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Morphometric Analysis of Tawa Basin, Madhya Pradesh, India using Remote Sensing and GIS Approach

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Abstract In the present study, an attempt has been made to determine geomorphological parameters of Tawa river basin situated at Hoshangabad District of Madhya Pradesh. The study area was delineated using Remote sensing and GIS. For detailed study, we used different DEM sources viz., Toposheet and DEM data for delineating watershed boundary and geographical information system (GIS) was used in evaluation of linear and aerial aspects of mophometric parameters. Physical characteristics of the watershed such as area, slope, shape and also drainage pattern in the catchment are some of the major factors that affect the volume of surface runoff. There exist streams from order number 1 to 4 in the basin. The study reveals that the drainage texture of the study area is coarse in nature and shape of the basin is elongated due to which it is less efficient to discharge of surface runoff.

Keywords Morphometric analysis, Tawa basin, Remote sensing, GIS approach, Geomorphological parameters.

Introduction

Water is the prime requirement for the existence of life and thus it needs to be conserved for sustainable use. As it is a well-known fact that 70% of earth's surface is covered with water. However, 97% of this available water is saline and fresh water share in this overall fresh water is only about 3%. Only 12% of this 3% fresh water is available for direct extraction from surface and sub-surface resources, rest is not directly available for utilization. Due to increase in population, urbanization, changes in consumption pattern of water, global warming, pollution, reasons water availability is decreasing day by day. India is heading towards water scarce country from water stress country due to decreasing per capita water availability.

Rainfall is limited to 3 months in India and natural recharge is restricted to this period only. Generally water stress is experienced in post–monsoon period. To overcome this, rainfall runoff harvesting is necessary. Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms (Clarke 1966, Chopra et al. 2005, Choudhari et al. 2018, Chow 1964, Jadhav and Babar 2014, Javarayigowda et al. 2018). Morphometric parameters govern hydrological response of a basin. Quantitative evaluation of morphometric parameters when linked with hydrologic characteristics of basin lead to simple and useful procedure to simulate the hydrologic behavior of basin. Remote sensing coupled with GIS provides tools to prepare various thematic maps. Considering all these aspects, an effort has been made to study geomorphological parameters of Tawa basin of Hoshangabad District in MP, India.

Study area

Narmada is one of the largest river of India with

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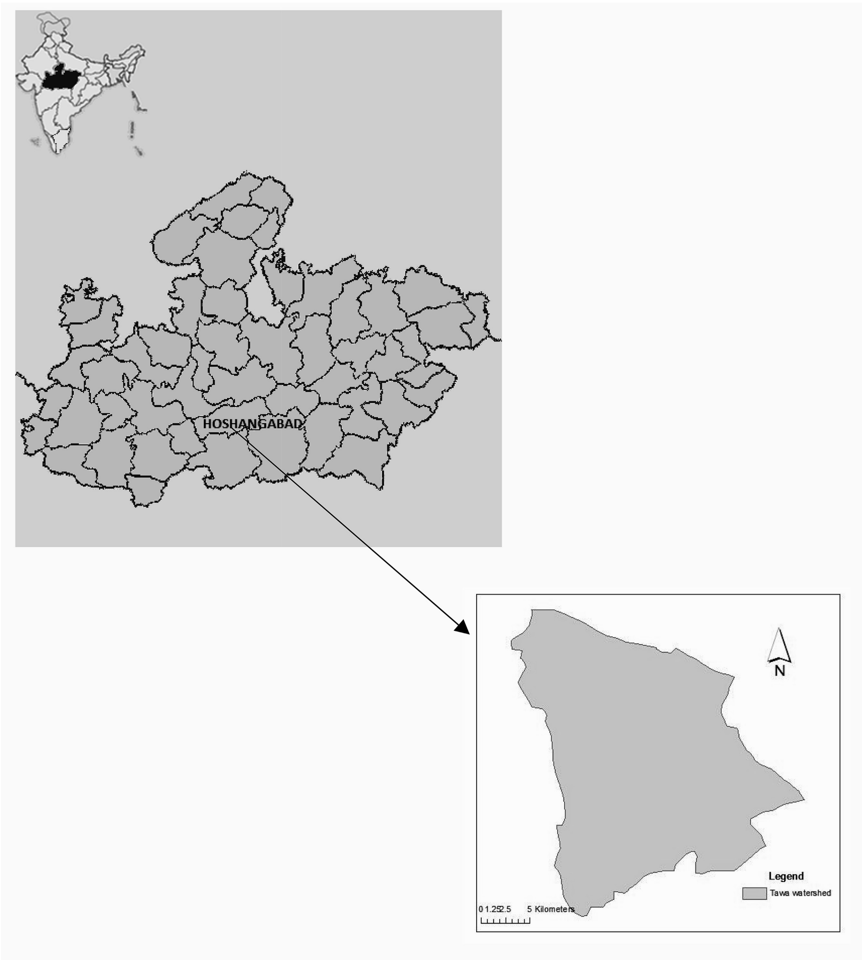

Fig. 1. Tawa basin location map.

total length of 1,312 km and overall drainage area of 98,796 km^2. Largest tributary of Narmada is Tawa, which is the study area of our research. The drainage basin of Tawa is about 6,354.56 km^2 and it is the largest left bank tributary of Narmada River with the total length of 172 km. Rise of Tawa River is from Mahadeo hills of Satpura range in the Chhindwara District of Madhya Pradesh near Cherkathari village at an elevation of 900 m. It is situated at a north latitude of 22°13′ and an east longitude of 78°23′. The major tributaries of Tawa River are Denwa, Suktawa and Machna. The watershed boundary was delineated on the basis of the drainage lines and contours available on the DEM data of the study area with help of ArcGIS and QGIS Grass software. From geological point of view, the whole Tawa watershed basin consists of various lithological formations which include Basalt, Vindhyan sandstones and recent alluvium deposits. Satpura ranges in south and Narmada River in the north surrounds the study area. The slopeis steep at the foothills of Satpura range but moderate to gentle towards Narmada River. Around two-third area of Tawa basin is covered by clay to clay loam type soil. The location map of study area is given in Fig. 1.

Materials and Methods

For the purpose of morphometric analysis of the Tawa basin, attempts were made to delineate watershed

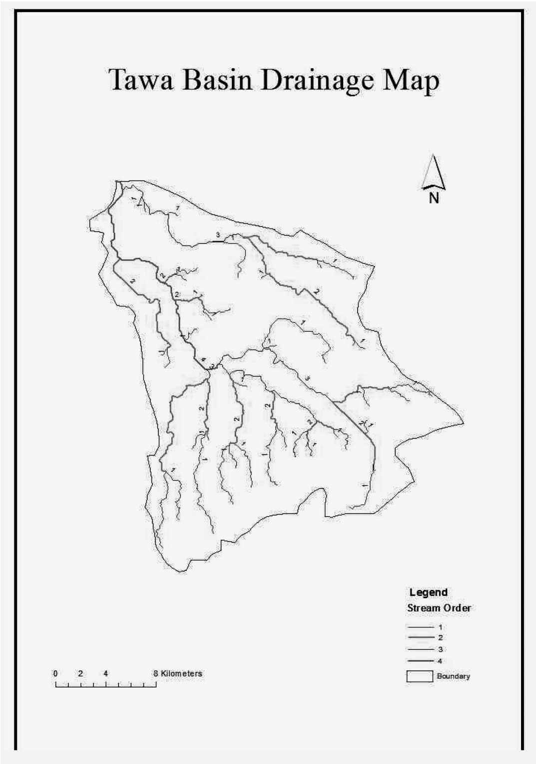

Fig. 2. Drainage map of study area.

by using QGIS Grass tool and ArcGIS 10.4.1 and calculate morphological parameters with the aid of materials collected. Methods adopted with a view to fulfil the objectives of this study are enumerated.

Delineation of watershed

Watershed boundaries were roughly delineated using Google Earth software with the purpose to have a knowledge about the geological coordinates of the area. The study area lies on scale SOI topographic map no. 55F/12, 13, 14, 15, 16 and 55J/2, 3, 4, 6, 7 and 8 between latitude 22°30′ 00′′ to 22°50′ 00′′ N and longitude 77°45′ 00′′ to 78°00′00′′ E on scale 1 : 50,000. With inserting coordinates in USGS Earth explorer, SRTM data of study area was downloaded. A shape file of watershed was created after delineation in ArcGIS software. The drainage map (Fig. 2) with the orders of the watershed was prepared with the help of ArcGIS 10.4.1. Attribute table of various parameters was prepared of watershed boundaries and drainage shape.

Quantitative morphometry

Morphometric analyses of selected watershed was done. The linear and areal aspects of the watersheds extracted from DEM have been carried out using the standard mathematical formulae and the details are given in the (Table 1) (Makwana et al. 2018, Mishra et al. 2014, Polisgowdar et al. 2013, Subramanya 2013, Thomas et al. 2016).

Morphometric parameters

Morphological parameters are significant and suitable to classify several hydraulic physiognomies of catchment such as, stage of stream, shape, patterns, permeability of bed rock, health of streams, (Babar 2005, Yadav et al. 2014). In the present study, morphometric parameters of the Tawa basin determined with respect to various linear aspects are given below.

Linear aspects

Stream order (N_u) : It classifies the pattern of branches that unite to form the principle order stream leaving the catchment. At the start of the network, the smallest stream is designated as order 1. Two streams of order 1 meet to form a stream of order 2. In order words, two streams of lower order join to form a higher order stream. The principal order stream or trunk stream has the highest order which discharge out of drainage basin. Streams are called headwater streams which are having order 1 to 3 and constitute waterways in the upper reaches of basin. The medium sized streams are having order from 4 to 6. Rivers are having order more than 6. The stream order 12 is known to be largest. For designating the nature of drainage pattern of a watershed stream order is helpful. The stream order in Tawa basin varies from 1 to 4 (Table 1) showing presence of headwater streams and medium sized stream in the basin.

Bifurcation ratio (R_b) : R_b is the evaluated as the ratio of the number of stream of any lower order stream to the number of stream of next higher order. It ranges generally from 2–4. A high R_b shows areas of sleepy dipping rocky strata, where narrow valleys are confined between the ridges. The R_b in Tawa basin varies from around 3–4 (Table 1) which indicates that

Table 1. Description of Morphological parameters of a watershed.

Morphological parameter	Formula	Reference
Linear parameters		
Stream order (u)	Hierarchical rank	Strahler (1964)
Stream length (L_u)	Length of the stream	Horton (1945)
Mean stream length (L_{sm})	$L_{sm} = L_u / N_u$ Where, L_u : Total length of streams of order u N_u : Total number of streams of order u	Strahler (1964)
Bifurcation ratio (R_b)	N_u / N_{u+1} Where, N_u : Total number of streams of order u N_{u+1} : Total no. of stream segments of next higher order	Schumm (1956)
Mean bifurcation ratio (Rbm)	Rbm = Mean of all order bifurcation ratio	Strahler (1957)
Stream length ratio (R_L)	$R_L = L_u / L_{u-1}$ Where, L_u : Total stream length of order u L_{u-1} : Total stream length of next lower order	Horton (1945)
Aerial parameters		
Drainage density (D_d)	$D_d = \sum_{u}^{k} L_u / A$ Where, Lu : Total stream length of all order (km) A : Basin area (km^2) k : Highest stream order	Horton (1945)
Drainage texture (R_t)	$R_t = N_u / P$ Where, P : Perimeter of basin (km) N_u : Total number of all orders	Horton (1945)
Stream density (S_d)	$S_d = \sum N / A$ Where, $\sum N$: Total no. of streams of all orders A : Basin area (km^2)	Horton (1932, 1945)
Form factor (F_f)	$F_t = A / L^2$ Where, A : Basin area (km^2) L : Basin length (km)	Horton (1932, 1945)
Elongation ratio (R_e)	$Re = 2 \sqrt{(A / \pi)} / L = 1.128 \sqrt{A} / L$ Where, A : Basin area (km^2) L : Basin length (km) π : 3.14	Schumm (1956)
Shape factor (S_f)	$S_f = 1/F_f = L^2 / A$ Where, F_f: Form factor A : Basin area (km^2) L : Basin length (km)	Horton (1932, 1945)
Circulatory ratio (R_c)	$R_c = 4 \pi A / P^2$ Where, A : Basin area (km^2) P : Perimeter of basin (km) π : 3.14	Miller (1953), Strahler (1964)
Compactness coefficient (C_c)	$C_c = 0.2821 P / \sqrt{A}$ Where, A : Basin area (km^2) P : Perimeter of basin (km)	
Constant of channel maintainance (C)	$C = 1/D_d$	Schumm (1956)

Table 1. Continued.

Morphological parameter	Formula	Reference
	Where, D_d = Drainage density	
Length of overland flow (L_g)	$L_g = 1/2D_d$ Where, D_d = Drainage density	Horton (1945)

geological structure are not significantly disturbing the drainage pattern of the basin.

Stream length (L_u) : The stream length reveals the component characterises of various sizes of various components of drainage network and its contributing area. It is a very important and most significant hydrological characteristics of the watershed as it helps in revealing surface runoff feature of a basin. Generally with increase in stream order, stream length decreases. Length of streams in Tawa basin follow general observations and with increase in stream order from 1 to 4, stream length also increases from 108.28 km to 22.44 km (Table 1).

Stream length ratio (R_L) : It is calculates using the ratio of stream length of given order to the stream length of next lower order (Horton 1945). It varies from 0.74 to 0.56 (Table 1) in Tawa basin.

Aerial aspects

Drainage density (D_d) : It is the total length of streams of all orders per unit basin area. It is a measure of how well the drainage basin is drained through the stream network. The drainage density is classified as Coarse if $D_d \leq 5$ km / km^2 ; Medium if D_d 5–10 km/ km^2 and Fine if $D_d > 5$ km / km^2. Drainage density depends upon climatic and watershed characteristics. Drainage density in Tawa basin 0.489 km / km^2 (Table

Table 2. Calculated morphometric parameters.

Linear aspects

Stream order	Stream number	Length of stream (km)	Mean stream length (km)	Stream length ratio	Bifuration ratio	Mean bifur-cation ratio
1	44	108.2831	2.46	–	3.38	
2	13	81.067	6.23	0.748	3.25	2.65
3	4	39.4881	9.87	0.487	4	
4	1	22.44	22.44	0.56	–	

Aerial aspects

Sl. No.	Parameters	Value
1.	D_d	0.489
2.	R_t	0.55
3.	S_d	0.120
4.	F_f	0.44
5.	R_e	0.753
6.	S_f	2.27
7.	R_c	0.525
8.	C_c	1.37
9.	C	2.04
10.	L_g	1.02

2) which indicates coarse texture.

Drainage texture (R_t) : It is defined as the total number of streams of all orders perperimeter of the basin (Horton 1945). In Tawa basin as per Table 2, it is evaluated as 0.55, which indicates coarse texture.

Stream density (S_d) : Stream density is the representation of the pattern of the drainage channels in the catchment. It is calculated as number of streams per unit basin area. In Tawa basin it is calculated as 0.12 (Table 2) which represents a low density of streams in area.

Basin shape : Shape of a basin is characterized by various parameters which are form factor, shape factor, compactness coefficient, circulatory ratio and elongation ratio. The values evaluated for Tawa basin are enlisted in Table 2.

Form factor (F_f) : It is the ratio of basin area to the basin length square. Form factor indicates flow intensity of a basin of a defined area. It value varies from 0 to 1, 0 for a highly elongated basin shape and 1 for a perfect circular shape. Tawn basin form factor value is evaluated as 0.44 which indicates that it less circular and more elongated in shape.

Elongation ratio (R_e) : It is a dimensionless term and is calculated as ratio of diameter of the circle of the same area as the watershed and the maximum length of the basin (Schumn 1956). Elongated ratio of Tawa basin is calculated as 0.75 (Table 2) which shows basin is elongated in shape, which is less efficient in discharge of runoff. Rest of the aerial parameters are enlisted in Table 1 and 2.

Results and Discussion

To achieve the goal of the present research, DEM from the Shuttle Radar Topographic Mission (SRTM) and DEM extracted from Survey of India Toposheet was exported to a Geographic Information System (GIS) environment to extract all possible morphological parameters of the catchment in the area. Further, comparison of morphological parameters of watershed in the study area was done (Vaidya et al. 2013, Yadav et al. 2016).

Delineation of watershed

Area of watershed is evaluated as 513.223 km^2 and perimeter as 110.814 km after delineation. The drainage map of watershed (Fig. 2) shows that the maximum no. of stream order is 4. The basin length was determined as 33.9 km.

Morphometric parameters

The calculated parameters are shown in Table 2.

Conclusion

The aim of the present study was to collect, compare, process and analyzed the DEM data in with help of GIS tools for delineation of catchment boundary and determination of morphological parameters of Tawa River basin of Hoshangabad District, Madhya Pradesh. Morphometric analysis relating to linear aspects and aerial aspects of the Tawa basin has been carried out using the standard mathematical formulae. Morphometric parameters of the basin are closely linked with the channel patterns of the drainage network wherein the topological characteristics of the stream segments in terms of open links of the network system are analyzed. The evaluation of morphometric parameters starts with designation of stream orders to each stream which was done in ArcMap 10.4.1, the highest order determined in Tawa basin was 4. A lower drainage density of the basin indicates that basin is having coarse texture may be due to watershed physical characteristics or climatic characteristics. Aerial factors reveal that the shape of the basin is more elongated in shape and less circular. Remote sensing and GIS techniques and tools aid an efficient and accurate way to delineate watershed and quantify attributes of watershed. The study of quantitative geomorphology of a watershed is highly beneficial to understand the runoff properties, watershed prioritization soil and water conservation, natural resource management at micro level, useful in watershed planning and management.

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