Hydro-Morphometric Analysis of Manair Basin for Water Resources Management

Gajanan Ramteke
Scientist SC, Water Resources Division
gkramteke@gmail.com

M. Kavitha
Scientist SC, Land Resources Division
Telangana State Remote Sensing Applications Centre
Planning Department, Government of Telangana
kavithahemanth@gmail.com

Abstract
The study identified the importance of basin attributes for water resource management using remote sensing data and GIS techniques for Manair basin, Telangana, India. Basin boundary, flow accumulation, flow direction, flow length, stream ordering have been determined using hydrology tools and raster surface tools of ArcGIS 10.0. Different thematic maps and morphometric parameters for drainage network, basin geometry, drainage texture analysis, relief characteristics, slope, LULC have been prepared with GIS tools. It is revealed from present study that morphometric analysis and hydrological evaluation at basin scale using RS and GIS is more applied and precise compared to conventional techniques.

Keywords—Remote Sensing, GIS, Morphometric Analysis, Manair Basin, Basin Management

INTRODUCTION
Growing population, urbanization and industrialization are leading to over-utilization of water resources, thus exerting pressure on the limited civic amenities many of which are on the brink of collapse (Jha et al., 2007). Assessment of water resources quantitatively is being critical task on account of ever increasing demand for water over past. Water plays principal role in the sustainability of livelihoods, agriculture and regional economy (De Fraiture et al, 2010). Water management is the primary safeguard against drought and plays a fundamental role in achieving food security at the watershed, sub basin and basin from local to global planes (Gebre et al., 2015).

Hydro-morphometric analysis of a water resource is considered to be the most satisfactory method for proper water resource management, planning and implementation of conservation measures. The characterization of hydro-morphologic parameters helps to understand the hydrological response, behaviour of basin and synthesizing its water balance (Mirzavand and Ghasemieh, 2013).

A number of researchers studied hydro-morphologic characteristics of the various basins using conventional methods (Horton, 1932; Horton, 1945; Smith, 1950; Strahler, 1952; Schumm, 1956 and Strahler, 1957). Remote Sensing (RS), Geographic Information System (GIS) are effective tools to overcome most of the problems of land and water resources planning and management on the account of usage of conventional methods (Rao et al., 2010). Biswaset al. (1999); Srinivasaet al. (2004); Javed et al. (2009); Mishra and Nagarajan (2010); Pareta and Pareta (2011); Vincy et al. (2012); Magesh et al. (2013); Sreekumar and Aslam (2016); da Cunha and Bacani (2016) conducted studies using remote sensing data and GIS.
techniques for hydro-morphologic characteristics of the various terrains. Remote sensing based Digital Elevation Models (DEMs) are used to extract varied hydro-morphologic parameters of drainage basins, including drainage networks, catchment divides, slope gradient and aspect (Jenson 1991; Vijith et al., 2015 and Desai et al., 2016). These parameters are a prerequisite for selection of water recharge sites, hydrological modelling, rainfall-runoff modelling, watershed delineation, groundwater prospect mapping and associated investigation (Kalin et al., 2003; Thakkar and Dhiman, 2007 and Gebre et al., 2015).

Land use and land cover pattern is most important factor for assessment of water resource conditions of an area. Water resources are under severe pressure due to land use practices and climate change. Land use pattern and their estimation describe the anthropogenic utilization of land resources mostly agriculture and urbanization (Singh et al., 2012 and Nian et al., 2014). Hydrological inferences from land use pattern can help understand the shifting scenario of water demand from different activities such as agricultural requirement, domestic needs, and industrialization. It also can be used to understand the rainwater infiltration, ground water recharge and surface runoff rate of the watershed (Sylla et al., 2012 and Rawat et al., 2013). The prime aim of present study is to explore and identify various hydro-morphometric parameters to understand the geometry of the basin for the planning and management of water resources in a sustainable way. Hydro-morphometric evaluation is conducted to understand hydrologic behaviour of Manair basin through GIS techniques DEM, and satellite images analysis.

STUDY AREA
The study was conducted for Manair river basin, a tributary of Godavari River comprising an area of 13134.06 km². It is spatially located in northern part of Telangana State of India and lies between 17°42’1” to 18°42’27” North latitude and 78°13’52” to 80°1’15”East longitudes. Manair basin is part of K6Dm4 agro-ecological sub-region. It is situated in North Telangana Plateau. It has hot moist semi-arid climate with deep loamy and clayey mixed Red and Black soils, and about 120-150 days of length of growing period.

The mean annual temperature of study area ranges between 10°C - 46°C. The average annual rainfall of the area ranges between 700 - 1100 mm. This area is characterized by erratic rainfall and frequent droughts. Most of the rainfall in the region is received during the South-West monsoon, between June and September. Agricultural practices and the production are almost dependent on the onset of monsoon. River and tributaries in the Manair basin are seasonal with bulk of the flow taking place during the monsoon period. Surface water is major source of irrigation.

Data Sources
Topographical data: Shuttle Radar Topography Mission (SRTM), Digital Elevation Model with 90 m spatial resolution Remote Sensing Data: Landsat-8 satellite imagery with 30 m spatial resolution Soil Map: Soil map, National Atlas and Thematic Mapping Organization, DST, GoI.

Fig.1. Location map of Manair basin
METHODOLOGY
Hydrology tools of ArcGIS 10.0 are used to model the flow of water across a surface. These tools are used to model the movement of water across a surface, the concepts and key terms regarding drainage systems and surface processes. It extracts hydrologic information from a digital elevation model for hydrologic analysis. Hydrology tools are applied individually or used in sequence to create a stream network and delineate basin boundary (Table 1).

<table>
<thead>
<tr>
<th>Tool</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fill</td>
<td>Fills sinks in a surface raster to remove small imperfections in the data.</td>
</tr>
<tr>
<td>Flow Accumulation</td>
<td>Creates a raster of accumulated flow into each cell. A weight factor can optionally be applied.</td>
</tr>
<tr>
<td>Flow Direction</td>
<td>Creates a raster of flow direction from each cell to its steepest downslope neighbour.</td>
</tr>
<tr>
<td>Flow Length</td>
<td>Calculates the upstream or downstream distance, or weighted distance, along the flow path for each cell.</td>
</tr>
<tr>
<td>Stream Link</td>
<td>Assigns unique values to sections of a raster linear network between intersections.</td>
</tr>
<tr>
<td>Stream Order</td>
<td>Assigns a numeric order to segments of a raster representing branches of a linear network.</td>
</tr>
<tr>
<td>Stream to Feature</td>
<td>Converts a raster representing a linear network to features representing the linear network.</td>
</tr>
<tr>
<td>Watershed</td>
<td>Determines the contributing area above a set of cells in a raster.</td>
</tr>
</tbody>
</table>

Morphometric analysis is implemented to interpret the watershed characteristics such as linear aspects of the drainage network: stream order, bifurcation ratio, stream length and areal aspects of the drainage basin consists form factor ratio, circularity index, elongation ratio, stream frequency, drainage density and texture ratio of the basin are calculated.

Supervised classification scheme is performed to assess the land use land cover pattern and their spatial variation from recent freely available satellite data of Lasndsat-8 January, 2017 which has 30 m spatial resolution in the present study. A standard classification approach is applied for the satellite image using Erdas Imagine software starting from defining of the training sites, extraction of signatures from the image and then classification was performed. Finally, Maximum Likelihood Classification (MLC) method is applied. Common land use land cover categories identified in the watershed are cropland, settlement, fallow land, forest, wasteland/barren rocky, water body and river.streams. Soil map obtained from National Atlas and Thematic Mapping Organization, DST, GoI is geo-referenced and digitized for study basin AoI. Loamy and clayey mixed Red and Black soils are observed in the basin.

RESULTS AND DISCUSSION
The purpose of present study to extract morphometric properties of basin is to obtain information in quantitative form with relation to the geometry of the watershed that can be correlated with hydrologic information. The measurement and mathematical analysis of the configuration of the earth's surface and of the shape and dimensions of its landform provides the basis of the investigation of maps for a geomorphological survey.

Drainage network
Stream order ($S_o$)
Strahler (1952) proposed the stream ordering system. In present study, Strahler method has been used for streams in basin (Fig. 2, IV order and above streams are shown to avoid clumsiness in figure). In Strahler method, first order streams are having no stream tributaries and that flows from the stream source. A second-order segment is created by joining two first-
order segments, a third-order segment by joining two second order segments, and so on. The ninth stream order observed as highest in the basin (Table 2). Dendritic drainage pattern formed by the interlinking of streams is observed. Dendritic drainage has a spreading, tree-like pattern with an irregular branching of tributaries in many directions and with any angle. It is observed that the maximum frequency is in the case of first order streams. It has also noticed that there is a decrease in stream frequency as the stream order increases.

**Stream number (Nₙ)**
The total of order wise stream segments is known as stream number. Horton (1945) states that the numbers of stream segments of each order form an inverse geometric sequence with order number. Total number of streams identified in Manair basin are 171766.

**Stream length (Lₙ)**
Total stream lengths of Manair basin have various orders. Horton's law of stream lengths supports the theory that geometrical similarity is preserved generally in watershed of increasing order (Strahler, 1964). Stream length based on the method proposed by Horton (1945) has been computed and depicted in Table 2.

**Mean stream length (Lₘₙ)**
Mean Stream length is a dimensional property revealing the characteristic size of components of a drainage network and its contributing watershed surfaces (Strahler, 1964). It is obtained by dividing the total length of stream of an order by total number of segments in the order. Mean stream length for Manair basin is calculated and placed in Table 2.

![Fig. 2. Drainage network map of Manair basin](image)

**Bifurcation ratio (Rₗ)**
The bifurcation ratio is dimensionless property and defined as ratio of the number of stream segments of a given order to the number of segments of the next higher (Strahler, 1964). Bifurcation ratio values generally ranges from 3.0 to 5.0. Mean bifurcation ratio for Manair basin is calculated as 4.43. The lower values of Rₗ are characteristics of the
watersheds, which have suffered less structural disturbances and reflect the drainage pattern has not been distorted because of the structural disturbances. The higher value of $R_b$ indicated strong structural control on the drainage pattern and also streams that have a higher average flood potential due to numerous tributary segments drain into relatively few trunk transporting stream segments. This shows its usefulness for hydrograph shape for basins similar in other respect. An elongated basin has higher bifurcation ratio than normal and approximately circular basin.

**Length of main channel ($C_l$)**
This is the length along the longest watercourse from the outflow point of basin to the upper limit to the basin boundary. Computed main channel length using ArcGIS 10.0 software is 259.73km.

<table>
<thead>
<tr>
<th>$S_n$</th>
<th>$N_n$</th>
<th>$R_b$</th>
<th>Stream Length, km</th>
<th>$L_{sum}$, km</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>135991</td>
<td>4.80</td>
<td>33705.08</td>
<td>0.25</td>
</tr>
<tr>
<td>II</td>
<td>28335</td>
<td>4.87</td>
<td>13776.56</td>
<td>0.49</td>
</tr>
<tr>
<td>III</td>
<td>5817</td>
<td>4.61</td>
<td>6590.91</td>
<td>1.13</td>
</tr>
<tr>
<td>IV</td>
<td>1262</td>
<td>4.48</td>
<td>3282.81</td>
<td>2.60</td>
</tr>
<tr>
<td>V</td>
<td>282</td>
<td>4.70</td>
<td>1712.83</td>
<td>6.07</td>
</tr>
<tr>
<td>VI</td>
<td>60</td>
<td>4.00</td>
<td>826.33</td>
<td>13.77</td>
</tr>
<tr>
<td>VII</td>
<td>15</td>
<td>4.00</td>
<td>389.53</td>
<td>25.97</td>
</tr>
<tr>
<td>VIII</td>
<td>3</td>
<td>5.00</td>
<td>132.68</td>
<td>44.23</td>
</tr>
<tr>
<td>IX</td>
<td>1</td>
<td>3.00</td>
<td>124.01</td>
<td>124.01</td>
</tr>
<tr>
<td>Sum</td>
<td>171766</td>
<td>4.43</td>
<td>60540.74</td>
<td>218.52</td>
</tr>
</tbody>
</table>

**Basin Geometry**

**Basin area ($A$)**
The area of the basin is another important parameter like the length of the stream drainage. Schumm (1956) established an interesting relation between the total watershed areas and the total stream lengths, which are supported by the contributing areas. The computed basin area using ArcGIS 10.0 software is 13134.06 km$^2$.

**Basin perimeter ($P$)**
Basin perimeter is the outer boundary of the basin that enclosed its area. It is measured along the divides between basins and may be used as an indicator of basin size and shape. The perimeter of Manair basin is computed as 677.05 km.

**Form factor ($F_f$)**
According to Horton (1932), form factor may be defined as the ratio of basin area to square of the basin length. The value of form factor would always be less than 0.7854 (for a perfectly circular watershed). Smaller the value of form factor, more elongated will be the watershed. Basins with high form factors have high peak flows of shorter duration, whereas elongated basin with low form factor indicating lower peak flows of longer duration. Form factor value of the basin is 0.309 and suggested that the shape of the basin is elongated.

**Elongation ratio ($R_e$)**
Elongation ratio is defined as the ratio of diameter of a circle of the same area as the basin to the maximum basin length (Schumm, 1956). Strahler states that this ratio runs between 0.6 and 1.0 over a wide variety of climatic and geologic types. The varying slopes of watershed can be classified with the help of the index of elongation ratio, i.e. circular (0.9-0.10), oval (0.8-0.9), less elongated (0.7-0.8), elongated (0.5-0.7), and more elongated (< 0.5). The elongation ratio of study area is...
0.49, which represents that the basin is more elongated with low relief.

**Circularity ratio (R_c)**
Miller (1953) defined dimensionless circularity ratio (R_c) as ratio of basin area to the area of circle having the same perimeter as the basin. R_c is influenced by the length and frequency of streams, geological structures, land use/land cover, climate, relief and slope of the basin. A circularity ratio of the basin is 0.359 which indicates strongly elongated and highly permeable homogenous geologic materials. The observed circularity ratio of the basin indicates that the basin is elongated in shape, has low discharge of runoff and highly permeable subsoil conditions.

**Compactness Coefficient (C_c)**
Compactness coefficient of the basin is the ratio of perimeter of watershed to circumference of circular area, which equals the area of the basin. The C_c is independent of size of basin and dependent only on the slope. Compactness coefficient of Manair basin is observed equal to 1.67.

**Drainage Texture Analysis**

**Stream frequency (F_s)**
Stream frequency (F_s) frequency is the total number of stream segments of all orders per unit area Horton (1932). F_s for Manair basin is calculated as 13.08 which exhibits a positive correlation with the drainage density value of the area indicating an increase in stream population with respect to increase in drainage density.

**Drainage density (D_d)**
Drainage density is a measure of the total length of the stream segment of all orders per unit area (Horton, 1932). Drainage density is a better quantitative expression to the dissection and analysis of landform, although a function of climate, lithology and structures and relief history of the region can finally use as an indirect indicator to explain, those variables as well as the morphogenesis of landform. The drainage density for study area is calculated as 4.61/km. The Drainage density less than 2 indicates very coarse, between 2 and 4 is related to coarse, between 4 and 6 is moderate, between 6 and 8 is fine and greater than 8 is very fine drainage texture. It is observed from the calculated value of drainage density that, Manair basin has moderate texture.

**Drainage intensity (D_i)**
Faniran (1968) defines the drainage intensity, as the ratio of the stream frequency to the drainage density. The study shows a low drainage intensity of 2.84 for the basin. This low value of drainage intensity implies that drainage density and stream frequency have little effect on the extent to which the surface has been lowered by agents of denudation. Low drainage intensity may affect the surface runoff to quickly remove from the watershed.

**Length of overland flow (L_g)**
Horton (1945) used this term to refer to the length of the run of the rainwater on the ground surface before it is localized into definite channels. Horton defined it to be equal to half the reciprocal of the drainage density. The length of overland flow of Manair basin is 0.11 km.

**Infiltration number (I_f)**
The infiltration number of a basin is defined as the product of drainage density and stream frequency and given an idea about the infiltration characteristics of the watershed. The higher the infiltration number, the lower will be the infiltration and the higher runoff. The infiltration number of the study basin is 60.29, which shows high runoff potential.
Relief Characteristics

Relief (R)
Difference in the elevation between the highest point of the basin and the lowest point on the valley floor is known as the total relief of the river basin. In the study area, the value of relief is found to be 557 m.

Relative Relief (\(R_{hp}\))
The maximum basin relief is obtained from the highest point on the watershed perimeter to the mouth of the stream. Relative relief is calculated using the formula: \(R_{hp} = \frac{H \times 100}{P}\), where P is perimeter in metres. Relative relief of the basin comes to 0.082.

Slope
Slope is the measure of change in surface value over distance and can be expressed in degrees or as a percentage. Slope is a critical parameter which directly controls runoff and infiltration of any terrain\(^{[1-15]}\). Slope of the study area is derived from SRTM DEM with 90 m spatial resolution (Fig. 3). DEM is processed in ArcGIS 10.0 using slope tool under raster surface toolbox. The slope map of the study micro-watershed is grouped in to six classes in per cents. 0% - 3% (flat or almost flat), 3% - 8% (gentle sloping), 8% - 15% (sloping), 15% - 30% (moderately steep), 30% - 50% (steep) and >50% (very steep). It is observed that the most of the area of Manair basin comes under flat and gentle slope which indicates almost flat topography of the area. Gentle slopes were designated in the ‘excellent’ category for groundwater management as the nearly flat terrain is the most favourable for infiltration.

Aspect
The aspect identifies the downslope direction of the maximum rate of change in value from each raster cell to its neighbours. Aspect can be thought of as the slope direction. The values of the output raster will be the compass direction of the aspect. The aspect map is important parameter for understanding the impact of sun on the area’s local climate. Aspect has major effects on vegetation distribution. The aspect map of the study area is derived from SRTM DEM and represents the compass direction of the aspect. 0\(^\circ\) is true north; a 90\(^\circ\) aspect is to the east (Fig. 4). The result indicates that a high percentage of east-facing slopes. These slopes have relatively higher soil moisture content and moderate vegetation compared to west facing slope of the basin.
Land Use/Land Cover
Land use and land cover maps and their inputs are vital parameters to understand, managing and monitoring the hydrological conditions of the watershed (Wagner et al., 2013). LULC of the basin is determined from Landsat-8, 30 m resolution data and showed in table 3 and Fig. 5. The land use land cover map of the basin constitutes water body (3.1%), forest (7.0%), settlement (4.1%), wasteland/barren rocky (30.6%), river/streams (1.4%), and crop land (47.2%), fallow land (6.6%). The larger portion of the basin is covered by cultivated land[16-30]. Assessment of land use pattern of the basin reveals that most part (>50.0%) of the area comes under agricultural and fallow land which indirectly supports the future for watershed development and management.

TABLE 3. LULC of Manair basin

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>LULC</th>
<th>Area, km²</th>
<th>% Area to basin area</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Waterbody</td>
<td>403.1</td>
<td>3.1</td>
</tr>
<tr>
<td>2</td>
<td>Settlements</td>
<td>538.32</td>
<td>4.1</td>
</tr>
<tr>
<td>3</td>
<td>Cropland</td>
<td>6201.87</td>
<td>47.2</td>
</tr>
<tr>
<td>5</td>
<td>Fallow land</td>
<td>865.64</td>
<td>6.6</td>
</tr>
<tr>
<td>6</td>
<td>Forest</td>
<td>913.49</td>
<td>7.0</td>
</tr>
<tr>
<td>8</td>
<td>Wasteland/Barren</td>
<td>4021.12</td>
<td>30.6</td>
</tr>
<tr>
<td>9</td>
<td>River/Stream</td>
<td>190.52</td>
<td>1.4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>13134.06</strong></td>
<td><strong>100.0</strong></td>
<td></td>
</tr>
</tbody>
</table>

Soils
Soil type map of the basin is presented in Fig. 6. Most of the basin area is covered with red type soils. Medium black type soils are located near the outlet of the basin which has high soil fertility high runoff potential and low infiltration characteristics. It is observed from map that patches of red gravelly type soil are distributed over the spatial extent of the basin. A red earth comprises 78.47% area of the basin.

Effects of Morphometric Analysis on Hydrological Processes
Morphometric analysis of basin on RS data and GIS plays a significant role for proper hydrological study of any terrain which indirectly maintains the hydrogeological condition of the basin. The quantitative analysis of basin attributes is found to be of great utility in basin delineation, soil and water conservation and basin management. Morphometric parameters can be integrated with the other hydrological characteristics of the Manair basin; the
strategy of siting recharge and water-harvesting measures provides better groundwater development and management plan. The drainage pattern classification of the study basin is dendritic in nature. This may be due to more or less homogeneous lithology and structural controls. Slope of the micro-watershed plays a key role in determining infiltration and runoff production.

CONCLUSION
The study of Manair basin reveals that RS data and GIS based approach in evaluation of morphometric parameters and their influence on landforms and soils characteristics at river basin level is more appropriate than the conventional methods. GIS techniques have high accuracy of mapping and measurement proves to be a proficient tool in morphometric analysis. The result observed in present study would be the scientific database for further detailed hydrological investigation and finds out the alternative solutions for water management in the basin.

REFERENCES


