

Morphometric evaluation of Swarnrekha watershed, Madhya Pradesh, India: an integrated GIS-based approach

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Abstract The quantitative analysis of the watershed is vital to understand the hydrological setup of any terrain. The present study deals with quantitative evaluation of Swarnrekha Watershed, Madhya Pradesh, India based on IRS satellite data and SRTM DEM. Morphometric parameters of the watershed were evaluated by computations of linear and areal aspect using standard methodology in GIS environment. ARC GIS software was utilized for morphometric component analysis and delineation of the watershed using SRTM digital elevation model (DEM). The watershed is drained by a fifth-order river and shown a dendritic drainage pattern, which is a sign of the homogeneity in texture and lack of structural control. The drainage density in the area has been found to be low which indicates that the area possesses highly permeable soils and low relief. The bifurcation ratio varies from 3.00 to 5.60 and elongation ratio is 0.518 which reveals that the basin belongs to the elongated shape basin and has the potential for water management. The main objective of the paper is to extract the morphometric parameters of the watershed and their relevance in water resource evaluation management. The results observed from this work would be useful in categorization of watershed for future water management and selection recharge structure in the area.

Keywords Morphometric analysis · GIS · Swarnrekha watershed · Madhya Pradesh · India

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Introduction

One of the most concerning issues currently being faced by the society is the increase in world's population and its impact on the availability of fresh water. Presently high inhabitant's expansion, fast urbanization and climate change along with the irregular frequency and intensity of rainfall make difficulty for appropriate water management and storage plans. Therefore, there is an urgent need for the evaluation of water resources because they play a primary role in the sustainability of livelihood and regional economics throughout the world (Singh et al. 2011, 2013). Recent studies show an increase in urban sprawl and population growth in the developing countries like India which leads to enormous stress on the water resources of the country. This excess need puts a strain on the available surface and groundwater supplies, which might result in an acute water shortage.

The drainage morphometric analyses are prerequisite for selection of water recharge site, watershed modeling, runoff modeling, watershed delineation, groundwater prospect mapping and geotechnical investigation (Magesh et al. 2011; Thomas et al. 2012). Quantitative morphometric analysis of watershed can provide information about the hydrological nature of the rocks exposed within the watershed. A drainage map of basin provides a reliable index of permeability of rocks and their relationship between rock type, structures and their hydrological status. Watershed characterization and management require detailed information for topography, drainage network, water divide, channel length, geomorphologic and geological setup of the area for proper watershed management and implementation plan for water conservation measures (Sreedevi et al. 2013).

The over exploration of groundwater and variation in rainfall are the major concerns for depletion of groundwater resource and their degradation in terms drying of

potential aquifer in the area (Singh et al. 2013, Ellis and Revitt 2010; Rao 2008; Eyquem 2007).

Morphometric analysis for evaluation of drainage basin, their characterization and classification has been performed from the early nineties by the pioneer workers for linear, aerial and relief aspect and interpretation of their interrelationship with reference to land and water management. (Horton 1945; Smith 1950; Strahler 1957). Knowledge of satellite data and relative GIS methods has also been used along with traditional methods of drainage basin analyses. Information regarding the hydrological nature of the exposed rocks in a drainage basin can be extracted by quantitative morphometric analysis of drainage basin (Subramanyan 1974; Rao and Babu 1995; Pakhmode et al. 2003; Sreedevi et al. 2005).

Further advancement in computer-based technology precise work has been accomplished using advanced techniques like geographical information system and related tools for automated determination of the basin parameters, which results in time-efficient, accurate and reliable results (Grohmann 2004; Gangalakunta 2004; Grohmann et al. 2007; Hlaing et al. 2008; Javed et al. 2009). Remote sensing and GIS-based drainage basin evaluation has been carried out by number of researchers for different terrains and it is proved to be a very scientific tool for generation of precise and updated information for characterization of drainage basin parameters (Thomas et al. 2012; Pankaj and Kumar 2009; Singh and Singh 2009; Das and Mukherjee 2005).

Digital elevation models (DEMs), such as from the Shuttle Radar Topography Mission (SRTM), or the ASTER GDEM product (USGS, Denver, Colorado, USA), have been used to extract different geomorphological parameters of drainage basins, including drainage networks, catchment divides, slope gradient and aspect, and upstream flow contributing areas (e.g. Mark 1984, Tarboton 1997). GIS-based watershed evaluation using Shuttle Radar Topographic Mission (SRTM) data has given a precise, fast, and an inexpensive way for analyzing hydrological systems (Farr and Kobrick 2000; Grohmann et al. 2007). Recently remote sensing data and digital elevation models were utilized to extract the catchment hydrological parameters for management of water resources and they concluded that DEMs are very accurate tool for morphometric parameter evaluation and watershed delineation for watershed management (El Bastawesy et al. 2013).

Very recently number of case studies based on remote sensing, GIS and satellite-borne digital elevation data were used for morphometric analysis and watershed prioritization for different geological and hydrological setups for water resource evaluation and management (Singh et al. 2014; Gajbhiye et al. 2014; Kaliraj et al. 2014; Rai et al. 2014). The findings of all the studies show that integrated application of remote sensing and GIS is the potential tool

for water resource evaluation and extraction of hydrological parameters of any terrain.

In the present study, an integrated approach of GIS, remote sensing and DEM has been used for generation and interpretation of drainage parameters for water resource management of Swarnrekha Watershed. The watershed selected for the present work is the important source of water for agriculture and domestics purpose in the area.

Study area

The Swarnrekha watershed is the major part of urban and suburban area of Gwalior and Morena district and lies between 26°06'N–26°26'N latitude and 78°01'E–78°13'E longitude. The elevation ranges from 160 to 350 m average mean sea level (AMSL) and the study area is located in the northeastern part of the Gwalior district in the central India with an area about 292 km² (Fig. 1). It is covered in the Survey of India (SOI) toposheet numbers 54J/3 and J/4 on a 1:50,000 scale. The climate of the basin is extreme with hot summers and cold winters. It experiences southwestern monsoon rains in June–September with an annual rainfall of 600 mm. May is the hottest month with a maximum temperature of 45 °C and minimum temperature 4 °C in the month of December. Gwalior is one of the erstwhile princely cities with population of over 1.2 million having semi-arid climate marked by extreme temperatures and erratic rainfall patterns. The overall climate of the region is dry, except during the south-west monsoon season (June–October). Groundwater is the major source of water supply for drinking, agricultural, and other activities in the area and groundwater level depletion over a time is the major concern. The incessant water scarcity and the ever increasing demand for agriculture and industries have put immense stress on the limited groundwater resources in the area and have pronounced the need for locating additional sources. The river Swarnrekha, which is the tributary of Yamuna River Basin flowing through Gwalior urban and suburban area, is the major source of water supply in the area.

Hydrogeological and geological setup of the watershed

The Gwalior basin is located on the northwestern fringe of the Bundelkhand massif and is intracratonic in nature, and the complete lithological unit lies on the Bundelkhand granite which comprises basal arenaceous Par formation which is overlaid by a sequence of volcanic sediments of the Morar formation. The Gwalior group (which dips in due north) shows continuity and similarity with the Bijawar group (Singh et al. 2011). The basic structure is quite

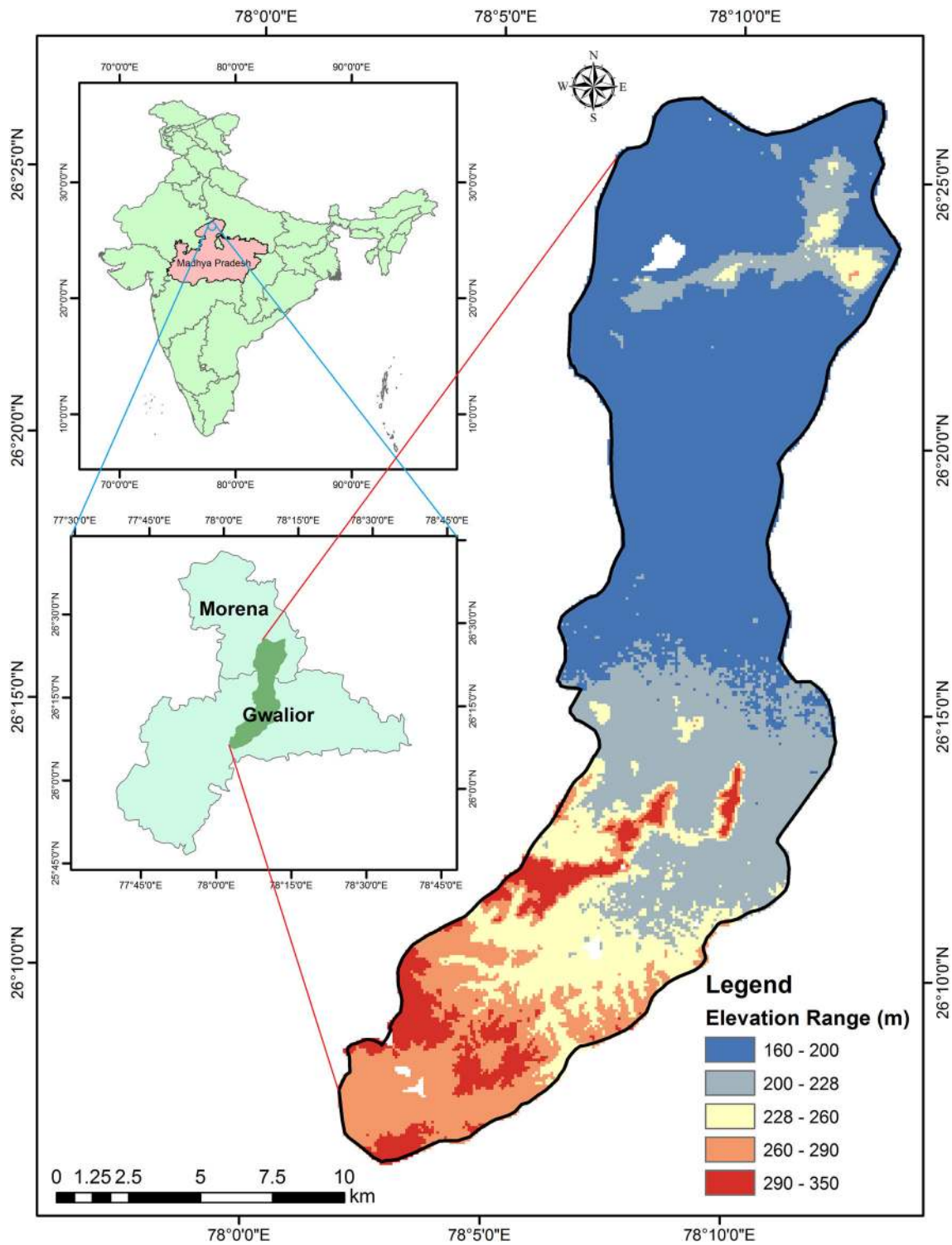


Fig. 1 Location map showing elevation range of the study area

similar as the base is made up of quartzite; the shallow water conditions are characteristics of ferruginous shale with chert and jasper; and transgression follows after the rapid development of the basin formation. In few parts of

the basin, the Gwalior group shows fine or coarse doleritic sills and dykes. The hard rocks of the region comprise sandstone and shale as they belong to the Archaean group to Precambrian group; however, the doleritic dykes are

Table 1 The data used for the present study

Type of data	Details	Sources
SRTM digital satellite images	Path 145, row 042, year 2000	University of Maryland, USA
Toposheets	54J/3, 54J/4, scale 1:50,000	Survey of India, Dehradun, India
Geological quadrangle map	Scale 1:250,000	Geological Survey of India, Hyderabad, India

recent alluvium deposits where granite is the base rock of the study area. By the regional geological map of the area which has been prepared based on the satellite images and geological maps, the Gwalior basin shows much of the Morar formation shale with lower region of Par formation of sandstone. Surrounding the region is the Kaimur group sandstone and Bundelkhand granite. The chief groundwater deposits in the region are formed by the weathered shale zones, alluvial deposits and sandstone forming a coarse- or medium-grained unconsolidated aggregation. The thickness of aquifer formation increases to the northern portion of the watershed with three major water bearing formation at 100 m depth. The fracturing, openness, size of the fracture and the interconnection nature between the fractures dominate the water yielding capacity of the rocks. The Swarnrekha watershed is mostly covered with alluvium which varies in thickness and constitute the major aquifer system of the area. The intracratonic Gwalior basin is present on the northwestern fringes of granitic Bundelkhand massif and Gwalior litho-units group rest over Bundelkhand granite. These comprise basal arenaceous Par formation overlain by volcano-sedimentary sequences of Morar formation consisting of ferruginous shale with bands of chert, jasper and limestone. The predominant rocks comprise sandstone, shale, quartzite, doleritic dykes and alluvium. The thickness of this weathered zone is generally greater in the northern portion. The Gwalior Group of rocks overlies the Vindhyan group and is the youngest rock in the region.

Database generation and detail methodology

The quantitative analysis of drainage basin provides background information about the hydrological conditions and nature of rock formation exposed within the watershed. Morphometric analysis of a basin provides an indication about permeability and storage capacity of the rocks, and gives an indication of the yield of the basin. In the present paper, satellite-borne SRTM DEM and Survey of India topographical sheets were utilized for generation of database and extraction of various drainage parameters. The watershed boundary of the study area was automatically delineated using SRTM data which are freely available on the website (<http://glcf.umd.edu>). Details of data used are shown in Table 1.

The morphometric parameters such as number of stream segments, stream order, drainage pattern, subbasin length, perimeter and area were delineated from the SRTM DEM (90 m) data and verified with Survey of India topographical map (1:50,000). The observed parameters were used for computation the morphometric characteristics such as drainage density, stream frequency, bifurcation ratio, form factor, circulation ratio, relief ratio and overland flow using mathematical equations (Table 2) in the GIS environment. Moreover, the slope and relief of the area were extracted from the same data source using spatial analyst tool in ArcGIS 10 software. The following procedure was followed for morphometric analysis of Swarnrekha watershed.

1. Firstly, SRTM DEM was downloaded from USGS site and primary processing was performed.
2. The Geocoded SOI toposheets were correlated with SRTM data for delineation of watershed.
3. Watershed area of Swarnrekha is delineated from SRTM data along with the SOI toposheets of the study area using Erdas Imagine Software.
4. All the extracted parameters from SRTM and Survey of India topographical sheets, like the number and lengths of streams of each different order, drainage area, basin perimeter and total basin length, and width were calculated using ARC GIS software; drainage density, drainage frequency, shape, form factor, circulatory ratio, and elongation ratio, were calculated from these parameters. The methodologies adopted for the computation of morphometric parameters are given in Table 2 and results are presented in Table 3.

Results and discussion

Quantitative evaluations of drainage basin are the primary-level water resource management at watershed level in hard and soft rock areas. Quantitative description of drainage network and basin characteristics has been carried out for the Swarnarekha Watershed. Hydrological parameters such as number and lengths of streams of different order, drainage area, basin perimeter and maximum basin lengths were calculated after cleaning and then topology building of the drainage layer in GIS software; from these

Table 2 The parameters adopted for morphometric parameters computation

S. no.	Morphometric parameters	Calculational Formulae	References
1.	Stream order	Hierarchical rank	Strahler (1964)
2.	Stream length	The length of the stream	Horton (1945)
3.	Mean stream length (L_{sm})	$L_{sm} = L_u/N_u$; L_u = total stream length of order u, N_u = total no. of stream segments of order u	Strahler (1964)
4.	Stream length ratio (R_L)	$R_L = L_u/(L_u - 1)$; L_u = total stream length of order u, $(L_u - 1)$ = total stream length of the next lower order	Horton (1945)
5.	Stream frequency (F_s)	$F_s = N_u/A$; N_u = total no. of streams of all orders, A = area of the basin	Horton (1932)
6.	Drainage density (D)	$D = L_u/A$; L_u = total stream length of all orders, A = area of basin	Horton (1932)
7.	Drainage texture (R_t)	$R_t = N_u/P$; N_u = total no. of streams of all orders, P = perimeter of the basin	Horton (1945)
8.	Bifurcation ratio (R_b)	$R_b = N_u/(N_u + 1)$; N_u = total no. of stream segments of order u, $(N_u + 1)$ = number of segments of next higher order	Schumm (1956)
9.	Form factor (R_f)	$R_f = A/L_b^2$; A = area of basin, L_b^2 = square of the basin length	Horton (1932)
10.	Elongation ratio (R_e)	$R_e = 2\sqrt{(A/\pi)}/L_b$; A = area of the basin, $\pi = 3.14$, L_b = basin length	Schumm (1956)
11.	Circularity ratio (R_c)	$R_c = 4\pi(A/P^2)$; A = area of the basin, $\pi = 3.14$, P = perimeter of the basin	Miller (1953)
12.	Relief ratio (R_h)	$R_h = H/L_b$; H = total relief of the basin, L_b = basin length	Schumm (1956)
13.	Length of overland flow (L_o)	$L_o = 1/(2D)$; D = drainage density of the basin	Horton (1945)
14.	Relative relief (R_r)	$R_r = 100H/P$; H = total relief of the basin, P = perimeter of the basin	Schumm (1956)

Table 3 Linear aspect of the watershed

Stream order	No. of streams	Bifurcation ratio	Mean bifurcation ratio	Total length of streams (km)	Mean length of the streams (km)	Average mean length of the streams (km)	Length ratio
1st	460		4.69	315.93	0.69	0.95	
2nd	126	3.65		151.41	1.20		0.479
3rd	28	4.5		76.29	2.72		0.504
4th	5	5.6		41.12	8.22		0.539
5th	1	5		5.55	5.55		0.135

parameters, various drainage characteristics such as bifurcation ratio (Rb), drainage density (Dd), stream frequency (Fs), circulatory ratio (Rc), and elongation ratios (Re) are calculated for evaluation of watershed. All the important watershed parameters were discussed under following important sections: linear, aerial and relief aspects. Linear aspects of the watershed refer to the analysis of stream order, stream number, bifurcation ratio and stream length ratio. Stream ordering is the first step of quantitative analysis of the drainage basin. In the present study, stream ordering has been carried out using Strahler’s system of

stream calculation under GIS environment. The adopted mathematical equations for computation of drainage parameters have been summarized in Table 2.

The watershed contains a dendritic drainage pattern which indicates homogenous subsurface strata of the study area. The stream ordering has been ranked based on a method proposed (Strahler 1964) from the streams extracted from SRTM DEM and updated from Survey of India toposheets. The order-wise stream numbers and their linear characteristics are shown in Table 3. The drainage pattern analysis of the watershed indicated that the area is

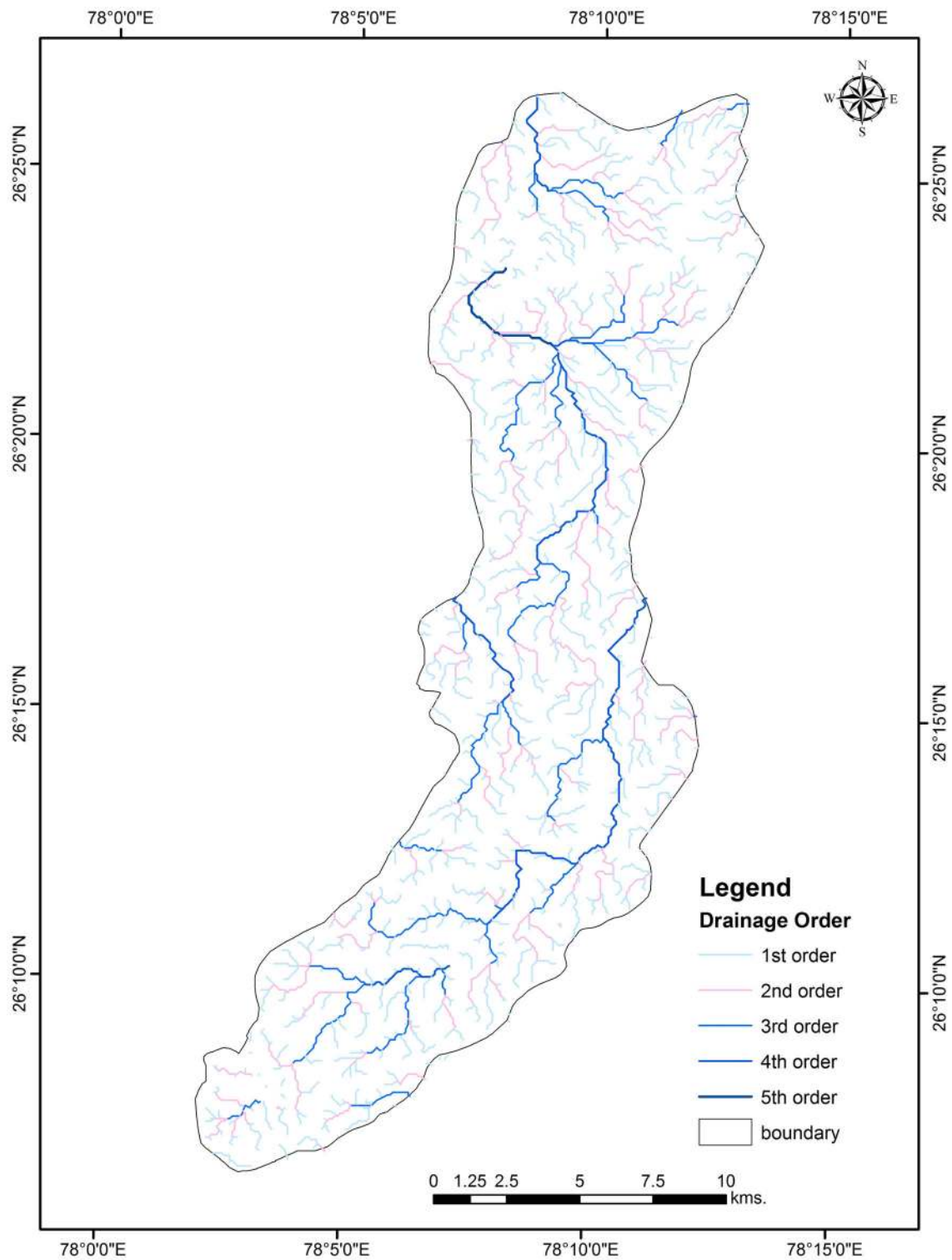
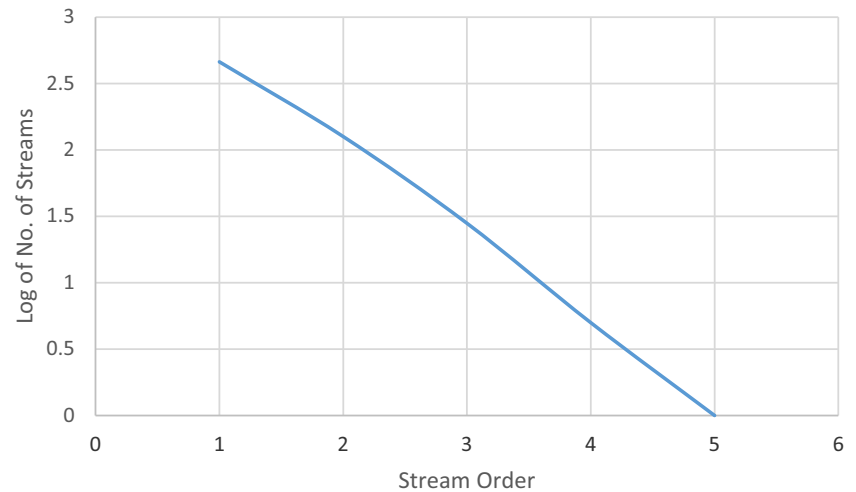


Fig. 2 The drainage stream ordering of Swarnrekha river watershed

having a lake of structural tectonic control. Maximum number of stream was found in the first order and as the stream order increases with a decrease in stream number. The drainage map of watershed with stream order is shown

in Fig. 2. Hydrologically dendritic drainage pattern is a symbolic of homogeneity in texture and lack of structural control. The number of streams in each order gives a fair idea of the distribution of the water channels of the smallest

Fig. 3 Plot of inverse linear relationship between drainage networks**Table 4** Areal aspects of the watershed

Basin area (km ²)	Perimeter (km)	Width (km)	Form factor	Elongation ratio	Circularity ratio	Drainage density	Stream frequency	Drainage texture	Relief ratio
292.49	103.36	8.16	0.211	0.518	0.344	2.02	2.12	5.99	0.005
Texture ratio	Length of overland flow								
4.45	0.25								

to largest level in the region and how well the area is covered in the water flow network. These stream segments were plotted against stream order and show an inverse geometric sequence; mostly the drainage networks show an almost linear relationship (Fig. 3).

The relationship between the bifurcation ratio and the stream length ratio is determined by hydrogeologic, physiographic, and geological characteristics. Value of total length, mean length and length ratio of different stream orders of the watershed are shown in Table 3. The mean bifurcation ratio of watershed is 4.69, indicating that the drainage pattern is not much affected by tectonic and structural disturbances. Stream frequency (F_s) or channel frequency is the total number of stream segments of all orders per unit area and values indicate positive correlation with the drainage density of the basin, suggesting an increase in stream population with respect to increase in drainage density (Horton, 1932). The observed stream frequency (F_s) is 2.12 for the basin and exhibit a positive correlation with the drainage density value of the area, indicating the increase in stream population with respect to increase in drainage density (Table 3). Horton (1932) has introduced the drainage density as an expression to indicate the closeness of spacing of channels. The drainage density of the watershed is 2.02 (Table 4). The value of D_d suggested that area have low drainage density in the northern portion of the watershed. The low drainage density is likely

to result in the area of highly resistant permeable subsoil material under dense vegetation and low relief. High drainage density is the resultant of weak impermeable subsurface material, sparse vegetation and mountainous relief. Multi-spectral satellite images of the study area also suggest that the area has good vegetation in terms of shrub's and agricultural lands in addition to reserve forests and dense forests.

Drainage texture (R_t) is one of the important concepts of geomorphology which means the relative spacing of drainage lines. According to Horton (1945), R_t is the total number of stream segments of all orders per perimeter of that area. The observed R_t is 5.99 which indicates the moderate drainage texture. The moderate drainage texture and lower value of drainage density (2.02) indicate the presence of highly resistant permeable material with low relief (Table 4). Low drainage density and moderately drainage texture indicate the presence of permeable soil strata within the watershed. Texture ratio depends on the underlying lithology of the area, the infiltration capacity and relief aspect of the watershed terrain. The present area has a texture ratio of 4.45 and hence shows a moderate nature. Form factor (Horton 1932) is a ratio of the basin area to square of the basin length. The area, perimeter and length of the watershed are basic measurements which are useful in generating dimensionless ratios for indexing the watershed shape. The R_f value for the watershed is 0.211

which suggests its elongated shape. A watershed with low form factor and an elongated shape denotes its flatter peak of flow for long period. A flood flow for such an elongated shape will be easier to manage in due course of time (Table 4). Elongation ratio is defined as the ratio between the diameter of the circle of the similar area as of the drainage basin with a maximum length equal to that of the basin (Schumm 1956). Depending on the climatic and geological conditions of the area, the value of the R_c varies considerably between 0.6 and 1.0, those with value close to the highest, i.e. 1.0 are categorized as typical low relief and with value of 0.6 and nearby are associated with high relief and steep slope (Strahler 1964). The values are grouped in all as three categories: circular (with values >0.9), oval ($0.8 \leq \text{value} \leq 0.9$) and elongated (value <0.8). The elongation ratio of the current study area is 0.518 which places it in the category of elongated basin (Table 4). Miller (1953) defined a dimensionless circularity ratio (R_c) as the ratio of the basin area to the area of circle having the same perimeter as the basin. R_c was influenced by the length and frequency of streams, geological structures, land use/land cover, climate, relief and slope of the basin. Circularity ratios range 0.4 to 0.5 which indicate strongly elongated and highly permeable homogenous geology, and the observed circularity ratio of the basin is 0.344 (Table 3) which indicates that the basin is elongated in shape, low discharge of runoff and highly permeability of the subsoil condition.

The elevation difference between the highest and the lowest points on the valley floor of a basin is known as the total relief of that basin. The relief ratio (R_h) is termed as the ratio of maximum relief to horizontal distance along the longest dimension of the basin parallel to the principal drainage line (Schumm 1956). It measures the overall steepness of a drainage basin and is an indicator of the intensity of the erosion process operation on the slope of the basin. In the present study, the R_h value of the basin 0.005 shows the major portion of the basin having gentle slope (Table 4). As per Horton (1945), the length of overland flow is half of reciprocal of the drainage density. It is defined as the water length above ground before concentrating into definite stream channels. The present study has L_g equal to 0.25 indicating a very young topography.

Conclusions

GIS-based morphometric analysis using remote sensing and GIS quantitative morphometric have been proved as an efficient tool for hydrological evaluation and drainage network analysis of watershed. The computation of linear, areal and relief parameters of the Swarnrekha watershed

confirms that there is a positive correlation between hydrological behavior of the basin and their associated landforms which is the potential for water management activities. The average slope of the watershed is towards south to north which justifies the surface and subsurface water movement within the watershed. The drainage network of the area is mainly dendritic type indicating homogeneity in texture and lack of structural control which could thereby help in understanding the various terrain parameters viz. bedrock nature, infiltration capacity, runoff, drainage density, etc. A low stream frequency and drainage density indicate a high rate of permeability of the subsurface formation. The morphological characteristics and hydrological parameters of Swarnrekha watershed, such as bifurcation ratio, circularity ratio and relief ratio, have special significance in deciding the overall pattern and changes in the subbasin, shape and drainage pattern of the area. The results observed from the analysis could be helpful in prioritizing watershed with respect to soil and water conservation and management. Thus, concluding remote sensing information and GIS tools together form a powerful, effective and efficient method to study the hydrologic and morphometric characteristics of a drainage basin. This work shall prove useful and beneficial to the planners and decision makers for proper natural resource management even at micro-level of the Swarnrekha watershed.

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