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Morphometric Analysis of Bhesra Kalan Micro-watershed using Remote Sensing and GIS Technique

Chandradeep Singh Rathore, Manjeet Singh, Mahesh Kothari and K.K. Yadav

Department of Soil and Water Engineering, College of Technology and Engineering
MPUAT, Udaipur-313 001, India
E-mail: chandradeepsinghrathore4@gmail.com

Abstract: The present study has been carried out to analyse morphometric characteristics of Bhesra Kalan micro-watershed of Udaipur (Rajasthan) by using remote sensing and GIS technique. The area of the micro-watershed is 1060 ha. Bhuvan DEM data of 30 m spatial resolution and topographical maps have been utilised to analyse stream network and determine geomorphological parameters (linear, areal and relief aspects) using in the GIS environment. The drainage network of the research area came out to be dendritic and the 4th order stream observed as trunk order. The bifurcation ratio (3.24) indicates an undistorted drainage network and low structural disturbance in area. Form factor (0.227), elongation ratio (0.538) and circulatory ratio (0.276) shows elongated shape of watershed. Drainage density (2.626 km km^{-2}) implies permeable sub-surface material with sparse vegetation, mountainousrelief and coarse drainage. The value of constant of channel maintenance (0.381 km^{2}km^{-1}) shows steep slope, high surface runoff and low permeability in the watershed. The low value of relief ratio (0.052) characterises less resistant rocks in area. The ruggedness number (0.922) indicates the steep slope of the watershed. The findings of this study provide complete information about the watershed's geomorphological characteristics, which may help in watershed planning and management and explore groundwater potential.

Keywords: Morphometric characteristics, Micro-watershed, Remote sensing, GIS, Watershed planning

Morphometric analysis of streams is a vital factor for watershed characterisation (Chandniha and Kansal 2017). It is a quantitative method of defining drainage features and conveys key data about the watershed's topography, runoff, hydrogeological attributes of rock layers and geological conditions (Umrikar 2017). Geomorphic assessment of watershed is generally utilised for developing regional hydrological models to solve various watershed related problems when there is the unavailability of accessible database (Gajbhiye et al 2014). The viable management of watershed resources should be necessary objective for future strategic planning and management (Gautam and Awasthi 2020). The physical and hydrological conditions and morphometric parameters decide the reaction of a specific watershed to various hydrological processes and their behaviour (Bansode and Ajabe 2018). Geomorphic analysis of a watershed can be well understood by its drainage pattern, aerial and relief aspects, and slope of the region (Nag and Chakraborty 2003). The different geomorphological parameters including linear aspects (stream order, stream number, stream length, bifurcation ratio), areal aspects (form factor, basin shape factor, circulatory ratio, elongation ratio, drainage density, stream frequency) and relief aspects (maximum relief, relative relief, relief ratio, ruggedness number) need to be measured for morphometric analysis of watershed (Shaikh and Birajdar 2015). The geomorphological analysis of watershed using traditional methods is labour intensive, inconvenient and time-consuming (Bera et al 2018). Remote sensing and GIS (Geographical Information System) are widely acknowledged as effective geospatial tools for creating drainage maps and determining the morphometric characteristics ofwatersheds (Singhand Urmila 2012). There are several researchers and scientists who performed morphometric analysis of watershed using remote sensing and GIS (Dhabale et al 2014, Asode et al 2016, Kumar et al 2017, Rai et al 2017, Savita et al 2017, Asfaw and Workineh 2019, Siddi Raju et al 2020 and Singh et al 2020). In the present research, an attempt is made to understand the morphometric characteristics of the Bhesra Kalan micro-watershed of Udaipur (Rajasthan) using remote sensing and GIS.

MATERIAL AND METHODS

Study area: Bhesra Kalan micro-water lies in Girwa Tehsil of Udaipur district of Rajasthan, India and covers 1060 ha area and lies between 24°37'33" N to 24°39'48" N latitude and 73°45'20" E to 73°48'28" Elongitude. The watershed area covered under toposheet no. G43T14 (Fig. 1). The mean annual rainfall of the area is 662 mm. The watershed falls in the agro-climatic zone- IVA of Rajasthan, i.e. Sub-humid southern plains of Aravalli hills. The study area comprises moderately dissected hills and valleys, low dissected hills and valleys, pediment pediplain complex, water bodies and others. The maximum and minimum elevations above sea level are 865 m and 511 m, respectively.

Data and Software used: The data and software used to evaluate the geomorphological characteristics are represented in Table 1.

Morphometric analysis: Morphometric analysis is the systematic representation of watershed's geometry and its stream channel system to determine(I) Linear aspects of drainage network (stream order, stream number, bifurcation ratio, stream length, stream length ratio) (II) Areal aspects of watershed (form factor, basin shape factor, circulatory ratio, elongation ratio, drainage density, stream frequency, constant of channel maintenance) and (III) Relief aspects of channel network (maximum relief, relative relief, relief ratio, ruggedness number). The geomorphological parameters can be determined using DEM data as a base layer and by applying suitable operations given in the ArcMap toolbar.

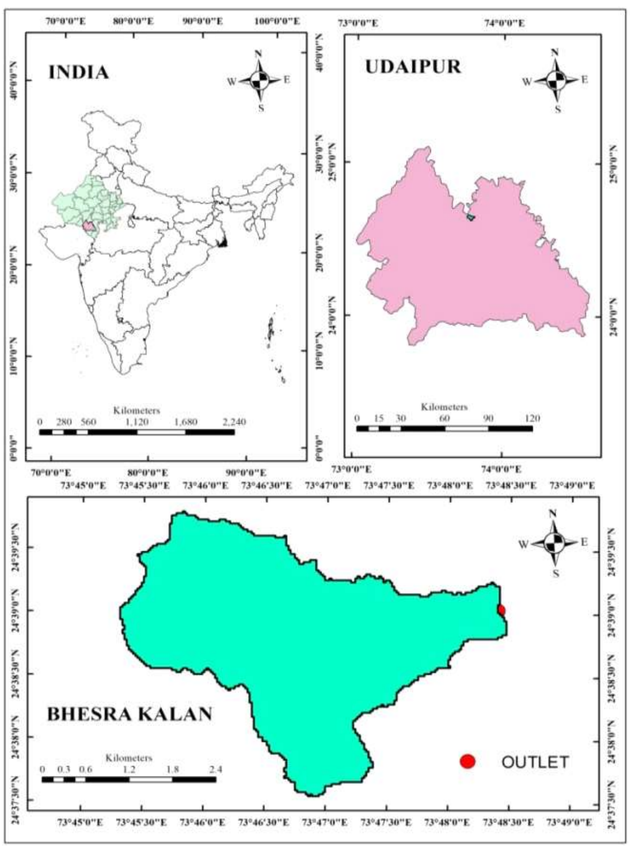

Fig. 1. Study area

Determination geomorphological characteristics: The geomorphological parameters can be determined by using DEM data as a base layer and by applying suitable operations given in the ArcMap toolbar as tools > spatial analyst tools > hydrology. The flowchart as shown in Figure 2 shows the procedures to obtain different morphometric aspects of watershed.

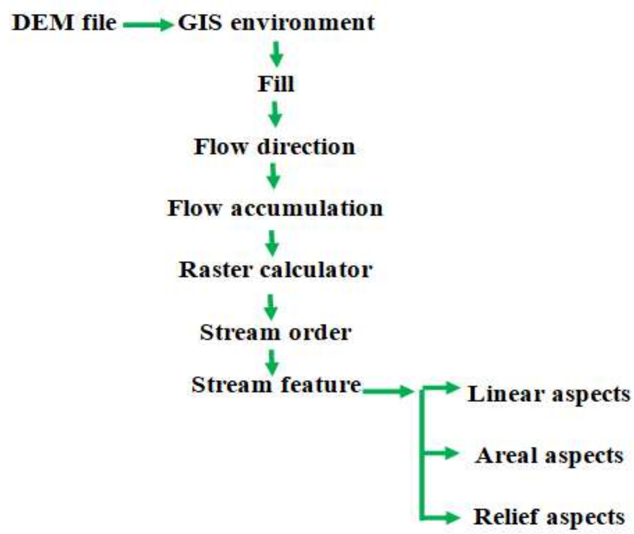

Fig. 2. Flowchart of procedure of determining geomorphological parameters

RESULTS AND DISCUSSION

After delineating the watershed, a drainage mapwas generated by applying operations from the hydrology tool available in the software toolbar (Fig. 3). The output drainage map of the study area hasdifferent stream orders (Fig. 4). Based on the measurements from the digitized drainage patterns and watershed boundary, the values of different geomorphological parameters of the watershed were calculated according to the formulas mentioned in (Table 2). The evaluated values of geomorphological characteristics are shown in Table 3.

Stream analysis: Stream analysis consists of grouping

Table 1. Software and data acquisition

Software used	Use	
ArcGIS 10.1	To delineate and determine geomorphological characteristics of the area under research.	
Data acquisition	Description	Source
Maps	Toposheet (1:50,000 scale)	Survey of India (SOI)
Remote sensing data	DEM (Digital Elevation Model)	bhuvan.nrsc.gov.in

stream segments in different orders (1st to 4th order), measuring stream lengths (14.147 km, 7.293 km, 6.191 km and 0.212 km), calculating cumulative stream length (27.843 km) and calculating mean stream lengths (0.488 km, 0.810 km, 3.096 km and 0.212 km).

Relationship between stream number/cumulative stream length and stream order/stream number: The correlation coefficient for the straight-line fit between the logarithm of stream number (ordinate) and stream order (abscissa) for the study area comes out to be 0.98, which is quite satisfactory (Fig. 5). The same kind of graph was plotted between the logarithm of cumulative stream length (ordinate) and stream order (abscissa) for verifying Horton's law (Fig. 6). It came out to be a straight line of fit with a satisfactory correlation coefficient of 0.86, which was entirely satisfactory.

Linear aspects of drainage network: The linear aspects include stream order, stream number, stream length, bifurcation ratio and stream length ratio. The study revealed that the watershed is of 4th order type with a dendrite drainage pattern (Singh 2005, Singh et al 2019). The stream numbers for the stream order 1st, 2nd, 3rd and 4th were 29, 9, 2 and 1, respectively and their corresponding stream length was

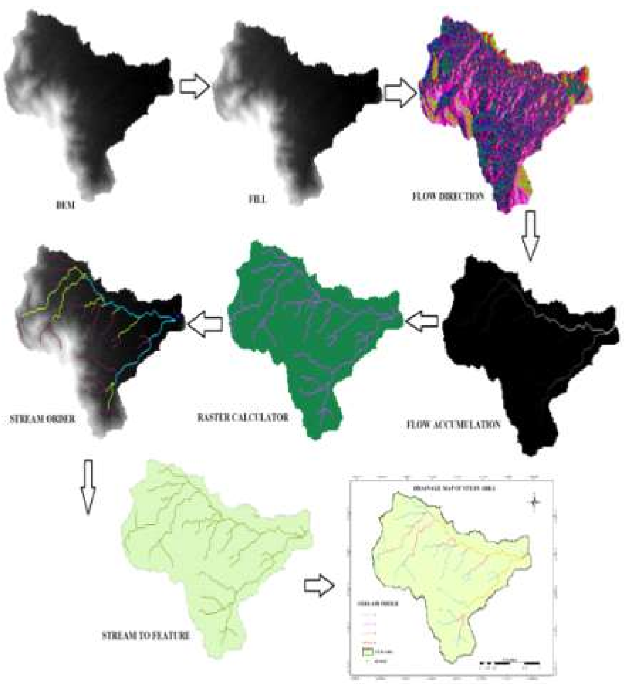

Fig. 3. Procedure of generating drainage map

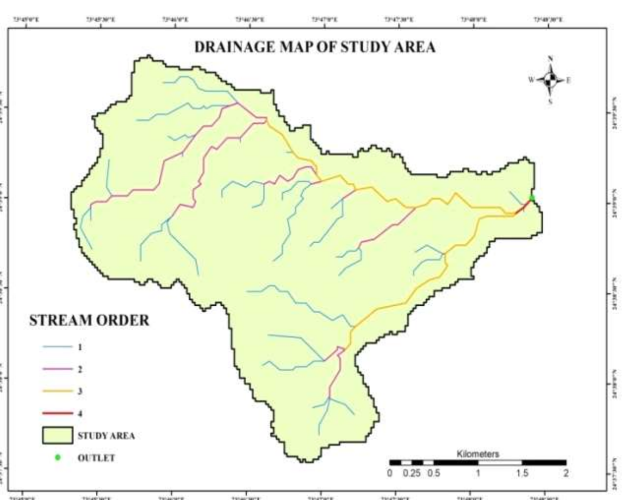

Fig. 4. Drainage map of the study area

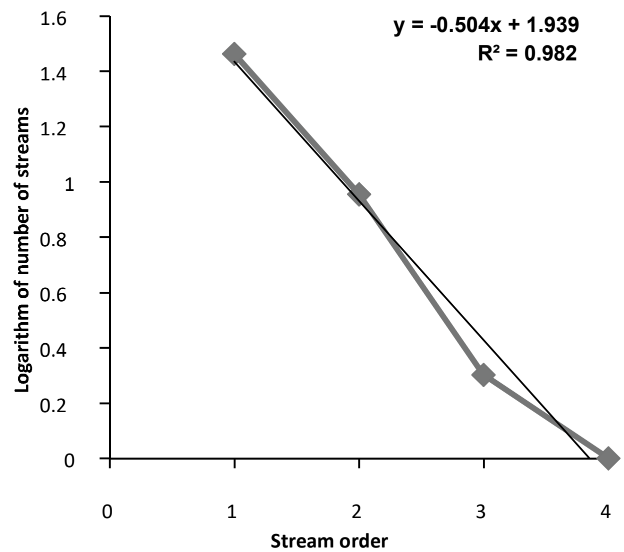

Fig. 5. Regression of logarithm of stream number and stream order

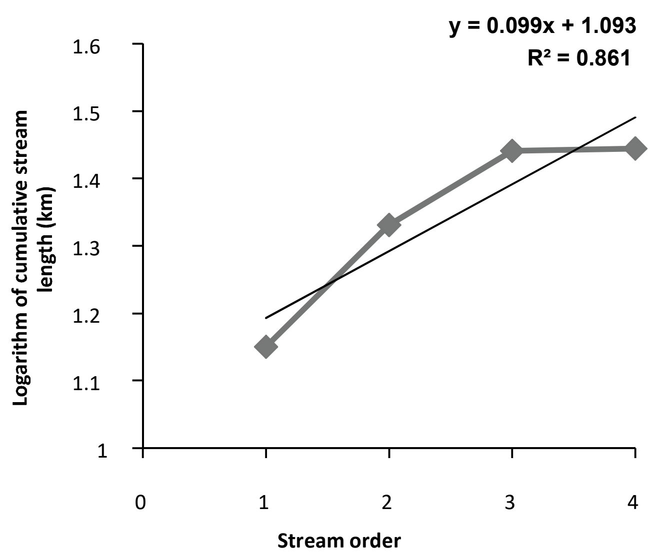

Fig. 6. Regression of logarithm of cumulative stream length and stream order

14.147, 7.293, 6.191 and 0.212 km, respectively. The bifurcation ratio (R_b) for the Bhesra Kalan micro-watershed was in the range of 2.00 to 4.50 with an average of 3.24 and this low value shows that the watershed is less affected by the structural disturbance and the drainage pattern has not been distorted (Nag and Chakraborty 2003). The elongated basins have low R_b, while the circular basins have higher R_b values, which show that the area under study is elongated. The average value of stream length ratio (R_L) for the watershed evaluated as 1.850. R_L value between the successive stream orders of the watershed varies cause of differences in slope and topographic conditions (Singh 2005). The stream length ratio has an important relationship with the basin's surface flow discharge and erosional stage (Dahiphale 2014).

Areal aspects of watershed: The areal aspects include form factor, basin shape factor, circulatory ratio, elongation ratio, drainage density, stream frequency and constant of channel maintenance. The form factor value estimated as 0.227 indicates the shape of the watershed to be elongated and hence, a flat peak flow for a longer duration can be obtained in the watershed. Flood flow of elongated basins is much easier to manage in comparison to circular basins. The

Table 2. Calculation of geomorphological parameters.

Morphometric parameter	Formula	Reference
Stream order and stream number	Hierarchical order	Strahler (1964)
Bifurcation ratio	$R_b = N_u/N_{u+1}$	Schumm (1956)
Mean stream length	$\bar{L}_u = \bar{L}_u/N_u$	Strahler (1964)
Stream length ratio	$R_L = \bar{L}_u/\bar{L}_u\text{-}1$	Horton (1945)
Form factor	$R_f = A/L^2_b$	Horton (1945)
Basin shape factor	$B_s = L^2_b/A$	Horton (1945)
Circulatory ratio	$R_c = 4\pi A/P^2$	Miller (1953)
Elongation ratio	$R_e = 2\sqrt{(A/\pi)}/L_b$	Schumm (1956)
Drainage density	$D_d = \Sigma L_u/A$	Horton (1932)
Stream frequency	$Fs = \Sigma N_u/A$	Horton (1932)
Constant of channel maintenance	$C = 1/D_d$	Schumm (1956)
Maximum watershed relief	$H = Z - z$	Strahler (1957)
Relative relief	$R_R = (H/P) * 100$	Melton (1957)
Relief ratio	$R_r = H/L_b$	Schumm (1956)
Ruggedness number	$R_N = H * D_d$	Strahler (1958)
Time of concentration	$TC = 0.0195\ L^{0.77}\ S^{-0.385}$	

Where, N_u= total no. of streams of order u, N_{u+1}= total number of streams of next higher order, Lu= length of stream of order u, $\bar{L}u$ = mean stream length of order u, $\bar{L}u_{-1}$ = stream length of its next lower order, A= area of watershed, L_b= maximum basin length, P= perimeter of watershed, $\sum L_u$= total length of streams of all orders, $\sum N_u$= total number of streams of all orders, D_d= drainage density, Z= maximum watershed relief, z= minimum watershed relief, H= maximum watershed relief, L= Length of channel reach, S= Average slope of the channel reach

Table 3. Evaluated morphometric parameters of watershed

Parameters	Calculated value
Linear aspects	
Area	10.60 km^2
Perimeter	21.95 km
No. of stream order (N_u)	
I	29
II	9
III	2
IV	1
Stream length (L_u)	
I	14.147 km
II	7.293 km
III	6.191 km
IV	0.212 km
Bifurcation ratio (R_b)	
R_{b1}	3.22
R_{b2}	4.50
R_{b3}	2.00
Average	3.24
Average stream length	
I	0.488 km
II	0.810 km
III	3.096 km
IV	0.212 km
Stream length ratio (R_L)	
R_{L1}	1.661
R_{L2}	3.820
R_{L3}	0.068
Average	1.850
Areal aspects	
Form factor (R_f)	0.227
Basin shape factor (B_s)	4.397
Circulatory ratio (R_c)	0.276
Elongation ratio (R_e)	0.538
Drainage density (D_d)	2.626 $kmkm^{-2}$
Stream frequency (F_s)	3.867 km^{-2}
Constant of channel maintenance (C)	0.381 km^2km^{-1}
Relief aspects	
Maximum watershed relief (H)	354 m
Relative relief (R_R)	1.612%
Relief ratio (R_r)	0.052
Ruggedness number (R_N)	0.922
Time of concentration (T_c)	63.32 min

calculated value of basin shape factor for the study area was 4.397, showing the elongated watershed. The runoff discharge in an elongated basin is less efficient than a circular basin (Singh et al 2021).

The circulatory ratio (R_c) value ranges from 0 to 1, in which ratio value approaching 1 shows circular shape while value approaching 0 shows elongated watershed. The ratio is more influenced by the stream length and stream frequency than slope and drainage pattern. The value of Rc for the watershed came out to be 0.276, which refers to the elongated shape of the watershed. The elongation ratio (R_e), according to its values, is categorised as circular (0.9-1.0), oval (0.8-0.9), less elongated (0.5-0.7) and more elongated (<0.5) by Strahler (1964). Strahler (1968) showed that the R_e value when approaches to 1 indicated very low relief and when value is in the range of 0.5 to 0.8, the area has strong relief and steep ground slope. The value of R_e estimated as 0.538 enable the watershed to fall in a less elongated category with strong relief and steep slope.

Drainage density is a measure of how well or poorly a watershed is drained by stream channels. A low drainage density value indicates a relatively low density of streams and thus slow response (Srivalli and Singh 2017). The low drainage density (D_d = 2.626 kmkm^{-2}) indicated that the area had permeable sub surface material with sparse vegetation, mountainous relief and coarse drainage (generally shows when value is less than 5.0).The value of stream frequency (F_s = 3.867 km^{-1}) showed that the watershed had moderately resistant sub-surface material with low infiltration and moderate runoff. The value of constant of channel maintenance (C) came out to be 0.381 km^{2}km^{-1}, which was quite low indicated area having steep slope, high surface runoff and low permeability.

Relief aspects of channel network: The relief aspects include maximum watershed relief, relief ratio, relative relief and ruggedness number. The maximum watershed relief was 354 m. The relative relief is the ratio of maximum watershed relief to the perimeter of the watershed (1.612 %).The relief ratio is estimated as 0.052. The low value of relief ratio is the characteristic feature of less resistant rocks of the area (Singh et al 2021). Ruggedness number (R_N) is a dimensionless term indicating structural complexity of the terrain. It is a measure of surface unevenness (Selvan et al 2011, Singh et al 2018). The R_N value of 0.922 for the study area show the steep slope of watershed. The time of concentration for the present study area computed as 63.32 min, which shows some barriers in the flow path and runoff takes less time in reaching the outlet from the remotest point. The morphometric analysis of the study area shows that the watershed is of elongated shape with a steep slope.

CONCLUSIONS:

The morphometric analysis of Bhesra Kalan micro-watershed was carried out to determine the watershed's linear, areal and relief aspects using Arc GIS 10.1 software. The drainage pattern of the watershed was observed as dendritic with 4th order stream as trunk order. The linear relationship between the logarithm of stream number and stream order and logarithm of cumulative stream length and stream order verified their conformity with Horton's laws (1945) with a satisfactory correlation coefficient. The low value of the bifurcation ratio showed less structural disturbance and undistorted drainage pattern in the study area. The form factor value reflected a flat peak flow for longer duration in the watershed. A comparatively higher elongation ratio than the circulatory ratio implied elongated shape of the watershed. A low drainage density indicated that the area had permeable subsurface material with sparse vegetation. The maximum watershed relief was 354 m. The relief ratio and ruggedness number showed the availability of less resistant rocks and steep slopes in the watershed. The present morphometric analysis of the study area indicates the elongated shape of the watershed with steep slopes. This study may assist the local policymakers and authorities for sustainable watershed management as well as augmenting the groundwater potential in the sub-humid to semi-arid regions.

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