement of linear and shape features, vital for any hydrological investigation like assessment of groundwater potential, conservation of groundwater, basin/sub-basin management and appraisal of environment (Magesh et al., 2012; Sreedevi et al., 2013). Remote Sensing and Geographical Information System (GIS) techniques are used as scientific tool in determining the quantitative description and evaluation of basin geometry.

While considering watershed development, it is very difficult to consider entire watershed. So the bigger watershed area is divided into several smaller sub-watersheds and is prioritized on the basis of their different geomorphological characteristics (Srinivasa et al., 2008). Remote sensing and GIS techniques have been successfully used by many scholars for the prioritization of sub-watersheds (Khan et al., 2001; Srinivasa et al., 2008). Morphometric analysis is used for the prioritization of micro-watersheds even without the availability of soil map (Biswas et al. 1999). Nookaratnam et al. (2005) carried out morphometric analysis for the prioritization of micro-watersheds to identify site for check dams using the sediment yield index (SYI) model with the help of remote sensing and GIS. Many scholars have carried out study on prioritization of sub-watersheds based on morphometric characteristics of the river basin, for watershed management (Suresh et al., 2004; Thakkar & Dhiman, 2007; Patel et al. 2012; Gajbhiye et al., 2014; Chandniha & Kansal, 2017; Choudhari et al., 2018;

ISSN: 2005-4297 IJCA

Malik et al., 2019). Javed et al., 2009 attempted prioritization of sub-watersheds based on morphometric and landuse analysis using Remote Sensing and GIS technique in Kanera watershed of Madhya Pradesh. Kumar et al., 2011 used geomorphology and morphometric characteristics to prioritize the sub-watersheds for identification of surplus and deficit zones of groundwater. Biswas & Chakraborty, 2016 considered morphometric parameters and landuse as basic elements to prioritize the sub-watersheds using Remote Sensing and GIS.

In the present study morphometric analysis and prioritization of sub-watersheds are carried out for 14 sub-watersheds of Jamuna river watershed positioned between Hojai and Karbi Anglong district of Assam state using Remote Sensing and GIS techniques. In view of the above, the present study is carried out with the following objectives: (i) to compute the morphometric parameters of the sub-watersheds of Jamuna river watershed using Remote Sensing and GIS techniques and (ii) to prioritize sub-watersheds by ranking the computed morphometric parameters and (iii) assign priority ranks to sub-watersheds for conservation-and management.

II. STUDY AREA

The Jamuna watershed is located in Hojai and Karbi Anglong district of Assam and it lies between 25°41′ N to 26°27′ N latitude and 92°44′ E to 93°40′ E longitude (Figure 1). The Jamuna river rises in Khumbaman hills of Diphu sub-division (Karbi Anglong) and drains for a distance of about 173 km from its source to its confluence with Kopili river at Jamunamukh (Borah and Deka, 2019). The total area of the watershed is 3903 km^2 of which, 753.6 km^2 (20%) area lies in Hojai district and remaining 3149.4 km^2 area (80%) lies in Karbi Anglong district. The north side of the watershed is bounded by Mikir hills, while Nambor Reserve Forest and Dhansiri Reserve Forest form the eastern and southern boundary of the study area. In the western side of the watershed is Kopili river, a major tributary of the river Brahmaputra. Jamuna river is a major tributary of Kopili river and an important perennial river system of Karbi Anglong (Borah and Deka, 2018). The elevation of the watershed varies from 57 m to 1360 m above mean sea level. The eastern and northern part have steep slope and it becomes gentle towards the western side the watershed.

The Jamuna watershed experiences sub-tropical monsoon climate with some variations due to its geographical location. The watershed is surrounded by plateaus of Karbi Anglong on south and south-east and on the north by the hilly ranges of Mikir hills creating a barrier to the inflow of moisture bearing winds which create the area as rain shadow zone. The average annual rainfall in the watershed is 1224 mm. Major part of the watershed is hilly, only a small portion of the south-western part of the area has alluvial plain. About 48% of the study area is covered with forest.

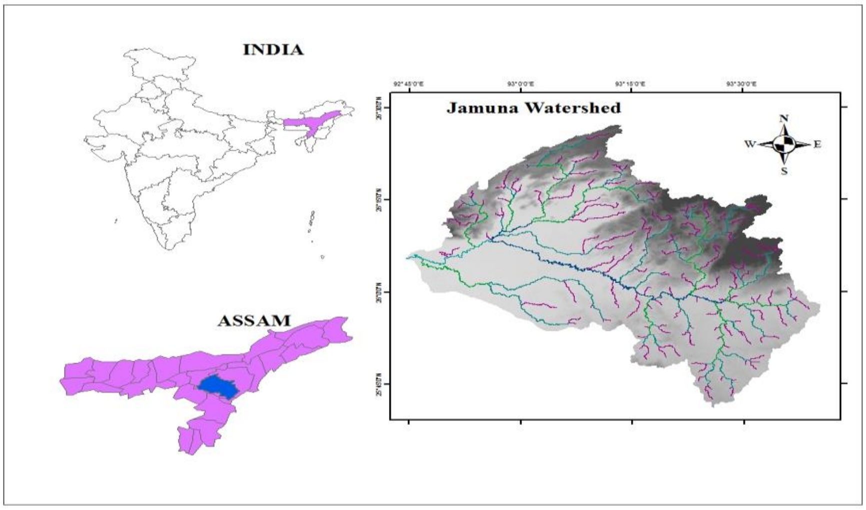

Figure 1 Locational Map of Jamuna Watershed Assam State

III. DATA USED

Survey of India (SOI) toposheets ((83B/12, 83B/15, 83B/16, 83C/13, 83F/3, 83F/4, 83F/7, 83F/8, 83F/11, 83F/12, 83G/1, 83G/5, 83G/6, 83G/9) of 1:50,000 scale are collected and geo-referenced using ArcGIS Ver.10.2. LANDSAT OLI (Operational Land Imager) images having path and row 136:42 and 135:42 of 29 November,2018 are downloaded from *(https://earthexplorer.usgs.gov/)*. In this study ASTER GDEM data of 30m resolution is downloaded and used (*https://earthexplorer.usgs.gov/)*. Besides, ground truth data is also used as one of the important inputs in the analysis.

IV. METHODOLOGY

The watershed boundary is automatically extracted from ASTER GDEM with the help of geo-processing technique available in ArcGIS Ver.10.2 software. It is further rectified using Survey of India toposheets by following the water divide line of the streams. The entire drainage segments are digitized separately as lines for each stream order from toposheets and satellite images following Strahler's method of stream ordering (Strahler, 1964). The sub-watersheds boundaries are demarcated on the basis of contour value, slope and flow direction. The entire watershed is divided into fourteen sub-watersheds (Figure 2). The area, perimeter and basin length of each sub-watershed, number of streams in each order, length of the streams are directly computed from the vector layer in ArcGIS. The other morphometric parameters such as bifurcation ratio, stream length ratio, drainage density, stream frequency, drainage texture, length of overland flow, constant of channel maintenance, form factor, circulatory ratio, elongation ratio, and compactness coefficient are computed by the formulae as suggested (Table 1). Prioritization rating of sub-watersheds of Jamuna river is carried out by ranking the computed morphological parameters.

Table 1 Formulae adopted for Calculation of various Morphometric Parameters

Sl no	Morphometric Parameters	Formulae	References
		Linear Aspects	
1	Stream order (μ)	Hierarchical order	Strahler(1964)
2	Stream length (Lμ)	Length of the stream	Horton (1945)
3	Stream length ratio (R_L)	$R_L=\bar{L}_{\mu}/\bar{L}_{\mu-1}$ (Average stream length of any order to the average stream length of the next lower order)	Horton (1945)
4	Bifurcation ratio(R_b)	$R_b=N_{\mu}/N_{\mu+1}$ (Total no of stream segment of a given order to the no of stream segments of next higher order)	Horton (1945)
		Areal Aspects	
5	Drainage density(Dd)	$Dd=L_{\mu}/A$ Where L_{μ}=total stream length of all orders, A= area of the watershed	Horton (1945)
6	Stream frequency (Fs)	$Fs=N_{\mu}/A$ Where N_{μ}= total no of streams of all orders, A=area of watershed	Horton (1945)
7	Drainage texture (Dt)	$Dt= N\mu/P$ Where Nμ=total no of streams of all orders, P= perimeter of the watershed	Horton (1945)

ISSN: 2005-4297 IJCA

8	Form factor (Rf)	$Rf=A/Lb^2$ Where A=area of watershed, Lb=length of watershed	Horton (1932)
9	Elongation ratio(R_e)	R_e=(2√A/л)/Lb Where A=area of watershed, л=3.41, L_b=length of watershed	Schumm (1956)
10	Circularity ratio (R_c)	R_c=4лA/P^2 Where A=area of watershed, л=3.41, P=perimeter of watershed	Miller (1953)
11	Length of overland flow (L_g)	L_g= ½ Dd	Horton (1945)
12	Compactness coefficient (Cc)	$0.2821 \times P/A^{0.5}$	Horton (1945)
13	Basin shape	Lb^2/A Where Lb = basin length	Horton (1945)

V. RESULTS AND DISCUSSION

Bifurcation ratio (Rb)

According to Schumm 1956, bifurcation ratio is related to the branching pattern of a drainage network. It is defined as the ratio of the number of streams of any given order to the number of streams in the next higher order in a drainage basin (Schumm, 1956). Bifurcation ratio shows a small range of variation in different regions or different environments except, where the geological control dominates (Strahler, 1957). The values of Rb vary from 3.08 -5.13 for the sub-watersheds (Table 2). It is noted that the Rb values fluctuates from one order to the next order. These fluctuations occur may be due to the geological and lithological variations of the river basin (Strahler, 1964). The higher value of Rb indicates a strong structural control in the drainage pattern whereas, the lower value indicates that the sub-basin is less affected by the structural disturbances (Strahler, 1964).

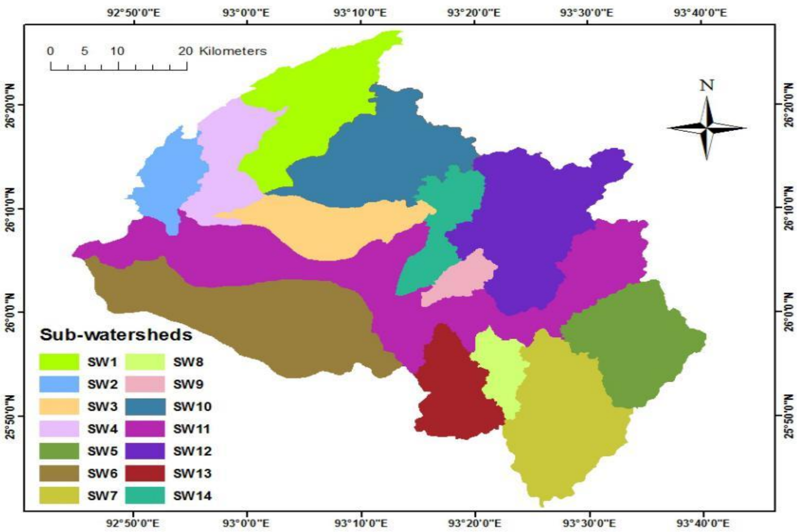

Figure 2 Sub-Watersheds of Jamuna Watershed

ISSN: 2005-4297 IJCA

Drainage density (Dd)

Drainage density (Dd) is defined as the ratio of the total length of stream of all orders in a watershed to the total area of the watershed (Horton, 1945). It is governed by various factors like climate, resistance to weathering, slope, vegetation cover, soil texture, and runoff intensity (Vittala et al., 2004). It helps in determining the physical properties of the underlying rocks in the watershed (Borah and Deka, 2020). Low drainage density is an indicator of highly resistant and permeable regions with dense vegetation cover and low relief; whereas higher drainage density indicates regions with weak and impermeable subsurface material, sparse vegetation and high relief (Nag, 1998). The drainage density in sub-watersheds of the study area shows a variation from 1.04 to 3.81km/km^2 in SW2 and SW10 respectively (Table 2).

Stream frequency (Fs)

Stream frequency (Fs) is defined as the number of streams per unit area (Horton, 1945). It depends upon the basin lithology and indicates the texture of the drainage network (Magesh et al., 2011). Low stream frequency indicates the presence of a permeable subsurface material and low relief. The stream frequency in the sub-watershed of the study area vary from 1.05 (SW2) to 6.64 (SW9) (Table 7). It is observed that the stream frequency values for the sub-watersheds exhibit a positive correlation with drainage density values of the area indicating that there is an increase in number of streams with increasing drainage density.

Table 2 Sub-Watershed wise Morphometric Parameters

Sub-watersheds	Area (km^2)	Perimeter (km)	Nu	Rb	Dd	Fs	Dt	Lg	Rf	Re	Rc	Cc	Bs
SW1	308.3	112.20	6	4.19	3.44	5.07	13.93	1.72	0.26	0.58	0.31	1.80	3.79
SW2	507.3	123.69	6	3.45	1.04	1.07	4.42	0.52	0.20	0.50	0.42	1.55	4.99
SW3	280	79.14	6	4.08	3.28	5.05	17.87	1.64	0.50	0.80	0.56	1.33	1.97
SW4	355.3	97.19	6	4.4	3.29	5.51	20.14	1.65	0.35	0.67	0.47	1.45	2.84
SW5	175.9	86.15	7	2.93	2.45	2.91	5.94	1.23	0.31	0.63	0.30	1.83	3.21
SW6	171.5	69.57	6	3.80	3.40	5.59	13.79	1.7	0.38	0.70	0.45	1.50	2.60
SW7	739.6	302.7	8	3.48	2.08	2.74	6.70	1.04	0.10	0.36	0.11	3.14	9.65
SW8	347.4	116.87	6	4.06	2.44	3.85	11.46	1.22	0.32	0.64	0.32	1.77	3.05
SW9	119.8	63.13	6	3.77	3.66	6.64	12.60	1.83	0.30	0.63	0.38	1.63	3.22
SW10	429.5	128.07	6	4.65	3.81	6.51	21.86	1.90	0.37	0.69	0.33	1.74	2.68
SW11	53.85	37.87	5	3.86	3.36	4.98	7.07	1.68	0.29	0.61	0.47	1.45	3.40
SW12	202.1	80.6	5	4.33	1.33	1.67	4.20	0.66	0.18	0.48	0.39	1.60	5.35
SW13	135.6	82.55	5	5.13	3.62	6.17	10.14	1.81	0.21	0.52	0.25	1.99	4.68
SW14	78.19	51.88	5	4.32	3.47	5.89	8.88	1.73	0.26	0.58	0.36	1.65	3.80

Drainage texture (Dt)

Horton (1945) defined drainage texture as the total number of stream segments of all order in a basin per perimeter of the basin (Table 1). A number of factors such as climate, rainfall, vegetation, lithology, slope, infiltration capacity and stage of development have a great influence on drainage texture of a basin (Smith, 1950). Smith (1950) classified drainage texture into five different textures, i.e., very coarse (<2), coarse (2 to4), moderate (4 to 6), fine (6 to 8) and very fine (>8). The values of drainage texture of all the sub-watersheds are presented in Table 2. It varies from 4.20 (in SW12) to

21.86 (in SW10). The value of Dt suggest moderate to very fine drainage texture in all the sub-watersheds of the study area.

Length of overland flow (Lg)

According to Horton (1945), the length of overland flow is the length of water over the ground before it gets concentrated into specific stream channels. It inversely relates to the average slope of the channel and is entirely synonymous with the length of sheet flow to a significant degree (Horton 1945). It significantly affects the quantity of water required to exceed a certain threshold of erosion. The value of Lg varies from 0.52 in SW2 to 1.90 in SW10 (Table 2).

Form factor (Rf)

Horton (1932) defined form factor as the ratio of the basin area to the square of the basin length. The value of form factor should always be less than 0.78 (the value for a perfectly circular Basin) (Nag, 1998)

. Smaller the value of form factor, more elongated will be the basin. High-form factor value of watershed indicates higher peak flows of shorter duration, whereas elongated watersheds with low-form factors experience similar peak flows of longer duration (Biswas et al. 1999). Lower form factor value of the sub-watersheds of Jamuna river indicate elongated shape except SW3 having Rf value 0.5 indicates the sub-circular shape of the basin (Table 2).

Elongation ratio (Re)

According to Schumm (1956), the elongation ratio is the ratio of diameter of the circle of the same area as the drainage basin and the maximum length of the basin (Table 1). The 'Re' values generally vary from 0.6 to1.0 over a wide variety of climate and geology. The Re value close to 1.0 indicates very low basin relief, whereas the value which ranges between 0.6 and 0.8 is associated with high relief and steep slope (Strahler 1964). The Re values of all the sub-watersheds range from 0.36– 0.80 (Table 2).

Circularity ratio (Rc)

Miller, 1953 defined 'Circularity ratio' 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 circularity ratio is mainly influenced by the length and frequency of streams, geological structures, land use/land cover, climate, relief and slope of the basin (Vittala et al., 2004). The values of circularity ratio vary from 0 (in line) to 1 (in a circle). The Circulatory ratio for all sub-watersheds is in the range of 0.11 to 0.56 (Table 2), which reveals the elongated shape of the basin.

Compactness coefficient (Cc)

Compactness coefficient is the ratio of perimeter of watershed to circumference of equivalent circular area of the watershed (Horton 1945). It is the shape parameter of a watershed and is used to express the relationship between actual hydrologic basins to the exact circular basin having the same area as that of hydrologic basin (Javed et al., 2009). The values of Cc in the study area vary from 1.33 (SW3) to 3.14 (SW7) (Table 2).

Basin shape (Bs)

The basin shape can be defined as the ratio of the square of the basin length to area of the basin (Horton 1945). The values of basin shape in the Jamuna watershed vary from 1.97 to 9.65.

Prioritization of sub-watersheds

Morphometric analysis of drainage basin is very important for prioritization of sub-watersheds as it gives an idea about basin characteristics in terms of slope, topography, soil condition, runoff characteristics, surface and ground water potential. The linear basin parameters such as bifurcation ratio, drainage density, stream frequency, drainage texture, length of overland flow have a positive relationship with erodibility i.e. greater the value, more is the erodibility; whereas, shape parameters such as elongation ratio, compactness coefficient, circularity ratio, basin shape and form factor have an inverse relationship with erodibility i.e. lower the value more is the erodibility (Nookaratnam et al., 2005). Hence ranking of each sub-watershed is carried out depending on the values of different morphometric parameters. The highest value of linear parameters is given a rating of rank 1, second highest value is rated as rank 2 and so on, and the least value is rated last in rank. On the other hand, the lowest value of shape parameter is given a rating of 1, the next lowest value is given a rating of 2 and so on, as these parameters show negative correlation with soil erosion (Biswas et al. 1999; Nooka Ratnam 2005; Thakkar and Dhiman 2007). Thus, the ranking of the sub-watersheds has been determined by assigning the highest rank based on highest value in case of linear parameters and lowest value in case of shape parameters (Table 3). After the rating has been done based on every single parameter for all linear and shape parameters of each sub-watershed, the rating values are averaged to arrive at a compound value (Cp) (Biswas et al. 1999; Nooka Ratnam 2005). The sub-watershed having the least Cp value is given the highest priority while the sub-watershed with the highest Cp value is assigned the last priority (Javed et al., 2009). The sub-watershed 10 with a Cp value of 4.5 get the highest priority followed by SW13 and SW10 having Cp values 5.1 and 5.7 respectively (Table 3). The sub-watersheds are then categorized into three classes of priority zones viz. high (4.5-6), medium (6.1-7.6) and low (> 7.6) priority on the basis of the range of Cp values. Thus, SW10, SW13, SW14 and SW1 fall in the high priority, SW23, SW4, SW6 and SW11 fall in medium priority and SW2, SW5, SW7, SW8 and SW12 in the low priority category (Table 3). The highest priority indicates the greater degree of erosion in the particular sub-watershed which needs immediate conservation measures to be taken. The final prioritized map of the study area is shown in Figure 3.

Table 3 Prioritization of Sub-Watersheds based on Morphometric Parameters

Sub-watersheds	Rb	Dd	Fs	Dt	Lg	Rf	Re	Rc	Cc	Bs	Cp value	Priority	Priority category
SW1	6	5	7	4	5	5	5	4	10	9	6	4	high
SW2	13	14	14	13	14	3	3	10	4	12	10	12	low
SW3	7	9	8	3	9	13	12	13	1	1	7.6	7	medium
SW4	3	8	6	2	8	10	9	12	2	4	6.4	5	medium
SW5	14	10	11	12	10	8	7	3	11	6	9.2	11	low
SW6	10	6	5	5	6	12	11	11	3	2	7.1	6	medium
SW7	12	12	12	11	12	1	1	1	13	14	8.9	10	low
SW8	8	11	10	7	11	9	8	5	9	5	8.3	8	low
SW9	11	2	1	6	2	7	7	8	6	7	5.7	3	high
SW10	2	1	2	1	1	11	10	6	8	3	4.5	1	high
SW11	9	7	9	10	7	6	6	12	2	8	7.6	7	medium
SW12	4	13	13	14	13	2	2	9	5	13	8.8	9	low
SW13	1	3	3	8	3	4	4	2	12	11	5.1	2	high
SW14	5	4	4	9	4	5	5	7	7	10	6	4	high

VI. CONCLUSION

The present study exhibits the utility of Remote Sensing and GIS techniques in prioritizing sub-watersheds based on morphometric analysis. The quantitative morphometric analysis is carried out in 14 sub-watersheds of Jamuna river watershed using geospatial technique for determining the linear aspects such as stream order, bifurcation ratio, stream length and aerial aspects such as drainage density (Dd), stream frequency (Fs), drainage texture (Dt), form factor (Rf), circulatory ratio (Rc) and elongation ratio (Re). The result of morphometric analysis of different sub-watersheds suggest that sub-watershed 10 with a Compound value (Cp) value of 4.5 get the highest priority followed by

SW13 and SW10 having Compound value (Cp) values 5.1 and 5.7 respectively. It means these sub-watersheds are prone to relatively higher erosion and soil loss. Hence, appropriate soil erosion control measures are required to be taken in these sub-watersheds to prevent the land from further erosion and soil loss.

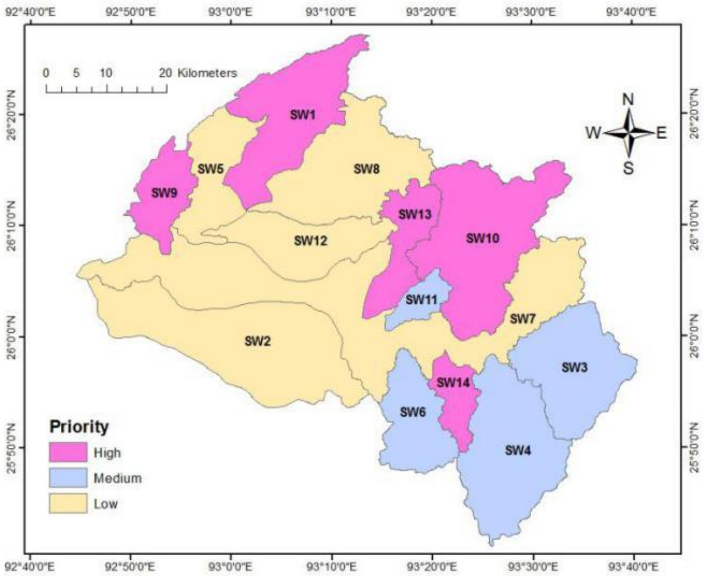

Figure 3 Prioritization map of Jamuna watershed

Acknowledgement

The authors want to thank department of Geography, Gauhati University and department of Geography, Bodoland University for giving permission to submit the paper.

References

1. Biswas R. & Chakraborty S. (2016) Watershed Prioritization Based On Geo-Morphometry And Land Use Parameters - An Approach To Watershed Development Using Remote Sensing And GIS, Neora Watershed, Darjeeling And Jalpaiguri Districts, West Bengal, India. *Journal of Applied Geology and Geophysics*, 4 (3) 36-49 DOI: 10.9790/0990-0403013649
2. Biswas S., Sudhakar S. & Desai V.R. (1999) Prioritisation of subwatersheds based on Morphometric analysis of Drainage basin: A Remote Sensing and GIS approach. *Journal of the Indian Society of Remote Sensing*, 27 (3), 155-166 DOI: 10.1007/BF02991569
3. Borah & Deka(2018) Conjective use of aster dem, landsat (etm plus) satellite data and topographic maps for morphometric analysis of Jamuna watershed, Kopili river, Assam. *The Indian Geographical Journal*, 93 (1), 49-65
4. Borah & Deka (2019) Hypsometric analysis of Jamuna watershed, Assam with application of Geographical Information System. *International Journal of Emerging Technologies and Innovative Research*, 6 (6), 676-684
5. Borah & Deka (2020) Quantitative Geomorphic evaluation of Dimoru watershed, Assam, India: a Geographical Information System Approach. *International Journal of Advanced Science and Technology*, 29 (4) 1874-1885
6. Chandniha S. K. & Kansal M. L. (2017) Prioritization of sub-watersheds based on Morphometric analysis using Geospatial technique in Piperiya watershed, India. *Applied Water Science*, 7: 329–338 DOI 10.1007/s13201-014-0248-9

7. Choudhari P. P., Nigam G. K., Singh S.K. & Thakur S. (2018) Morphometric based prioritization of watershed for Groundwater potential of Mula river basin, Maharashtra, India. *Geology, Ecology, and Landscapes,* 2(4): 256–267 doi.org/10.1080/24749508.2018.1452482
8. Gajbhiye S., Mishra S.K. & Pandey A. (2014) Prioritizing erosion-prone area through Morphometric analysis: an Remote Sensing and GIS perspective. *Applied Water Science,* 4: 51–61 DOI 10.1007/s13201-013-0129-7
9. Horton R.E. (1932) Drainage Basin Characteristics. Trans Amer Geophys Union 13: 350–361
10. Horton R.E. (1945) Erosional Development of Streams and their Drainage Basins: Hydrophysical Approach to Quantitative Morphology. Bull Geo Soc Am 56: 275–370
11. Javed A., Khanday M.Y. & Ahmed R. (2009) Prioritization of Sub-watersheds based on Morphometric and Land Use Analysis using Remote Sensing and GIS Techniques. *Journal of Indian Society Remote Sensing,* 37: 261–274
12. Khan, M. A., Gupta, V. P. & Moharana, P. C. (2001) Watershed prioritization using Remote Sensing and Geographical Information System: A case study from Guhiya, India. *Journal of Arid Environment,* 49, 465–475
13. Kumar A., Jayappa K.S. & Deepika B. (2011) Prioritization of sub-basins based on geomorphology and Morphometric analysis using Remote Sensing and Geographic Information System (GIS) techniques. *Geocarto International,* 26(7): 569–592 doi.org/10.1080/10106049.2011.606925
14. Malik A., Kumar A. & Kandpal H. (2019) Morphometric analysis and prioritization of sub-watersheds in a hilly watershed using weighted sum approach. *Arabian Journal of Geosciences,* 12: 118 DOI .org/10.1007/s12517-019-4310-7
15. Miller V.C. (1953) A Quantitative Geomorphologic Study of Drainage Basin Characteristics in the Clinch Mountain area, Virginia and Tennessee, Project NR 389042, Tech Report 3, Columbia University Department of Geology, ONR Geography Branch, New York
16. Nag S.K. (1998) Morphometric analysis using remote sensing techniques in the Chaka sub-basin, Purulia district, West Bengal. *7,* 26 (1&2): 69-76
17. Nookaratnam K., Srivastava Y.K., Rao V.V., Amminedu E. & Murthy K.S.R. (2005) Check dam positioning by prioritization of micro-watersheds using SYI model and Morphometric analysis- Remote Sensing and GIS perspective. *Journal of the Indian Society Remote Sensing,* 33(1): 25–38 DOI: 10.1007/BF02989988
18. Patel D.P., Gajjar C.A. & Srivastava P.K. (2012) Prioritization of Malesari mini-watersheds through morphometric analysis: a remote sensing and GIS perspective. *Environment Earth Science* DOI 10.1007/s12665-012-2086-0
19. Schumm S.A. (1956) Evolution of Drainage Systems and Slopes in Badlands at Perth Amboy, New Jersey. Geol Soc Am Bull 67:597–646
20. Smith K.G. (1950) Standards for grading texture of erosional topography. Am J Sci 248: 655-668
21. Strahler A.N. (1964) Quantitative Geomorphology of Drainage Basins and Channel Networks. Ven Te Chow (ed) Hand book of Aplied Hydrology. McGraw Hill Book Company, New York
22. Sreedevi P.D., Owais S., Khan H.H. & Ahmed S. (2009) Morphometric Analysis of a Watershed of South India Using SRTM Data and GIS. *Journal Geological Society of India,* 73, 543-552 DOI: 10.1007/s12594-009-0038-4
23. Srinivasa V.S., Govindaiah S. & Honne Gowda H. (2008) Prioritization of sub-watersheds for Sustainable Development and Management of natural resources: An integrated approach using Remote Sensing, GIS and socio-economic data. *Current Science,* 95 (3), 345-354
24. Suresh M., Sudhakar S., Tiwari K.N. & Chowdary V.M. (2004) Prioritization of Watersheds Using Morphometric Parameters and Assessment of Surface Water Potential Using Remote Sensing. *Journal of the Indian Society of Remote Sensing,* 32 (3), 249-258
25. Thakkar A.K. & Dhiman S.D. (2007) Morphometric Analysis and Prioritization of Miniwatersheds in Mohr Watershed, Gujarat Using Remote Sensing and GIS Techniques. *Journal of the Indian Society of Remote Sensing,* 35 (4), 313-321
26. Vittala S.S., Govindaiah S. & Gowda H.H. (2004) Morphometric analysis of sub-watersheds in the Pavagada area of Tumkur district, South India using remote sensing and GIS techniques. *Journal of the Indian Society of Remote Sensing,* 32(4): 351-362