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IDENTIFICATION OF GROUNDWATER PROSPECTING ZONE MAPPING (GPZP) OF IN AND AROUND SETTIKERE AREA, TUMKUR DISTRICT, KARNATAKA, INDIA, USING REMOTE SENSING AND GIS TECHNIQUES

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ABSTRACT

Ground water is being extracted mostly through bore wells in the area. Due to increase in number of bore wells over a period of time mostly for irrigation purpose, the depth to ground water levels have become deeper and deeper and touched more than 70 m bgl at certain locations. Ground water occurs mostly in fractured system which is in semi-confined to confined condition. The ground water is mostly suitable for domestic and irrigation purposes. The present study is an attempt to evaluate the groundwater system of Settikere area, Tumkur district. Hydrogeological investigations require an integrated approach. Though groundwater is replenish able natural resources, when withdrawals exceed the limits of dynamic recharge, it will cause irreversible damages. As in nature, South India is a hard rock terrain. In recent years, bore wells for agricultural purposes have been drilled on a massive scale by the farmers without carving for minimum interference distance to be maintained between the extraction structures. Thereby, groundwater levels are drastically affected. The present study suitable areas for groundwater potential zones in the region have been identified by using RS and GIS techniques.

Keywords: *Groundwater, Recharge, Hard Rock Bore Wells Agriculture Structures Remote Sensing and GIS*

INTRODUCTION

Water is an important source for all living beings and prevails as the basic point for all activities of human beings. The acute shortage of water has been steadily increasing and on the other hand the pollution level of water has been increasing every year due to reoccurrence of drought, rapid growth of population, expansion of irrigation and rate of industrialization and urbanization. The availability of surface water is not assured at all seasons, especially during summer because of poor rainfall enacting inability of surface water resource to fulfill the supply for all requirements enabling groundwater as the only alternate resource to meet out the above mentioned requirements. Geomorphology is a scientific study of landforms and the processes that shape them. Geomorphological processes are generally complex and reflect inter-relationship among the variables such as climate, geology, soil and vegetation (Buol *et al.*, 1973). Hydro-geomorphology has been defined as an interdisciplinary science that focuses on the interaction and linkage of hydrologic processes with landforms or earth materials and the interaction of geomorphic processes with surface and subsurface water in temporal and spatial dimensions (Sidle and Onda, 2004). By studying the hydro-geomorphological conditions of the basin, it is possible to decipher the groundwater potentiality. Hydrogeology, It helps in quantification of groundwater potentiality of an area and in developing a digital model of the aquifer system for forecasting the water levels with or without additional stress. Combined analysis of landforms (geomorphology), rocks as well as structures (geology) such as faults, folds, fractures etc. in relation to groundwater occurrence with the help of remote sensing and ground truth verification is considered very useful in preparing integrated geomorphic and geologic maps for targeting groundwater. Remote sensing technology is ideal for hydrological and hydro-geological studies since terrain does control movement and accumulation of surface and groundwater (Shrivastava, 1974). Drainage analysis is adopted for the purposes of integrated land and water resources management (d) and groundwater studies (Mishra *et al.*, 2011). Several software packages provide methods for analyzing drainage basin parameters in raster grids of remote sensing

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images. However, it is evident that software for measuring watershed morphometric parameters using a GIS approach is required. Remote sensing and Geographic Information System (GIS) have become the leading tools in the field of hydrological science. The importance of remote sensing technology for geomorphological studies has increased due to the establishment of its direct relationship with allied disciplines such as, geology, soils, vegetation/ landuse & hydrology. The interpretation of satellite data in conjunction with sufficient ground truth information makes it possible to identify and outline various ground features such as geological structures, geomorphic features and their hydraulic characters (Das *et al.*, 1997, Srinivas Rao *et al.*, 2000); and these may serve as direct or indirect indicators of the presence of groundwater (Ravindran and Jayaram, 1997; Sreedevi *et al.*, 2001; Girish Gopinath and Seralathan, 2004).

MATERIALS AND METHODS

Method

This was multidisiplinary studies involving a field survey and a variety of techniques such as Remote sensing, Geographical information system and aerial image interpretation were used and understand the geological and geomorphological conditions of Settikere sub-watershed and prepare the drainage, geomorphology and slope maps using geospatial techniques and analysis the bore well inventory data to find out the significance of groundwater occurrence and identify the groundwater potential zones for development by integration of various thematic maps and GIS techniques for further development.

Study Area

The study area is bounded in between latitudes $13^{\circ}18'30''$ N to $13^{\circ}22'$ N and longitudes $76^{\circ}33'$ E to $76^{\circ}36'30''$ E. It forms part of Survey of India Toposheet 57C/11 and covers an area of 92 square Km. Major part of the area belongs to Settikere area of Tumkur district (Figure 1) the watershed is drained by 1st to 5th order streams. The drainage is dendritic with flow direction from south to north. And ultimately forms the Torehalla stream. The drainage is part of the Krishna basin and Vedavati sub basin. The average annual rainfall in the study area is 680 mm. The area exposes mainly rock types belonging to the Peninsular Gneissic Complex, Schistose rocks of Sargur group and Dharwar super group, Younger intrusive (basic dykes) and in thin patches of Quaternary gravels. The Schistose rocks occupy the NW to SE direction in the central portion of the area. Granitic gneisses occupy the north and southern part of the area. Granite occurs as a small patch in the south-eastern part of the study area near Bande gate village. Various soil type viz., clayey soil, clayey skeletal, clayey mixed, sandy clay and gravelly clayey soils are found in the study area. Agriculture is the main stay of the people and the major crops grown are coconut, aurecanut and ragi

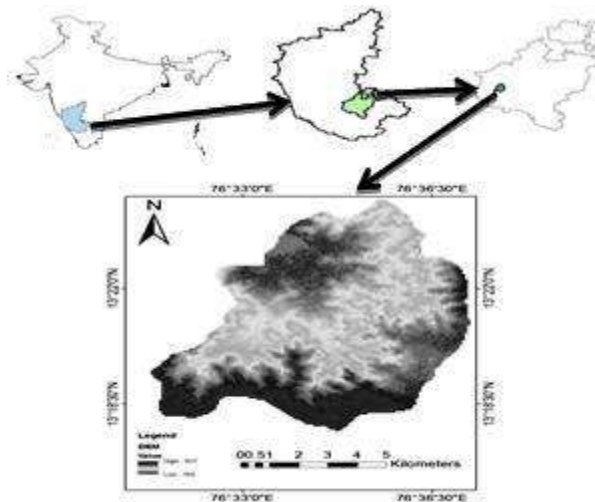


Figure 1: Location of the study area

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Photographs 1: Dolerite dyke exposure near Kedigehalli



Photographs 2: Exposure of schist in Kedigehalli



Photographs 3: A Quartz vein exposure in sasula



Photographs 4: A distance view of valley near Bande gate



Photographs 5: Weathered gneiss along Ajjanahalli



Photographs 6: A reservoir near Bande gate

Plate 1: Field surveys in the region are presented photographs (P1to P6)

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Multi-criteria Evaluation Frame Work and Remote Sensing and Geographical Information System Management:

The identification of suitable areas for groundwater potential zones is a multi objective and multicriteria problem. The main steps in generating the maps in this study area were as follows.

1. Selection of criteria
2. Assessment of the suitability levels of criteria for groundwater potential zones
3. Collection of spatial data for the criteria through various sources including a GPS surveys to supplement and generate maps using GIS tools.
4. Soil map, land use/Land cover (Derived from available Remote sensing data), slope (topography), runoff coefficient, Rainfall surplus precipitation.

Geology of the Study Area

The study area is a part of the hard rock terrain of the Karnataka state and comprises of mainly two rock types represented by quartz sericite schist and Tonalite gneiss. There are some exposures of granite which are noticed as hillocks, located near Bandegate, Chunganahalli, Kodlagra and Dugudihalli. Exposures of the Gneissic body are located near Hosapalya, Tittigorvana playa, Gantiganapalya, Chunganahalli and Kodlagra. The near surface exposures of these granites in the low laying areas are weathered and decomposed up to depth of 20 m. They are intersected by number of pegmatite veins with well-developed joints. The peninsular gneiss forms the basement rock and is confined mainly to the eastern part of the study area. The gneisses are comparatively more fractured and weathered than the granites. This hard rock contains no primary porosity. Hence water percolates through secondary porosity formed by fracturing and weathering (Plate 1. Figure 2). The entire area has a semi-arid condition. Data from the India meteorological observatory shows mean minimum temperature of 30°C and a mean maximum temperature of 37°C. The rainy season is from May to October with an annual rainfall of 699mm. Paddy, ragi, jowar and horticultural crops like vegetables, coconuts and flowers are grown in the valley fill region of the area.

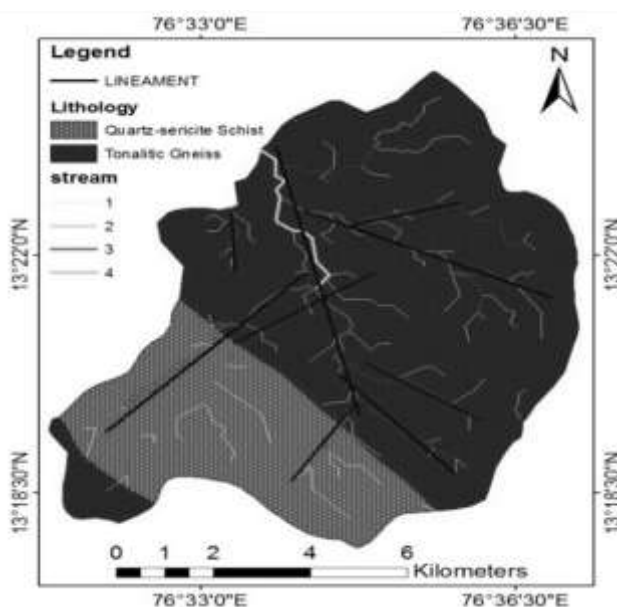


Figure 2: Lithological map of the study area

MATERIALS AND METHODS

In the present study area an attempt has been made to delineate and characterize groundwater potential zones of the area by using GIS and Remote sensing data. Topographical maps prepared by Survey of India on 1:50,000 scales are used to generate the base map of the study area. The hard copy of map was

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converted to digital form using scanner. The digital files were imported in ERDAS IMAGINE 2014 to convert them into image format and further processes were carried out on this image file only. For georeferencing the map, control points were to be established and then the known geographic coordinates of these control points were entered, followed by minimizing residuals. Residuals are the difference between the actual co-ordinates of the control points and the coordinates predicted by the geographic model created using the control points. They provide a method of determining the level of accuracy of the geo referencing process. They were projected to Geographic Projection and mosaic to get the study area. Digitization is essentially a vectorization of raster data by tracing a mouse over features displayed on a computer monitor. After image data was been geo-referenced and reprojected to geographic projection system. Drainage networks and contours were manually traced using mouse and vector features were created. Drainage lines were digitized and stream ordering was done in accordance with Strahler's (1957) method (Figure 3). The different thematic maps viz., geomorphology, slope and lineament has been prepared through the standard visual interpretation techniques using topographic maps and its corresponding IRS 1 C and I D geocoded FCC of both LISS III and SRTM Satellite data. The lineament map has been prepared through the analysis of satellite data considering mainly the drainage lineaments and vegetation anomaly. The ground verification of interpreted data has been carried out in the field and necessary modifications are incorporated in the thematic maps. GIS software like Arc GIS10 has been used for digitization, computation and output generation purposes. The Open well, Bore well and exploratory well sample parameters (Age, Depth, Fracture and Yield) have been collected and they have been plotted in GIS environment using Inverse Distance Weighted (IDW) method. All the thematic maps are overlain above another in terms of weighted overlay methods using the spatial analysis tool in Arc GIS 10. Satellite images from IRS-1C, LISS-III sensor, on a scale of 1:50,000 (geo-coded, with UTM projection, spheroid and datum WGS 84, Zone 43 North) have been used for delineation of thematic layers such as lithology, geomorphology, lineament and slope. These thematic layers were converted into a raster format (30 m resolution) before they were brought into GIS environment. The groundwater potential zones were obtained by overlaying all the thematic maps in terms of weighted overlay methods using the spatial analysis tool in ArcGIS 10. During weighted overlay analysis, the ranking was given for each individual parameter of each thematic map.

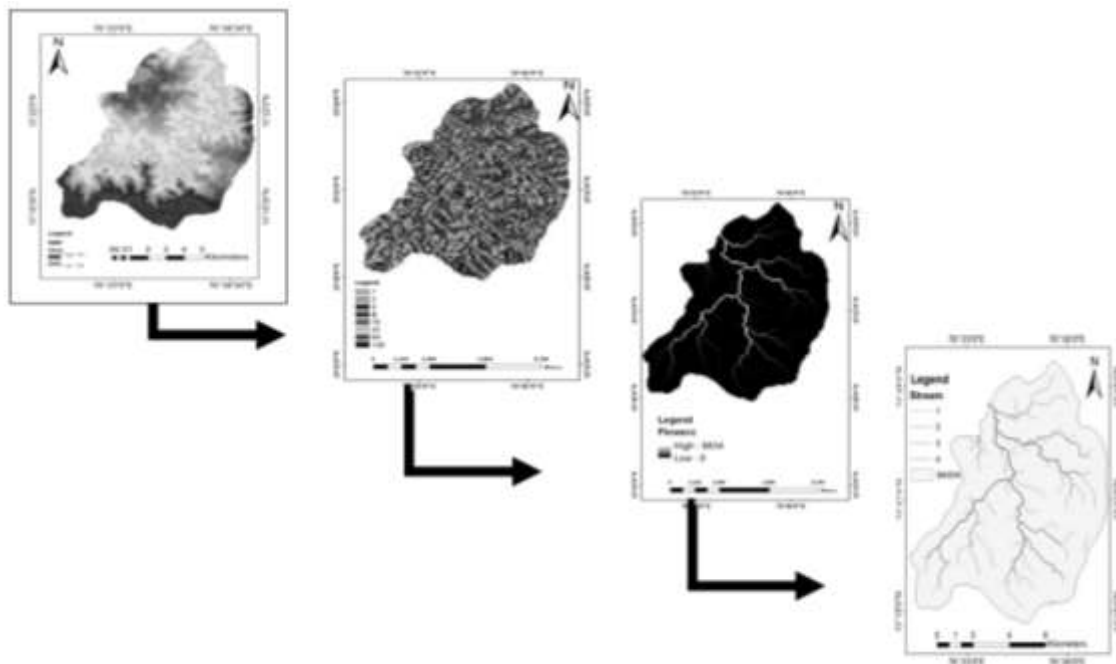


Figure 3: Digital Elevation model, Flow direction, Flow accumulation & Stream Order map of the study area

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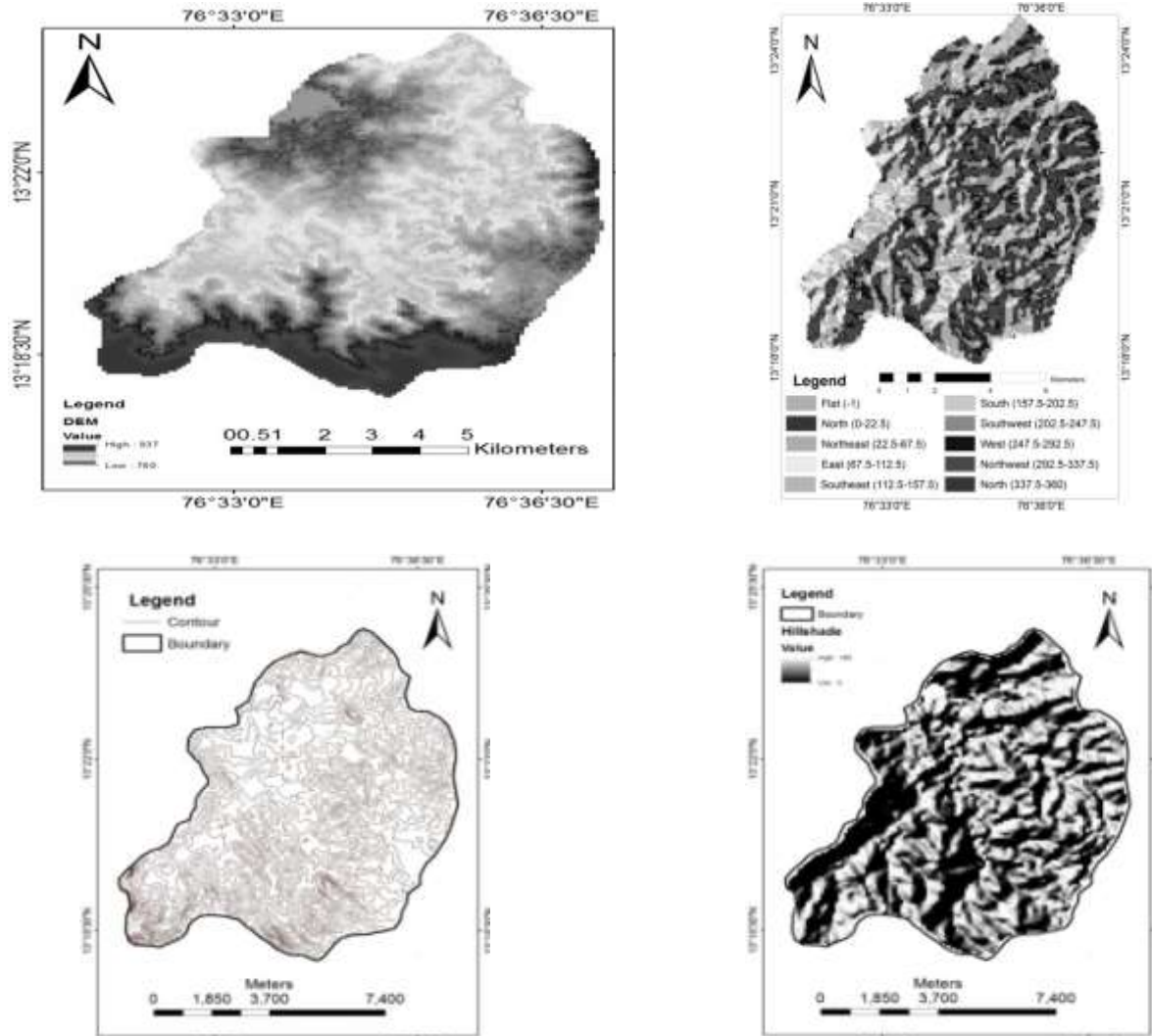


Figure 4: DEM, Slope, Aspect, Hill shade and Contour maps of the study area

Morphology of the Area:

Morphometric study has got its foundation from stream flow analysis. Morphometric analysis is the quantitative description and analysis of landforms as practiced in geomorphology that may be applied to a particular kind of landform or to drainage basins and large regions. Morphometric analysis of a watershed provides a quantitative description of the drainage system, which is an important aspect of the characterization of watersheds. Morphometric analysis requires measurement of linear features, aerial aspects and gradient of channel network of the drainage basin. Identification of drainage networks within basins or sub basins can be achieved using traditional methods such as field observations and topographic maps or alternatively with advanced methods using remote sensing and GIS. Morphometric analysis using GIS technique has emerged as a powerful tool in recent years. GIS technique is very useful in analyzing the drainage morphometry. In India, some of the recent studies on morphometric analysis using remote sensing and GIS technique are being done. Evaluation of morphometric parameters necessitates the analysis of various drainage parameters such as ordering of the various streams, measurement of basin area and perimeter, length of drainage channels, drainage density, stream frequency, bifurcation ratio, basin relief and Ruggedness number. The main objective of this study is using GIS technology to compute various parameters of mini watershed morphometric characteristics.

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Morphometric Parameters

Morphometric analysis is the measurement and mathematical analysis of the configuration of the Earth's surface, shape and dimensions of its landforms. This analysis can be achieved through measurement of linear, aerial and relief aspects of basin and slope contributions. In the present study, the morphometric analysis for the parameters namely stream order, stream length, bifurcation ratio, stream length ratio, basin length, drainage density, stream frequency, elongation ratio, circularity ratio, form factor, relief ratio, etc. The formulae adopted for computation of the various morphometric parameters are given in Table 1.

Table 1: Morphometric analysis of parameters

Sl. No.	Morphometric Parameters	Formula	Reference
Drainage network:			
1	Stream order	Hierarchical rank	Strahler (1964)
2	Stream number (Nu)	Order wise stream segments	Horton (1945)
3	Stream length (Lu)	Length of the Stream	Horton (1945)
4	Mean stream length (Lsm)	$Lsm = Lu / Nu$	Strahler (1964)
5	Stream length ratio (Slr)	$Slr = Lu / Lu - 1$	Horton (1945)
6	Bifurcation ratio (Br)	$Rb = Nu / Nu + 1$	Schumm (1956)
7	Mean bifurcation ratio (Mbr)	Mbr = Average of bifurcation ratios of all orders	Strahler (1957)
Basin geometry:			
8	Basin length (Bl)	Longest dimension of the basin parallel to the principal drainage line.	Schumm (1956)
9	Basin area (A)	Total area of basin in sq.km	GIS analysis
10	Basin perimeter (Bp)	Outer boundary of the basin that enclosed its area.	GIS analysis
11	Basin shape (Bs)	$Bs = Bl^2 / A$	Horton (1956)
12	Form factor (Ff)	$Ff = A / Bl^2$	Horton (1932)
13	Elongation ratio (Er)	$Er = (2 (\sqrt{(A / Pi) }) / Bl$	Schumm (1956)
14	Drainage texture (Dt)	$Dt = Nu / P$	Horton (1945)
15	Circularity ratio (Cr)	$Cr = (4 * Pi) * (A / Bp^2)$	Miller (1953)
Drainage texture analysis:			
16	Stream frequency (Sf)	$Sf = Nu / A$	Horton (1932)
17	Drainage Density (Dd)	$Dd = Lu / A$	Horton (1932)
18	Drainage intensity (Di)	$Di = Sf / Dd$	Faniran (1968)
19	Infiltration number (In)	$In = Sf * Dd$	Faniran (1968)
20	Drainage pattern	Based on influence of slope, lithology and structure.	Howard (1967)
21	Length of overland flow (Lof)	$Lof = (1 / Dd) * 2$	Horton (1945)
Relief characterization:			
22	Total relief (Tr) or relative relief	Elevation difference in kms between highest point of a watershed and the lowest points on the valley floor.	SOI toposheet
23	Relief ratio (Rr)	$Rr = Tr / Bl$	Schumm (1956)
24	Ruggedness number (Rn)	$Rn = (Dd * Tr) / 1000$	Strahler (1964)

Abbreviations: A: Area of the basin (sq.km), Bl: Basin length, Bp: Basin perimeter (km), Bs: Basin shape, Cr: Circularity ratio, Dd: Drainage density, Di: Drainage intensity, Dt : Drainage texture, Er:

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Elongation ratio, Ff: Form factor, In: Infiltration number, Lof: Length of overland flow, Lsm: Mean Stream Length, Lu: Total stream length of order 'u', Lu - 1: The total stream length of its next lower order, Nu: Total no. of stream segments of order 'u', Nu + 1: Number of segments of the next higher order, Pi: 'Pi' value i.e., 3.14, Br: Bifurcation ratio, Mbr: Average of bifurcation ratios of all orders, Rn: Ruggedness number, Rr: Relief ratio, Sf: Stream frequency, Slr: Stream length ratio, Tr: Total relief in kms

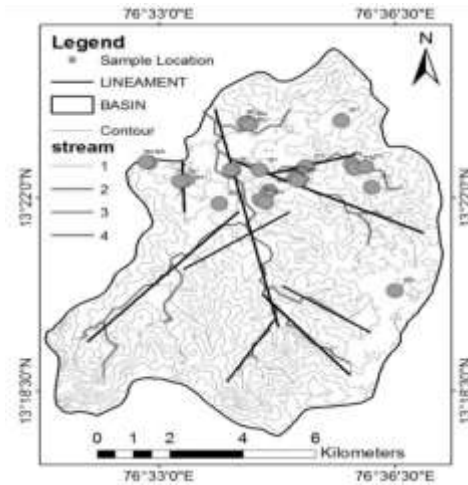


Figure 5: Stream order of the study area

Drainage Network

In the application of the Strahler stream order to hydrology, each segment of a stream or river within a river network is treated as a node in a tree, with the next segment downstream as its parent. When two first-order streams come together, they form a second-order stream. When two second-order streams come together, they form a third-order stream. Streams of lower order joining a higher order stream do not change the order of the higher stream. Thus, if a first-order stream joins a second-order stream, it remains a second-order stream. It is not until a second-order stream combines with another second-order stream that it becomes a third-order stream.

Stream Order ($S\mu$): The designation of stream order is the first step in any drainage basin analysis. The primary step in drainage basin analysis is to designate stream orders. The stream ordering has been done as per the Strahler's (1964) ordering scheme. Higher stream order is associated with greater discharge. The trunk stream, through which all discharge of water and sediment passes is therefore the stream segment of highest order. The basin order goes up to 5th in the given study area.

Stream Number ($N\mu$): The counting of stream channels in a given order is known as stream number. The number of stream of each order and the total number of streams were computed. It is also understood that the total number of stream decreases with stream order increases. There are 138 first order streams, 34 second order streams, 10 third order streams, 3 fourth order streams and 1 fifth order stream. Therefore there are a total of 186 streams in the given are of study area.

Stream Length (Lu): The stream length of a basin is the measure from the mouth of a river to the drainage divide. The total length of stream segments is highest in first order streams and decreases as the stream order increases. This may be due to the streams flowing from a region of higher to lower altitude, change in rock type and moderately steep slopes and probable uplift across the basin (Vittala *et al.*, 2004 and Chopra *et al.*, 2005). Addition of the lengths of all streams, in a particular order, defines total stream length.). The stream length of first, second, third, fourth and fifth order are 103.37, 28.64, 22.48, 14.96 and 6.53km respectively. Therefore the total length of the stream is about 175.99 km.

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Mean Stream Length (Lsm): is a characteristic property related to the drainage network components and its associated basin surfaces (Strahler, 1964). It is calculated by dividing the total stream length of order (u) by the number of streams of segments in the order. The mean stream length decreases from higher order to the next lower order. However, in some basins this may vary and this can be explained as a cause for changes in topographic elevation and slope of the area. The mean stream length in the study area for the first, second, third, fourth and fifth order are 0.75, 0.84, 2.25, 4.99 and 6.35km respectively.

Stream Length Ratio (Slr): It is defined as the ratio of the mean length of the one order to the next lower order of the stream segments (Horton, 1945). The result showed the RL values exhibits an increasing trend lower order. The stream length ratio for the given area is given in the following table.

Bifurcation Ratio (Br): It is defined as the ratio of the number of stream segments of given order to the number of segments of the next higher order. The higher value of Br in any area will suggest a strong structural control in the drainage pattern. Whereas a lower value of Br indicates that the area has been less affected by structural disturbances (Strahler, 1964; Vittala *et al.*, 2004 and Chopra *et al.*, 2005). The bifurcation ratio for the study area is given in the following table.

Mean Bifurcation Ratio (Mbr): To arrive at a more representative bifurcation number, Strahler (1952) used a weighted mean bifurcation ratio obtained by multiplying the bifurcation ratio for each successive pair of orders by the total numbers of streams involved in the ratio and taking the mean of the sum of these values. The mean bifurcation ratio of the study area is 3.45.

Basin Geometry

Basin Length (Bl): Several people defined basin length in different ways, such as Schumm (1956) who defined the basin length as the longest dimension of the basin parallel to the principal drainage line. The basin length determines the shape of the basin. High basin length indicates elongated basin. The basin length of the study area is 13km.

Basin Area (Bp): The area of the watershed 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 studied basin has a total area of about 92 square km

Basin Perimeter (p): It is the outer boundary of the watershed that encloses its area. It is measured along the divides between watersheds and may be used as an indicator of watershed size and shape. The perimeter of the studied sub basin is 45km.

Form Factor (Ff): This 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 0.754 (for a perfectly circular watershed). Smaller the value of form factor, more elongated will be the watershed. The watershed with high form factors have high peak flows of shorter duration, whereas elongated watershed with low form factor ranges from 0.42 indicating them to be elongated in shape and flow for longer duration. The given study area has a form factor of 0.51. It is an elongated basin.

Elongation Ratio (Er): It is defined as the ratio of diameter of a circle of the same area as the basin to the maximum basin length. A circular basin is more efficient in the discharge of runoff than an elongated basin. The values of vary from 0.6 to 1.0 over a wide variety of climatic and geologic type. values close to 1.0 are typical of region of very low relief, whereas values in the range 0.6 to 0.8 are usually associated with high relief and steep ground slope. It can be grouped into three class namely circular (>0.9), oval (0.9-0.8), and less elongated (<0.7). The given study area has a form factor of 0.51. It is less elongated basin.

Circularity Ratio (Cr): The circularity ratio or Cr of the basin is the area of a circle having the same circumference as the perimeter of the basin. It is influenced by the length and frequency of stream, geological structures, landuse/ landcover, climate, relief and slope of the basin. It is a significant ratio that indicates the dendritic stage of a watershed. Low, medium and high values of Cr indicate the young, mature, and old stages of the life cycle of the tributary watershed. The circulatory ratio for the given basin is 0.57.

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Drainage Texture Analysis

Drainage Texture (Dt): It is the total number of stream segments of all orders per perimeter of that area. The drainage texture depends upon a number of natural factors such as rainfall, vegetation, climate, rock and soil type, infiltration capacity, relief and stage of development. The drainage texture is classified into five class such as very coarse (<2), coarse (2-4), moderate (4-6), fine (6-8), very fine (>8). In the study area, all the SWS value range above 10 which comes under the class very fine drainage texture.

The drainage texture of the area is 4.11 and thus the drainage texture is given as moderate

Stream Frequency (Sf): The stream frequency (Sf) or channel frequency is the total number of stream segments of all order per unit area. Sf mainly depends on the lithology of the basin and the texture of the drainage network. The Sf and the drainage density values of the SWS are positively correlated. This indicates that the increase in stream population is connected to that of drainage density. The stream frequency is for the given area of study is 2.02.

Drainage Density (Dd): Drainage density is defined as the closeness in spacing of channels. It is a measure of the total length of the stream segment of all order per unit area. Slope gradient and relative relief are the main morphological factor of drainage density. Dd is significant as a factor determining the time of travel by water in a terrain. Low drainage density generally result in the area of highly resistant or permeable subsoil material and high drainage density is the resultant of weak or impermeable subsurface material. Low drainage density leads to coarse drainage texture while high drainage density leads to fine drainage texture. The drainage density for the given area of study is 1.91 per km.

Drainage Intensity (Di): The drainage intensity is the ratio of the stream frequency to the drainage density. 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. With these low values of drainage density, stream frequency and drainage intensity, surface runoff is not quickly removed from the watershed, making it highly susceptible to flooding, gully erosion and landslides. The drainage intensity of the given area is 1.06.

Infiltration Number (In): The infiltration number of a watershed 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 run-off. The infiltration ratio for the given area is 3.85.

Drainage Pattern (Dp): In the watershed, the drainage pattern reflects the influence of slope, lithology and structure. Finally, the study of drainage pattern helps in identifying the stage in the cycle of erosion. Drainage pattern presents some characteristics of drainage basins through drainage pattern and drainage texture. It is possible to deduce the geology of the basin, the strike and dip of depositional rocks, existence of faults and other information about geological structure from drainage patterns. Drainage texture reflects climate, permeability of rocks, vegetation, and relief ratio, etc. The longer the time of formation of a drainage basin is, the more easily the dendritic pattern is formed. The streams in the given area exhibits dendritic to sub-dendritic type of drainage pattern.

Length of Overland Flow (Lof): This term refer to the length of the run of the rainwater on the ground surface before it is localized into definite stream channels (Horton, 1945). Since this length of overland flow, at an average, is about half the distance between the stream channels. . The length of the overland flow for the given study area is 1.05.

Relief Characterization

Relief Ratio (Rr): Difference in the elevation between the highest point of a watershed and the lowest point on the valley floor is known as the total relief of the river basin. The relief ratio may also be defined as the ratio between the total relief of a basin and the longest dimension of the basin parallel to the main drainage line. The relief ratio for the given area is 0.01.

Ruggedness Number (Rn): Ruggedness number is the product of the basin relief and the drainage density and usefully combines slope steepness with its length. The ruggedness number for the given study area is 0.00.

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Table 2: Results of morphometric analysis

Sl No	Parameters	Stream Order						Total
		I	II	III	IV	V	VI	
1	Number of streams	138	34	10	3	1	0	186
2	Stream Length in Km (Lu)	103.37	28.64	22.48	14.96	6.53	0	175.99
3	Mean Stream Length in Km (Lsm)	0.75	0.84	2.25	4.99	6.53	-	
4	Stream Length Ratio (RL)	II/I	III/II	IV/III	V/IV	VI/V		
5		0.28	0.78	0.67	0.44	-		
6	Bifurcation Ratio (Rb)	I/II	II/III	III/IV	IV/V	V/VI		
7		4.06	3.4	3.33	3	-		
8	Mean Bifurcation ratio (Rbm)	3.45						
9	Perimeter (P) Km	45						
10	Basin length (Lb) km	13						
11	Basin Area (km ²)	92						
12	Basin shape(Bs)	1.97						
13	Total Relief(km)	0.2						
14	Relief Ratio(Rf)	0.01						
15	Drainage density (D)(km/km ²)	1.91						
16	Drainage Texture(Dt)	4.11						
17	Drainage Intensity(Di)	1.06						
18	Stream frequency(Fs)	2.02						
19	Form factor(Rf)	0.51						
20	Circularity ratio(Rc)	0.57						
21	Elongation Ratio(Re)	0.8						
22	Length of overland flow (Lg)	1.05						
23	Infiltration number(In)	3.85						

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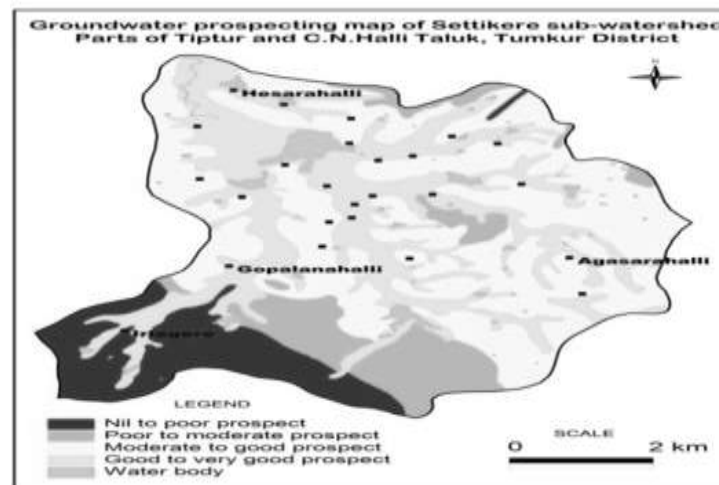


Figure 6: Groundwater Prospective Zones

RESULTS AND DISCUSSION

Groundwater is a vital natural resource for the reliable and economic provision of potable water supply in both urban and rural environment. Hence it plays a fundamental role in human well-beings, as well as that of some aquatic and terrestrial ecosystems. At present, groundwater contributes around 34% of the total annual water supply and is an important fresh water resource. An assessment for this resource is extremely significant for the sustainable management of groundwater systems. Delineating the potential groundwater zones using remote sensing and GIS is an effective tool. In recent years, extensive use of satellite data along with conventional maps and rectified ground truth data has made it easier to establish the base line information for groundwater potential zones (Tiwari and Rai, 1996; Das *et al.*, 1997; Thomas *et al.*, 1999; Harinarayana *et al.*, 2000; Muralidhar *et al.*, 2000; Chowdhury *et al.*, 2010). Remote sensing not only provides a wide-range scale of the space-time distribution of observations, but also saves time and money (Murthy, 2000; Leblanc *et al.*, 2003; Tweed *et al.*, 2007). In addition it is widely used to characterize the earth surface (such as lineaments, drainage patterns and lithology) as well as to examine the groundwater recharge zones (Sener *et al.*, 2005). Applications of remote sensing and GIS for the exploration of groundwater potential zones are carried out by a number of researchers around the world, and it was found that the involved factors in determining the groundwater potential zones were different, and hence the results vary accordingly. Teeuw (1995) relied only on the lineaments for groundwater exploration and others merged different factors apart from lineaments like drainage density, geomorphology, geology, slope, land-use, rainfall intensity and soil texture (Sander *et al.*, 1996; Das, 2000; Sener *et al.*, 2005; Ganapuram *et al.*, 2008). The derived results are found to be satisfactory based on field survey and it varies from one region to another because of varied geo-environmental conditions. Development of groundwater in the study area is through construction of dug wells, dug-cum-bore wells and bore wells. However, recharging those groundwater sources is curtailed by frequent dry seasons and failure of monsoons. The minimum depth of the water table in the study area is 5m in favorable localities adjoining rivers, canal system and abutting tanks, whereas the water table in remote areas is found very deeper up to 50 to 60 m resulting in acute water shortage. Exploitation of groundwater resources has increased in the past decades, leading to the over-consumption of groundwater, which eventually causes ecological problems such as decreased groundwater levels, water exhaustion, water pollution and deterioration of water quality. Integration of remote sensing with GIS for preparing various thematic layers, such as lithology, drainage density, lineament density, slope and geomorphology with assigned weightage in a spatial domain will support the identification of potential groundwater zones. Therefore, the present study focuses on the identification of groundwater potential zones in the study area using the advanced technology of remote sensing and GIS.

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Groundwater Prospective Zones

In the present study, an attempt has been made to generate groundwater prospects map through the integration of various thematic maps viz., slope, geology, geomorphological, lineament maps along with bore well details using remote sensing and GIS techniques. The demarcation of groundwater prospective zones was made by grouping of the interpreted layers into different prospective zones viz., 1) good to very good, 2) moderate to good, 3) poor to moderate and 4) poor to nil and area statistics of each zone.

Good to Very Good Prospective Zone

Valley fills and moderately weathered Pediplain fall under these zones with the yield varies from 1000 to 6300 gph and high lineament density. This zone varies from 8.05 to 11.38 km² in the basin.

Moderate to good prospective zone

These zones formed by shallow weathered Pediplain with the yield of 600 to 1000 gph and moderate lineament density. The maximum area and minimum area of 24.04 and 15.91 km² are noticed in the study area respectively.

Table 3: Area of geomorphic units

Sl.No	Groundwater prospects	Area (sq.km)
1	Poor to nil prospective zone	1.37 to 15.05
2	Poor to moderate prospective zone	15.53 and 0.67
3	Moderate to good prospective zone	24.04 and 15.91
4	Good to very good prospective zone	8.05 to 11.38

Poor to Moderate Prospective Zone

These zones are formed by pediment inselberg complex and pediments and contribute for limited to moderate recharge with low lineament density. The bore well data are not available for these zones. The minimum and maximum area of 15.53 and 0.67 km² has been observed in the study area.

Poor to Nil Prospective Zone

The denudational, residual hills and inselberg fall under this class in all sub-watersheds with the lineament density is very low and bore well data are not available for these zones. This zone varies from 1.37 to 15.05 km². The minimum area is confined to Devadabetta sub-watershed and maximum area is confined to Talaradahalli sub-watershed.

Slope

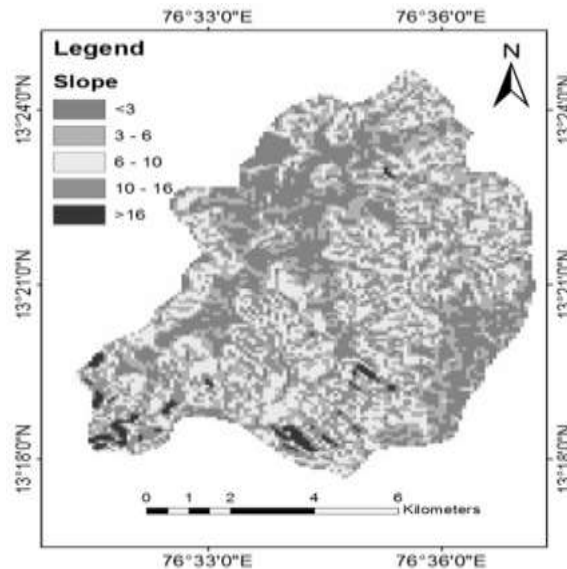


Figure 7: Slope of the study area

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The slope analysis has been carried out in the study area. The different category of slope percentages of the study area is ranging from $<3^{\circ}$. Majority of the study area belongs to slope class of nearly level ($3-6^{\circ}$). Very gentle slope ($10-16^{\circ}$), and gently slope ($>16^{\circ}$). Few remaining slope classes are noticed in western part of the hilly regions of the study area (Figure 7).

Lineament Tectonics

Lineaments are usually extracted and interpreted from satellite imagery manually or automatically. The extracted linear features were further screen for non-geological features such as roads, fences, field boundaries, by comparing the lineament map with the corresponding toposheet map of the survey area and field verification, thereby deleting non-geological features and leaving only possible geological lineament. The extension of large lineaments representing a shear zone or a major fault and can extend from hilly terrain to alluvial terrain. It may form a productive groundwater reserve. Similarly intersection of lineaments can also be probable sites of groundwater accumulation. Therefore, areas with high lineament density may have important groundwater prospects even in hilly regions which otherwise have nil groundwater prospects than area with low density. In the study area 9 lineaments have been mapped through analysis of satellite data. The analysis reveals that majority of lineaments are oriented in SW-NE, SE-NW and NS.

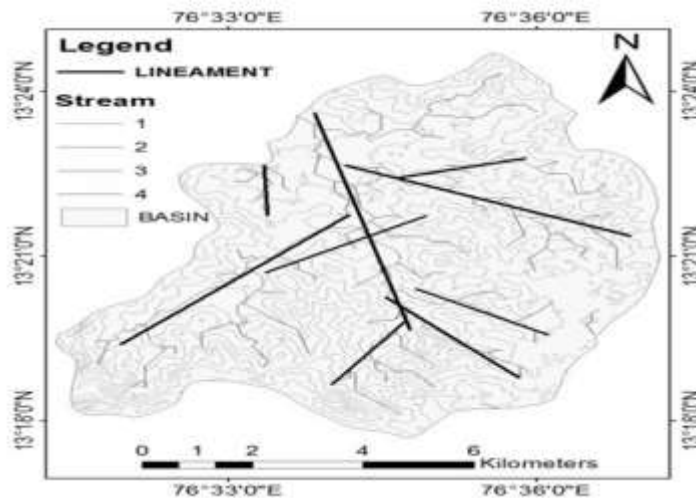


Figure 8: Lineament of the study area

The lineament map representing mainly the drainage lineaments and dykes of the basin has been prepared and presented (Figure 8). The bore well locations near lineaments are best followed by the areas between two lineaments in the basin.

It can be concluded that the lineaments are acting pathways for groundwater movement as a result; the maximum number of existing wells are located near the lineaments. It is well known that larger lineaments have larger zone of lineaments and larger amount of deformation in associated with them and nearness of the lineament to recharge source add further to its groundwater prospect. The dykes probably act as barriers for the movement of groundwater as indicated by the presence of bore wells away from the dykes.

Hydro geomorphology

The geomorphological map has been prepared based on specific tone, texture, size, shape and association characteristics of remotely sensed data. The geomorphological units observed both in the younger granites and peninsular gneisses are classified as follows: denudation hills, residual hills, inselberg, pediment inselberg complex, pediments, shallow weathered pediplains, moderately weathered pediplains and valley fills.

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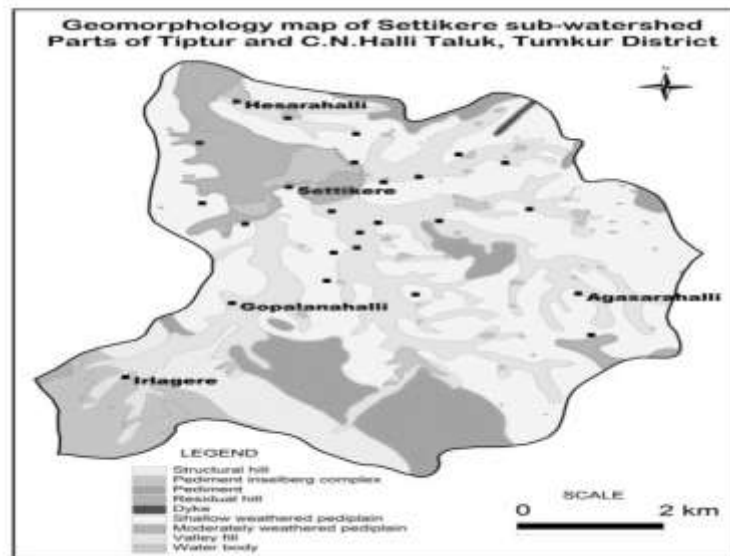


Figure 9: Hydro geomorphology of the area

Structural Hills

Structural hills are representation of the geologic structures such as- bedding, joint, lineaments etc. In the study area, they are located in the eastern parts having greenish and reddish tone with rough texture on the satellite image. Approximately, the area under structural hills covers 37.330sq.km in geomorphic maps.

Pediment Inselberg Complex (PIC)

Pediments dotted with a number of inselberg both in granites and gneisses which cannot be separated and mapped as individual units are referred as pediment inselberg complex (Srinivasa Vittala *et al.*, 2004).

Pediments

Pediments occur as gently undulating plains with moderate slope dotted with outcrops of both younger granites and gneisses in all parts of sub-basin and maximum in southern and eastern parts. These are confined to base of the various hills of the sub-basin.

Residual Hills (RH)

Residual hills are the end products of the process of pediplanation, which reduces the original mountain masses in a series of scattered knolls standing on the Pediplains. In the imagery, they exhibit grey tone and coarse texture in black and white images and dark green color in false color composite.

Dyke

A dike or dyke in geology is a sheet of rock that formed in a crack in a pre-existing rock body. It is a type of tabular or sheet intrusion, that either cuts across layers in a planar wall rock structures, or into a layer or un-layered mass of rock.

Shallow and Moderately Weathered Pediplains (PPS and PPM)

These are confined to almost all parts of the sub-basin occupying the areas between the pediments and valley fills and varying from nearly level to gentle slope. These units consists of fairly a thick weathered zones underlined by granites and gneisses. On the basis of the thickness of weathered zone (NRSA, 2000) the pediplains have been subdivided into two zones namely PPS and PPM. The thickness of PPS and PPM weathered zones are up to 20 m and 20-25m respectively, as observed from the bore well data and ground truth checks in the granites and gneisses. These units are noticed in almost all parts of sub-basin.

Valley Fills (VF)

The valley fills in the study area are developed in both granites and gneisses. These occupy the lowest reaches in topography with nearly level slope and composed mainly of pebbles, sand, silt and other detrital materials. These units are observed in south-western and north-western parts of the sub-basin.

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Water body

It is an area of impounded water, areal extent and often with a regulated flow of water. It includes man made reservoir/tanks/canal, besides natural lake, rivers/streams.

Observation

Hydro geomorphological investigations include the delineation and mapping of various landforms, drainage characteristics and structural features that could have a direct control on the occurrence and flow of groundwater (NRSA 2000, Soman 2002). Many of these features are favorable for the occurrence of groundwater and are classified in terms of groundwater potentiality. In the present study, the geomorphological map was prepared based on specific tone, texture, size, shape and association characteristics of remotely sensed data and significant geomorphic units were identified and delineated viz., denudational hill, residual hill, inselberg, pediment inselberg complex, pediment, shallow weathered Pediplain, moderately weathered Pediplain and valley fill shallow (Figure 9).

Table

<i>Sl.No</i>	<i>Geomorphic Unit</i>	<i>Area (sq.km)</i>
1	<i>Structural Hills</i>	8
2	<i>Pediment inselberg complex (PIC)</i>	7
3	<i>Pediments</i>	12
4	<i>Residual Hills (RH)</i>	9
5	<i>Dyke</i>	2
6	<i>Shallow and Moderately Weathered Pediplains (PPS and PPM)</i>	23 and 5
7	<i>Valley Fills (VF)</i>	18
8	<i>Water body</i>	5
9	<i>Denudation hills</i>	3

Denudation hills consist of highly fractured gneisses covered with big boulders and sparse vegetation occurring due to the accumulation of weathered material. These hills are marked by sharp to blunt crest lines, rugged tops and light grey in color. These occur as a group of massive hills with resistant rock bodies that are formed due to differential erosion and weathering. They are observed only in the south-eastern part of the study area and cover a total area of 3 sq. km. Residual hills are generally resulted from the end product of Pedi planation, which reduces the original mountains into a series of scattered knolls standing on the Pedi plains (Thornbury 1990). These units are considered as poor potential zones, as they have unfractured rock material, low infiltration and behave largely as runoff zone. In the present study, these types of residual hills features have been observed in the north-western part covering an area of about 9 sq. km. Inselberg are with moderate steep to very steep slope and occur as smooth and rounded isolated hills abruptly rising above surrounding plains. They are very negligible (1 sq.km) and observed in the northwestern part of the study area. Pediment inselbergs complex are pediments dotted with a number of inselbergs which cannot be separated and mapped as individual units. They have very low potential of groundwater occurrence. These features are observed in southeastern part of the study area (17 sq. km). Pediments occur as gently undulating plains with moderate slope dotted with outcrops and are often covered with thin layers of soil in the study area. They are mostly confined to base of the various hills. Many small pockets of pediment formations (12 sq. km) were observed throughout the study area. These units are characterized by the presence of relatively thicker weathered material. These units consist of fairly thick weathered zones underlined by granites and gneisses. Depending upon the depth and thickness of weathered materials, these are broadly classified as shallow and moderately weathered Pediplains (23 and 5 sq. km respectively) which are spread in almost all direction of the study area occupying the areas between the pediments and valley fills and varying from nearly level to gentle slope. Shallow valley fill zones are located adjacent to pediments/Pediplains. They vary in shape and extent. Wide and extensive valley fills are formed within the faulted lines. These occupy all along the major lineaments in the study

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area. Minor and narrow valley fills are located along the Pediplains. The valley fill zones are mostly occupied by major and minor streams. They have been demarcated on the basis of their reddish tone on satellite images. In the present study, the shallow valley fills covers an area of 18 sq.km spread over in all the directions.

Table 4: Open Well, Bore Well and Exploratory Well parameter

<i>Lat</i>	<i>Long</i>	<i>GPS no.</i>	<i>Location</i>	<i>years in use</i>	<i>MS L (m)</i>	<i>Depth in ft</i>	<i>Fractures in m</i>	<i>Yield in inch</i>	<i>Lithology</i>	<i>Soil Type</i>
13.3899	76.5949	567	Dugudihalli	20	797	200	50	1.5	Granitic basement	Red Soil
13.3768	76.5974	568	Kodlagra	22	805	140	80	2	Gneissic basement	Fine soil
13.3755	76.5982	570	Kodlagra	70	809	60	50		Granitic basement	fine Soil
13.3698	76.6024	571	Kodlagra	15	825	150	120	1.5	Gneissic basement	Red Soil
13.376	76.5861	573	Chunganahalli	7	791	250	80	2.5	Granite basement	Fine Soil
13.376	76.6008	576	Chunganahalli Kodipalya	5	790	400	400	1.5	Gneissic basement	Fine Soil
13.3727	76.5834	579	Chunganahalli	80	789	50				
13.3719	76.5841	580	Chunganahalli	80	793	70	20			
13.375	76.5748	581	Gantiganapalya	40	784	130	80	2.5	Gneissic basement	Fine Soil
13.3687	76.577	582	Tittigorvanapalya	30	792	350	150	3	Gneissic basement	Fine Soil
13.366	76.575	583	Ajjanahalli	30	787	350	70	2		
13.3652	76.5763	584	Ajjanahalli	30	791	300	120	2		
13.3649	76.5648	585	Somalapura	10	796	70	50	2		
13.372	76.5566	586	Makvvalli	8	777	700	200	2		
13.3715	76.5552	587	Makvvalli	20	787	300	200	3		
13.3773	76.5474	588	Gollarahatti	20	807	500	200	3		
13.3774	76.5468	589	Gollarahatti	20	801	500	250	3		
13.3748	76.5681	590	Hosapalya	15	795	450	150	2.5		
13.3751	76.5677	591	Hosapalya	25	774	500	300	2.5	Gneissic basement	Fine soil
13.3893	76.572	592	Ballenahalli	20	778	400	250	2.5		
13.3892	76.5711	593	Ballenahalli	20	781	400	250	3		
13.3888	76.5721	594	Ballenahalli	10	777	500	250	4		
13.3386	76.6081	595	Gyarehalli	15	853	300	150	2		
13.2996	76.5262	596	Bandegate	10	881	600	400	2.5	Granite basement	Fine soil
13.2996	76.5257	597	Bandegate	10	876	700	400	2.5	Granite basement	Fine soil

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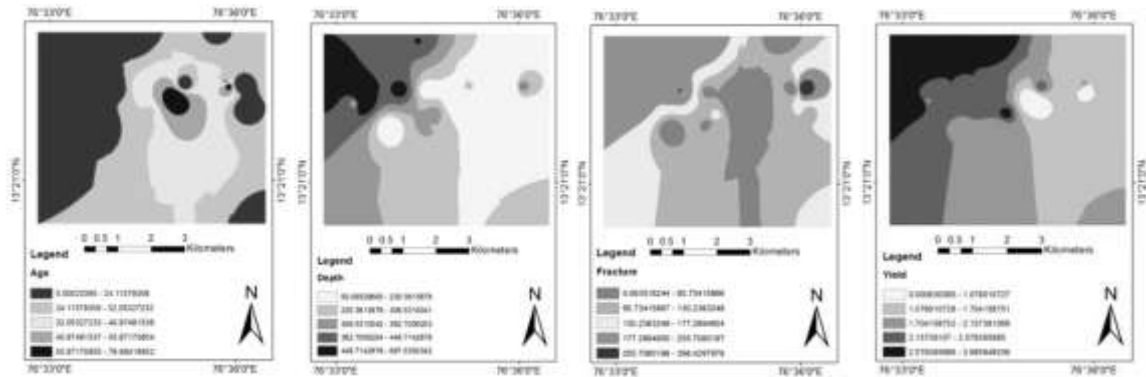


Figure 10: IDW interpolation map for well parameters of Age, Depth, Fracture and Yield respectively

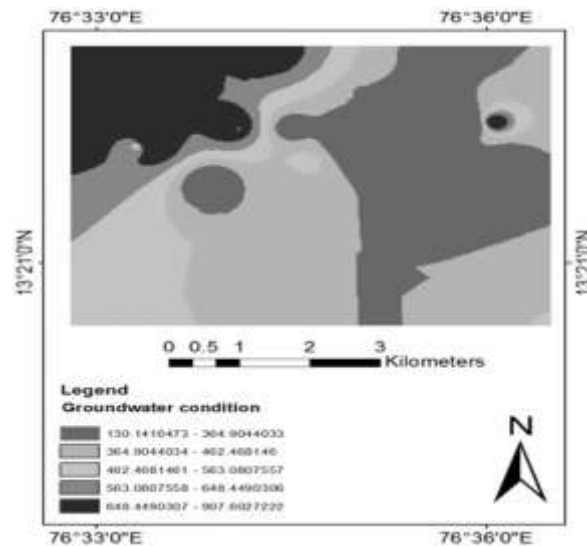


Figure 11: Overlay analysis for well parameters of Age, Depth, Fracture and Yield

Conclusion

The integrated groundwater potential zone map indicate that valley fills and moderately weathered pediplains with nearly level to gentle slopes are good to very good, shallow weathered pediplains are moderate to good with very gentle to gently slopes, pediment inselberg complex and pediments are poor to moderate with moderate to strong slope and denudational, residual hills and inselbergs are very poor to poor groundwater prospect zones with moderate steep to very steep slope category. Analysis reveals that all the bore wells are located in these categories but no borewells located in the sloping areas from moderate slope (5-10%) to very steep (>35%). From this study, it is concluded that nearly level, very gentle and gentle sloping areas (VF and PPM) are better than the much steeper hilly areas from the groundwater point of view the streams exhibit dendritic to sub dendritic type of drainage pattern and comprise of granite and gneissic rock formations of Achaean age. On the basis of different geomorphic units, four categories of groundwater potential zones were delineated as (i) very good to good (ii) good to moderate (iii) moderate to poor and(iv) Poor to nil. Recent studies have concluded that delineation and mapping of various landforms, drainage characteristics and structural features could have a direct control on the occurrences and flow of ground water. By recognizing the various geomorphological landforms and structures one can locate the ground water potential sites and construct bore wells for agricultural and domestic use. Lineation is an important structure that helps to locate potential sites for water. They may either follow topography or drainage of an area. Most of the wells drilled in the study area falls along the

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valley fill which indicates that they are the most potential sites as compared to other landform features. Remote sensing and GIS have proved to be efficient tool in drainage delineation and update in the present study and this updated drainage has been used for the morphometric analysis. The morphometric analysis of the drainage networks exhibits dendritic to sub dendritic drainage pattern and the variation in stream length ratio might be due to changes in slope and topography. The variation in values of bifurcation ratio among the sub-watersheds is ascribed to the difference in topography and geometric development. The stream frequencies of the study exhibits positive correlation with the drainage density values indicating the increase in stream population with respect to increase in drainage density. Drainage density is very coarse to coarse texture. Elongation ratio shows that circular shape, while the remaining marks elongated pattern. The study comes across the conclusion that the Morphometric study for sub watershed especially for those which exposed seasonal fluctuation has a boost impact for water development, water sustainability and water resource management. The result presented and the conclusion derived in this project will suggested and recommended to develop better water usage mechanisms for better application of the watershed.

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