Drainage basin morphometric analysis

Morphometric analysis of a drainage basin demonstrates the dynamic equilibrium that has been achieved due to interaction between matter and energy. It helps to understand the prevailing geo-hydrological characteristics of the drainage basins. In the present study, morphometric analysis has been carried out using remote sensing and Geographical Information System (GIS) techniques to assess the geo-hydrological characteristics of four sub-watersheds of Etmadpur area of Agra district, Uttar Pradesh. The morphometric parameters of the sub-watersheds are discussed with respect to linear, areal and relief aspects. The Etmadpur watershed characterized by dendritic to sub-dendritic drainage pattern. The high values of Bifurcation Ratio (Rb) among all the sub-watersheds indicate the possibilities of structural control over the drainage pattern. The Circularity Ratio (Rc) values ranges from 0. 20 to 0. 62; while its value for B-II and B-III sub-watersheds indicate them to be almost circular and structurally influenced, whereas the for B-I and B-IV watersheds are found in the order of less than 0. 57 which indicates that the sub-watersheds are elongated ones. The values of Elongation Ratio (Re) for these sub-watersheds vary from 0. 36 to 0. 73, suggesting high relief and steep ground slope. The values of Form Factor (Rf) for B-I and B-IV sub-watersheds are 0. 18 and 0. 10, respectively; whereas for B-II and B-III sub-watersheds, the Rf values are 0. 40 and 0. 42, respectively. Thus, it has been observed that B-I and B-IV sub-watersheds are elongated in shape whereas B-II and B-III sub-watersheds are almost circular in shape.

The morphometric analysis of the drainage basin and channel network play a vital role for understanding the geo-hydrological behavior of drainage basin and expresses the prevailing climate, geology, geomorphology, structural, etc. antecedents of the catchment. The relationship between various drainage parameters and the aforesaid factors are well recognized by many workers [1, 2, 3, 4, 5]. Recently, many researchers have used remote sensing data and analyzed them on GIS platform for understanding the morphometric properties of the catchment [6, 7, 8]. The objective of the present study is to analyze the morphometric attributes of Yamuna river basin around Etmadpur tehsil of Agra district as so far any systematic work on the morphometry of the region has not been carried out.

Etmadpur tehsil is a part of marginal alluvial plain and lies close to Yamuna river in the north-eastern part of Agra and is located at a distance of 21. 8 km from Agra city and about 101 km from Etawah district (Fig. 1). The major part of the area is covered by Indo-Gangetic Quaternary alluvial deposits which overly the rocks of Vindhyan Supergroup. The study area lies between the parallels of 27°5′ and 27°20’N latitudes, 78°5′ and 78°20’E longitudes.

Physiographically, the Agra district is divided into five distinct regions viz., Khadar lowland, Trans-Yamuna plain, Yamuna upland, South-West Upland and Yamuna Chambal Ravines. The study area has a long irregular land, narrow towards the extremities and fairly wide in the centre. Physical character of the units differs greatly from each other. The level land between Yamuna and Chambal consists of mere ridge and narrow strip flanked on either side by ravines leading to the river.

The climate of the area is semi-arid and characterized by hot summer and temperature reaches as high as 47°C during summers (April to June). The monsoon months (July to September) receive about 152 cm of rainfall.

Geologically, the area is a part of Indo-Gangetic plain and characterized by alluvium which is an intermixture of gravel, sand, silt and clay in various proportions, deposited during the Quaternary period. The soil of Agra is loose, sandy and calcareous. The rock units belong to the Vindhyan Supergroup represented by the upper Bhander and lower Rewa sandstones, exposed in the west and southwest of Agra in the form of structural hills. The top soil in general is coarse and angular sand with small fraction of clay. However, in the study area, the soil is fine loam in central part, sandy in the northern part and clayey in the southern part. The general geological succession of the study area as given by is as followed [9]:

Generalized Geological Succession

- Quaternary
- Upper Pleistocene to Recent
- Newer Alluvium
- Older Alluvium
- Laterite and Clay
- Sand and gravel
- Sand, clay, silt and kanker
- Laterite and Clay
- Unconformity
- Pre-Cambrian
- Vindhyan Supergroup

- (Upper Vindhyan)
- Upper Bhander Sandstone
- Lower Rewa Sandstone
- Hard &compact sandstone
- Hard &compact sandstone

Methodology

The drainage map (Fig. 3) of the study area has been prepared using IRS-1D LISS-III Geo-coded False Colour Composites (FCC) (bands 2, 3 and 4) (28 March, 2003) and corroborated with information on SOI topographical maps 54 I/3, 54 I/4, 54 I/7 and 54 I/8 on 1: 50, 000 scale with selected ground truth. The morphometric parameters of all the sub watersheds have been calculated using GIS softwares (ArcGIS and ArcView). Perimeter and area of the sub watersheds are also calculated online by the ‘ measurement tool’ of ISRO Bhuvan satellite data (at http://bhuvan2. nrsc. gov. in/). Digital Elevation Model (DEM) data from Shuttle Radar Topographic Mission (SRTM) of 90m resolution (on http://srtm. csir. cgiar. org/) of the study area has been used in the present study. The quantitative analysis of morphometric parameters is given in Table-1 and the results summarized given in Table-2.

Results and Discussion

The study of basin morphometry relates basin and stream network geometries to the transmission of water and sediment through the basin. The size of a drainage basin acts upon the amount of water yield; the length, shape and relief, affect the rate at which water is discharged from the basin and total yield of sediments. Systematic description of the geometry of a drainage basin and its stream channel requires measurement of linear aspects of the drainage network, areal aspects of the drainage basin, and relief (gradient) aspects of the channel network and contributing ground slopes [10]. In the present study, the morphometric analysis is carried out with respect to parameters like stream order, stream length, bifurcation ratio, stream length ratio, basin length, drainage density, stream frequency, elongation ratio, circularity ratio, form factor, relief ratio, etc. using mathematical formulae as given in Table-1 and the results are summarized in Table-2.

Linear Aspects

The linear aspects of morphometric analysis of sub-watershed include stream order, stream length, mean stream length, stream length ratio and bifurcation ratio.

Stream Order

The designation of stream orders is the first step in drainage basin analysis and expresses the hierarchical relationship between stream segments, their connectivity and the discharge arousing from contributing catchments. In the present study, the stream ordering has been carried out using Strahler method [10]. The order wise stream numbers and length of four sub-watersheds are counted and listed in Table-2 which indicates that B-I, II, III and IV sub-watersheds have streams upto fourth order. The numbers of stream segments present in each order are counted and it is observed that the number of stream segments decreases as the stream order increases. This observation is in accordance with the Horton’s Law [1]. This law is followed in the study area and the geometric relationship is shown graphically in the form of straight line when the log value of these variables (stream order and stream number) and (stream order and stream length) plotted (Fig. 4 and Fig. 5), suggesting the area to be in normal basin category.

Stream Length (Lu)

The stream length is computed based on the Horton Law [1] for all the four sub-watersheds. The number of streams of various order in the sub-watershed counted and their lengths are measured. In the study area, total length of stream segments is maximum for first order and decreases as stream order increases. This is a normal trend and indicates that the terrain is gently sloping, low relief and homogenous lithology. However, in all four sub-watersheds, the stream segments of various orders, varies considerably (Table-2).

Bifurcation Ratio (Rb)

The bifurcation ratio is the ratio of the number of stream segments of given order to the number of segments of next higher order. Bifurcation ratio is an index of relief and dissection [1, 11]. It is well demonstrated that bifurcation ratio shows a small range of variation for different regions or for different environment except where geological control dominates2. It has been found that the bifurcation ratio characteristically ranges between 3. 0 and 5. 0 for watershed in which geology is reasonably homogeneous and no structural disturbances.

Bifurcation ratio for different sub-watersheds of the study area have been determined and given in Table-2. The slope of semi log plots of stream order vs. stream number (Fig. 4) gives the bifurcation ratio. The irregularities in the bifurcation ratios of the four sub-watersheds are possibly dependent upon the drainage basin [12]. The lower values of Rb indicate that the sub-watershed has suffered less structural disturbances [10] and the drainage pattern is not distorted. Furthermore, the low Rb values signify a high drainage density, low permeability of the terrain and indicate areas with uniform surficial materials where geology is reasonably homogeneous. The mean bifurcation ratio, which is the average of bifurcation ratios of all orders, varies from 4. 4 to 6. 4 (Table -2). The highest value of mean bifurcation ratio is found in sub-watershed-IV suggesting structural control in the area and low permeability whereas all other basins are geologically homogenous. This also suggests that the drainage basin morphometry of sub-watershed-IV may have been affected by human activities.

Mean Stream Length (Lsm)

The mean stream length is calculated by dividing the total stream length of given order and number of stream of that order (Table-2 and Fig. 5). In the study area, it is noted that Lsm varies from 0. 48 to 23. 0 km and its value for any given order is greater than that of the lower order and less than that of its next higher order in all the sub-watersheds except sub-watershed B-III, which is abnormally increased, possibly due to variation in the slope and topography in this sub-watershed.

Stream Length Ratio (RL)

The stream length ratio can be defined as the ratio of the mean stream length of a given order to the mean stream length of next lower order and having important relationship with surface flow and discharge [1]. Stream length ratio between the streams of different order in each sub-watershed of the study area is variable (Table-2) e. g., sub-watershed B-II show an increasing trend in the stream length ratio from lower order to next higher order which indicate their mature geomorphic stage whereas, sub-watersheds I and III show changes in RL from one order to another which indicate the late youth to mature stage of geomorphic development [13].

Aerial Aspects

The aerial aspects include drainage density, drainage texture, stream frequency, form factor, circularity ratio, elongation ratio and length of overland flow. The results are summarized in Table-2 and discussed in following paragraphs.

Drainage Density (D)

The drainage density is an important indicator of the linear scale of landform element in stream eroded topography and defines as the total length of stream of all orders/drainage area and may be an expression of the closeness of spacing of channels [14]. The significance of drainage density is recognized as a factor determining the time travel by water [15].

The low drainage density is favored in regions of highly permeable subsoil material, under dense vegetative cover where relief is low, while high drainage density is favored in regions of weak or impermeable sub-surface materials, sparse vegetation and high mountain relief. The low drainage density is also indicative of relatively long overland flow of surface water. The drainage density in the study area is low (Table -2) and varies from 1. 95 to 2. 89 km/km2, thus indicates clearly that the region has highly permeable subsoil, dense vegetation cover and low relief. The drainage density factor is also related with the climate, surface roughness and runoff in the area of interest.

Drainage Texture (Rt)

The drainage texture considered as one of the important concept of geomorphology which show the relative spacing of the drainage lines [1]. The drainage density less than 2 indicates very coarse, between 2 and 4 as coarse, between 4 and 6 as moderate, between 6 and 8 as fine and greater than 8 as very fine drainage texture [16]. In the present study, it was found that the drainage density values (Table-2) are variable and suggests that the study area falls into very coarse to coarse texture category and indicates good permeability of sub-surface material in the study area.

Stream Frequency (Fs)

The stream frequency is defined as the total number of stream segment of all order per unit area [14]. The stream frequency for all four sub-watersheds of the study area show positive correlation with the drainage density (Fig. 6) which indicates that the stream population increases with the increase of drainage density in all four sub-watersheds (Table-2).

Infiltration Number (If)

Infiltration number of a drainage basin is the product of drainage density and stream frequency of a basin. It is the number by virtue of which an idea regarding the infiltration characteristics of the basin is obtained. The higher value indicates low infiltration and high runoff. In the present study, sub-watershed B-I has the highest value while B-III has the lowest value (Table-2) thus, indicating lowest and highest infiltration, respectively.

Form Factor (Rf)

The form factor is the ratio of basin area to square of the basin length and is a quantitative expression of drainage basin outline [14]. The Rf values (Table-2) in the study area varies from 0. 10 to 0. 42, thus indicate that the sub-watersheds B-II and B-III are almost circular in shape whereas the lower values of form factor in the remaining sub-watersheds, indicate that they are elongated ones.

Circularity Ratio (Rc)

Circularity ratio is the ratio of the basin area to the area of a circle having the same circumference perimeter as the basin, which is dimensionless and expresses the degree of circularity of the basin [17]. This also indicates the tendency of small drainage basin in homogeneous geologic materials to preserve geometrical similarity.

The Rc values, vary between 0. 57 and 0. 62 (B-II and B-III), indicate that these sub-watersheds are more or less circular in shape, whereas Rc values 0. 45 and 0. 20 for sub-watershed B-I and B-IV, respectively indicate that these are more or less elongated (Fig. 7) and are characterized by moderate to low relief and drainage system seems to be partially controlled by the structural disturbances (Table-2).

Elongation Ratio (Re)

Elongation ratio is the ratio of diameter of a circle of the same area as the drainage basin and the maximum length of the basin [11]. A circular basin appear to more efficient in the discharge of run-off than that of an elongated basin 13. The Re values generally ranges between 0. 6 and 1. 0 over a wide variety of climate and geologic types. Values near to 1. 0 are the characteristics of the region of very low relief, while values in the range of 0. 6 – 0. 8 usually occur in the areas of high relief and steep ground slope10. These values are further categorized as circular (> 0. 9), oval (0. 9-0. 8) and less elongated (<0. 7). The Re values in the study area vary between 0. 69 and 0. 84 (Table-2), which indicate moderate to slightly steep ground slope. The lowest value in case of B-IV sub-watershed indicate high relief and steep slope whereas sub-watersheds B-II and B-III have Re values as 0. 73 and 0. 72, respectively which indicate almost plain land with moderate to low relief and low slope.

Length of Overland Flow (Lg)

Length of overland flow is defined as the length of flow path, projected to the horizontal, non channel flow from point on the drainage divide to a point on the adjacent stream channel [1]. Lg is one of the most important independent variable affecting both hydrologic and physiographic development of drainage basins and relates reciprocally to the average slope of the channel and is quiet synonymous with the length of sheet flow to a large extent [1]. The length of overland flow depends primarily on the degree of relief fragmentation, and hence on the drainage density. Overland flow is significantly affected by infiltration (exfiltration) and percolation through the soil, both varying in time and space. The computed value of all four sub-watersheds varies from 0. 98 to 2. 25. Table- 2 reveals that Lg values for B-IV sub-watershed is less with high drainage density when compared with B-I, B-II and B-III sub-watersheds.

Relief Aspects

The relief aspects determined include relief ratio, relative relief and ruggedness number. The results of the analysis are given in Table-2.

Relief Ratio (Rh)

The relief ratio is obtained when basin relief " H" is divided by the maximum basin length (Lb) which results in a dimensionless ratio which is equal to the tangent of the angle formed by two planes intersecting at the mouth of the basin called relief ratio which measures the overall steepness of a drainage basin and is an indicator of the intensity of erosional process operating on slope of the basin [18]. The values of Rh in all the sub-watersheds are given in Table-2 which ranges from 0. 00041(B-IV) to 0. 00054 (B-II) and thus indicates low relief and moderate to gentle slope.

Relative Relief (Rhp)

This term was used by Melton [19]. The relative relief of different sub-watersheds have been determined and given in Table-2. It is noted that B-III sub-watershed has (0. 026) maximum value of relative relief and B-IV sub-watershed has the (0. 016) minimum value. Furthermore, visual study of the SRTM DEM (Fig. 2)(indicates that the elevation varies from 128m to 167m which represent the land surface has gentle to moderate slope.

Ruggedness Number (HD)

It is the product of maximum basin relief (H) and drainage density (D), where both parameters are in the same unit. An extreme high value of ruggedness number occurs when both variables are large and slope is not only steep but long as well [20]. In the present study, the value of ruggedness number (Table-2) is low which indicates gentle slope of all the sub-watersheds.

Conclusions

Remote sensing and GIS is accepted to be powerful geospatial techniques in preparing the drainage map and understanding the watershed’s morphometric parameters. Detailed morphometric study of all sub-watersheds represents dendritic to sub-dendritic drainage pattern and a variation in the values of Rb among the sub-watersheds is attributed to the difference in topography and geometric development. The Fs values for all sub-watersheds demonstrate a positive correlation with the Dd values thus, indicating the increase in the stream population with respect to increase in drainage density and the values also indicate permeable sub-soil material. In this study, the drainage density, stream frequency and drainage intensity values is an indication that the intensity of dissection in the area is very low. Low drainage densities are often associated with widely spaced streams due to the presence of less resistant materials (lithologies or rock types), or those with high infiltration capacities. Shape parameters of the sub-watersheds indicate that the B-I and B-IV sub-watersheds are more or less elongated whereas, B-II and B-III are more or less circular. Relief aspects and visual interpretation of DEM of the study area indicate gentle to moderate slope, low run off and high infiltration.