Jour. Agric. Physics, Vol. 2, No. 1, pp. 52-56 (2002)

Morphometric Analysis of a Watershed Using Remote Sensing and GIS – A Case Study

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ABSTRACT

A study was carried out on the quantitative evaluation of morphometric parameters of a watershed in western Rajasthan. The drainage map of the area was generated through visual interpretation of FCC image of IRS-1A/1B LISS-II on a base map prepared from SOI toposheet (1 50,000 scale) Stream characteristics include number and length of streams of different orders, drainage density, drainage frequency, bifurcation ratio and texture ratio The shape parameters are form factor, circularity and elongation ratio and shape index High value of drainage density implies the impermeable subsurface material, sparse vegetation and high relief, which are mainly the characteristics of the eastern part of the watershed A very high texture ratio indicates high runoff and erosion potential of the area Bifurcation, circularity and elongation ratio values indicate elongated to nearly circular watershed shape A high form factor value is suggestive of high peak flows of shorter duration The study proves that morphometric analysis is a viable method of characterizing the hydrological response behaviour of the watershed. It is also well understood that satellite remote sensing is emerging as the most effective, timesaving and accurate technique or tool for morphometric analysis of a basin/ watershed till date

Key words *Morphometry, Drainage, Watershed, Remote sensing, GIS.*

Watershed, as a basic manageable geo-hydrological unit, in which rainfall occurring on the highest point (ridge point) drains at a common point, can be seen as a basic erosional landscape element where land and water resources interact in a predictable manner (Biswas *et al.*, 1999). Characterization of rainfall-runoff behaviour of a watershed should be the very primary study in any watershed management programme. Quantitative analysis of drainage system (morphometric analysis) is an important aspect of characterization of watersheds/ drainage basins. This method was first developed by Horton (1945) and modified by Strahler (1964, 1969). Though conventional methods were successfully applied in characterization of drainage basins (Choubey and Shankaranarayan, 1990, Ghosh, 1989, Sharma *et al.*, 1989, Strahler, 1957), but these were found to be time consuming and difficult, particularly for large areas. Recently, Satellite Remote Sensing with its synoptic view coupled with GIS has evolved as unique tool for quantitative description of watershed/ drainage basins. This paper is based on a study conducted on the quantitative evaluation of morphometric parameters of Birantiya Kalan watershed in western Rajasthan, in order to characterize the hydrological response behaviour of the watershed for suitable soil and water conservation management alternatives.

Materials and Methods

Birantiya Kalan watershed with an area of 90 19 km^2, is situated in the Raipur block of Pali district, Rajasthan and is characterized by low to medium hills in the eastern half and a vast alluvial plain in the west (Fig. 1). The area is a subtropical, semi-arid terrain and characterized by dry hot summer and dry cold winter. Mean annual rainfall has been 472 mm mostly occuring in July-September. According to 'Atlas of Rajasthan', the study area falls in the IIB zone, which is named as the "Transitional plain of Luni Basin". It is also reported that the study area falls under region 2 of the agro-ecological map (NBSS Publ.24).

Morphometry represents the measurement and analysis of landform characteristics. Watershed/ Drainage basin is considered as the most satisfactory basic unit for morphometric analysis because it is an areal unit defined by characteristics that can be measured quantitatively, thus providing an objective basis for analyzing and classification (McCullagh, 1978). Quantitative analysis of watershed requires various drainage and shape parameters need to be measured. For this purpose, the drainage map of the area was prepared through visual interpretation of FCC image of IRS-1A/1B LISS-II on a base map prepared from SOI topomap (1: 50,000 scale) coupled with ground checks. The

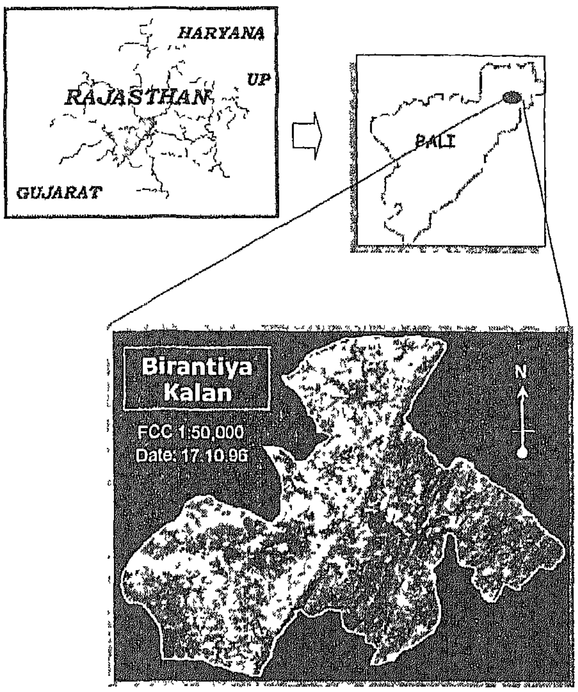

Fig. 1. Index map of the watershed under study

drainage lines were digitized, topology was generated and an item, 'order' was added to store the drainage order values. In-house GEOMORSIS package (RRSSC-J, ISRO/DOS) was used for semi-automatic drainage ordering by Strahler method. Care was taken for continuity of the drainage network. The feature attribute table was stored as ARC Attribute Table (AAT). The morphometric parameters are calculated using various data analysis operations in ARC/INFO GIS.

Results and Discussion

Morphometric Analysis

The method of quantitative analysis of watersheds or drainage basins was developed by Horton (1945) and was further modified by Strahler (1964). Good correlations were established between the morphometric and the hydrologic characters of the watershed (Singh and Ghose, 1973; Singh *et al.*, 1977; Singh and Sharma, 1977). These were found to be useful for integrated developmental planning of watershed or basin. The use of remote sensing made the task more speedy and reliable. The watershed morphometry of the study area has been worked out in an attempt to develop relationships between watershed parameters and runoff characteristics, basin shape, sub-soil materials, infiltration and relief characteristics.

The morphometric parameters of the watershed under study and their salient features are listed in Table 1.

Table 1 Morphometric parameters of the watershed under study

	Watershed morphometry parameters	Values
1.	Area, A	90.19 km^2
2.	Perimeter, P	60.66 km
3.	Maximum Length of the watershed, L_m	15.02 km
4.	Average Length of the watershed, L_b	9.97 km
5.	Total Stream Length, L	201.11 km
6.	Total Stream No., N	248
7.	Relief, ΔH	120 m
8.	Bifurcation Ratio, R_b	3.98
9.	Texture Ratio, N_1/P	1.49
10.	Drainage Density, D_d	2.26 km km^{-2}
11.	Drainage /Stream Frequency D_f	2.78 km^{-2}
12.	Constant of Channel Maintenance, $1/D_d$	0.44 km^2 km^{-1}
13.	Form Factor, R_f	0.89
14.	Circularity Ratio, R_c	0.304
15.	Elongation Ratio, R_e	0.709
16.	Shape Index, SI	1.16
17.	Ruggedness No.	0.272

Drainage network characteristics

Drainage patterns, total stream length, drainage density, bifurcation ratio, and first order stream frequency influence the hydrological behaviour of a watershed. The drainage pattern of the watershed with stream ordering is presented in the map (Fig. 2).

Drainage pattern of an area refers to the design of the stream courses and their tributaries. The slope of the land, lithology and structure influences it. The drainage pattern of the study area was

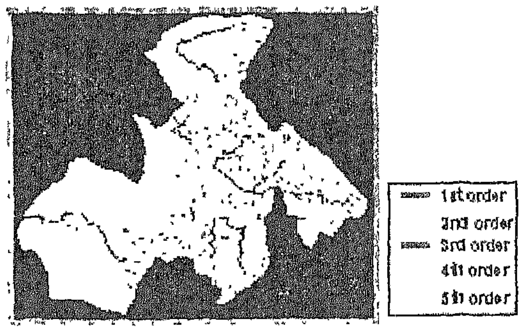

Fig 2. Drainage map of the study area

found to be of medium texture. It can be interpreted that the permeability is low to medium. The braided type drainage pattern of the area is the indication of moderate to severe erosion hazards.

Stream length and stream order

Length of the stream of an order is the indicative of the contributing area of the watershed of that order. The mean length of a particular order (L_n) is computed by dividing cumulative stream length by numbers of segments of that order (N_n). The cumulative and mean stream lengths of different orders are presented in Table 2. The first order stream length is 120.42 km, which is about 60 per cent of the total stream length. Number of first order stream is found to be maximum which indicates that this order contributes maximum to the overall drainage and hydrological behaviour of the watershed. Total stream length is calculated as 201.11 km. The plot of logarithm of stream length along ordinate, and stream order along abscissa for the watershed gave a straight-line fit and the plot on a semi-logarithm paper (number of streams on the logarithm scale and the order on the linear scale) is nearly a straight line (Fig.3a & 3b). To establish the relation between the stream order (n) and the cumulative stream length ($1^n \Sigma_1 n^n \Sigma L_n$), the logarithm of cumulative stream length was plotted against the stream order, a nearly straight line is obtained (Fig 4). This straight-line fit indicates that the ratio between Lı and u is almost constant throughout the successive order of the watershed and suggests that geometrical similarity be preserved in the watershed of increasing order. This observation was found to be in close proximity to the observation by Nautiyal (1994).

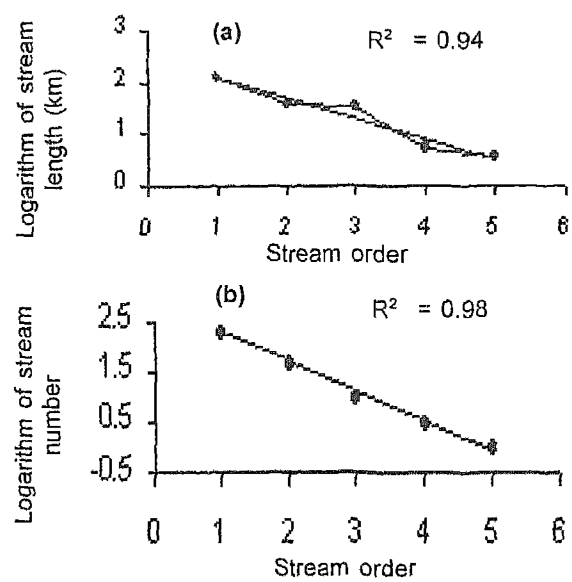

Fig. 3. (a) Logarithm of stream length and (b) steam number as a function of stream order

Table 2. Length and number of streams of different orders

Stream order	Stream length (km)	Cumulative stream length (km)	Number of streams	Mean stream length (km)
1	120.42	120.42	187	0.64
2	39.41	159.83	47	0.84
3	32.49	192.32	10	3.25
4	5.19	197.51	3	1.73
5	3.60	201.11	1	3.60
Total	201.11		248	

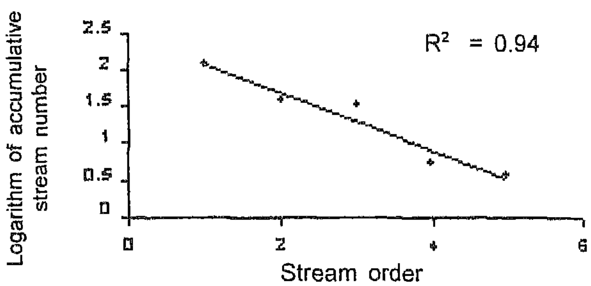

Fig. 4. Logarithm of cumulative stream number vs. stream order

Drainage density

Drainage density is a measure of the length of the stream segment per unit area. The drainage density is affected by the factors that control characteristic length of the watershed. Higher drainage density (2.26 km/km^2) is associated with the basin of impermeable subsurface material, sparse vegetation and high relief, which are the characteristics of the eastern part of the watershed. Drainage density as well as stream frequency and infiltration number (drainage density*stream frequency) is low in the western half of the watershed, which indicates a permeable soil cover with good vegetation and low relief. Constant of channel maintenance is the inverse of drainage density, the value of which is 0.44. It is a measure of the area required to maintain each unit length of a stream (Schumm, 1956; Singh, 1995). Texture ratio of the watershed was found to be 1.49, which is indeed a high value. This high value clearly indicates a high runoff from the area.

Drainage density and texture ratio can be considered as two indices of erosion intensity (Morgan, 1986). High values of drainage density and texture ratio indicate high runoff and erosion potential of the basin area.

Bifurcation ratio

This term is used to express the ratio of the number of streams of any given order to the number of streams of the next higher order. The medium value of bifurcation ratio is 3.98, which indicates an intermediate flood discharge between extended peak and a sharp peak. It also implies greater number of first order channels. This value also indicates that the watershed has suffered less structural disturbances and the drainage pattern has not been distorted because of structural disturbances (Strahler, 1964; CGWB, 1992). The first order stream frequency contributes largely in the watershed. The bifurcation ratio of around 4 also indicates that the streams flow on rocks of uniform resistance to erosion. The bifurcation value is indicative of shape of the basin also. The medium value says about *extended circular shape of the watershed.*

The average value of the bifurcation ratio can also be calculated by determining the slope of the regression lone of logarithm of stream number (ordinate) and stream order (Fig.3b). The regression coefficient is identical with the logarithm of the bifurcation ratio.

Basin shape factors

Form factor, circularity ratio and elongation ratio can be used for evaluation of stream flow characteristics of a drainage basin. Form factor is a good indicator of outline form of a drainage basin, the value of which is 0.89. This high form factor value indicates that the watershed has high peak flows for shorter duration. The circularity ratio is computed as 0.304 and the elongation ratio as calculated is 0.709. These values indicate elongated to nearly circular basin shape, which may give rise to elongated peak flow.

Higher drainage density, stream frequency and infiltration number are associated with impermeable subsurface material, sparse vegetation and high relief which is mainly the characteristics of the eastern half of the watershed. These indicate a relatively high runoff potential of the watershed. Medium value of bifurcation ratio implies that the watershed has been less affected by structural disturbances. High form factor value suggests that the watershed has high peak flows for shorter duration. The elongation ratio computed indicates elongated to nearly circular shape of the watershed. It can be concluded that morphometric analysis is a viable method of characterizing the hydrological response behaviour of the watershed. It is also well understood that satellite remote sensing is emerging as the most effective, time saving and accurate technique or tool for morphometric analysis of a basin/ watershed till date.

Acknowledgement

The first author is grateful to Dr. J. R. Sharma, Head and Project Director, Regional Remote Sensing Service Centre, Jodhpur for providing the required facilities. Thanks are due to the Scientists and Technical personnel of the Centre for their very kind help and encouragement. The support and encouragement from the Professor, Head and other Scientists of the Division of Agricultural Physics is duly acknowledged

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