# Hydrological Inferences from Watershed Analysis using Remote Sensing & GIS

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***Abstract:*** This study highlights the importance of ASTER Global Digital Elevation Model (ASTER GDEM) and satellite images for evaluation of drainage and extraction of their relative parameters for the region in Kurnool Town, A.P, India. Hydrological parameters such as drainage analysis, topographic parameters and land use pattern were assessed and interpreted for watershed management of the area. Using ARC GIS software hydrological module to calculate and depict watershed and morphometric analysis of the watershed using ASTER GDEM. The flow sequence of the watershed shows the dendritic type drainage network from the first to the sixth order which is a sign of the homogeneity of the watershed and the lack of structural control. It was found that the drainage density of the area was low to moderate, indicating that the area had high permeable soils and low fluctuations. The bifurcation ratio was 9.32, and the elongation was 0.39, which indicated that the basin belonged to the elongated basin type. Land use map of the watershed was generated from latest available multispectral satellite data and entire watershed covers in agricultural land, rocks, fallow, residential areas and water bodies. Current research shows that compared with other existing technologies, watershed scale hydrological assessment based on Aster GDEM is more accurate.

***IndexTerms*** **- DEM, GIS, Hydrological parameters, Watershed**

## I. Introduction

The current high levels of population expansion, rapid urbanization and climate change, and irregular rainfall frequencies and intensities make it difficult to manage and stockpile rational water resources. There is therefore an urgent need to assess water resources, which play a major role in livelihoods and regional economic sustainability throughout the world. This is the main safeguard against drought and plays a central role in local and national and global food security. The growing population and urbanization have led to the overuse of resources, exerting pressure on the limited civic facilities that are on the verge of collapse (Singh et al., 2013; Jha et al., 2007). Quantitative morphological analysis of watershed can provide information about hydrological properties of exposed rocks in river basins. Basin Drainage Map provides reliable rock permeability index and its rock type, structure and its hydrological status. Watershed characterization and management require detailed topographic information, drainage networks, moisture, channel lengths, geomorphology and geological settings for appropriate watershed management and implementation of water conservation measures plan (Sreedevi et al., 2013).

Remote sensing data and higher resolution from satellite platforms make these technologies seem ready to have a better impact on land resource management initiatives involving the monitoring of LULC mapping and change detection in the different spatial areas of semi-arid regions is experiencing the combined effects of population growth and climate change (Singh et al., 2011). Surface hydrological indications are one of the promising scientific tools for assessing and managing water resources. Drainage form analysis is a prerequisite for selecting water supply points, watershed modeling, runoff simulation, watershed delineation, groundwater prospect and geotechnical engineering investigation (Magesh et al., 2011; Thomas et al., 2012). Drainage network analysis is commonly used to understand the major geological changes in the watershed, topographic information and tectonic sets and their interrelationships. Watershed assessments based on remote sensing and geographic information systems have been carried out by researchers from different terrain and have proved to be a very scientific tool for generating accurate and updated watershed parameter description information (Grohmann, 2004; Korkalainen et al., 2007; Hlaing et al., 2008; Javed et al., 2009; Pankaj and Kumar, 2009). Previous drainage morphological parameters were extracted from topographic maps or field surveys. The extraction of drainage parameters over the past 20 years is more popular with digital terrain information, which is known as the digital Elevation Model (DEM), which is faster, more accurate, newer, and unable to express the watershed analysis method. (Moore et al., 1991; Maathuis, 2006). One of the most recent near global elevation data sets recorded during the 11 day Shuttle Radar Topographic Mission is based on a C-band interferometric radar configuration. This information, representing the radar reflective surface (which may be vegetation, man-made features or bare earth), was collected in 2000 (Maathuis, 2006).

Digital Elevation Models (DEM), such as the Space Shuttle Radar Topographic survey task (SRTM) or Aster GDEM products (USGS, Denver, Colorado State, USA), have been used to extract different watershed terrain parameters, including drainage networks, catchment zoning, slope and slope direction, and upstream flow contribution areas (Mark, 1984; Tarboton, 1997). GIS based watershed assessment using the Space Shuttle Radar topographic map Mission (SRTM) data provides an accurate, fast and inexpensive way to analyze hydrological systems. (Farr and Kobrick, 2000; Grohmann et al., 2007; Panhalkar, 2014). Recently Bastawesy et al. (2013) the hydrological parameters of the watershed were extracted by remote sensing data and DEM, and the storage area was defined for the Equatorial Lake area in Uganda. They conclude that digital elevation model (DEM) is a very accurate tool for the assessment of morphological parameters and Watershed division in watershed management. In addition, the low intensity and unstable monsoon caused further shortages of surface water supply. As a result, the demand for groundwater resources has increased significantly year by year, resulting in a sharp drop in groundwater levels. Over-exploitation of groundwater has caused the aquifer area in several parts of the country to dry out. Therefore, the replenishment of the river basin water resources management plan must be increased at the basin level (Ellis and Revitt, 2010; Rao,2008; Eyquem,2007).

current study is semi-arid and receives maximum recharges through rainfall. The region is in urgent need of basin-based comprehensive morphological analysis to understand the geography of the region. By using ASTER GDEM, satellite imagery and GIS analysis, water resources management was carried out on basin watershed analysis and basin morphology measurements in the kurnool area of Andhra Pradesh. The main purpose of the current work is to survey and determine various drainage parameters, and to understand the geometry of the watershed in a sustainable manner to protect and manage the water resources. The results observed in current work can serve as a scientific database for further detailed hydrological surveys and finds out Alternative solutions for collecting water in the study area by constructing various suitable structures (Check dam, Storage tanks, Recharge shaft) based on observed calculations.

**II. STUDY AREA**

The study area (Fig.1), watershed lies between geographic latitudes $15^0 28'$ and $15^0 52'$ N and longitudes $77^0 48'$ and $78^0 12'$ E. It has an average elevation of 273 meters. Kurnool is a Metropolitan city and the headquarters of Kurnool district in the Indian state of Andhra Pradesh. The climate is tropical with temperatures ranging from 26 °C to 46 °C in the summer and 12 °C to 31 °C in the winter. The average annual rainfall is about 705 millimeters. The district is underlain by different geological formations ranging in age from Archaean to recent. The major part of the district in west is occupied by granite gneisses, while the eastern part is underlain by quartzites, shales and limestones of Kadapa and kurnool group. Black cotton soil is most predominant in kurnool.The recent alluvium is confined to the major stream and river courses like Krishna, Tungabhadra, Gundlakamma and Kuderu.

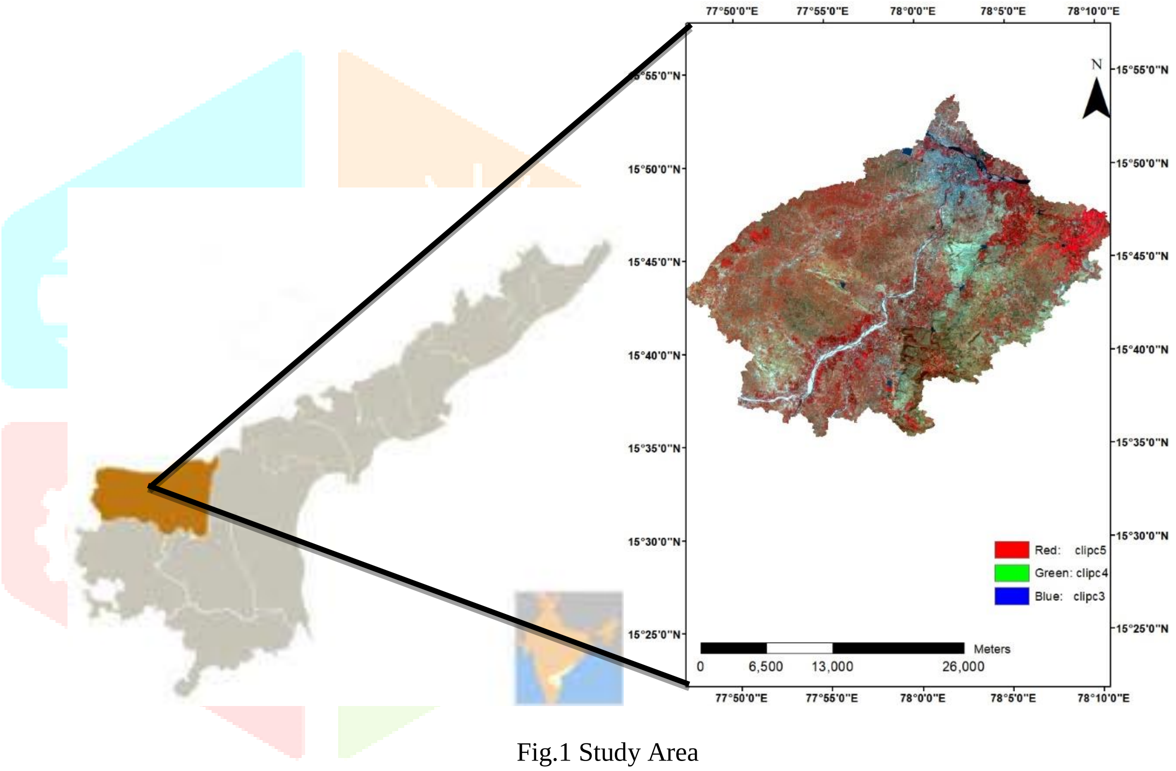


Fig.1 Study Area

## II. PREPARATION OF DATA AND METHODOLOGY

The assessment of drainage patterns and their quantitative analysis provide background information on the rock hydrological conditions and properties exposed within the basin. The morphological analysis of the basin provides an indication of permeability, rock storage capacity and basin production. In this article, a comprehensive use of multi-spectral satellite data and digital elevation model (DEM) is used to generate databases and extract various drainage parameters. Details of data used are shown in Table 1. The following procedure was followed for watershed analysis.

Table 1 Data used in the present work.

| Type of data/software | Details of data | Sources |
|---|---|---|
| Landsat 8 satellite imagery | Path/row: 144/49 dated 05/01/2018 | https://landsat.usgs.gov |
| ASTER GDEM | Resolution- 1ARC-SECOND dated 17/10/2011 | USGS website |

a) Landsat 8 Satellite image utilized to generate the land use/land cover map and updation of drainage map of the basin.
b) Digital Elevation Model (DEM) of the catchment was extracted from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data obtained during October 2011 with resolution of 1 Arc second (downloaded from the US Geological Survey website). The ASTER Global DEM was utilized to prepare topographic, slope and delineation of drainage map of the basin Using Spatial Analyst tool of ARC GIS 10.2
c) All the extracted parameters from satellite images and ASTER GDEM such as 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, etc., were calculated from these parameters. The methodologies adopted for the computation of morphometric parameters are given in Table 2.

Table 2 Methodology adopted for computations of morphometric parameters.

| S.NO. | PARAMETERS | FORMULAE | REFERENCES |
|---|---|---|---|
| 1 | Stream order (U) | Hierarchical rank | Strahler (1964) |
| 2 | Stream length($L_u$) | Length of the stream | Horton (1945) |
| 3 | Mean stream length($L_{sm}$) | $L_{sm} = L_u/N_u$ | Strahler (1964) |
| 4 | Stream length ratio($R_l$) | $R_L = L_u/(L_u +1)$ | Horton (1945) |
| 5 | Bifurcation ratio($R_b$) | $(R_b) = N_u/(N_u + 1)$ | Schumm (1956) |
| 6 | Mean bifurcation ratio($R_{bm}$) | $R_{bm}$ = average of bifurcation ratios of all order | Strahler (1957) |
| 7 | Drainage density($D_d$) | $D_d = L_u/A$ | Horton (1945) |
| 8 | Drainage texture(T) | $T = D_d \times Fs$ | Smith (1950) |
| 9 | Stream frequency($F_s$) | $F_s = N_u/A$ | Horton (1945) |
| 10 | Elongation ratio($R_e$) | $R_e = D/L$ | Schumm (1956) |
| 11 | Circularity ratio($R_c$) | $R_c = 4\pi A/P^2$ | Strahler (1964) |
| 12 | Form factor($F_f$) | $F_f = A/L^2$ | Horton (1945) |

## IV. RESULTS AND DISCUSSIONS

Quantitative analysis of the watershed, using GIS software to evaluate the calculation and topology construction of different morphological parameters. Important linear and Arial parameters and their characteristics are calculated such as basin area, perimeter , basin length , bifurcation ratio (Rb), drainage density (Dd), stream frequency (Fs) circulatory ratio (Rc), elongation ratios (Re) etc. The drainage pattern of the basin has a six order flow of dendritic.

### *4.1. Stream number (Nu) and stream orders*

The basin contains a dendritic pattern that shows the homogeneous subterranean strata in the study area. In this study, flow ordering has been sorted from topographic maps and satellite imagery digital streams according to the proposed method (Strahler, 1964). The maximum number of streams is found in the first order, and as the order of the streams increases, the number of streams decreases. The stream order of the basin varies from 1st to 6th orders stream (Fig.2). According to the rules put forward by Horton in 1945, ARC GIS software was used to calculate river sorting. It is found that the total length of the flow section is the largest in the first-order flow and decreases as the flow order increases. This change in flow order may indicate flow from high altitude and lithologic changes. The Total length of streams in the basin is about 5520.85km. The mean stream length (Lsm) and their ratio have been also calculated in GIS (Table 3). Understanding the stream in the drainage system constitutes a drainage pattern, while the latter is mainly to reproduce the structure/lithology control of the underlying rock. The study area possesses dendritic drainage patterns, despite stream lengths and other hydrological properties. They are generally characterized by a treelike branching system, which indicates the homogenous and uniformity.

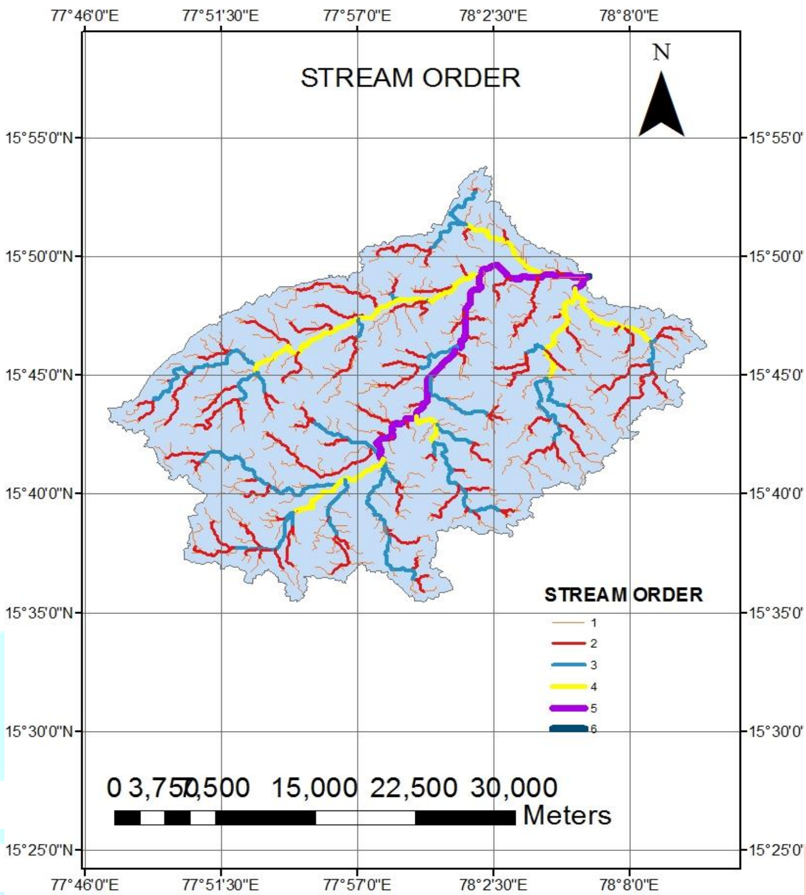


Fig.2 Drainage map with stream order of the watershed, Kurnool, A.P

### *4.2. Stream length (Lu), mean stream length (Lsm) and stream length ratio ($R_L$)*

According to the law of watershed proposed by Horton in 1945, the river length, average river length and river length ratio were calculated using GIS. In general, the total length of the flow segment decreases as the flow sequence increases (Table 3). River lengths and their ratios are very important parameters for the study of hydrological characteristics of river basins because they are the permeability of rocks in the basin. It also shows whether there are major changes in the hydrological characteristics of the rock surface below the basin. (Singh et al., 2013). The relationship between bifurcation ratio and stream length ratio is determined by hydrogeology, topography and geological characteristics. The values of total length, mean length and length ratio of different stream orders of the basin are shown in Table 3.

### *4.3. Bifurcation ratio (Rb)*

The term bifurcation ratio (Rb) can be defined as the ratio of the number of flow segments in a given sequence to the number of segments in the next higher segment. The bifurcation ratio between 3 and 5 in this basin is considered to be a feature of the basin with minimal structural disturbances (Strahler, 1964). The mean bifurcation ratio of the basin is observed as 9.32 (Table 3). This shows that the drainage pattern of the basin is affected by structural disturbances. The observed Rb is different from the first order to the next. These irregularities depend on the geological and lithologic development of the basin.

Table 3 Linear aspect of the watershed

| Stream order(w) | No. of streams($N_u$) | Bifurcation ratio($R_{bf}$) | Mean bifurcation ratio($R_{bm}$) | Total length of streams(km) | Mean length of strams(km) | Length ratio ($R_l$) |
|---|---|---|---|---|---|---|
| 1 | 508 | | 9.32 | 1117.3 | 0.91 | 1.94 |
| 2 | 263 | 1.93 | | 1114.2 | | |
| 3 | 129 | 2.04 | | 1303.24 | | |
| 4 | 71 | 1.82 | | 756.47 | | |
| 5 | 39 | 1.82 | | 792.64 | | |
| 6 | 1 | 39 | | 437 | | |
| | Total= 1011 | | Total | =5520.85 | | |

### *4.4. Drainage density (Dd) and drainage texture (T)*

Horton (1932) introduced the drainage density as an expression of the compactness of the channel spacing. It is an indicator that measures the total length of the river segment for all orders per unit area, and is controlled by the slope gradient and relative river basin saturation. The drainage density of the study area has been calculated and the value is 1.47 (Table 4). Smith (1950) divide Drainage Density into Five Different Textures. Drainage density less than 2 means very rough, between 2 and 4 is related to roughness, between 4 and 6 is moderate, between 6 and 8 is fine and greater than 8 is very fine drainage texture. It has been observed that if the drainage texture is 5.64, then there is a highly resistant permeable material with a low relief. Changes in drainage structure (T) values depend on many natural factors such as climate, rainfall, vegetation, rock, soil type and its permeability, and watershed mitigation. The relationship between the geology and hydrology analysis of the basin in the semi-arid area is low in drainage density, which usually results in highly resistant or infiltrating underground materials and dense vegetation. High drainage density is caused by weak surface materials, thin vegetation and mountainous topography. The low drainage density in the basin shows that they consist of permeable subsurface material, good vegetation coverage, and low uplift, resulting in more infiltration capacity in the basin.

### *4.5. Stream frequency (Fs)*

Flow frequency (Fs) or channel frequency is the total number of flow segments per unit area for all orders (Horton, 1932). The Fs value indicates a positive correlation with the drainage density of the basin, indicating that the population of the river basin has increased the increase in the drainage density. The observed basin with a watershed frequency (Fs) of 1.33 is positively correlated with the drainage density in the area, indicating an increased drainage density in the basin population. (Table 4).

### *4.6. Elongation ratio (Re)*

Elongation (Re) is the ratio of the diameter of the circle with the same area as the watershed to the maximum length of the basin (Schumm, 1956). The value of Re usually varies from 0.6 to 1.0 under various climatic and geological conditions. Values close to 1.0 are typical for very low undulations, while values in the 0.6-0.8 range are usually associated with high undulations and steep ground gradients (Strahler, 1964). These values can be divided into three categories: (a) circular (> 0.9), (b) elliptical (0.9-0.8), and (c) elongated (<0.7).The elongation ratio of the basin is 0.58, which suggests that the basin belongs to the elongated shape basin and low relief (Table 4).

### *4.7. Circularity ratio ($R_c$)*

Dimensionless circularity ratio (Rc) is defined as ratio of basin area to the area of circle having the same perimeter as the basin (Miller, 1953). Rc is affected by the length and frequency of the river, geological structure, land use/land cover, climate, topography and slope. The circular ratio of the basin is 0.30, which indicates the strong elongation and high permeability of the homogeneous geological material. The observed circularity ratio of the basin indicates that the basin is elongated, with low runoff and high permeability soil conditions. (Table 4).

### *4.8. Form factor ($F_f$)*

According to Horton (1932), form factor (Ff) may be defined as the ratio of the basin area to square of the basin length. The form factor indicates the flow intensity of a basin for a defined area. The form factor value should always be less than 0.7854. The smaller the value of the form factor, the longer the basin. Basins with high form factors experience greater peak flow for shorter durations, while longer basins with smaller form factors experience lower peak flow for longer durations. The observed form factor value of the basin is 0.264 suggesting that the shape of the basin is elongated (Table 4). An elongated basin with a low form factor indicates that the basin will have a longer flat peak flow.

Table 4 Areal aspect of the watershed

| Basin area (km2) | Perimeter (km) | Length( km) | Form factor | Elongation ratio(Re) | Circularity ratio(Rc) | Drainage density(k m) | Stream frequency | Drainage texture |
|---|---|---|---|---|---|---|---|---|
| 758.8 | 179 | 77.98 | 0.26 | 0.39 | 0.297 | 1.47 | 1.33 | 5.64 |

### *4.9. Aspect map*

The aspect map usually refers to the direction the hillside faces. The orientation map is an important parameter to understand the influence of the sun on the climate of the local area. It is generally a west-facing slope and in the afternoon it is the hottest time of the day. In most cases, the west-facing slope is warmer than the eastern-facing slope. Aspect maps have important influence on the distribution of regional vegetation types. The aspect map derived from ASTER DEM represents the compass direction of the aspect. 0_ is true north; a 90_ aspect is to the east (Fig.3). The watershed shows the even distribution of slopes and slopes that are slightly eastward. Therefore, these slopes have higher water content and higher vegetation than west slopes.

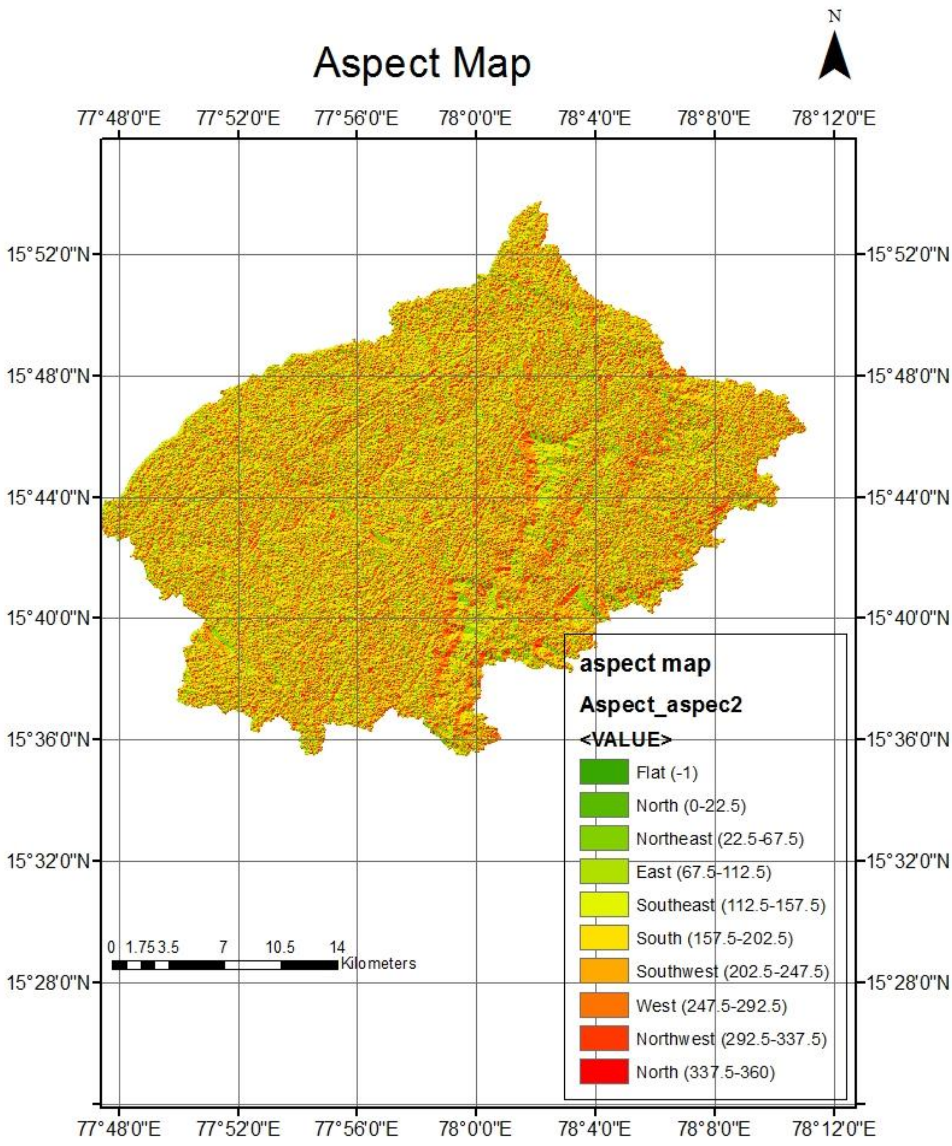


Fig.3 Aspect map of the watershed

***4.10. Slope map***

Slope is a measure of the change in surface value with distance. It can be expressed in degrees or percentages. In a raster format, a digital elevation model (DEM) is a grid in which each cell is a reference to a common data value. Extracting elevations from remote sensing requires dedicated software packages, but most GIS software packages have routines for point or contour interpolation. Any two points on the grid are sufficient to determine the slope. Once the slope is calculated, the largest difference can be found and the gradient can be determined (Burrough and McDonnell, 1998; Maathuis, 2006; Jha et al. 2007). The terrain elevation map of the study area is now developed from the digital elevation model (DEM) extracted from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data. To do this, the DEM is subjected to two-direction gradient filters (one in the x direction and the other in the y direction). Using the ARCGIS Spatial Analyst tool, the generated map is used to generate a slope map of the study area. The slope map of the study area has grouped in five classes in degrees viz. 1–$3^0$ (Gentle), 3–$5^0$ (Moderate), 5–$10^0$ (Steep), 10–$35^0$ (Very Steep) and >$35^0$ (Very Very Steep) (Fig.4It has been observed that most of the basin area is under a gentle slope, indicating that the terrain in the area is almost flat. Soft slopes have been designated as "excellent" groundwater management categories because near-flat terrain is the most conducive to infiltration. Due to slight undulations in the terrain, the moderate slope will also enter a good area, resulting in maximum seepage or partial runoff. Steep formations and high surface runoff and negligible infiltration are marked in good areas such as construction of dams etc. Slope is a key parameter that directly controls the runoff and penetration of any terrain. Runoff in higher slope areas results in less penetration. This factor greatly controls the development of aquifers.

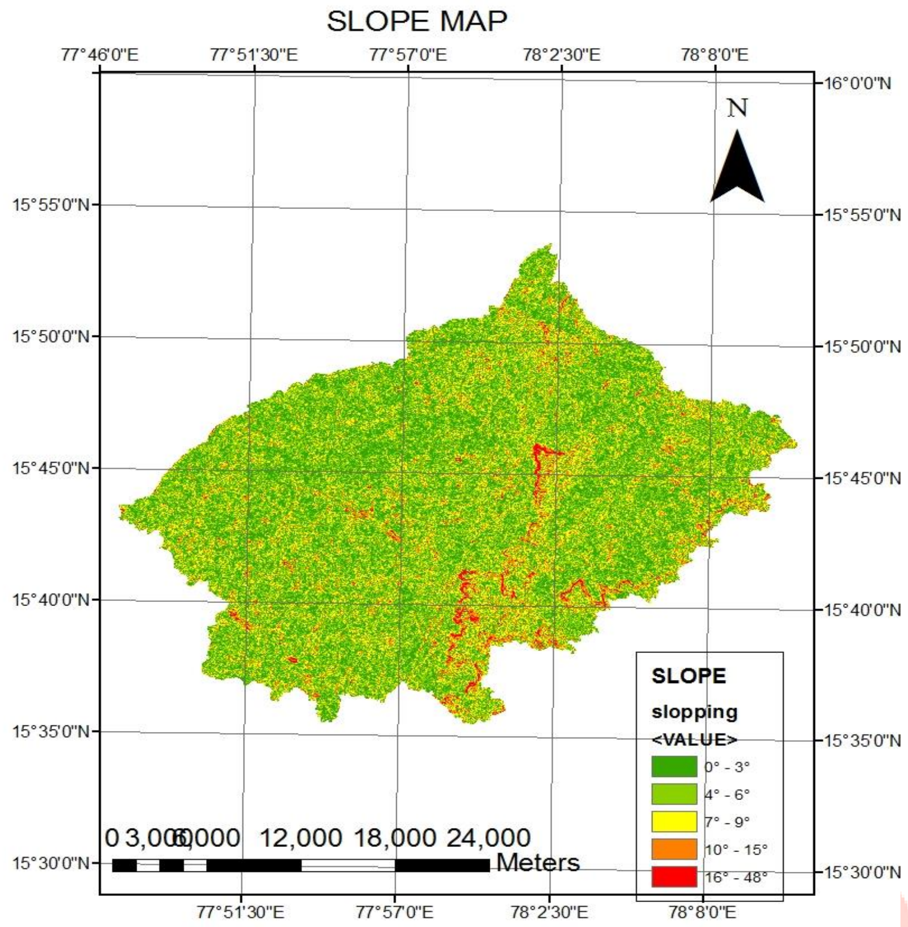


Fig.4 Slope map of the watershed

### *4.11. Land use/land cover mapping*

Changes in land use and land cover patterns are the most important factors in assessing groundwater quality in any area. Due to land use practices and climate change, water resources are under tremendous pressure. Changes in land use patterns and their estimates describe human activities, especially agriculture and the use of land resources in any region. Due to land use practices and climate change, water resources are under tremendous pressure. Changes in land use patterns and their estimates describe the use of land resources by human activities, especially urbanization. (YanYun et al., 2014; Singh et al., 2012). Hydrological inference from land-use methods can help understand different activities such as agricultural demand, domestic demand, industrialization, and other changes in different activities, and can also be used to understand the infiltration, recharge, and runoff rates of a river basin. Changes in land use patterns become an important part of hydrological monitoring and natural resource management (Rawat et al., 2013; Sylla et al., 2012).

Analysis of land use changes in hydrological processes is a major requirement for the future (Turner et al., 2003), these include changes in water demand brought about by changing land use practices (eg, irrigation and urbanization); changes in hydrological processes; changes in water supply during groundwater recharge and runoff. The land use map and its role is a very important parameter to understand the hydrological status of the river basin. Its management methods are discussed by the researchers. (Wagner et al., 2013; Singh et al., 2013). Supervised classification scheme to assess the spatial patterns of land-use patterns and its recent free-of-charge satellite data of Lasndsat-8 January, 2018 which have 30 m spatial resolution. Using Erdas Imagine 14 software to classify, starting with defined training points, extracting features from images, and then classifying. Finally, the maximum likelihood classification (MLC) classification method is applied. Field surveys have also been conducted to identify land use/land cover maps for river basins to verify suspicious categories. The common land use category is determined according to the water demand, i.e agricultural land, water body, fallow land, rock, etc., (Fig.5). The evaluation of the land use pattern of the catchment shows that most of the area belongs to agriculture, fallow and barren land, which provides support for indirectly supporting the future of basin development and management.

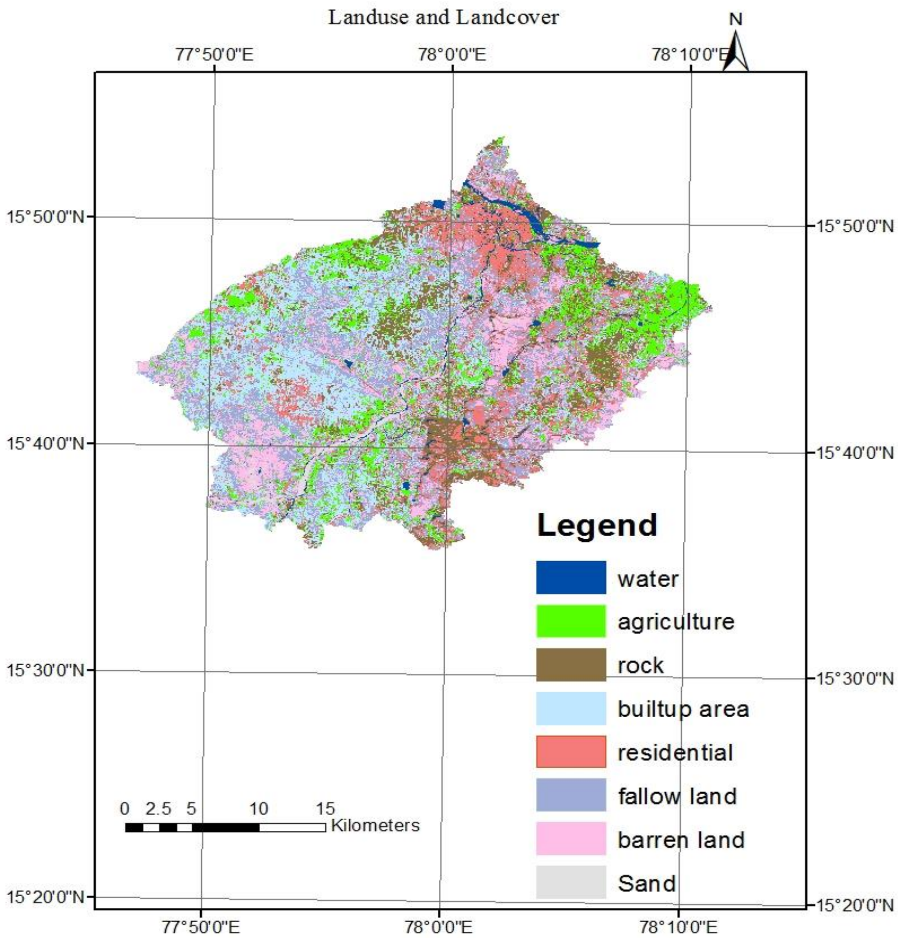


Fig.5 Land use/land cover map of the watershed

## V CONCLUSIONS

Hydrological analysis of the part of the town of Kurnool confirmed that the basin had low relief and elongated shape. The drainage network of the basin is mainly dendritic, indicating that its texture is uniform and lacks structural control, which helps to understand various topographical parameters such as bedrock properties, permeability, runoff, etc. Lower drainage density and flow frequency indicate high permeability of underground formations. Low drainage density area is conducive to the identification of groundwater potential areas. Slope plays a very important role in determining penetration and runoff. Infiltration is inversely associated with slopes, ie gentler slope, higher is permeability and less is runoff, and vice versa. Using GIS, remote sensing data and digital elevation model (DEM) for large-scale watershed analysis can effectively understand any topographical parameters such as bedrock properties, permeability, surface runoff, etc., This helps to better understand the state of land formation and its processes, drainage management and the evolution of groundwater potential in watershed planning and management. This work will help planners and decision makers to manage natural resources at any microscopic level of sustainable development to achieve a sustainable watershed development plan.

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