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Characterisation of geomorphological features of Devasugurnala watershed at Krishna basin of Karnataka using Geographical Information System (GIS)

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ABSTRACT

The study was undertaken to estimate the geomorphological characteristic features using Geographical Information System (GIS) for Devasugurnala watershed in the Raichur district, Karnataka. Devasugurnala watershed lies in the North-Eastern Dry Zone of agro climatic set up. Watershed joins Krishna river near Devasugur village. The Devasugurnala watershed was delineated into 17 sub watersheds using Arc SWAT. The linear aspects of drainage network, aerial aspects of watershed and relief aspects of stream network were determined. The thematic maps like drainage pattern, contours, watershed boundary and Gram Panchayat were also developed for the watershed.

1. INTRODUCTION

The watershed is the basic unit of all hydrologic analysis and design. Usually a watershed is defined for a given drainage point at which analysis is being made and is referred to as the watershed "outlet". The response of a watershed to different hydrological processes and its behaviour depends upon various physiographic, hydrogeological and geomorphological parameters. Though these are watershed specific and thereby unique, the characterization of a watershed provides an idea about its behaviour. Watershed characterization involves measurement of parameters that influence the characteristic behaviour of a watershed whereas analysis aims at the critical study of these parameters to arrive at conclusions on watershed response and behaviour.

Garbrecht and Martz (1993) performed an automated extraction of channel network and sub-watershed characteristics from raster DEM by using DEDNM which is a modular to allow easy modifications and reorganisation to meet specific needs. DEDNM keeps all data in dynamic memory during execution to minimise time consuming I/O operations. It was also found that the delineated area through computerised approach is better compared to area determined by the topographical map (Guarav *et al.,* 2002). Nookaratnam *et al*. (2005) studied Sediment Yield Index model and morphometric analysis using remote sensing and GIS for positioning of check dam by prioritization of micro watersheds. Recently, Sharma *et al*. (2010) have carried out morphometric analysis of sub-watersheds of Uttala river. Arc GIS provides a multipurpose hydrologic analysis for watershed, water resource and land use. Digital Elevation Model (DEM) of 30 m resolution was used and catchment area was determined to be 475 km^2 for Wadi Al-kangar in North of Khartoum, Sudan (Mohamed *et al*., 2011). Yasmin *et al.* (2012) studied the morphometric analysis of Milli watershed and concluded that GIS technique is competent tool for analysis of morphometric features. Rao *et al.* (2013) characterised the morphology of different order streams and studied alterations in cross sections of different order streams of Mahi river in Gujarat. A study was conducted to characterize the geomorphology of watershed. The information is useful for planning and implementation of erosion control measures. In the present study, an attempt has been made to estimate the geomorphological characteristic features of Devasugurnala watershed of Raichur district of Karnataka.

2. MATERIALS AND METHODS

The study was undertaken in the Devasugurnala

watershed (Fig.1), which lies in North Eastern dry zone in the Raichur district of Karnataka. Locally, the main stream present in the watershed is called "Dodda Halla". It lies between 16°16′42″ to 16°37′68″ N Latitude and 77°04′97″ to 77°48′71″ E Longitude. The watershed drains to Krishna river near Devasugur village and join the Priyadarshini Jurala water project located near Gadwal village of Mehaboobnagar district of Andhra Pradesh.

Advance tools like Arc GIS and Arc SWAT were used to delineate the Devasugurnala watershed boundary of the watershed. The watershed is coming under 56H/3, H/4, H/7 and H/8 toposheets of 1:50,000 scale and these were obtained from Survey of India (SoI), Bangalore. The geomorphological analysis is the systematic description of watershed's geometry and its stream system to measure the linear aspects of drainage network, aerial aspects of watershed and relief aspects of stream network. The morphological parameters directly or indirectly reflect the entire watershed based on causative factors affecting runoff and sediment loss. The parameters can be conveniently worked out from the toposheets using the capability of GIS tools. The drainage map of the study area was used for quantitative geomorphological analysis of both linear and aerial aspects of the drainage basin. The geomorphological information pertaining to each of the watershed was obtained with reference to its size, shape, slope, relief, stream density, vegetation, land use and stream network system. The time of concentration (T_c) which is defined as the time required for runoff water to move from the most remote point of the watershed to its outlet was calculated by using Kirpitch formula. The formulae used for finding out geomorphological characteristic features are presented in Table 1.

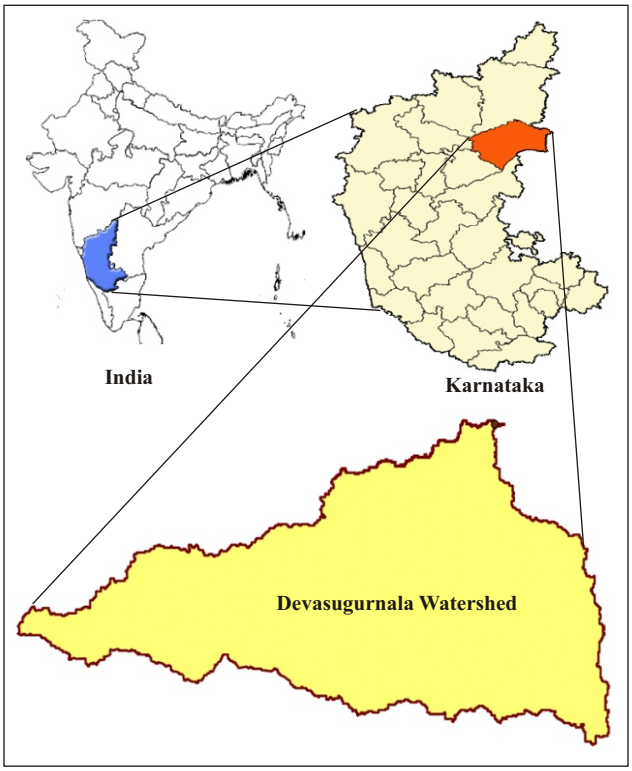

Fig. 1. Location map of study area

Table:1
Characteristics features of Devasugur nala watershed and formulae used

Characteristic feature	Formula	Particulars
Stream order	Hierarchical rank, Strahler (1964)	-
Average basin width (B)	$B = \frac{A}{L_b}$	A= area L_b= basin length
Bifurcation ratio (R_b)	$R_b = \frac{N_u}{N_{u+1}}$	N_u= order of stream N_{u+1}= next order stream
Mean stream length ($\overline{L_u}$)	$\overline{L_u} = \frac{\sum_{i=1}^{N} \overline{L_u}}{N_u}$	($\overline{L_u}$) = length of stream of particular order
Stream length ratio (R_L)	$R_L = \frac{\overline{L_u}}{\overline{L_{u-1}}}$	($\overline{L_u}$) = length of stream of particular order
Length of overland flow (L_g)	$L_g = \frac{1}{2\ D_d}$	D_d = drainage density
Drainage density (D_d)	$D = \frac{\sum_{i=1}^{u} L_u \times N_u}{A}$	N_u= number of streams
Stream frequency (F)	$F = \sum_{i=1}^{u} \frac{N_u}{A}$	A = area of watershed
Form factor (R_f)	$R_f = \frac{A}{L_v^2}$	L_v= basin valley length
Circulatory ratio (C_r)	$C_r = \frac{4\pi}{P_b^2}$	P_b= perimeter of basin
Elongation ratio (E_r)	$E_r = \frac{2R'_e}{L_b}$	R'_e= radius of circle having equal area as watershed
Compactness coefficient (C_c)	$C_c = \frac{P_b}{P'_b}$	P_b= perimeter of basin, P'_b= perimeter of basin having area equal to watershed
Ellipticity index (E_i)	$E_i = \frac{\pi L^2}{4A}$	L= length of watershed
Texture ratio (R_t)	$R_t = \frac{N}{P}$	N_1= number of first order streams P= perimeter of basin
Relative relief (R_R)	$R_R = \frac{H}{L_p}$	H= maximum watershed relief L_p= perimeter of watershed
Relief ratio (R_r)	$R_r = \frac{H}{L_b}$	H= maximum watershed relief
Ruggedness number (R_N)	$R_N = H \times D_d$	H= maximum watershed relief
Geometric number	Geometric $N_r = \frac{H \times D_d}{S_g}$	Sg = length of overland Flow
Time of concentration (T_c)	$T_c = 0.0195\ L^{0.77} S^{-0.385}$	L= length of watershed S = stream slope
Basin relief (S)/Slope	Basin relief = $\frac{HE - LE}{L}$	HE= highest elevation, LE= lowest elevation, L= horizontal distance between both points

Several thematic maps like watershed boundary, DEM, drainage, contour and Gram Panchayat of Devasugurnala watershed were prepared using the ArcGIS tools and SoI toposheets. The scanned toposheets were first incorporated into the ArcGIS 9.3 version followed by rectification and projection. The watershed boundary map shows the total area of catchment and its sub watershed boundaries. DEM map gives idea of elevations in watershed. Drainage map shows the streams of different orders that flow in the watershed. The total streams of the watershed were delineated and used for the determination of watershed characteristic features. In the contour map, different contour lines of varying elevation were delineated and slope of the watershed was calculated. The maximum and minimum elevation points in the watershed were determined. Gram Panchayat map shows different Village Panchayats coming under the watershed which will help for undertaking any conservation works.

3. RESULTS AND DISCUSSION

The Devasugurnala watershed was delineated and the result showed that watershed is elongated in shape, which joins the Krishna river near Devasugur village. The boundary of the watershed and 17 sub watersheds (Fig. 2) in the study area were delineated by using the Arc SWAT. The total area of the watershed and its perimeter was found to be 521.75 km^{2}and 180.23 km, respectively. The maximum length of watershed from remotest point to outlet was found to be 40.06 km.

Geomorphological Features of Devasugurnala Watershed

The geomorphological analyses were made from the digitized drainage pattern and watershed boundary.

Linear Aspects of Drainage Network

The drainage pattern of the Devasugurnala watershed is of the sixth order stream and consists 1445 first order, 315 second order, 62 third order, 15 fourth order, 3 fifth order and one sixth order stream (Table 2). The total length of all streams was found to be 1230.60 km. Main stream length (L_c) and main valley length (L_v) of the Devasugurnala watershed was found to be 39.8 and 40.06 km, respectively. The stream length ratio (R_L) of Devasugurnala watershed was found to be ranging from 0.26 for first order to 1.23 for the fifth order stream (Table 3). The study also indicates that the mean length of segments ($\overline{L}_u$) ranged between 0.56 for first order to 23.88 for sixth order stream (Table 3). The average bifurcation ratio of entire Devasugurnala watershed was found to be 4.36 and it varied from 3.0 to 5.08 for different stream orders of the watershed (Table 3) which confirmed with the research results obtained by Horton (1945). The bifurcation ratio (R_b) reflects geological and tectonic characteristics of the watershed. The value indicates that the watershed is elongated type and watershed having lower R_b values produces the sharp peak flow. It also indicates that watershed has suffered less structural disturbance and the drainage pattern has not been distorted by structural disturbance (Nag and Chakroborty, 2003). The stream

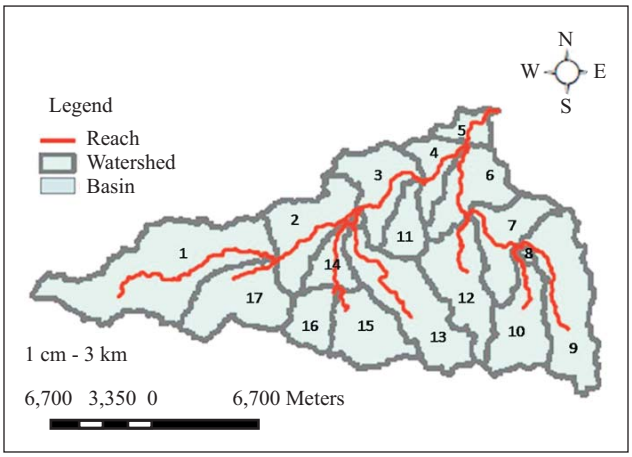

Fig. 2. Delineated boundary and sub watersheds of Devasugurnala watershed

Table: 2
Stream order and its length in Devasugurnala watershed

Parameters	Stream order						Total
	I	II	III	IV	V	VI	
No. of streams	1445	315	62	15	3	1	1841
Length of stream in km	821.98	209.79	110.37	45.25	19.33	23.88	1230.60

Table: 3
Stream length ratio of Devasugurnala watershed

Order (U)	Mean length of segments ($\overline{L}_u$) in km	No. of segments (N_u)	Bifurcation ratio (R_b)	Stream length ratio (R_L)
I	0.56	1445	4.59	0.26
II	0.66	315	5.08	0.53
III	1.78	62	4.13	0.41
IV	3.01	15	5.00	0.43
V	6.44	3	3.00	1.23
VI	23.88	1	-	-

length ratio (R_L) of Devasugurnala watershed was observed from 0.26 to 1.23 (Table 3). The ratio depicts that lower reaches of the watershed have longer channels (order 4 and 5) than the upper reaches (order 1, 2 and 3). This may be because of steeper slope in the upper reaches than in lower reaches.

Aerial Aspects of Watershed Area

The aerial aspects play a very important role in the watershed development and these are very essential characteristics of the watershed. The aerial parameters such as form factor, circulatory ratio, circulatory index, compactness coefficient, drainage density and elongation ratio of the watershed were found to be 0.32, 0.44, 0.20, 3.07, 2.35 and 0.64, respectively (Table 4). The lower value of form factor (0.32) indicates more sedimentation problems in the streams (Strahler, 1964). Similarly, because of lower value of form factor, it was confirmed that the Devasugurnala watershed was experiencing sedimentation problems. The low value of circulatory ratio (C_r) of 0.44 compared to elongation ratio (E_r) of 0.64 indicates that the watershed is approaching towards the elongated shape (Singh *et al*., 2003).

The drainage density of watershed indicates the closeness of spacing of channels, thus providing a quantitative measure of the average length of stream channel for the whole watershed. Further, it gives an idea about the physiographical properties of the underlying soils. The moderate value of drainage density indicates that the region is having weak or impermeable subsurface material, sparse vegetation and fine drainage texture (Malik *et al.*, 2011).

Relief Aspects of Stream Network

The relief aspects are important terrain parameters from utilization point of view and also in assessing disaster prone areas. The stream slope, maximum relief, time of concentration and basin relief from the watershed were found to be 0.24%, 98 m, 696.21 min and 3.48%, respectively (Table 5).

Based on calculated value of maximum relief (H), other relief aspects like relief ratio (R_r) and relative relief (R_R) were found as 0.0025 and 0.054, respectively. This was an indication of erosion and reflects that, the watershed should be treated with soil and water conservation measures. The possibility of a close correlation between relief ratio and hydrologic characteristics of a basin suggested by Schumm (1956) who found that sediment loss per unit area is closely correlated with relief ratios. The lower value of relief ratio (R_r) was observed due to the larger basin area. Time of concentration for the Devasugurnala watershed was found as 696.21 min which, in turn, gives an idea of delayed peak flow from the watershed (Suresh, 2012). The high value of time of concentration was found due to lower stream slope and higher basin length.

Thematic Map Generation

Drainage map

Based on the stream network, it was identified that the watershed is having dendritic pattern (Mittal, 2002). The entire drainage network is distributed over the watershed basin with stream order from one to sixth (Fig. 3). There were total of 1841 streams with total length of 1230.60 km flowing towards the northern direction and joining river Krishna.

Contour map

The digitized contour map of Devasugurnala watershed is presented in Fig. 4. The highest contour in the map was found to be 420 m on the boundary of watershed and lowest as 320 m at the outlet of the watershed.

Table: 4
Aerial aspects of Devasugurnala watershed

Aerial aspects	Value
Form factor (R_f)	0.32
Circulatory ratio (C_r)	0.44
Circulatory index (I_c)	0.20
Elongation ratio (E_r)	0.64
Compactness coefficient (C_c)	3.07
Ellipticity index (E_i)	2.41
Texture ratio (R_t)	8.01
Stream frequency (F_u), Nos. km^{-2}	3.53
Drainage density (D_d), km km^{-2}	2.35

Table: 5
Relief parameters of Devasugurnala watershed

Relief parameters	Value
Stream slope (S), %	0.24
Maximum relief (H), m	98
Relative relief (R_R)	0.054
Relief ratio (R_r)	0.0025
Ruggedness number (R_u)	0.23
Geometric number	0.066
Time of concentration (T_c), min	696.21
Basin relief (S), %	3.48

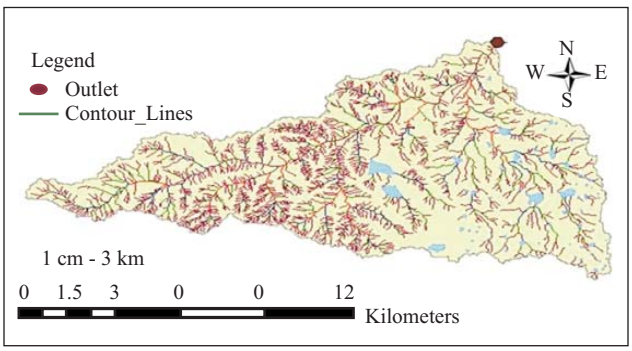

Fig. 3. Drainage network of Devasugurnala watershed

Gram Panchayat Map

A total of 16 Village Gram Panchayats and one Raichur city municipal area was delineated using ArcGIS 9.3. The each boundary of individual Panchayat shows the area coming under its jurisdiction. The Gonhal Village Gram Panchayat was observed to be the biggest Gram Panchayat covering more number of villages (Fig. 5).

Digital elevation model (DEM) map

The DEM of the study area was obtained from the Bhuvan website (http://bhuvan.nrsc.gov.in), Deptt. of Space, Govt of India, developed by NRSA, Hyderabad. The watershed boundary was overlaid and the DEM of the study area was extracted by using mask tool in Arc GIS 9.3 (Fig. 6). The extracted DEM of study area was used for the preparation of slope map and contour map.

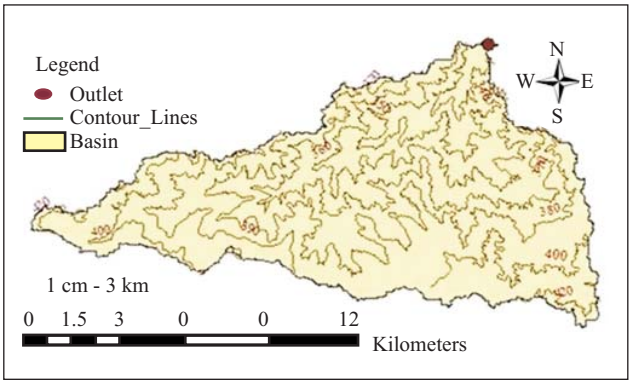

Fig. 4. Contours of Devasugurnala watershed

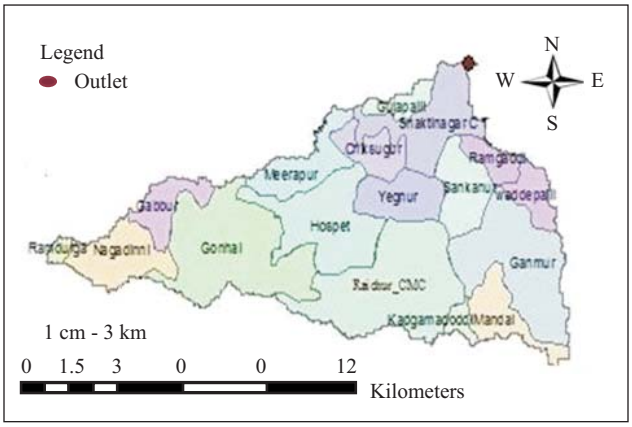

Fig. 5. Gram Panchayat boundaries in the Devasugurnala watershed

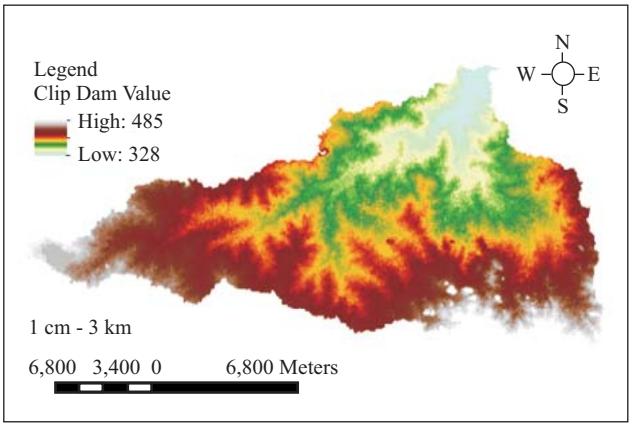

Fig. 6. DEM of Devasugurnala watershed

4. CONCLUSIONS

In the present study, the use of GIS was found to be effective and easy in deriving morphological characteristics of the watershed saving time and energy in comparison to other methods. With the help of drainage lines thematic map, it was concluded that this watershed is of dendrite type. From the average bifurcation ratio of 4.36, it can be concluded that the geologic structures do not distort the drainage pattern of the watershed. The bifurcation ratio of 4.36 also helped in knowing the shape of the watershed where it is neither too elongated nor too fan or fern shaped watershed.

The time of concentration of 696 minutes, hints regarding moderate to delayed runoff flow rather than peak flow. Due to presence of more number of first order streams, the more soil loss rates may be observed and so, soil and water conservation measures should be adopted for reducing the soil loss.

The drainage density was found to be moderate to high which indicates that the watershed is having impermeable sub-surface materials, sparse vegetation and rocky areas at certain places which, in turn, gives plenty of opportunity to plan for increasing infiltration opportunities at top soil layers, planning for proper land cover in terms of crops and plantation and surface rain water harvesting, respectively.

The various geomorphological features and thematic maps of the watershed will help in knowing the morphology of the watershed and deciding type, number and places of execution of different soil and water conservation measures. Considering slope, drainage pattern and rainfall of the area, the conservation measures will be proposed in the watershed.

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