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Drainage Morphometric Analysis of Watershed Basin of River Beas at Harike Pattan, Punjab-Using Remote Sensing and GIS Approach

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ABSTRACT

To understand the hydrological processes of a watershed and its characteristics, its morphometric analysis is necessary. Nowadays there is an increasing trend of using Remote Sensing (RS) and Geographic Information System (GIS) to delineation the drainage pattern and groundwater potential and its planning. In the present study Remote Sensing and GIS was used to understand the geometry of one of the watersheds of Harike Lake with much emphases on the evaluation of the morphometric parameters, which include linear parameters such as Stream number, Stream order (U), Stream Length (LU), Mean stream length (Lsm), Stream length ratio (RL), Bifurcation Ratio (Rb) relief parameters such as Basin relief (Bh), Relief Ratio (Rh), Ruggedness Number (Rn), Gradient ratio (Gh), Dissection index (Di) and aerial parameters viz: Drainage density (Dd), Drainage texture (T), Stream frequency (Fs), Form factor (Rf), Circulatory ratio (Rc), Elongation ratio (Re), Length of overland flow (Lg) and Constant channel maintenance(C). The study area is located at 31°21´23.58´´N latitude and 75°09´12.55´´E longitude in Punjab state of India. The Morphometric analysis revealed that that the watershed under study has 5th stream order drainage basin as per the Strahler method, having 625 total no. of streams, with 489 sq. km basin area with 120 km of perimeter. The drainage system of the basin is coarse with permeable subsurface strata and having good groundwater prospects.

Key words: GIS Harike, Morphometry, Punjab, Remote Sensing, Strahler, Watershed

I.INTRODUCTION

From the last two decades, Remote Sensing and GIS techniques have been widely used for delineation, updating and morphometric analysis of drainage basin. Morphometry refers to the size and configuration of mathematical analysis, the shape and dimensions of the earth's surface (Rekha *et al*., 2011; Wagener *et al*., 2001). Watershed Morphometry is a quantitative analysis of watershed characteristics related to aspects of geomorphology of the area. There are various features that are connected to the watershed some of them include shape, perimeter and area of watershed, stream length, elevation, drainage patterns and density, slope etc. There are major three morphometric parameters viz; linear morphometry, areal morphometry and relief morphometry that constitutes the quantitative measure of the watershed characteristics (Chandrashekar *et al*., 2015) and therefore analysis of watershed morphometry has a significant role in understanding the relationship between watershed parameters (Rama, 2014).

The drainage basin analysis is used for the assessment of groundwater potential and groundwater management and soil erosion estimation. Topography, climate and geology are the three main aspects that control the drainage pattern, drainage density and geometry of the fluvial systems (Mesa, 2006). Some important physiographic features of drainage basins such as size, shape, slope of drainage area, drainage density, size and length of the tributaries can be directly projected from drainage basin parameters (Gregory & Walling 1976; Rastogi *et al*., 1976). The detailed morphometric analyses provide a comprehensive knowledge about basin evolution and its role on development of drainage morphometry on landforms and their characteristics. It is a vital tool for the assessment of groundwater potential and management, pedology and environmental assessment (Sujatha *et al.*, 2015). Geologic and geomorphic history of the drainage basin can be well understood after analyzing its morphometric parameters (Strahler, 1964) and it is also a crucial step in understanding the watershed dynamics. Morphometry of a drainage basin also attempts to explain and predict the long-term aspects of basin dynamics resulting in morphological changes within the drainage basin (Thomas *et al*., 2011).

Remote sensing data can be used in conjunction with conventional data for delineation of ridgelines, characterization, priority evaluation, problem identification, assessment of potentials and management needs, identification of erosion-prone areas, evolving water conservation strategies, selection of sites for check dams and reservoirs etc. (Dutta *et al*., 2002). The present research elucidates the various drainage characteristics of one of the watersheds of Harike wetland located in the state of Punjab by analyzing the morphometric analysis using Remote Sensing and GIS. The study will be useful to understand hydrological behavior of direct catchment of river Beas near Harike wetland

II.STUDY AREA

The study area is located between the geographical coordinates of 31°09'-31°33' N latitude and 74°56'-75°15'E longitude. The location of the study area has been described in figure 1. The watershed basin has an area of approximately 489 km², and is shared between the two districts viz; Amritsar and Kapurthala of Punjab, India. The river Beas drifts across the watershed and the lowermost portion of the watershed infiltrates in the

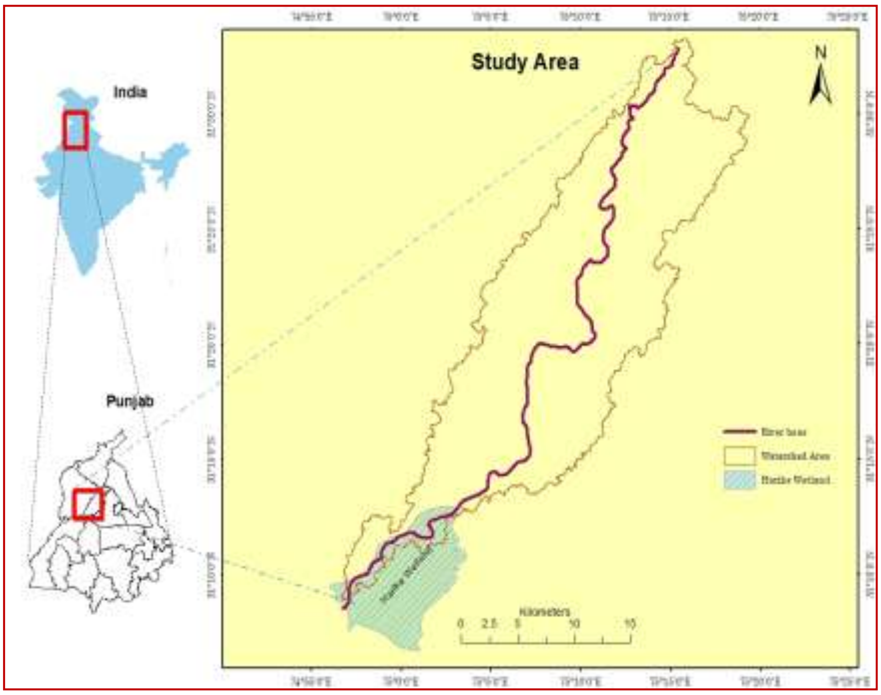

Figure 1: Location map of study area

Harike wetland, which is a Ramsar site in Punjab. The watershed under study is one of the direct catchments of the Harike wetland with elevation ranges between 168 to 278 meters. The study area has a semiarid climate, typical of North-western India. The maximum temperature may reach more than 48°C between May and June, while as minimum temperature can be as low as 4°C in January with annual average high temperature of 30.5°C with annual rainfall of 518 mm/year.

III.DATABASE AND METHODOLOGY

The study was carried out using the topographical maps H43D2, H43D3, H43D4, H43D6, H43D7 and H43C16 on 1:50000 scale from Survey of India (SOI). Due to low elevation, streams were not directly delineated from toposheets. However, Survey of India topographical maps were used in combination with watershed atlas of India and ASTER Dem of 30 meter resolution to delineate the watershed using ArcGIS 10.3. ASTER Global Digital Elevation Model (DEM) of 30 m resolution was downloaded from USGS website (https://earthexplorer.usgs.gov/). The study was carried out in GIS environment where ArcGIS 10.3 was used for georeferencing, digitization and map creation. . Strahler's method was used for stream order analysis. The fundamental parameters namely; stream length, area, perimeter, number of streams and basin length have been derived directly from drainage layer, which were later used to calculate other parameters like bifurcation ratio, stream length ratio, stream frequency, drainage density. The morphometric parameters computed were analyzed using the standard methods and formulae given in Table 1.

Table 1: Method of Calculating Morphometric Parameters of Drainage basin

	Morphometric Parameters	Formula/Definition	References
Linear parameters	Stream order (U)	Hierarchical order	Strahler,1964
	Stream Length (L_U)	Length of the stream	Hortan, 1945
	Mean stream length (L_{sm})	$L_{sm}=L_u/N_u$; Where, Lu=Mean stream length of a given order (km), Nu=Number of stream segment.	Hortan, 1945
	Stream length ratio (R_L)	R_L= Lu / Lu-1 Where, Lu= Total stream length of order (u), Lu-1=The total stream length of its next lower order.	Hortan, 1945
	Bifurcation Ratio (R_b)	R_b = Nu / Nu+1 Where, Nu=Number of stream segments present in the given order, Nu+1= Number of segments of the next higher order	Schumn,1956
Relief parameters	Basin relief (B_h)	Vertical distance between the lowest and highest points of basin	Schumn,1956
	Relief Ratio (R_h)	R_h = Bh / Lb Where, Bh=Basin relief,	Schumn,1956

		Lb=Basin length	
	Ruggedness Number (R_n)	R_n=Bh×Dd Where ,Bh = Basin relief, D_d=Drainage density	Schumn,1956
	Gradient ratio (Gh)	Gh=(H-h)/L where, H-h=Fall in height between highest and lowest points of elevation of watershed, L=Length of the main stream	Sreedevi *et al.*, 2005
	Dissection index (Di)	Di=RR/Hx where, RR=Relative relief, Hx=Highest elevation	Miller, 1949
Aerial Parameters	Drainage density (D_d)	D_d=L/A Where, L=Total length of stream, A= Area of basin.	Hortan, 1945
	Stream frequency (F_s)	F_s=N/A Where, L=Total number of stream, A=Area of basin	Hortan, 1945
	Texture ratio (T)	T=N_1/P Where, N_1=Total number of first order stream, P=Perimeter of basin.	Hortan, 1945
	Form factor (R_f)	R_f=A/(Lb)^2 Where, A=Area of basin, Lb=Basin length	Hortan, 1945
	Circulatory ratio (R_c)	R_c=4ðA/P^2Where A= Area of basin, ð=3.14, P= Perimeter of basin	Miller,1953
	Elongation ratio (R_e)	R_e=√(Au/ð)/ Lb Where, A=Area of basin, ð=3.14, Lb=Basin length	Schumn,1956
	Length of overland flow (L_g)	L_g=1/2D_d Where, Drainage density	Schumn,1956
	Constant channel maintenance(C)	Lof=1/D_d Where, D_d= Drainage density	Schumn,1956

IV.RESULTS AND DISCUSSION

Digital elevation model (DEM) has been shown in figure 2 along slope and drainage map of the basin. The drainage networks pattern mainly depends on the geology and precipitation of the region. The drainage pattern of the watershed basin is dentritic to subdentritic type.

V.LINEAR ASPECTS

Various linear aspects such as stream order, stream number, stream lengths, bifurcation ratio, length ratio etc. have been described below;

Stream Number (Nu)

With the increase in the stream order, the stream number (Nu) decreases. Table 2 describes the various stream numbers with associated orders.

Stream Order (U)

For stream ordering, Strahler's method (Strahler, 1964) of stream ordering system was used. Using GIS approach watershed basin under study follows the 5th stream order drainage network, which has been described in Table 2. Here also the Horton's Law of stream numbers (Horton, 1945) is obeyed, which states that the number of streams of different orders in a given drainage basin tends closely to approximate an inverse geometric ratio.

Stream Length (Lu)

Stream length (Lu) for the watershed has been calculated using Horton law. Stream length describes the surface runoff characteristics of a basin. The stream having smaller length is indicative of areas with larger slopes with finer textures whereas longer streams with relatively larger length are characteristics of flatter gradient. GIS software was used to measure the numbers of streams of various orders with their respective stream lengths in a watershed. The results revealed that the total stream length of the watershed basin is approximately 614 km. Length of the various stream orders has been shown in table 2. The stream order confirms the Horton's law of stream number which states that the number of stream segment of each order forms an inverse geometric sequence with order number.

Mean Stream Length (Lsm)

Mean stream length is a ratio of the Mean stream length of a given order to the mean stream length of next lower order (Horton, 19450). The mean stream length (Lsm) of a channel is a dimensional property revealing the characteristic size of components of a drainage network and its contributing basin surfaces. The mean stream lengths of various orders have been described in Table 2, where it is clear that mean stream length of stream increases with increase of the order.

Stream Length Ratio (RL)The stream length ratio is the ratio of the mean stream length of a given order to the mean stream length of next lower order (Horton, 1945). Results of RL have been shown in Table 4. The variation in RL is a sign of differences between slope and topography and hence it has an important control on discharge and different erosion stages of the watershed basin (Sreedevi *et al*., 2005). There is high erosion activity associated with higher stream length ratio and the increase of RL from lower to higher orders is generally characterized by the attainment of geomorphic maturity (Thomas *et al*., 2010).

Bifurcation Ratio (Rb)

Horton (1932) originally introduced the term bifurcation ratio' (Rb) to express the ratio of the number of streams of any given order to the number in the next lower order. In the study area mean Rb varies between 5 to 7.98 with mean Rb of the entire watershed basin as 5.1 (Table 2). The Rb range '3 to 5' for watersheds of a geologic structure does not exercise a dominant influence on the drainage pattern (Chow, 1964). Usually, these values are common in the areas where geologic structures do not exercise a dominant influence on the drainage pattern.

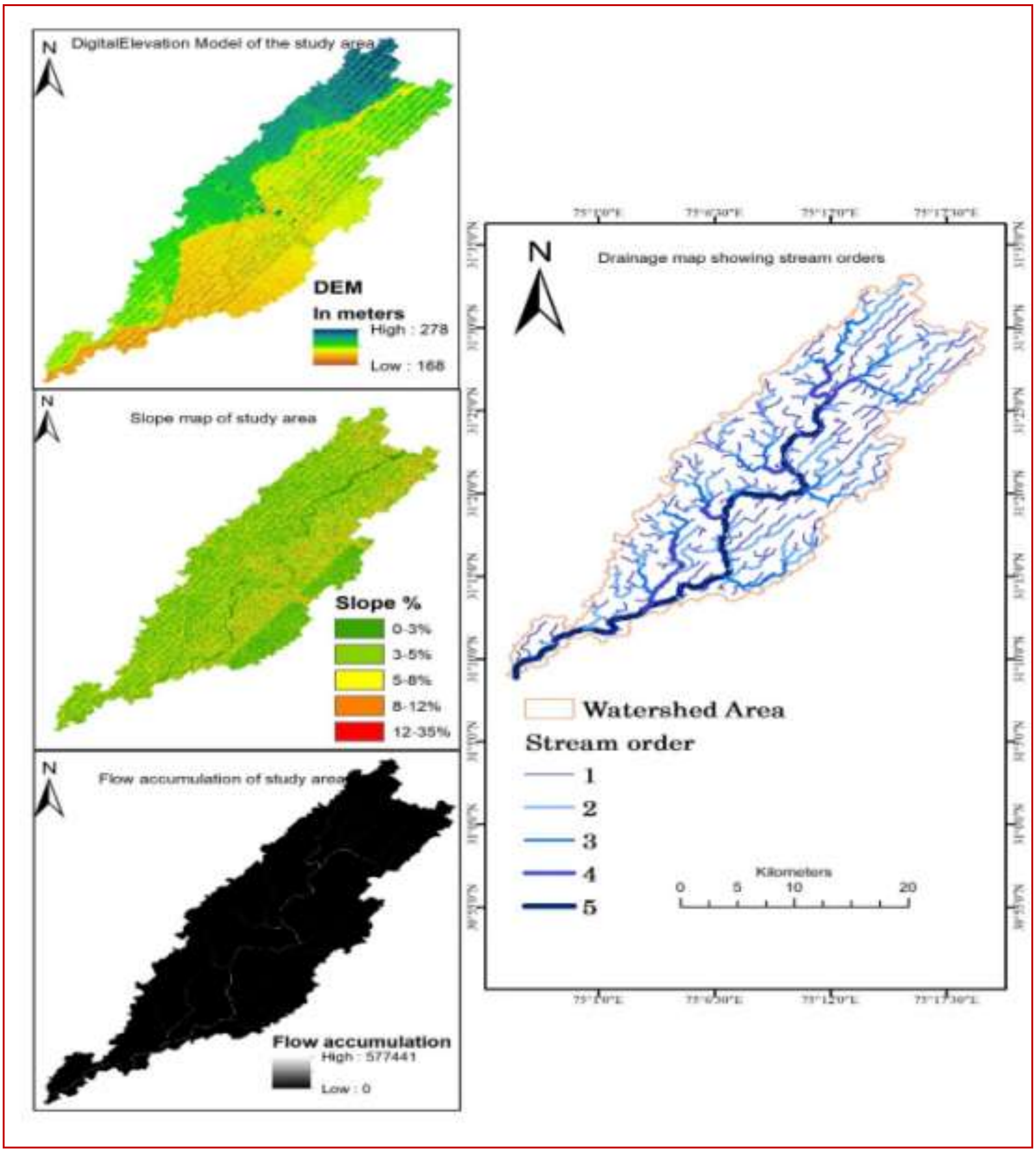

Figure 2: Drainage map of basin

VI.AERIAL ASPECTS

The various areal aspects include drainage parameters such as drainage density, stream frequency, Form factor (R_f) Circulatory ratio (R_c), Elongation ratio (R_e), Length of overland flow (L_g) and Constant channel maintenance(C) which have been discussed below

Drainage density (Dd)

The term Drainage density (Dd) was introduced by Horton in 1932. It is defined as the ratio of total channel length of all streams orders to the basin area and is usually expressed as km/km2. The drainage density is the measure of the closeness of spacing of channels of a drainage system and therefore provides a quantitative measure of the average length of stream channel for the whole basin (Horton, 1945; Strahler, 1964). High drainage density is due to the weak or impermeable subsurface material, sparse vegetation and mountainous relief. Low drainage density leads to coarse drainage texture (Strahaler, 1964). The drainage density of study area was recorded as 1.26 Km/Km2 falling under moderate drainage densities, which further indicates that the basin is highly permeable subsoil with vegetative cover (Nag, 1998).

Drainage Texture (T)

Drainage texture is a measure of relative channel spacing in a fluvial dissected terrain. There are number of natural factors such as rock and soil type, vegetation, climate, rainfall, infiltration capacity, relief and stage of development of a watershed (Smith, 1950). Simply drainage texture is the product of drainage density and stream frequency. The results revealed that the drainage texture for the whole watershed is 1.61 (Table 4). The soft and weak rocks which are unprotected by vegetation usually are having a fine texture, whereas massive and resistant rocks cause coarse texture. Rock texture is to a large extent dependent upon

Table 2: Some basic parameters of the Watershed basin							
Latitude	Longitude	Elevation (Km)	Minimum Elevation (km)	Maximum Elevation (km)			
31.35655	75.153487	0.224	0.168	0.278			
Stream Order = 5th	Stream Number		Stream Length (km)		Bifurcation Ratio	Mean stream length	Stream Length ratio
	I	535	I	53	7.98	0.10	-
	II	67	II	25	4.46	0.38	0.48
	III	15	III	59	3	3.93	2.36
	IV	5	IV	171	5	34.2	3.35
	V	1	V	306	-	306	1.78
	Total	625		614			

vegetation type and climate of the area (Darnkamp and King, 1971).

Stream Frequency (Fs)

Stream frequency (Fs), refers to the total number of stream segments of all orders per unit area. In a watershed stream frequency and drainage density exhibits a positive correlation where there is increase in stream population with increase in drainage density (Horton, 1932). The stream frequency for the watershed under study was found to be 1.28 (Table 4).

Elongation Ratio (Re)

Elongation ratio (Re) is defined as the ratio between the diameter of a circle with the same area as that of the basin (A) and the maximum length (L) of the basin (Schumm, 1956). The formula to calculate the elongation

Table 4: Result of morphometric analysis

ratio has been described in Table 4. Elongation ratio for the basin under study was recorded as 0.231 (Table 4) High Re values indicate that the areas are having high infiltration capacity and low runoff.

Circularity Ratio (Rc)

Circularity ratio a similar measure as that of the elongation ratio is defined as the ratio of the area of the basin to the area of the circle having the same circumference as the basin perimeter (Miller. 1953). Circularity ratio (Rc) is highly affected by the length and frequency of streams, lithology, geological structures, land use/land cover, climate, relief and slope of the basin (Chopra, 2005). The values of 'Rc' ranges between 0 (in line) to 1 (in a circle). In the present study the circulatory ratio of the basin was measured to be 0.426, which is the indication that there exists a strong structural control on the drainage development of the basin.

Length of Overland Flow (Lg)

The 'length of overland' is generally used to describe the length of flow of water over the ground before it becomes concentrated in definite stream channels. Horton, 1945 considered it as one of the most important independent variables affecting hydrologic and physiographic development of drainage basins. The watershed

Table 3: Standard and classification of the river basin elongation proposed by (Schumm, 1965) and later interpreted by (Strahle, 1964)

Elongation ratio	Shape of basin
<0.5	more elongated
0.5-0.7	elongated
0.7-0.8	less elongated
0.8-0.9	oval
0.9-0.10	circular

under study shows 'Lg' value of 0.396. More the values of 'Lg' indicates a long time of flow in the basin.

Sr. no	Parameter	Value
1	Basin Area (Km^2)	489
2	Perimeter (Km)	120
3	Basin order	5
4	Basin Length(Lb) (Km)	54
5	Drainage density (Dd) (Km/Km^2)	1.26
6	Stream frequency (Fs) (Km^2)	1.28
7	Drainage texture (T)	1.61
8	Gradient ratio (Gh)	0.0015
9	Basin Relief (Bh) (m)	110
10	Relief Ratio (Rh)	2.03
11	Dissection index (Di)	0.395
12	drainage ratio(T) (Km)	4.46
13	Ruggedness number (Rn)	0.138
14	Mean Bifurcation ratio (Rb)	5.11
15	Form Factor (Rf)	0.168
16	Circulatory ratio (Rc)	0.427
17	Elongation Ratio (Re)	0.231
18	Length of overland flow (Lg) (Km)	0.396
19	Constant channel maintenance (C) (Km)	0.793

Constant of Channel Maintenance (C)

Constant of Channel Maintenance was introduced by Schumm (1956) and refers to the inverse of drainage density, having the units of square feet per foot. Constant of Channel Maintenance provides information of the number of square feet of watershed surface required to sustain one linear foot of stream. The value of Constant of Channel Maintenance for the basin is 0.793. Which means that on an average 0.793 sq.ft surface is needed in basin for creation of one linear foot of the stream channel.

Form Factor (Ff)

Form factor (Ff) is defined as the ratio of the basin area to the square of the basin length (Horton, 1945). And measures the flow intensity of a basin of a defined area. The values for the form factor ranges between 0.1 to

0.8. Smaller the value of form factor, more elongated will be the basin. The smaller the value of the form factor, the more elongated will be the basin. Basins with high form factors experience larger peak flows of shorter duration, whereas elongated watersheds with low form factors experience lower peak flows of longer duration. The value of Form Factor for the whole basin is 0.168, indicating elongated basin with lower peak flows of longer duration than the average.

VII.RELIEF ASPECTS

Basin Relief (Bh)

Relief is the maximum vertical distance between the lowest and the highest points of a basin. It determines the stream gradient and affects flood pattern and volume of sediment that can be transported (Hadley and Schumm, 1961). Basin relief is used to predict the denudational characteristics of the basin (Sreedevi *et al*., 2004). The maximum and minimum elevation of basin are 278 and 168 m respectively, so the relief of the basin is 110 m.

Relief Ratio (Rh)

The relief ratio, (Rh) is ratio of maximum relief to horizontal distance along the longest dimension of the basin parallel to the principal drainage line (Schumm, 1956). Relief ratio generally increases with decreasing in drainage area and size of watersheds of a given drainage basin (Gottschalk, 1964). Relief ratio is a dimensionless height-length ratio and allows comparison of the relative relief of any basin irrespective of variation in scale or topography. It measures the overall steepness of a drainage basin and is an indicator of the intensity of erosion process operating on slope of the basin (Schumm, 1956). For the watershed basin the value of Relief ratio was 2.03 indicating low relief ratio, which is the result of high erodibility of the rock type in the region.

Ruggedness number (Rn)

Ruggedness number can be used to measure the flash flood potential of the streams (Patton & Baker 1976). It is the product of maximum basin relief (H) and drainage density (Dd), where both parameters are in the same unit and it usually combines slope steepness with its length. An extreme high value of ruggedness number occurs when both variables are large and slope is steep (Strahler, 1956). The value of ruggedness number for the present basin was 0.138 which indicates less steep slopes and less slope length.

Gradient ratio (Gr)

Gradient ratio is an indication of channel slope from which the runoff volume could be evaluated. (Sreedevi *et al*., 2005; Thomas *et al*., 2010). The basin under study has a gradient ratio of 0.0015, which indicates that the terrain is less hilly in nature.

Dissection index (Di)

Dissection Index (Di) is the ratio between absolute relief and relative altitude. The areas with low value of the index are generally found in the regions of high altitude where the erosion agents have yet to do considerable work. It expresses the relationship between the vertical distance of relief from the erosion level and relative

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relief. The value of Dissection Index (Di) for the basin was 0.395, which falls under low Dissection Index category indicating that the area has gently sloping topography and resistant rocks.

VIII.CONCLUSION

To carry out hydrological study of drainage system morphometric analysis is prerequisite. Remote sensing in combination with GIS techniques has been proved to be an accurate and effective tool for drainage delineation for watersheds. In the present study morphometric analysis of the Beas River basin at Harike wetland was carried out using Remote Sensing and Geographic Information System (GIS) approach. The results revealed that Beas river at Harike wetland shows 5^{th} order drainage basin. From the results, it is evident that the drainage system of the basin is coarse with drainage density of only 1.26 km/km^2 indicating the permeable subsurface strata. The basin is dominated by lower order streams. Low Relief ratio indicates that the discharge capability of basin is moderate with good groundwater potential. Elongation, circulatory ratio and drainage texture of the basin indicates that the basin is more elongated with fine texture. The present study can be more useful for predicting groundwater potential zones, rainwater harvesting and overall watershed management plans.

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REFERENCES

[1.] Chandrashekar, H., Lokesh, K. V., Sameena, M., & Ranganna, G. (2015). GIS-Based Morphometric Analysis of Two Reservoir Catchments of Arkavati River, Ramanagaram District, Karnataka. *Aquatic Procedia*, *4*, 1345-1353.

[2.] Chopra, R., Dhiman, R. D., & Sharma, P. K. (2005). Morphometric analysis of sub-watersheds in Gurdaspur district, Punjab using remote sensing and GIS techniques. *Journal of the Indian Society of Remote Sensing*, *33*(4), 531-539.

[3.] Chow, V. T. (1964). Handbook of applied hydrology. A compendium of water-resources technology. Ed. McGraw-Hill, New York, 1418 pp.

[4.] Dornkamp, J.C. and King, C.A.M. (1971) Numerical analyses in geomorphology, an introduction. St.Martins Press, New York, pp.372.

[5.] Dutta, D., & Sharma, J. R. (2002). *Watershed Characterisation, Prioritisation, Development Planning and Monitoring Remote Sensing Approach*. ISRO.

[6.] Gottschalk, L. C. (1964). Reservoir sedimentation. *Handbook of Applied Hydrology. McGraw Hill Book Company, New York, Section*, *7*.

[7.] Gregory, K. J., & Walling, D. E. (1976). *Drainage basin form and process: A geomorphological approach*. Edward Arnold (Publishers) Ltd.

[8.] Hadley, R. F., & Schumm, S. A. (1961). Sediment sources and drainage basin characteristics in upper Cheyenne River basin. *US Geological Survey Water-Supply Paper*, *1531*, 198.

[9.] Horton, R. E. (1932). Drainage- basin characteristics. *Eos, transactions american geophysical union*, *13*(1), 350-361.

[10.] Horton, R. E. (1945). Erosional development of streams and their drainage basins; hydrophysical approach to quantitative morphology. *Geological Society of America Bulletin*, *56*(3), 275-370.

[11.] Mesa, L. M. (2006). Morphometric analysis of a subtropical Andean basin (Tucuman, Argentina). *Environmental Geology*, *50*(8), 1235-1242.

[12.] Miller, V. C. (1953). Quantitative geomorphic study of drainage basin characteristics in the Clinch Mountain area, Virginia and Tennessee. *Technical report (Columbia University. Department of Geology); no. 3*.

[13.] Nag, S. K. (1998). Morphometric analysis using remote sensing techniques in the Chaka sub-basin, Purulia district, West Bengal. *Journal of the Indian society of remote sensing*, *26*(1), 69-76.

[14.] Patton, P. C., & Baker, V. R. (1976). Morphometry and floods in small drainage basins subject to diverse hydrogeomorphic controls. *Water Resources Research*, *12*(5), 941-952.

[15.] Rama, V. A. (2014). Drainage basin analysis for characterization of 3 rd order watersheds using Geographic Information System (GIS) and ASTER data. *J. Geomatics*, *8*(2), 200-210.

[16.] Rastogi, R. A., & Sharma, T. C. (1976). Quantitative analysis of drainage basin characteristics. *Jour. Soil and Water Conservation in India*, *26*(1), 18-25.

[17.] Rekha, B. V., George, A. V., & Rita, M. (2011). Morphometric analysis and micro-watershed prioritization of Peruvanthanam sub-watershed, the Manimala River Basin, Kerala, South India. *Environmental Research, Engineering and Management*, *57*(3), 6-14.

[18.] Schumm, S. A. (1956). Evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersey. *Geological Society of America Bulletin*, *67*(5), 597-646.

[19.] Smith, K. G. (1950). Standards for grading texture of erosional topography. *American Journal of Science*, *248*(9), 655-668.

[20.] Sreedevi, P. D., Subrahmanyam, K., & Ahmed, S. (2005). The significance of morphometric analysis for obtaining groundwater potential zones in a structurally controlled terrain. *Environmental Geology*, *47*(3), 412-420.

[21.] Strahler, A. N. (1964). "Quantitative Geomorphology of Drainage Basins and Channel Networks," In: V. T. Chow, Ed., *Handbook of Applied Hydrology*, McGraw-Hill Book Company, New York, Section 4-11.

[22.] Strahler, A.N. (1964) Quantitative geomorphology of drainage basins and channel networks. In: V.T. Chow (Ed.), Handbook of Applied Hydrology. McGraw-Hill, New York, pp.4.39-4.76.

[23.] Sujatha, E. R., Selvakumar, R., Rajasimman, U. A. B., & Victor, R. G. (2015). Morphometric analysis of sub-watershed in parts of Western Ghats, South India using ASTER DEM. *Geomatics, Natural Hazards and Risk*, *6*(4), 326-341.

[24.] Thomas, J., Joseph, S., & Thrivikramaji, K. P. (2010). Morphometric aspects of a small tropical mountain river system, the southern Western Ghats, India. *International Journal of Digital Earth*, *3*(2), 135-156.

[25.] Thomas, J., Joseph, S., Thrivikramji, K. P., & Abe, G. (2011). Morphometric analysis of the drainage system and its hydrological implications in the rain shadow regions, Kerala, India. *Journal of Geographical Sciences*, *21*(6), 1077-1088.

[26.] Wagener, T., Boyle, D. P., Lees, M. J., Wheater, H. S., Gupta, H. V., & Sorooshian, S. (2001). A framework for development and application of hydrological models. *Hydrology and Earth System Sciences Discussions*, *5*(1), 13-26.