Int. J. Exp. Res. Rev., Vol. 8: 66-73 (2016)

International Journal of Experimental Research and Review (IJERR)

ISSN: 2455-4855 (Online) ***Original Article***

Received: 8th November, 2016; **Accepted:** 8th December, 2016; **Published:** 30th December, 2016

Geo-spatial analysis of Watershed Characteristics Using Remote Sensing and GIS Techniques: A case study of Kassai watershed, West Bengal, India

Goutam Kumar Das[1] and Pijush Kanti Dandapath[2*]

[1]Technical Assistant (Cartographer), U.G. & P.G. Dept. of Geography, Bajkul Milani Mahavidyalaya; [2]Assistant Professor & Head, U.G. & P.G. Dept. of Geography, Bajkul Milani Mahavidyalaya, Purba Medinipur, West Bengal, India.

***Corresponding Author:** pkdandapath@gmail.com

Abstract

Watershed is a natural hydrological entity which allows surface run-off to a defined channel, drainage, stream or river at a particular point. It is the basic unit of water supply, which evolves over time. Morphometric analysis is a quantitative description and analysis of landforms as practiced in geomorphology that applied to a particular kind of landform or to drainage basins. Remote sensing (RS), Geographical Information System (GIS) has proved to be an efficient tool in delineation of drainage pattern and water resources management and its planning. In the present study, GIS and image processing techniques have been adopted for the identification of morphological features and analyzing their properties of the Kassai river Basin, West Bengal, India. The basin morphometric parameters such as linear and aerial aspects of the river basin were determined and computed. The study area covers 6929.134 km^2 comprising of 14 sub-watersheds. The drainage network of 14 sub-watersheds was delineated using Aster DEM remote sensing data and standard Survey of India topographical maps on 1:50,000 scale. The drainage network shows that the terrain exhibits dendritic to sub-dendritic drainage pattern. The highest stream order is fourth order. Estimated drainage density is approximately 0.35 per km^2 and has very coarse to coarse drainage texture. The mean bifurcation ratio is 4.14 that indicate uniform geological structure and lithologies in watershed area. The investigation has shown that as the order of stream increases total length of stream segments is decreases. Hence, it can be concluded that there is a relationship between stream numbers and stream lengths as per the Horton's law of stream length. The elongation ratio shows that Kassai watershed possesses elongated shape pattern. The study showed that GIS techniques proved to be a competent tool in morphometric analysis.

Kewwords: GIS, image processing, morphometric analysis, remote sensing, watershed.

Introduction

A watershed is an area of land that drains into a common water body, such as a stream, river or lake. A watershed can also be known as a basin or a catchment area. Human activities have a direct influence on the quality and quantity of surface water, groundwater and other natural resources in the watershed. Watershed comprises surface water, groundwater and other natural resources, which are influenced by human activities. Quality and quantity of downstream has direct connection with the upstream activity of stream. The drainage basin is used as an ideal areal unit for geo-morphometric analysis because it has inherent limited, convenient and usually clearly defined and unambiguous topographic unit. Moreover, available in a nested hierarchy of sizes on the basis of stream ordering and an open physical system in terms of inputs of precipitation and solar radiation of drainage basin. To observe the morphometric characteristics of drainage basin remote sensing and GIS techniques was used in this study. Remote sensing provides synoptic coverage, data from the inaccessible regions, economical and rapid method for constructing a base map in absence of detailed land surveys. Geographic Information System has a number of advantages over to the conventional mapping systems. Conventional maps are static, with fixed projection, scale and coordinate systems; it is difficult to combine multiple map sheets and overlays are restricted. GIS provides easy way to update and analyzed the spatial data. Morphometric studies constitute measurement and mathematical analysis of the configuration of the earth's surface and the shape and dimensions of its landforms. Various morphometric parameters needs to measure in a drainage basin include stream order, stream length, stream number, and basin area. Others morphometry parameters are basin shape factor (e.g. circularity ratio, elongation ratio, form factor and compaction ratio), basin perimeter, bifurcation ratios, drainage density, stream frequency and drainage intensity. Morphometry investigation of a watershed gives a quantitative description of the drainage system which is an important aspect of the characterization of watersheds.

Study area

Kassai river watershed is located at southern part of West Bengal, India and covering an area of 6929.134 km^2 and is located between 22^{0}13'9.27'' to 23^{0}28'16.657''N latitude and 87^{0}50'5.671'' to 85^{0}59'37.814'' E longitude (Fig. 1). The climate of the area is arid and is characterized by hot summer months with high rainfall.

Methodology

The study area is analysed for the quantitative morphological analysis of the watershed by using Survey of India Topographical map scale is 1: 50,000 surveyed during 1962 which is used as a reference, in addition with geocoded Aster DEM satellite imagery acquired during 2014. The Topographical map, DEM digital satellite imagery were geometrically rectified and georeferenced using digital image processing software ERDAS IMAGINE 9.0. To extract the drainage layer from the DEM satellite imagery, edge detection and linear enhancement filters were used for enhancing visual interpretation ability of the stream order on satellite image. The ArcGIS 10.1 software is used to delineate the watershed with the digitization of morphometric features and measurement of parameters. Strahler's method was used for determination of the hierarchical position of a stream within a drainage basin. Digital database

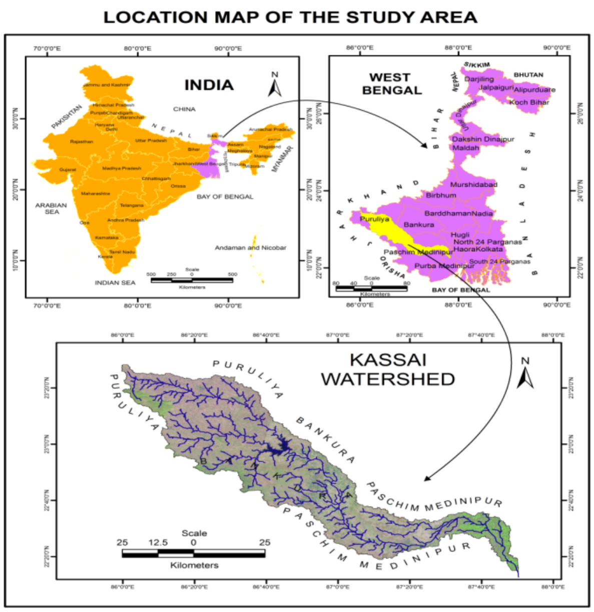

Fig 1. Location of the Kassai watershed.

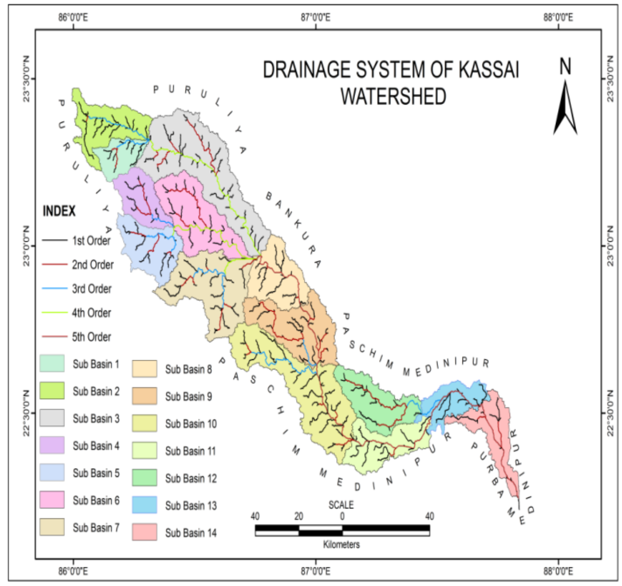

Fig 2. Drainage system of the Kassai watershed.

is created for drainage layer of river basin by assigning the attributes. Morphometric analysis is implemented to interpret the watershed characteristics such as linear aspects of the drainage network: stream order, bifurcation ratio, stream length and areal aspects of the drainage basin consists form factor ratio, circularity index, elongation ratio, stream frequency, drainage density and texture ratio of the basin were calculated.

Result and Discussion

One of the purposes of studying morphometry of watershed is to obtain information in quantitative form with relation to the geometry of the watershed that can be correlated with hydrologic information. Remote sensing studies allow the assessment of regional structures and their trends. The drainage characteristics of Kassai river have been analyzed with particular reference to fallowing:

Morphometric analysis

Morphometry study constitutes measurement and mathematical analysis of the configuration of the earth's surface and the shape and dimensions of its landforms. GIS techniques are used to compute and measure the morphometric parameters (Table-2) includes bifurcation ratio, stream length, form factor, circulatory ratio and drainage density etc.

Linear aspects of the basin

Stream order

The order of the stream is based on the connection of tributaries. Stream order is used to represent the hierarchical link among stream segments and allows drainage basins to be classified according to size. Stream order is a fundamental property of stream networks as it relates to the relative discharge of a channel segment. A number of stream-ordering systems in the present study have been used which was formulated by Arthur N. Strahler. According to the author, first order streams are having no

Table 1. Total area & Total Stream length of Kassai watershed.

Sub-Basin	Area in Km^2	1st order stream		2nd order stream		3rd order stream		4th order stream		Total	
		No.	Length in km	No.	Length in km	No.	Length in km	No.	Length in km	No.	Length in km
1st	200.413	9	39.961	2	2.256	1	17.825			12	60.042
2nd	405.552	14	46.427	2	56.025	1	22.466			17	124.918
3rd	1009.19	39	127.78	5	59.17	1	71.26			45	258.212
4th	291.639	9	33.619	2	22.344	1	13.769			12	69.732
5th	389.077	13	52.602	5	22.737	2	30.971	1	11.863	21	118.173
6th	595.991	19	81.66	2	40.92	1	44.55			22	167.129
7th	701.898	26	107.59	5	35.08	2	33.45	1	19.80	34	195.93
8th	408.315	13	81.09	3	11.36	1	31.68			17	124.129
9th	576.268	23	91.81	5	66.39	2	20.43	1	3.05	31	181.681
10th	901.865	31	170.77	5	23.72	1	79.77			37	274.258
11th	397.655	14	79.36	2	32.85	1	25.03			17	137.237
12th	424.067	14	46.427	2	56.025	1	22.466			17	124.918
13th	273.469	10	66.25	2	6.15	1	21.29			13	93.69
14th	353.735	12	40.19	3	16.59	1	37.32			16	94.103
Total	6929.134	246	1065.536	45	451.617	17	472.277	3	34.713	311	2024.152

stream tributaries and that flows from the stream source. A second-order segment is created by joining two first-order segments, a third-order segment by joining two second order segments, and so on. There is no increase in order when a segment of one order is connected by some other lower order. Strahler's stream order has been applied by many researchers for river systems. The highest stream order observed in the present study area is fourth order out of 311 observed streams. 242 first order, 45 second order, 17 third order and 3 fourth order streams were observed. Dendritic drainage pattern formed by the interlinking of streams is observed in the study area which indicates the homogeneity in texture and lack of structural control. Dendritic drainage has a spreading, tree-like pattern with an irregular branching of tributaries in many directions and with any angle. It is observed from the Table 1, that the maximum frequency is in case of first order streams. It is noticed that there is a decrease in stream frequency as the stream order increases (Table 1).

Bifurcation ratio

In morphometric analysis a generally used topological property is the bifurcation ratio. It is the ratio between the number of stream segments of one order and the number of the next higher order. A mean bifurcation ratio is usually used because the ratio values for different successive basins will vary slightly. With relatively homogeneous lithology, the bifurcation ratio is normally not more than 5 or less than 3. The lower bifurcation ratio values are characteristics of the watersheds which have suffered less structural disturbances. Bifurcation ratio, speculated to be controlled by drainage density, stream entrance angles, lithological characteristics, basin shapes, basin areas etc.

Tream length

GIS technique is used to count the number of streams of various orders in a sub-watershed and to measure their lengths from mouth to drainage divide (Table 1). The stream length has been computed based on the law proposed by

Table 2. Bifurcation ratios for 14 sub basins.

Order stream	**No. of Steam**			**Bifurcation ratio**			**Average Bifurcation ratio**			**Mean average**
	Sub-Basin 1	Sub-Basin 2	Sub-Basin 3	Sub-Basin 1	Sub-Basin 2	Sub-Basin 3	Sub-Basin 1	Sub-Basin 2	Sub-Basin 3	
1st order	9	14	39							
2nd order	2	2	5	4.5	7	7.8	3.25	4.5	6.4	4.72
3rd order	1	1	1	2	2	5				
Order stream	No. of Steam			Bifurcation ratio			Average Bifurcation ratio			Mean average
	Sub-Basin 4	Sub-Basin 5	Sub-Basin 6	Sub-Basin 4	Sub-Basin 5	Sub-Basin 6	Sub-Basin 4	Sub-Basin 5	Sub-Basin 6	
1st order	9	13	19							
2nd order	2	5	2	4.5	2.6	9.5	3.25	2.37	5.75	3.79
3rd order	1	2	1	2	2.5	2				
4th order		1			2					

Order stream	**No. of Steam**				**Bifurcation ratio**				**Average Bifurcation ratio**				**Mean avg.**
	Sub-Basin 7	Sub-Basin8	Sub-Basin9	Sub-Basin 10	Sub-Basin 7	Sub-Basin 8	Sub-Basin 9	Sub-Basin 10	Sub-Basin 7	Sub-Basin 8	Sub-Basin 9	Sub-Basin 10	
1st order	26	13	23	31									
2nd order	5	3	5	5	5.2	4.33	4.6	6.2	3.9	3.67	3.03	5.6	4.05
3rd order	2	1	2	1	4.5	3	2.5	5					
4th order	1		1		2		2						

Order stream	**No. of Steam**				**Bifurcation ratio**				**Average Bifurcation ratio**				**Mean average**
	Sub-Basin 11	Sub-Basin 12	Sub-Basin 13	Sub-Basin 14	Sub-Basin 11	Sub-Basin 12	Sub-Basin 13	Sub-Basin 14	Sub-Basin 11	Sub-Basin 12	Sub-Basin 13	Sub-Basin 14	
1st order	14	14	10	12									
2nd order	2	2	2	3	7	7	5	4	4.5	4.5	3.5	3.5	4.00
3rd order	1	1	1	1	2	2	2	3					

Table 3. Areal aspects of the basin.

Sub Basin	Drainage Density	Form factor	Circularity Index	Elongation ratio	Stream frequency	Drainage texture
1st	0.343	0.031	0.273	0.334	0.069	0.024
2nd	0.295	0.027	0.288	0.639	0.064	0.019
3rd	0.345	0.021	0.265	0.526	0.070	0.024
4th	0.304	0.012	0.243	0.527	0.068	0.021
5th	0.315	0.017	0.304	0.593	0.078	0.025
6th	0.304	0.027	0.530	0.623	0.061	0.019
7th	0.279	0.018	0.337	0.517	0.077	0.021
8th	0.280	0.021	0.281	0.529	0.064	0.018
9th	0.304	0.028	0.413	0.548	0.069	0.021
10th	0.239	0.060	0.359	0.522	0.058	0.014
11th	0.256	0.015	0.260	0.481	0.085	0.022
12th	0.308	0.026	0.311	0.484	0.067	0.021
13th	0.300	0.056	0.336	0.501	0.085	0.025
14th	0.266	0.040	0.183	0.594	0.074	0.020

Horton. Generally, the total length of stream segment is maximum in first order streams and decreases as the stream order increases. Total lengths of 14 sub basins are 1065.536, 451.617, 472.277 & 34.713 km respectively.

Areal aspects of the basin

Geometry of Basin shape

The shape of watershed is dependent on size of basin and length of master stream of the basin and basin perimeter. Thus shape of a basin affects stream flow hydrographs and peak flows. The important parameters describing the shape of the basin are form factor (F), circulatory index (C) and elongation ratio (R).

Horton's form factor (F)

Form factor is defined as the ratio of the area of the basin to the square of the length of the basin. The value of 'F' generally changes from 0 (highly elongated shape) to 1 (perfect circular shape). Therefore, higher the value of form factors, more the circular the shape of basin and vice-versa.

Here, F = A/L2,

Horton's form factor for 14 sub basins is 0.055592, 0.025989, 0.015136, 0.059977, 0.027861, 0.021337, 0.018284, 0.0265, 0.017458, 0.01199, 0.021114, 0.027176, 0.031155 & 0.039946 respectively. The present sub basins are having values near to 0 rather than 1. Thus, shapes of the all sub basins are more or less elongated. Elongated basins with low form factor indicate that the basin will have a flatter peak of flow for longer duration. Flood flows in elongated basins are easier to control than of the circular basins.

V.C. Millers Circularity Index (C) (1953)

Circulatory index is the ratio between the area of the basin and the area of the circle having the same perimeter as that of the basin.

Here, C = Area of the basin/ Area of the circle with same perimeter as the basin

The value of 'C' generally changes from 0 (a line) to 1 (circle). The higher the value of 'C', more the circular shape of the basin and vice versa. The value of 'C' Circularity index of 14 sub basins is 0.336462, 0.310513, 0.259538, 0.359064, 0.412759, 0.280752, 0.336598, 0.529819, 0.304194, 0.242691, 0.265082, 0.288371, 0.272716, and 0.182503 respectively.

S. A. Schumm's (1956) Elongation ratio (R)

Elongation ratio (R) is the ratio between the diameter of the circle having the same area (as that of the basin) and the maximum length of the basin.

Here, R = Diameter of the circle with same area as basin/ Basin length or F = II/4 x R2

The values of 'R' for 14-sub basins are 0.501292, 0.484158, 0.480523, 0.521804, 0.548202, 0.529225, 0.516898, 0.623488, 0.593098, 0.527448, 0.526403, 0.639022, 0.333925 and 0.594136 respectively.

Stream frequency (Fs)

Stream frequency is the measure of number of streams per unit area also called drainage frequency. Stream frequency of basin area is 0.044883 and that of 14-sub basins are 0.084825, 0.066576, 0.085217, 0.058291, 0.069395, 0.063759, 0.076934, 0.061227, 0.078089, 0.067638, 0.070413, 0.063669, 0.069478, 0.073501 respectively. Stream frequencies primarily depend on lithology of the basin and the texture of drainage network. The all sub basins having very poor categories of stream frequency.

Drainage Density (Dd)

Drainage density is the most important property of drainage morphometry, which is the total stream length of channel per unit area of drainage basin. Drainage density is a measure of how frequently streams occur on the land surface. It reflects a balance involving erosive forces and the resistance of the ground surface, and is thus related directly to climate, precipitation, permeability, lithology, and vegetation. A drainage density varies from less than 5 km/km2 when slopes are gentle, low rainfall, and permeable, fractured, highly jointed bedrock. On other hand, values of more than 500 km/km2 in upland areas are possible where rocks are impermeable, slopes are steep, and high rainfall. The drainage density of overall basin is 2.889077 and for 14-sub basins are 0.299591, 0.30802, 0.255861, 0.239104, 0.303726, 0.280422, 0.279143, 0.304003, 0.315272, 0.304101, 0.345116, 0.294571, 0.342598, and 0.266027 respectively.

Drainage Texture

The drainage texture depends upon a number of natural factors such as climate, rainfall, vegetation, rock and soil type, infiltration capacity, relief and stage of development. Drainage texture is used to indicate relative spacing of the streams in a unit area along a linear direction. The soft or weak rocks unprotected by vegetation produce a fine texture, whereas massive and resistant rocks cause coarse texture. The finer drainage textures observed in arid climatic condition and coarser is in a humid climate. The texture of a rock is commonly dependent upon vegetation type and climate. Drainage texture is the product of Drainage density and stream frequency. The drainage texture of the whole basin is 0.292, while those of the 14-sub-basins are 0.024, 0.019, 0.024, 0.021, 0.025, 0.019, 0.021, 0.018, 0.021, 0.014, 0.022, 0.021, 0.025, 0.020, respectively (Table-3). The all sub basin is showing good relationship with drainage texture.

Conclusion

In the present study, morphometric features of drainage are identified and mapped by satellite remote sensing data in conjunction with GIS software. GIS techniques used to study the kassai water basin proves to be competent tools in morphometric analysis and provide very high accuracy of mapping & measurement. The drainage density and stream frequency are the decisive factor for the morphometric classification of drainage basins. These are controllers of the runoff pattern, sediment yield and other hydrological parameters of the drainage basin. The drainage density of kassai river watershed, and sub-basins, reveal that the subsurface strata are permeable. This is a characteristic feature of coarse drainage as the density values are less than 5.0. The highest order of stream is fourth order. The numbers of lower order streams are more than the higher order streams. The low value of bifurcation ratio (3.79-4.72) indicates that the drainage of the basin is not affected by structural disturbances. This is possibly due to small area occupancy of the sub basin. The steam length decreases with the order increases. The morphometric analysis shows that the basin is having elongated in shape. Drainage network of the basin exhibits as mainly dendritic type which indicates the homogeneity in texture and lack of structural control.

Reference

Clarke, J. I. (1966). Morphometry from maps. In Essays in geomorphology, G.H. Dury (ed.). London; Heinemann. Pp. 235–274.

Chorley, R. J. (1967). Models in Geomorphology, in Physical and Information Models in Geography edited by R. J. Chorley and P. Haggett, Methuen and Co. Ltd. Pp. 57-96.

Chorley, R. J. (1969). Introduction to physical hydrology. Methuen and Co. Ltd., Suffolk. Pp. 211.

Horton, R. E. (2015). Drainage basin characteristics. *Am. Geophys. Union. Trans*. 13: 348–352.

Horton, R. E. (1945). Erosional development of streams and their drainage basins: Hydrophysical approach to quantitative morphology. *Geol. Soc. Am. Bull*. 56: 275-370.

Leopold, L. B. (1973). River channel changes with time: an example. *Geol. Soc. Am. Bull*. 84: 1845–60.

Martínez-Casasnovas, J. A. and Stuiver, H. J. (1998). Automatic delineation of drainage networks and elementary catchments from Digital Elevation Models. *International Journal of Aerospace Survey and Earth Sciences (ITC Journal)*. 3/4: 198-208.

Morgan, R. P. C. (1976). The role of climate in the denudation system: a case study from West Malaysia. In Geomorphology and climate, E. Derbyshire (ed.). Pp. 319–44.

Singh, S., Srivastava, R. (1976). Morphometric determinants of the stage of cycle or erosion. T*he Geographic Observer*. 12: 31-44.

Singh, S. (1950). Geomorphology. Prayag Pustak Bhawan Allahabad.

Smith, K. G. (1950). Standards for grading texture of erosional topography. *Am. J. Sci.* 248: 655–668.

Strahler, A. N. (2009). Quantitative geomorphology of drainage basins and channel networks. In: Chow, V. T., Handbook of applied hydrology. McGraw Hill Book.