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Study of Hydrological Behaviour of Chhoti Koli Sindh Watershed using Morphometric Parameters

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Abstract: *Morphometric analysis of Chhoti Koli Sindh watershed was carried out using geospatial technique. The outcome revealed that the entire study area has dendritic drainage pattern with uniform lithology. Stream length and mean stream length data also reaffirm uniform lithology and gentle slope. The low drainage density of watershed indicates less surface runoff. The morphometric analysis also indicates that the area is least susceptible to erosion. The bifurcation ratio value is less, which indicates that the present area has not under gone any tectonic disturbance. Circulatory and elongation ratios show that the watershed has elongated shape. The estimation of form factor and circularity ratio also confirm that the basin is elongated, with permeable subsurface, compactness coefficient value shows the longest time of concentration before peak flow. Relief ratio and length of overland flow let out the fact that the rain water has more residence time on the land which provides more time to percolate the water down ward and sheet flow is also larger than peak flow which reduces the run off. Value of farm factor indicating elongated shape, suggest flat hydrograph peak for longer duration, hence in elongated basins flood management is rather easier. From the analysis of morphometric parameters the hydrologic characters may be deduced.*

***Key Word**: Linear parameter; Relief parameter; Areal parameter; Chhoti Kali Sindh watershed; GIS*

I. Introduction

The available surface and subsurface water resources are under stress to meet the growing water demand due to rapidly increasing population and urbanization. Indiscriminate utilization of natural resources have already caused depletion of resources mainly water, soil and forests. It has finally left a degraded environment and caused ecological imbalance. Conservation of these resources is needed for sustainable development. The geomorphic setting is an essential prerequisite in understanding the water-resistance characteristics of hard rocks. The rock types and geological structures play important role in developing stream network and can be better understood by quantitative morphometric analysis. The term watershed applies at a naturally occurring hydrologic unit defined by natural boundaries and characterized by similar physical, topographic and climatic conditions, it is a natural hydrological entity from which surface runoff flows to a defined drain, channel, stream or river at a particular point. Defining the watershed in analytical or quantitative term helps in understating the functional relationship with runoff of the watershed [1]. The relationship between drainage basin parameters and hydrological parameter such as runoff characteristics, basin shape, sub soil material, infiltration and relief characteristics have been described by some workers [2]. The surface water flows and its time variation depends on the morphometric parameters of a particular watershed. The nature of drainage including its pattern and density, provides an indirect clue to the hydrogeological parameters in assessment of ground water resources [3]. Morphometric parameters such as drainage density and slope characteristics provide basis for evolution of runoff and groundwater potential of the area [4]. The morphometric characteristics at the watershed scale may contain important information regarding its formation and development because all hydrologic and geomorphic processes occur within the watershed [5]. The morphometric characteristics are also useful in hydrological studies as various morphometric parameters are used in delineating the characters like runoff and infiltration which throw light on the availability of water resources and help in their planning and management at the watershed scale. In the present study various morphometric parameters have been evaluated and attempt has been made to evaluate the hydrological conditions of the basin with the help of these parameters.

II. Study Area

Present study area Chhoti Koli Sindh (CKS) watershed situated between latitude 22º55' to 23º40' N and longitude 75º43' to 76º18' E; extends over 1767 sq. km and lies in three districts viz. Ujjain (Tehsils- Ujjain, Ghatiya, Mahidpur and Tarana), Dewas (Tehsils-Dewas and Tonkkhurd) and Shajapur (Tehsils- Agar and Shajapur) of Madhya Pradesh. Study area occupies 62 percent part of Ujjain, 32 percent of Dewas and 6 percent area of Shajapur district. The location of the study area and its remote sensing image is given in Fig.1.Geologicallly, the area is composed of the rocks of Deccan trap basalts at places and these rock are extensively weathered and buried under a thick soil cover. On the other hand out crops of basalts are also exposed with their characteristic features like coloumnar jointing, spheroidal weathering, vesicular and amygdaloidal structures.

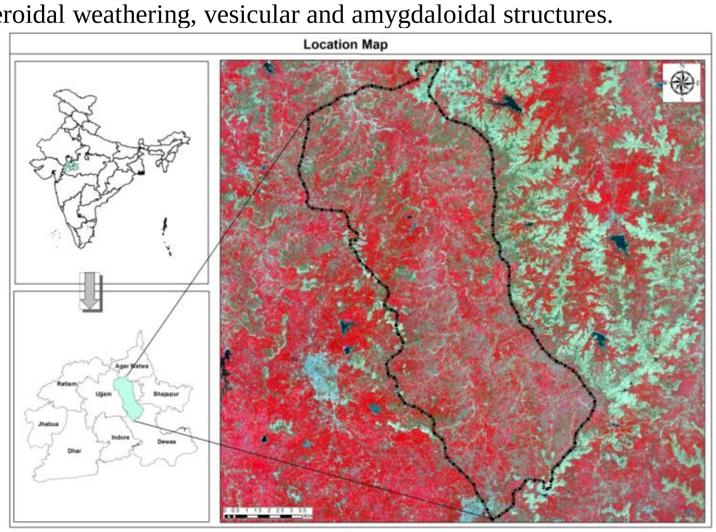

Fig.1. Showing location map of the study area

III. Methodology

In the present study, drainage map prepared with the help of quarter degree sheet (Fig.3) and finally corrected by superimposing over remotely sensed images and digitised using GIS software Arc GIS 9.1. Morphometric analysis included the measurement of linear, arial and relief parameters using the standard formulae given by [6], [7], [8] and others (Table.1) and the results obtained also tabulated (Table 2 and 3) and used to interpret the hydrology and other characteristics of the basin.

IV. Results and Discussion

4.1. Linear aspects

4.1.1 Stream Order (U); In the present area the stream orders have been worked out and summarized in Table 2 which reveals that the area goes upto VI order, total area of watershed also calculated that is 1766.48 km^2. Higher stream order associated with greater discharge, and higher velocity [9]. Further, the total number of stream segments decreases with stream order. This is referred to as Horton's' law of stream number, any deviation from this is indicative that the terrain is typified with high relief and moderately steep slope, underlain by varying lithology and probable uplift across the basin [10]. In practice, when logarithm of the number of streams of a given order, is plotted against the order, the points lie on a straight line [6], similar geometric relation was also found to operate between stream order and stream number in the watershed of this study area (Fig.2), suggesting that the whole area has uniform underlying lithology and there has been no probable uplift in the basin.

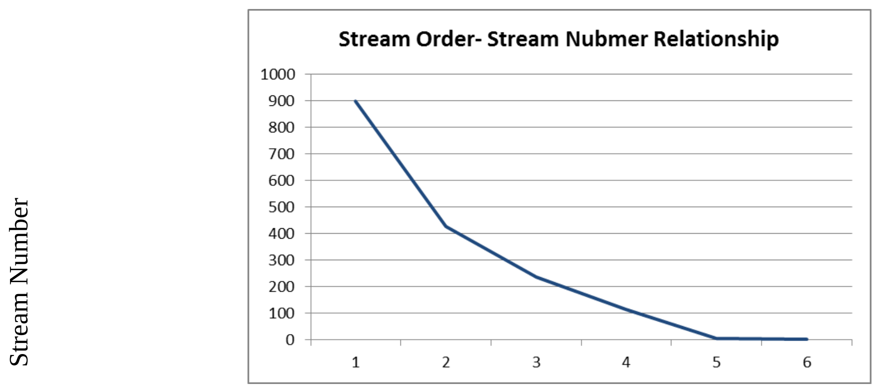

Fig. 2: Indicating an Inverse Correlation between Stream Order and Stream Number

4.1.2 Stream Length (Lu)/Mean Stream length (Lsm); The total length of individual stream segments of each order represents the stream length of that order. Stream length is the measure of length of a streams in each order, the stream length in each order increases exponentially with increasing stream order (Table 2).The total length of all the streams calculated is 1733.6 km. the dire[…]wer altitude. The length of VI order stream is just 55.15 km. It covers 2/3 length of the basin which is indicative of minimum altitude in the inner part than that of outer part of the basin. The result of stream length data also confirms that the area is underlained by uniform lithology with no basin upliftment. Value of mean stream length (Lsm) of each order for the whole watershed is shown in Table 2 these values indicate that Lsm in this watershed ranges from a minimum of 0.92 km for the I^{st} order stream to maximum of 55.15 km for 6^{th} order .Generally the value of mean stream length is greater than that of the next lower order but less than next higher order, departure from this may be due to some anomaly which is attributable to slope and topographic changes. However no such anomaly is shown in the present area hence, the topography and slope do not show large variation.

4.1.3 Bifurcation Ratio (Rb); Analysis shows that the calculated values of Rb are mostly low i.e. <3, except for one group where the ratio between 4^{th} to 5^{th} order and 5^{th} to 6^{th}, is about 19.17 and 6 respectively (Table 2), which may be due to some local variations and distortions. Besides, this all the ratios are below 3 suggesting that the area have not under gone any tectonic disturbance it is also worthy to mention that the present area is covered by the Deccan volcanic terrain which also been considered to be free from any major tectonic activity Rb does not precisely remain constant from one order to the next, because of possibility of variation in watershed geometry and lithology, but it tends to be constant through out the series, high Rb values indicate early hydrograph peak with a potential for flash flooding during the storm events [11]. The low Rb is observed, indicating delayed hydrograph peak, which ultimately enhances the rate of infiltration. In the present area the low values of bifurcation ratio also suggestive of delayed hydrograph peak and more favourd conditions for infiltration of rain water which increases the chance of occurrence of groundwater.

4.1.4 Drainage Texture (Rt); Rt is influenced by infiltration capacity [6]. Drainage texture is divided into five categories by [6] i.e.: Very Coarse (< 2), Coarse (2 to 4), Moderate (4 to 6), Fine (6 to 8), Very fine (> 8). The value of drainage texture calculated for the present watershed is 0.95 (Table 2), reveals that by and large the texture of this watershed is Very Coarse, indicative of more permeable nature of subsurface material that supports more infiltration of rain water under the surface.

4.2 Areal aspects

4.2.1 Stream Frequency/Channel Frequency (Fs); Stream frequency is the total number of streams of all orders per unit area [6]. The calculated value of Fs for the CKS watershed is 0.96 sq kms (Table 3). Stream frequency has been related to permeability, infiltration capacity and relief of watershed [13]. It is also important to note that Fs decreases as the stream number increases and higher number results more run off. Thus low value of stream frequency reflects that the watershed is covered with more vegetative cover that ultimately augments the infiltration capacity. As a result the discharge takes longer time to be on the surface due to less number of streams and that increased the rate of infiltration and reduced the runoff rates.

4.2.2 Drainage Density (Dd); Dd is a measure of the texture of the network, and indicates the balance between the erosive power of overland flow and the resistance of surface soils and rocks. The factors affecting drainage density include geology and density of vegetation. The vegetation density influenced drainage density by binding the surface layers and slow downs the rate of overland flow and stores some of the water for longer period of time. The effect of lithology on drainage density is well marked. In order to determine the drainage density, length of streams of all the orders per unit area is measured, for the present watershed calculated value of Dd is quite low i.e. 0.99 (Table 3). According to [14] in humid regions, it varies between 0.55 and 2.09 km/km^2. Generally, low value of drainage density is in regions underlained expected with highly resistant permeable material with vegetative cover and low relief. High drainage density value is observed in the regions of week and impermeable subsurface material and sparse vegetation and mountainous relief. The low Dd value in the present watershed , may be taken as indicator of permeable subsurface geological material, good vegetation and low relief which provide greater lag time to the rain water to stand over surface and leads to more infiltration of water and less runoff.

4.2.3 Texture Ratio (T); Texture ratio is one of the most important factors in the drainage morphometric analysis which depends on the underlying lithology, infiltration capacity, and relief aspect of the terrain [15]. The value of texture ratio is 4.05 (Table 3), which shows longer basin lag time that is also attributed to less runoff.

4.2.4 From Factor (Rf); The From factor value for the study area is 0.29 (Table 3), indicating that the shape of present basin is elongated, If the value of from factor is higher it reveals high peak flow for shorter time periods, opposite to it, low peak flow for longer time period attributed to low value of from factor [16]. Present study area also shows elongated shape that's why flow takes longer time period that lowers erosion and sediment transport capacities and hinders the floods because streams flow into the main stream for longer duration.

4.2.5 Elongation Ratio (Re); Generally, the value of elongation ratio (Re) varies from 0.6 to 1.0 associated with a wide variety of climate and geology. Value near 1.0 is typical for the regions of very low relief where as value from

0.6 to 0.8 are associated with high relief and steep ground slope [17]. These values can be grouped into three categories, namely, circular (>0.9), oval (0.9-0.7), and less elongated (<0.7). Re value for the present watershed is measured less than 0.30 (Table 3), which indicates that the watershed belongs to less elongated category.

4.2.6 Circularity Ratio (Rc); This parameter is defined as the ratio of the basin to the area of circle having the same circumference as the perimeter of the basin [18]. Many morphometric parameters influence Rc, such as frequency and length of slope, relief, climate, land use, land cover, and structure of the basin. Rc value for the present watershed 0.45(Table 3), indicating that the area has low relief and high permeable subsurface, permeable nature of the surface is also evidenced by the present geological conditions of the basin. As most part of the present area composed of weathered rocks and soils present over these rocks.

4.2.7 Constant of Channel Maintenance (C);In the present area value of C is 1.02 (Table 3). This is reciprocal of the drainage density (Dd) and this parameter (C) signifies how much drainage area is required to maintain a unit length of channel. Low value of this parameter indicates the presence of resistant soils, vegetation cover and plain terrain [19]. The low value of this also signifies the more permeability, thick vegetation and low relief and these characters also confirmed by the results the parameters like Rc, Re and Rf calculated for the present area.

4.2.8 Shape Factor (Rs); This parameter is similar in interpretation to circularity ratio, elongation ratio, and from factor. It discloses the circular character of the basin. The shape factor calculated for the present basin is 1.12 (Table 3), the greater the circular character of the basin, greater is the rapid response of the watershed after a storm event [20]. The value of shape factor for the CKS watershed is suggestive that the basin is elongated in shape and leads to the larger basin lag time.

4.2.9 Compactness Coefficient (Cc); Compactness coefficient expresses the relationship of a basin with that of a circular basin having the same area. A circular basin yields the shortest time of concentration before peak flow occurs in the basin. The value of the Cc equal to 1 denotes that the basin completely behaves as a circular basin. Where as the value of the Cc less than one shows the elongated nature. The value of Cc calculated for the watershed is 0.89 (Table 3), indicating the greatest deviation from the circular nature and on the basis of this parameter alone, it will have the longest time of concentration before peak flow occurs in the basin [21]. This lower value of Cc of the present watershed led to longer time of concentration to attain peak flow conditions that reduces the risk of flood.

4.2.10 Shape Index (Sw); This also known as basin shape and the rate of water and sediment yield along the length and relief of the drainage basin is largely affected by the shape. The shape index values for the present watershed is worked out; that is 3.4 as shown in Table 3, Higher value of shape index shows basin elongation and week flood discharge period. This condition also evidenced by the result of Cc value of this watershed.

4.3 Relief aspects

4.3.1 Relief Ratio (Rh);The Rh normally decreases with increase in drainage and size of the watershed. The relief ratio is a factor controlling surface runoff. Lower the relief ratio lower is the surface runoff and lower is intensity of erosion. In the study area estimated value of relief ratio is 2.06 (Table 4), indicating that the major portion of the basin has gentle slope which increases the residence time of rain water which in turn increases the infiltration rate; the analysis of slope map of present area (Fig.4)also discloses the gentle slope.

4.3.2 Length of Overland flow (Lg); This is the most important variable effecting both hydrologic and hydrographic development of drainage basins [6]. It defines the length of water over the ground before it concentrated into a channel. The value of Lg is 0.51 (Table 4), which is low value. This low value also shows that the rate of sheet flow is larger than that of peak flow.

4.3.3 Raggedness Number (Rn); Ruggedness Number indicates the structural complexity of the terrain in association with relief and drainage density. It also implies that the area is susceptible to soil erosion [22] in the present watershed, the calculated value of ruggedness number is 0.015(Table 4), which indicates that the area is least susceptible to erosion and free from structural complexity.

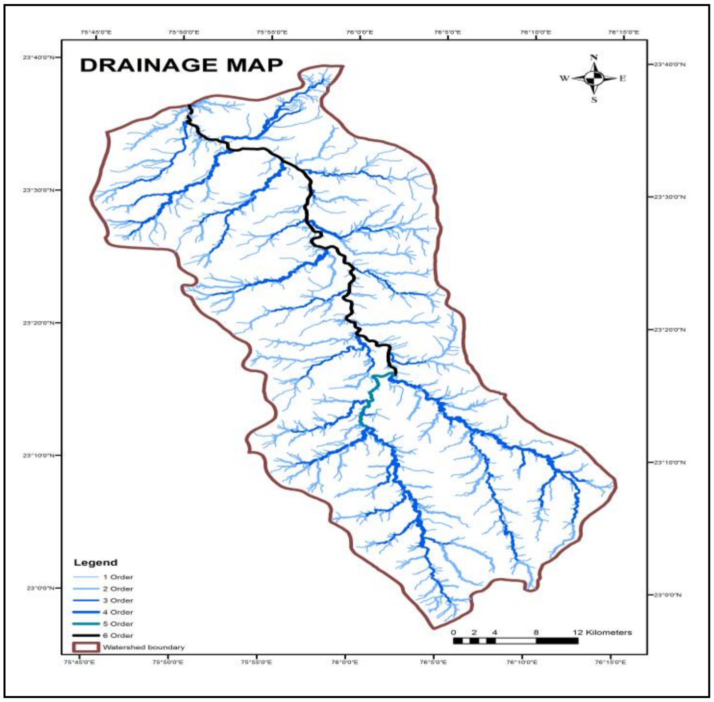

Fig.3. Drainage network map of the study area

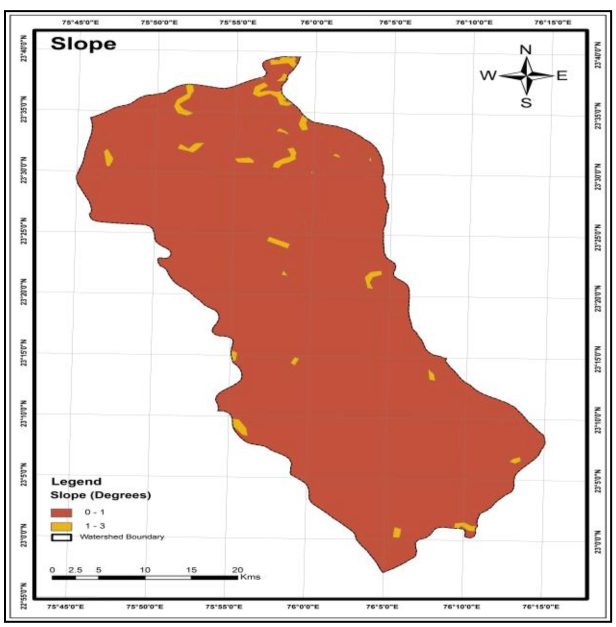

Fig.4. Slope map of the study area

Table 1: Mathematical Formulas for Computation of Morphometric Parameters

	Morphometric parameter	Formula	Reference
Linear aspects	Stream Order (u)	Hierarchicl rank	[23]
	Stream Length (Lu)	Length of the stream	[6]
	Mean Stream Length (Lsm)	Lsm = Lu/Nu Where, Lsm = Mean stream length Lu = Total Stream length of the order u Nu = Total number of stream segments of order u	[23]
	Bifurcation Ratio (Rb)	Rb = Nu/Nu+1 Where, Rb =Bifurcation ratio Nu = Total number of stream length segment of order 'u' Nu+1 = Number of stream segment of the next higher order	[8]
	Drainage Texture (Rt)	Rt= Nu /P Where, Rt= Drainage Texture Nu= Total no. of stream segment of all orders P= Perimeter of basin (Km^2)	[6]
Areal aspects	Stream Frequency (Fs)	Fs = Nu/A Where, FS= Stream frequency Nu = Total no of stream segment of all orders. A= Area of the basin (Km^2)	[6]
	Drainage Density (Dd)	Dd = Lu/A Where ,Dd = Drainage density Lu= Total stream length of all order A= Area of the basin (Km^2)	[6]
	Texture Ratio (T)	$T=N_1/P$; Where, N_1= Total no. of streams in first order; P=Perimeter of basin	[7]
	From Factor (Rf)	$Rf= A/Lb^2$; Where ;A= Area of basin; ,Lb=Basin length;	[24]
	Elongation Ratio (Re)	$Re = 2 \sqrt{(A/\pi)}/Lb$ Where, Re = Elongation ratio Pi = 'π' value i.e. 3.14 Lb = Basin length A = Area of the basin (Km^2)	[7]
	Circularity Ratio (Rc)	$Rc = 4\pi \times A/p^2$ Where Rc = Circularity Ratio π = 'π' value i.e.3.14 A = Area of the basin (Km^2) P= Squre of perimeter (Km)	[6] [18]

	Constant Channel Maintenance (C)	C=1/D; Where D= Drainage density	[7]
	Shape Factor (Rs)	Rs= Pu/Pc; Where, Pu= Perimeter of circle of watershed area; Pc=Parameter of watershed	[25]
	Compactness coefficient (Cc)	Cc=Pc/Pu: Where, Pc=Parameter of watershed; Pu= Perimeter of circle of watershed area	[26]
	Shape Index (Sw)	Sw= Lb^2/A; Where as,Lb=Basin length; A= Area of basin	[6]
Relief aspects	Relief Ratio (Rh)	Rh = H /Lb Where, Rh = Relief ratio H = Total relief (relative relief) of the basin in Kms. Lb = Basin length	[7]
	Length of Overland Flow (Lg)	Lg = 1/D×2 Where, Lg = Length of overland flow D = Drainage density	[6]
	Ruggedness Number (HD)	HD = H×Dd Where, HD = Ruggedness number H = Basin relief Dd = Drainage density	[8]
	Basin Relief (HG)	HG = H_1-H_2 Where, HG = Basin relief in meters H_1 = Highest elevation within the basin in meters H_2 = Lowest elevation within the basin in meters	[8]

Table 2. Values of Linear aspects calculated for the present watershed

Stream order	No. of Stream	Stream length	Mean Stream length	Rb =Nu/Nu+1	Bifurcation Ratio	Drainage Texture
I	900	830.23	0.92	I/II	2.11	0.95
II	426	444.64	1.04	II/III	1.80	
III	237	257.29	1.09	III/IV	2.06	
IV	115	134.87	1.17	IV/V	19.17	
V	6	11.42	1.90	V/VI	6.00	
VI	1	55.15	55.15			
Total	1685	1733.6				

Table 3. Values of Aerial aspects calculated for the present watershed

S.No.	Parameters	Watershed
1	Area (km^2)	1766.48
2	Stream frequency (Fs)	0.96
3	Drainage density (Dd)	0.99
4	Texture ratio (T)	4.05
5	Form factor (Ff)	0.29
6	Elongation ratio (Re)	0.3
7	Circularity ratio (Rc)	0.45
8	Constant channel maintenance	1.02
9	Shape factor (Rs)	1.12
10	Compactness coefficient (Cc)	0.89
11	Shape index (Sw)	3.4

Table 4. Values of Relief aspects calculated for the present watershed

S.No.	Parameters	Watershed
1	Basin relief	168
2	Relief ratio (Rh)	2.06
3	Overload flow (L)	0.51

V. Conclusion

On the basis of the above it may be concluded that the whole study area has uniform underlying lithology there has been no probable uplift in the basin. The hydrological conditions in this watershed controlled by the geomorphology, topography, and by the presence of vegetative cover. The value of bifurcation ratio of the present area is below 3 (except IV/V order) this less value of bifurcation indicates that the present area is free from any tectonic disturbance. Being a Deccan volcanic terrain the present is not known for major any tectonic activity, value of Rb also show the delayed hydrograph peak, The analysis of from factor, circularity ratio and compactness coefficient suggest that the shape of basin is elongated, the major portion of the basin has gentle slope which increases the residence time of rain water on the surface and that reduces runoff with a longer sheet flow which in turn increases the infiltration of rain water. The Ruggedness number of the study area has been worked out as 0.015 indicating that the area is least susceptible to erosion. Similarly the values of texture ratio, drainage density and constant of channel maintenance worked out for the present watershed divulge that the present area has permeable sub-surface, low relief and good amount of vegetation, these parameters collectively support the rain water to stay over the surface for more duration that also reduces the runoff and augment the rate of percolation and finaly enriches augment the groundwater resources of that area.

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