Bulletin of Environment, Pharmacology and Life Sciences
Bull. Env. Pharmacol. Life Sci., Vol 9[3] February 2020 : 08-16

Online ISSN 2277-1808
Journal's URL:http://www.bepls.com
CODEN: BEPLAD
Global Impact Factor 0.876
Universal Impact Factor 0.9804
NAAS Rating 4.95

ORIGINAL ARTICLE **OPEN ACCESS**

Assessment of Morphometric Parameter Using Remote Sensing and GIS: A Case Study

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ABSTRACT
The knowledge about geomorphological properties of any watershed play a distinctive role in response to hydrological behavior such as runoff components, erosion of soil, sediment delivery ratio, etc. Availability of water is the distinguishing factors for prompt development and sustainability of lives. A number of various characteristics responsible for regulation of amount of precipitation in the form of runoff at the outlet in any watershed. In the present study, The qualitative analysis of the morphometric characteristics of Madar watershed in Udaipur district have been computed using satellite data, toposheet in Arc GIS interface. Total geographical area of 35.239 km² were obtained for the study area.The digital elevation map (DEM) of the study area showed that elevation varies from 629 m to 1065 m representing hilly region. Various linear, areal and relief aspect properties were examined using data obtained from geographic information system (GIS). Relation among stream order with logarithm of number of streams and logarithm of cumulative stream length, were also analyzed and found in good aggregation with each other. The results obtained showed that the study area need to be treated with some conservation measures and water harvesting structures as properties showed that influence of sediment loss is more and less conservation of water.
Keywords: *Geographical Information System; Morphometric analysis; Remote Sensing; DEM; Drainage Map*

Received 29.12.2019 Revised 06.01.2020 Accepted 26.01.2020

INTRODUCTION

To justify the laws of various hydrologic processes in a watershed, hydrologists and scientists have come across many challenges, particularly in case of an ungauged watershed or remotest area where hydrological data are rarely available. Many empirical and approximate formulas have been developed to relate rainfall with runoff at the outlet. In case of ungauged basins, it has been endeavored for researchers and other earth scientists to evaluate and simulate geomorphological parameters of watershed and naturally shaped streams of different orders to its hydrological behavior by reconnaissance survey or other traditional methods although it is very time consuming and tedious work.

Drainage characteristics are the most important units of fluvial and consequently an efficient geometric characteristics of watershed. It consists of the topology of the stream pattern, and behavior of drainage pattern, texture, shape, and relief [1]. The drainage characteristics is that physical properties of watershed which is responsible for runoff generation and hence sediment losses to the watershed. The quantitative assessment of basin morphometry using drainage characteristics has been extending to depicts the inter-relationships between characteristics of watershed in response to resulting runoff and sediment yields.

In order to giving practical approach to the systematic, accurate, reasonable and approach to planning of sustainable watershed management and development, delineation of a watershed boundary is a pre-requisite. Sarangi *et al.*[15] studied the performance watershed delineation, and assessment of stream pattern from Digital Elevation Models (DEMs) using GIS interfaces. Khan *et al.* [6]analyzed supervised and automated delineation in the Upper Indus Basin (UIB), Pakistan. It depicted that dissimilarity between various estimates diagnoses contrast in watershed delineation using initial extent of the DEM and the uncontrolled effect of filling of the DEM. Freitas *et al.* [2] efficiently define terrain models using

Triangulated Irregular Networks (TIN) from which drainage pattern, and other important watershed parameters has been extracted with their tectonic applications in hydrology. The description of drainage basin characteristics is proposed by R.E. Horton [4] in 1932 which is a great step forward to watershed management. Morphometric assessment of the eight mini-watersheds were studied by Thakkar and Dhiman [20]and they examined prioritize eight sub-watershed of Mohr watershed situated in Gujarat, India using remote sensing and GIS techniques. Rudraiah *et al.*[14] assessed the various morphometric characteristic of a part of Kagna river in Karnataka, India using Arc Info and ArcView GIS software. Furthermore, Sreedevi *et al.* [18] studied morphometric analysis and their influence on hydrological behaviour using satellite for obtaining Digital Elevation Model (DEM), delineation of watershed, aspect grid and slope mapsat Wailapalli watershed, India. The thematic map was prepared using 'GIS' interface for computation of various morphometric parameters. For lower gostani river basin (LGRB) area in Andhra Pradesh, assessment of morphological characteristics were analyszed using 'GIS' and image processing techniques [12]. Kanth and Hassan [5]studied the quantitative assessment of morphometric parameters which is primary account in watershed prioritization for watershed, planning of soil and water conservation measures for the watershed. Norini *et al.* [10] studied that alluvial fans using DEM in GIS interface are prominent geomorphic features available in almost all global climates on Earth, and also found on Mars.

Considering all aspects, an endeavor has been made to examine the morphometric assessment of the Madar watershed.

MATERIALS AND METHODS

The study area i.e. Madar watershed is located in Bargaon Tehsil in Udaipur District which is Southern part of Rajasthan, India. The study area lies in between 73⁰35' to 73⁰36' E longitude and24⁰40' to 24⁰42' N latitude. It falls under agro-climatic zone-IV A of Rajasthan i.e. "Subhumid Southern Plains of the Aravalli hills". The average annual rainfall' received 607 mm mostly during monsoon months of June to September. The variation of temperature of the area in the range between 19-48ºCduring summer while the temperature ranges between 3.2 to 28.90 ºC during winter. Udaipur district of Rajasthan is a part of the peninsular region and hence possesses peninsular characteristics. Archean rock system are mainly found in the study area. The main rock formations are phyllites, schist, and quartzite. The total watershed area is about 3001.90 ha. The Madar watershed consisting of undulating uplands fields and hills. The location map of the study area is shown in Fig. 1.

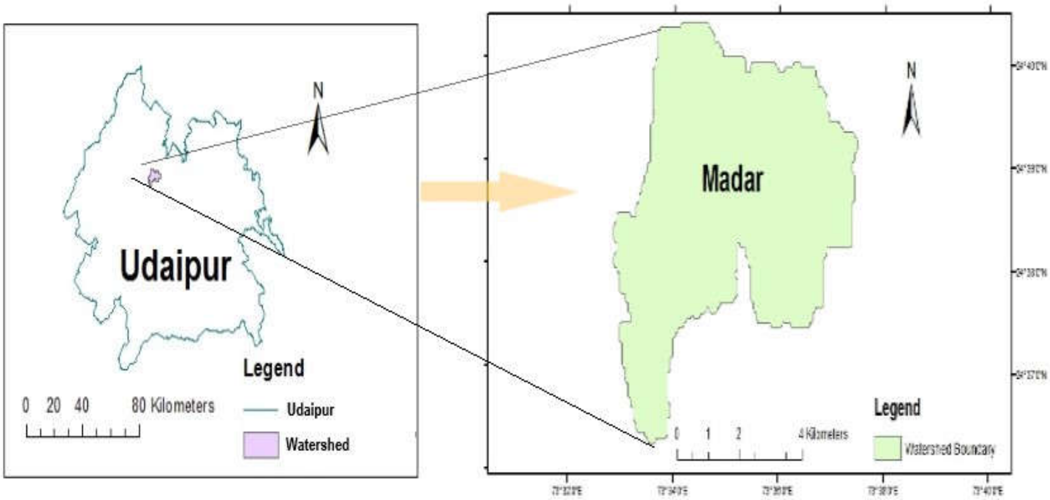

Fig.1. Location of the study area

Methodology

Watershed is an automated delineated in ArcGIS 10.1 interface using 'SRTM' which is remote sensed satellite data. The 'SRTM' data were used to obtain digital elevation model and further delineation of watershed in ArcGIS interface. The output name given to the extracted watershed delineated DEM file as*madar_dem.* The DEM file obtained also gives the variations of elevation in watershed. Atoposheet which was obtained from Panchayat office, Udaipur was also for delineation of watershed. The scanned toposheet was georeferenced in ArcGIS interface and was used for validating the delineation of watershed by above method and creating a shape file for further analysis. The georeferenced toposheet were also used for extracting drainage pattern of the watershed. The streams were digitized using 'editors tool' in

GIS interface with the help of toposheet and obtained drainage map of the study area. From drainage map obtained, number of streams with their order and length were analyzed. Further, the drainage map is also obtained using DEM file (*madar_dem*). The procedure given below is followed for drainage pattern extraction using DEM file in ArcGIS interface for geomorphology analysis.

Fill

The spatial analyst tool in arc tool box, the hydrology subtool consists 'fill' element in which working directory consider DEM file i.e. *madar_dem* as input surface raster, and assign output raster as *madar_fill and save them*. This is mainly done to exclude warping in the DEM and hence to guide flow water to outlet.

Flow Direction

The flow direction for a given pixel is evaluated using this function. The eight directions pour point (D8) method was used to suggest the grid direction of the stream fall from that cell to his alternate neighbouring cells. Consider'fill output' i.e. *madar_fill* as the input for flow direction function, and name the output surface raster as *madar_fdr* in working directory subtool of hydrology in spatial analyst tool.

Flow Accumulation

This toolis used to compute the accumulated number of cells that are draining to any specific cell using flow direction grid. Select the file of flow direction raster(*madar_fdr)*as the input for flow accumulation raster, and assign output as *madar_fac*in the same working directory.

Stream Network

To evaluate a stream, the flow accumulation is used as input raster which gives interconnecting cells (or pixel) that drain to a individual cell. It is presumed that a stream is constituted when a certain area (threshold) drains to a certain point. This threshold value can be used to determined by the number of cells in the flow accumulation grid. Take flow accumulation raster file (*madar_fac)*as an input*,* and save the output raster as *madar_stream.*

Stream Link

For computing stream linking assign *madar_stream* as the input stream raster, along with *madar_fdr* select as the flow direction raster, and assign the output raster as *str_link*. This main function is to gives a separate number for each link or segment in the stream raster.

Stream Order

To generates stream order for watershed area 'stream order tool' was used in spatial analyst tool. Provide '*madar_stream'* filealong with flow direction file (*madar_fdr)*as the input for flow direction raster and save it as output raster as *str_order.* There are two methods available for estimating stream order, preference accordingly.

Stream to Feature

This tool is helpful to converts stream raster to a polyline feature class. Assign *madar_stream* as the input for stream raster, *madar_fdr* as input for the flow direction raster and assign the output as *stream.shp* and save it*.* When process completes, a shape file, named *stream* will be added to the map document.

The details obtained from drainage characteristics were used for geomorphological analysis.

Geomorphological Analysis

The assessment of geomorphological parameters is the standardized explanation for watershed geometry, and its stream network system to account the various linear, areal and relief aspects of drainage network of that watershed. The morphometric parameters are the leading factors which directly or indirectly affect runoff and sediment loss processes. The morphometric parameters were assessed in the form of 'linear, areal and relief aspects' for extracted drainage characteristics were calculated based on given formula presented in Table 1.

Table 1. Formula for computation of morphometric parameters.

S.No.	**Geomorphic parameters**	**Formula**	**Reference**
	Linear aspect		
1.	Stream order	Hierarchical order	[19]
2.	Stream Length (L_u)	Length of the Stream (km)	[4]
3.	Stream length Ratio (R_L)	$R_L=L_u/L_{u-1}$ where, Lu= Total number of stream segment of order'u', L_{u-1}=Stream length of next lower order.	[4]
4.	Bifurcation Ratio (R_b)	$R_b = N_u / N_{u+1}$ where, N_u=Total Number of stream segments of order 'u', N_{u+1}= Number of segments of the next higher order.	[16]
	Arial Aspect:		

5.	Drainage Density (D_d)	$D_d = L/A$ where, L=Total length of Stream, A=Area of the Watershed	[4]
6.	Stream Frequency (F_s)	$F_s = N / A$. where, N= Total number of Stream, A= Area of the Watershed.	[4]
7.	Texture ratio (T)	$T = N_1/P$. Where N_1= Total number of first order stream, P= perimeter of watershed.	[4]
8.	Form Factor (R_f)	$R_f = A / (L_b)^2$. where, A=Area of the Watershed, L_b=Maximum Basin length	[4]
9.	Circulatory ratio (R_c)	$R_c = 4\pi A/P^2$ where, R_c = Circulatory ratio A = Area of watershed, P = Perimeter	[4]
10.	Elongation ratio (R_e)	$R_e = (2/L_b)*(A/P)^{0.5}$ where, R_e = Elongation ratio A = Area of basin, L_b= Length of basin	[16]
11.	Length of overland flow (L_o)	$1/ 2D_d$ where, L_o = Length of overland flow D_d = Drainage density	
12.	Constant channel maintenance	$1/ D_d$ where, D_d=Drainage Density.	
	Relief Aspects:		
13.	Basin Relief (B_h)	Vertical Distance between the lowest and highest point of watershed.	[16]
14.	Relief Ratio (R_h)	$R_h=B_h/L_b$ where, B_h=Basin Relief, L_b= Basin length.	[16]
15.	Ruggedness number (R_n)	$R_n=B_h*D_d$; where, B_h=Basin Relief,Dd= Drainage Density.	[16]
16.	Compactness Coefficient	$Cc = 0.2821*A/P^{0.5}$ where, Cc = Compactness Coefficient A = Area of basin	

RESULTS AND DISCUSSION

This section deals with the various results found on evaluating various morphometric parameters from drainage map obtained of the Madar watershed. Morphometric parameters for Madar watersheds were computed by details about streams featuring in watershed from drainage map obtained(Table 2).A number of morphometric parameters, i.e., mean bifurcation ratio, drainage density (D_d), mean stream length, stream frequency (F_s), length of overland flow (L_o), texture ratio (T), form factor (R_f), circulatory ratio (R_c) and elongation ratio (R_e) are responsible for erosion risk assessment parameters. A direct relationship with erodibility of sediment particles depends mainly on linear parameters such as texture, drainage density,stream frequency, bifurcation ratio, and length of overland flow have, and also the erodibility increases with increase in these values[13].The shape aspects of the watershed also effects the erosion of the sediment particles, and having inverse relation with erodibility of the sediment particles. The shape parameters includes elongation ratio, form factor, compactness coefficient, circulatory ratio, basin shape etc. Lower is the value, more is the erodibility[13].

Details obtained from drainage pattern as shown in Fig. 2, and Table 2, were used for evaluation of the geomorphological analysis have discussed below.

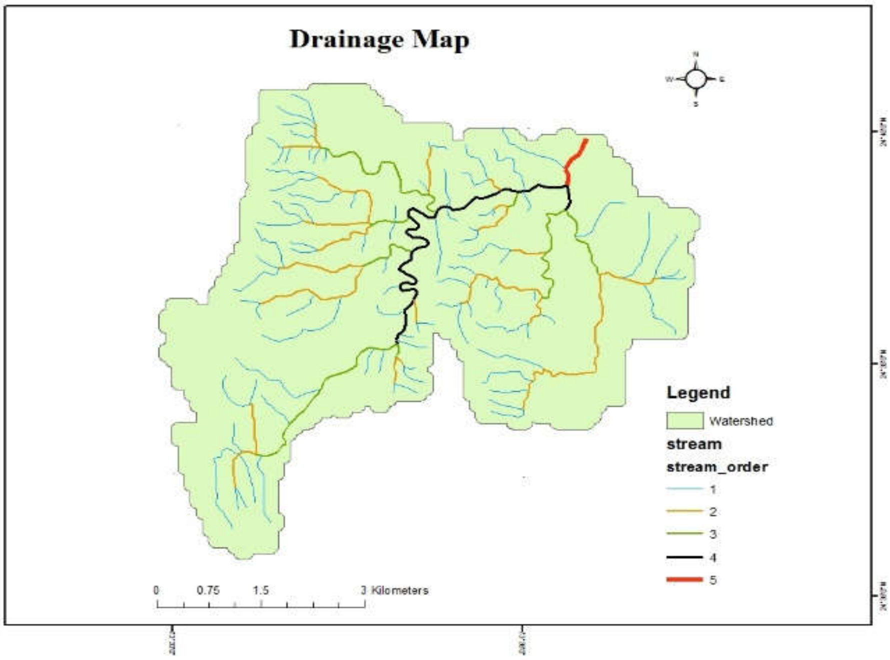

Fig. 2. Drainage Map of Watershed

Table 2. Morphological Characteristics of the Watershed under Study

S. No.	Characteristics	Estimated value
	Linear aspects	
1.	Area	30.01 km^2
2.	Perimeter	33 km
3.	No. of stream order	
	I	93
	II	50
	III	23
	IV	17
	V	1
4.	Stream length (L_u)	
	I	48.585 km
	II	19.427 km
	III	11.440 km
	IV	6.477 km
	V	0.843 km
5.	Average stream length	
	I	0.52 km
	II	0.38 km
	III	0.49 km
	IV	0.38 km
	V	0.42 km
6.	Bifurcation Ratio (R_b)	
	B.R.$_1$	1.86
	B.R.$_2$	2.17
	B.R.$_3$	11.5
	B.R.$_4$	2
	Average	4.39
7.	Stream length ratio (R_L)	
	R_{L2}	0.74
	R_{L3}	1.28
	R_{L4}	0.76
	R_{L5}	1.10
	Average	0.97
	Areal aspects	
8.	Form factor (R_f)	0.02
9.	Circulatory ratio (R_c)	0.346

10.	Elongation ratio (R_e)	0.072
11.	Texture Ratio (T)	5.121
12.	Drainage density (D_d)	2.89 km/km^2
13.	Stream frequency (Fs)	5.63 per km^2
14.	Constant of channel maintenance (C)	0.34
15.	Length of overland flow	0.17 km^2/km
	Relief aspects	
16.	Relief	629 m
17.	Relief ratio (R_r)	0.017
18.	Relative relief (R_R)	1.32 %
19.	Ruggedness number (R_N)	1.81
20.	Geometric number	0.50
21.	Compactness Coeff.(C_c)	1.70
22.	Time of concentration (T_c)	36.98 min

Linear Aspects of the watershed

It deals with the analysis various linear properties of watershed such as stream order, stream number, bifurcation ratio and stream length ratio. The watershed was found to be 5th order type and drainage pattern is dendritic[8]from the results found after the analysis. The numbers of stream in watershed 1st, 2nd, 3rd, 4th and 5th order is 93, 50,23, 17 and 2 respectively and their corresponding lengths are 48.58 km, 19.42 km, 11.44 km, 6.47 km and 0.84 km respectively. Generally, the average length of any stream of the particular order increases with the increase in the stream order. It is also found that the average length of a stream of a given order is greater than the immediate lower order but less than that of the next higher order which is confirmation of the property of the streams length corresponding with their order. Another important property like bifurcation ratio (R_b) deals with geological and tectonic characteristics of the watershed computed as 4.39 for the Madar watershed[4]. This value of R_b depicts that the study area has undergo less structural distortion, and the drainage pattern has not been contort by structural disturbance. The average stream length ratio estimated is 0.97 and RL_1, RL_2, RL_3, and RL_4 are 0.74, 1.28, 0.76 and 1.10 respectively which showed that length ratio for watershed tends to vary throughout the sequential orders of stream segments.

Areal Aspects of Watershed

Under this perspective of morphometric analysis, the study depicts the descriptive arrangement of area components mostly shape of the watershed which interferes with peak flow for watershed and flood hydrograph generation. Although, the shape of basin quantified from 'form factors' which is a dimensionless property. As the value of 'form factors' is low, the watershed will be more elongated.

The high peak has been obtained for flows of shorter duration to reach outlet along with a high value of form factor, and vice-versa. Circulatory ratio (R_c) of a watershed is influenced by the geological structures, length of streams, land use/land cover, perimeter, area, relief,and slope of the basin. Generally, low relief region obtained where the value of R_c is closed to the value1, however values in the range 0.6–0.8 are related with high relief region, and steep ground slope [16].Referring Table 2, it shows that the value for form factor (R_f), circulatory ratio (R_c) and elongation ratio (R_e) are 0.02, 0.34 and 0.072 respectively. Therefore, greater value of the circulatory ratio than elongation ratio results in circular formation of watershed than elongation.

Drainage density, and stream frequency are another distinguishing features of watershed. The factors such as resistance to weathering, land use/land cover dynamics, permeability of rock formation, climatic, etc has been influence on drainage density and hence stream frequency. In general, low value of 'D_d' found in the watershed having highly permeable sub-surface material along with good vegetative cover, and low relief in results to less runoff generation, whereas, high values of D_d assign to the watershed of weak, impermeable sub-surface material, scarce vegetation and hilly relief results into quick runoff generation[9].

The value of 'D_d' for Madar watershed is 2.89 km/km^2 indicates the closeness of spacing of stream channels. The stream frequency associates with permeability, infiltration capability and relief of watershed. The value of stream frequency is 5.63 per km^{2}depicts that the increase in stream density along with increase in drainage density. Furthermore, related to 'D_d' another morphologic property of drainage basin is 'constant of channel maintenance' which is inverse of 'D_d' and found to be 0.34 km^2/ km for this study area. The value indicates that the number of square meters of watershed surface needed to maintain one linear meter of channel.

Relief Aspects of watershed

Under this perspective, it had been seen that areas with high values of relief ratios depict high reliefs and steep slopes. Low values of relief ratios reveals that the presence of resistant basement rocks in watershed, and also low degree of slope. Estimated value of relief obtained from DEM is 629 m, based on which relief ratio (R_r) and relative relief (R_R) were calculated to be 0.017 and 0.013 respectively. This is a suggestion of erosion is predominant in watershed and the watershed be regulated with adequate soil and water conservation measures. In addition to these properties, ruggedness number(R_N) and geometric number were evaluated and the values are 1.81 and 0.50 respectively. With low value of ruggedness number(R_N), it is evident that the watershed is having steep slope.

Relation between 'stream number and stream order'

According to Horton's law, the graph of logarithm of stream number on ordinate, and stream order at abscissa results in a set of points lying along a straight line. In this study, Horton's law is satisfied by using this graph for the Madar watershed which shows a straight line [7]. The correlation coefficient fromscatter plot (Fig. 3) for the watershed is 0.8975, which is evident that the watershed are in good agreement with these properties.

Relation between 'cumulative length of streams, and stream order'

The relationship among stream order and their cumulative stream lengthhad been made on logarithmic scale. The scatter plot between logarithm of cumulative length of streams on ordinate axis, and stream order at abscissa for the watershed gives a straight line fit as shown in Fig. 4. The straight line fit from the plot depicts that good aggregation between cumulative stream lengths, and the successive order of the watershed, and suggested that geometrical resemblance is sustained in watershed along increasing stream order [7,3]. It is evident that the correlation coefficient for the straight line fit for the watershed is 0.9206, which is quite satisfactory.

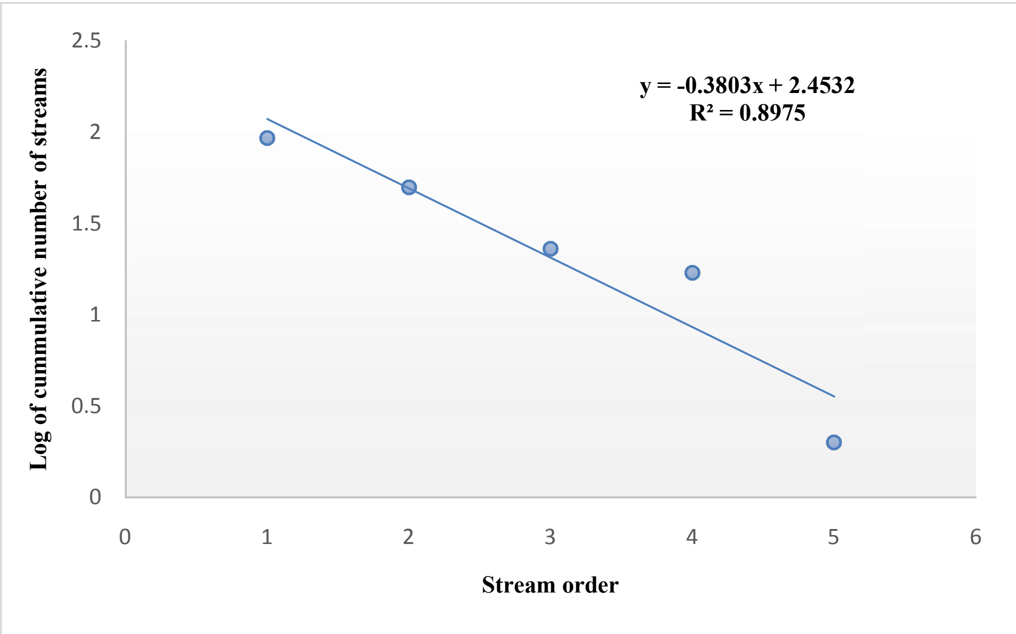

Fig. 3. Regression of logarithm of number of stream and stream order

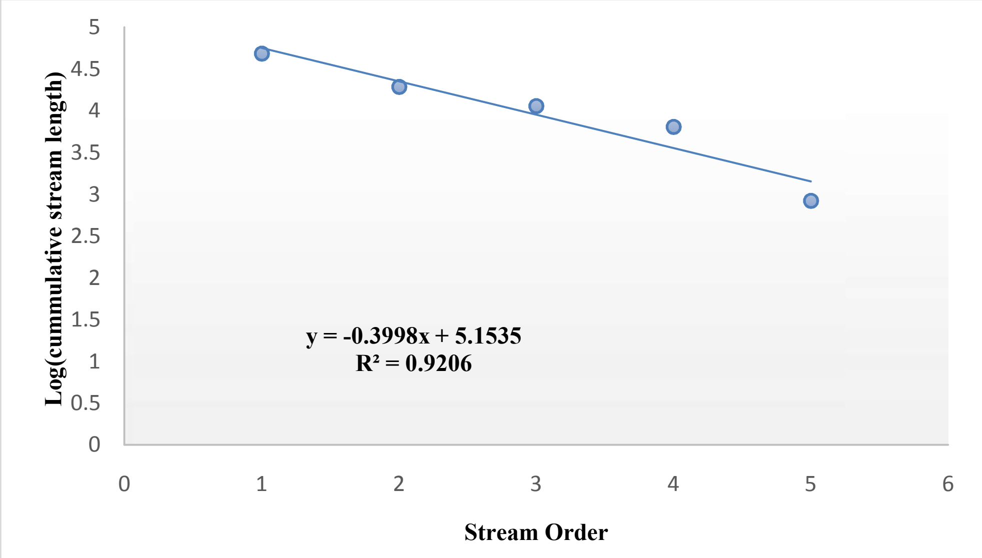

Fig.4. Regression of logarithm of cumulative stream length and stream order

CONCLUSION

The present study shows that the usefulness of GIS for morphometric analysis of Madar watershed of Udaipur District of Rajasthan. Total geographical area of 35.239 km^2 were obtained for the study area. The watershed delineation was carried out in GIS environment using DEM file. The toposheet for study area was also used for the same and creating a shape file for watershed. The stream extraction of the study area was done using digitizing the streams with the help of toposheet. Further, DEM file was also used for stream generations. The value obtained from drainage map was used for further geomorphological analysis i.e.' linear, areal and relief aspects' of watershed. The watershed was found to be 5th order type and drainage pattern is dendritic. The low value of bifurcation ratio (4.39) revealed that the watershed has suffered less structural disturbance and the drainage pattern has not been distorted by structural disturbance. The study has shown that the Madar watershed is in conformity with Horton's law of stream number and stream length. Greater value of the circulatory ratio (0.34) than elongation ratio (0.16) results in circular formation of watershed than elongation. The drainage density of watershed is 2.89 km/km^2 indicates the closeness of spacing of channels. Relief is 629 m based on which relief ratio (R_r) and relative relief (R_R) were found to be 0.017 and 0.013 respectively. With low value of ruggedness number (1.81), it is evident that watershed is having steep slope. This results is an indication of more erosion from the watershed, and reflects that the watershed be treated with appropriate soil and water conservation measures, and water harvesting structures in order to establish cultivation and livelihood in the watershed.

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CITATION OF THIS ARTICLE

M Kumar, P. K. Singh, A Kumari. Assessment of Morphometric Parameter Using Remote Sensing and GIS: A Case Study .Bull. Env. Pharmacol. Life Sci., Vol 9[3] February 2020 : 08-16