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Research Article

DELINEATION OF GROUNDWATER POTENTIAL ZONES USING SURFACE PARAMETERS: AN ANP APPROACH IN AND AROUND TIRUTTANI AREA, TAMILNADU, INDIA

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ABSTRACT

This paper is aimed to delineate the groundwater potential zone in and around Tiruttani block, Tamil Nadu, India. The study area is located in hardrock terrain. The surface parameters such as geology, geomorphology, soil, slope, land use/cover, drainage and lineament have taken for the study. The thematic maps of the above said parameters were produced using geospatial technologies. The Super Decision Making software that specially designed to execute the Analytical Networking Process have for the Groundwater Potential zone mapping. ANP has run for the surface parameters and the groundwater potential map has derived for the study area. In the study area 210.92 sq.km of the area was classified to have high groundwater potential zone, 341.2 sq.km of the area was classified as moderate groundwater potential zone and 423.84 sq.km of the area is of low groundwater potential zone.

INTRODUCTION

India is heading towards a freshwater crisis mainly due to improper management of water resources and environmental degradation, which has led to a lack of access to safe water supply to millions of people. This freshwater crisis is now evident in manyregions of India, changing in large scale and intensity depending mainly on the time of the year. Groundwater is the major source of drinking water in both rural and urban India. The groundwater behaviour in the Indian sub-continent is highly complicated due to the occurrence of diversified geological formations with considerable lithological and chronological variations, complex tectonic framework, climatologically dissimilarities and various hydrological conditions. Ninety percent of the rural and nearly thirty percent of the urban population of India depends on groundwater for their drinking and domestic water necessities (Reddy *et al*., 1996). Thus, groundwater is emerging as an alarming poverty reduction tool in developing countries and can be delivered to poor communities for more economically, quickly and easily than the conventional canal irrigation water (IWMI, 2001). The surface water bodies such as reservoirs and tanks depend only on monsoon rains. But due to vagaries of monsoon, these structures do not get an adequate filling and could not cater the needs of entire command areas. The capacity of these structures is also reduced due to various reasons resulting in poor storage conditions during monsoon seasons. The indiscriminate pumping and poor storage in the surface water structures cause great concern in lowering of groundwater level in many parts of the State in the last three decades.

Aim and Objectives

The present study aims to identify the potential groundwater zones of Thiruttani, Tiruvelangadu and Arakonam blocks, adjacent villages of Thiruvallur and Vellore district, Tamil Nadu, India, using surface and subsurface hydrogeological parameters through ANP modeling technique. The following objectives were framed and carried out systematically.

- Preparation of thematic layers on groundwater controlling surface parameters like geomorphology, lithology, lineament, land use/land cover, drainage and slope using remote sensing data and topographic sheets
- Generation of database on drainage density and lineament density
- Generation of GIS database for the surface parameters

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- Identification of potential groundwater zones using surface parameters through Analytical Network Process modeling Technique.

Study Area

Thiruttani is a town in the state of Tamil Nadu, located 78 kilometres from Chennai, 44 kilometres from Kanchipuram, 65 kilometres from Tirupathi, 160 kilometres from Thiruvannamalai and 15 kilometres from the state of Andhra Pradesh. The study area, Thiruttani , Thiruvelangadu, Arakonam blocks and adjacent 58 villages of Tiruvallur and Vellore district,is extracted from the toposheets numbers 57O/8, 57O/11, 57O/12, 57O/16, 57P/9 which is obtained from IRS ID 23.5m resolution with the help of Earth resource data analysis System (ERDAS) and ArcGIS 9.1 software. It is located in between northern latitudes 12°56’30"N and 13°18’30"N, and eastern longitudes 79° 30’ 30’’ E and 79° 47’ E. The area covers 976.95 km^2, and the work carried out on 1:50 000 working scale using Survey of India (SOI) toposheets 57O/8, 57O/11, 57O/12,57O/16, 57P/9.

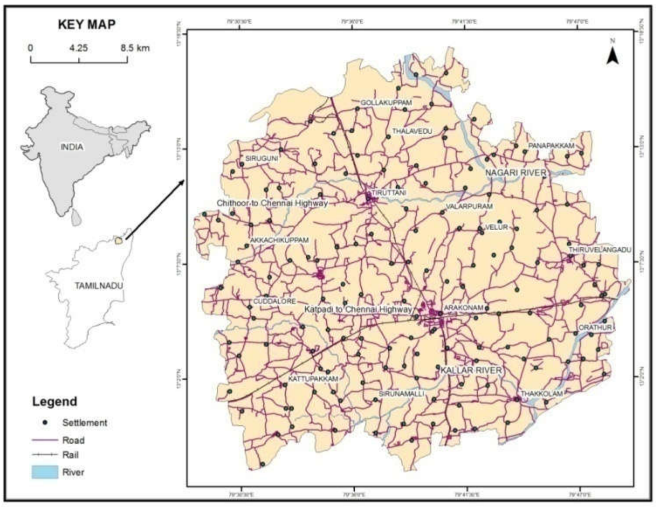


Fig 1 Key Map

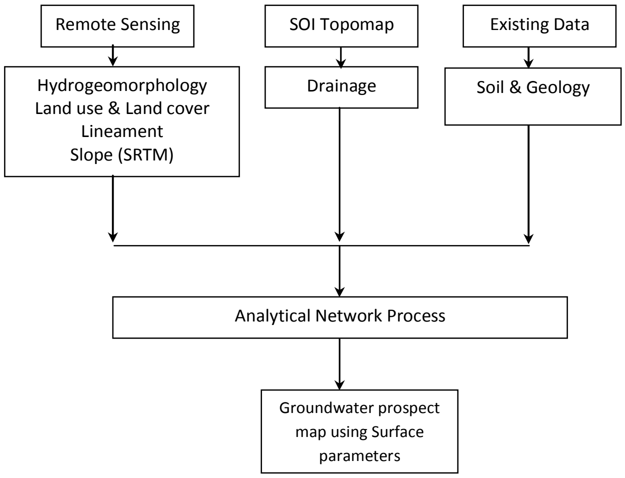
REVIEW OF LITERATURE

Integrated groundwater investigations are very costly, time-consuming and require skilled workforce (Sander *et al*., 1996). Geospatial technologies are not directly detected groundwater, the state of groundwater is inferred from different surface features. Geology, lineament, landforms, soils, land use/ land cover, surface water bodies, drainage and slope of the terrain are the indicators of groundwater that have been derived from satellite images and integrated into GIS environment. (Todd, 1980; Jha and Peiffer, 2006). Demarcation of potential groundwater zones and groundwater modelling involves a large volume of multidisciplinary data; an integrated application of GIS techniques has become a valuable tool. In the past, several researchers have used GIS techniques for the delineation of groundwater potential zones with successful results. These are the majority of which focus on hard rock terrains. Exploration and utilization of groundwater especially in hard rock terrains, requires athorough understanding of geology, geomorphology and lineament of an area, which is directly or indirectly controlled the terrain characteristics (Ravindran and Jayaram, 1997; Pradeep, 1998, Kumar *et al*., 1999). Remote sensing techniques have been used to narrow down the targeting area. Principal Component Analysis (PCA), Band Ratioing, Contrast Stretching and Filtering are the image processing techniques adopted for groundwater exploration (Gupta *et al*. 1989). Exploration of groundwater in hardrock terrain includes extract details on lithology, structure, lineaments and geomorphology from satellite images. The IRS, CARTOSAT and LANDSAT satellite data have been used generate the adequate information of the terrain (Krishnamurthy and Srinivasan, 1995; Krishnamurthy *et al*., 1996; Rao *et al*., 1996 and Anbazhagan *et al*. 2000). Structural features of hardrock terrain can be identified easily through topography, drainage, vegetation and soil texture by the visual interpretation of satellite images. Chi and Lee (1994) and Krishnamurthy *et al*. (1996) used remote sensing and GIS in diverse geological set up for the demarcation of groundwater potential zones in Kochang Korea and Marudiyar river basin, in Tamil Nadu, India respectively. Kamaraju (1996) considered the input information on groundwater characteristics of various parameters as descriptive form should be converted into “groundwater favorability index” (GWFI) values. The conversion carried out by rating the groundwater characteristics of the parameters regarding representative numeric, values. The GWPI ("groundwater potentiality index") values are computed based on the corresponding GWFI values of the groundwater controlling parameters. Shahid *et al*. (2000) used seven themes such as lithology, geomorphology, soil, water level fluctuation, drainage density, slope and surface water body to evaluate groundwater potentiality. They had given an equation for the spatial analysis of these seven themes.

The Analytical Network Process (ANP), a multi-criteria prioritization method to support decision making in complex and uncertain environments and suggests the analytic network process (ANP) approach for prioritizing decision elements. The proposed multi-criteria set-theoretic method accommodates super matrix computations and thereby provides the opportunity to capture the uncertainty associated with the cumulative influence of each factor on every other factor with which it interacts. As its comparison to current methods, ANP successfully derives meaning full priorities from complex and uncertain decision structures. The recent advances in multi-criteriadecision-making process generated economic and strategic changes in many aspects of modern business, e.g. manufacturing, logistics, finance and marketing. It is a general theory of relative measurement used to derive composite priority ratio scales from individual ratio scales that represent relative measurements of the influence of elements that interacts with the sub-criteria.

METHODOLOGY

Satellite data IRS 1D LISS III (P142 R51, P143 R51 dated 15.12.2015) collected from National Remote Sensing Agency (NRSA), Hyderabad have used for this study. ENVI 5.2 image processing software is used for importing and processing the digital data. There are four bands in the BIL (Band interleaved line) format of data. True colour and false colour composite images were generated from the data for the visual interpretation. The systematic approach has been taken for the geomorphological and structural interpretation. Land use/cover identification has done using FCC image. SRTM data was also used for generating digital elevation map and slope map.



Subsurface Data Base Generation Using Spatio Linear Tools

Geology

The geological formations in the region are from the Archaeans formation called Coromandal Formation (Badrinarayanan, 1978) of probable Holocene age has been recorded in this area. This formation is essentially quartz are nite which at places grades in depth to clayey sand and sandy clay. The geological formations can be grouped into three units, namely (i) the Archaean crystalline rocks, (ii) consolidated Gondwana with Tertiary sediments and (iii) the recent Alluvium. Most of the geological formations are concealed by the alluvial materials, except for a few exposures of crystalline rocks like charnockites in the middle part of the study area.

Spatial distribution of Lithology features Area

Lithology	Area (Sq.km)
Argillaceous Sandstone	6.18
Purple Conglomerate, Sandstone and Shale	47.49
Sandstone with Calcareous Gridstone	82.12
Basic dyke	97.44
Charnockite	5.83
Epidote - Hornblende Gneiss	210.17
Fissile Hornblende - Biotite Gneiss	458.44
Granite	14.94
Sand and Silt	88.86
Sand, Silt and Clay Partings	16.23
Sandstone and Conglomerate	48.87

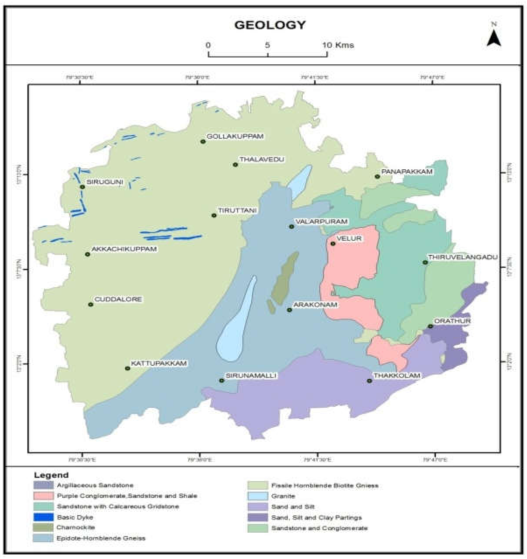


Fig 2 Geology map of the study area

Geologically there are eight major units Fissile Hornblende - Biotite Gneiss, Epidote - Hornblende Gneiss, Fluvial, Calcareous Gritty Sandstone and Clay, Basal Conglomerate, Shale with Limestone, Tiruttani Granite, Charnockite, and Basic Dykes. The Fissile Hornblende - Biotite Gneiss covers almost 47% of the western part of the study area. A central part covers the majority of Epidote - Hornblende Gneiss in the study area, Fluvial deposited in the southernpart, and also Calcareous Gritty Sandstone and Clay deposited eastern part of the study area. Seven Basal Conglomerate, Shale with Limestone patches are noted in the study area along the eastern margin. Small patches of Basic Dykes are oriented in the EW direction are noted in within the Fissile Hornblende - Biotite Gneiss of the study area and Two Thiruttani Granite patches in central and southern part of the study area. Charnockiteis noted in central part of the study area.

Calcareous gritty sandstone and clay are formed in the southern part of the Thiruttani it lies between Arakonam to Velur region. In the major part of the study area occupied by Fissile Hornblende and Biotite gneiss and also many other rocks are formed in the area like Epidote-Hornblende Gneiss, Basal Conglomerate, shale with Limestone Basic Dykes etc..

Geomorphology

Geomorphology is the field of geology deals the evolution of landforms and its endogenetic and exogenetic process. Tectonic processes and geological agents actively participate in the evolution of landforms. Hydrogeomorphology is a study deals with groundwater accumulation and movement in a terrain (Kale and Gupta, 2001). Ability to store and transmit the water is the hydrological characteristics of a rock/soil. Combination of hydrogeomorphological units is employed for the integrated approach of groundwater exploration.

Each unit of geomorphology has its property for the groundwater accumulation and transmission in the terrain (McFarlane *et al*. 1992). The colour, tone, texture, pattern, shadow, association, and drainage factors used for the interpretation of groundwater state of a terrain. Hydrogeomorphological features were interpreted both in FCC and TCC images and the features were classified. The supervised classification maximum likelihood method was employed for the geomorphological mapping.

The general physiography of this district is characterized by undulating topography with hill ranges. The prominent geomorphic units identified in the district through interpretation of satellite imagery are residual hills in the western part of the study area. The prominent geomorphic units identified in the district are Pediplain in the study area. Flood plains are seen along the banks of the rivers of the study area. These plains are formed due to deposition of sediments during the flood seasons. The periodic floods for several thousandyears resulted in the piling of the huge volume of sediments, spreading laterally for long distances. These floodplain areas have ideal conditions for carrying out agricultural activities.

In general, these areas are very fertile, owing to the periodic replenishment groundwater and soil, hence intensive agricultural activities are being carried out. The number of dyke complex is the important feature in the western part of the study area.

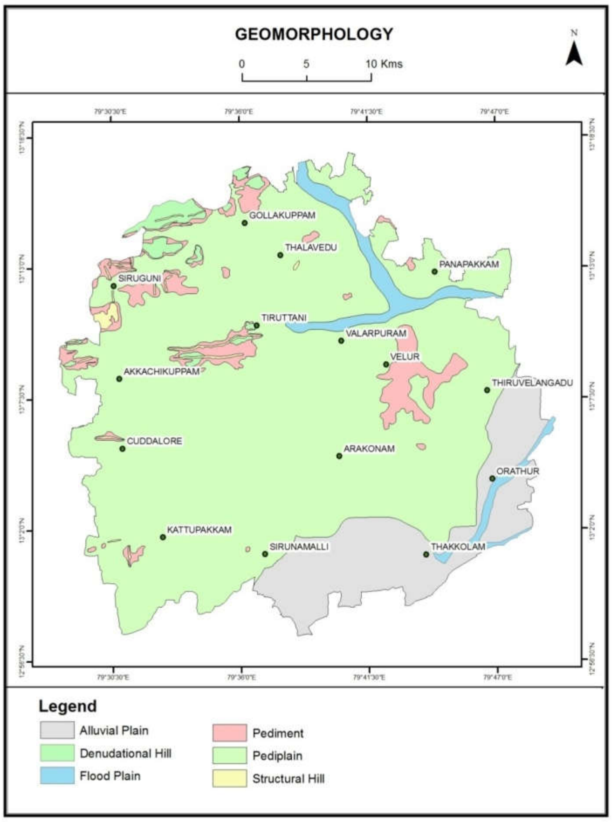


Fig 3 Geomorphology map

Spatial distribution of Geomorphic features Area

Geomorphology	Area (Sq.km)
Alluvial Plain	125.43
Denudation Hill	15.61
Flood Plain	33.60
Pediment	56.05
Pediplain	738.63
Structural Hill	6.64

Land use / Land Cover Mapping

Every single part of the Earth's surface are unique in the cover it possesses. Land use and land cover (LU/LC) are controlled by the exogenic processes of the Earth. Land use is the manner of human use of the earth surface. There are several land uses produced by human including agriculture, urban habitats, grazing, logging, and mining. Land cover can be defined that original state of land such as forest, desert, grass cover. Sometimes, land cover is broadened or altered for the human use. Land covers have altered as buildings, pavements, mines, dams and other human-made structures based on soil type, biodiversity, and surface and groundwater (Anderson 1972; Meyer 1995).

Groundwater potentiality and land surface characteristics are highly interrelated. The degree of infiltration and runoff are being controlled by the land use/land cover. The degree of vegetation cover and the albedo (degree of absorption/reflection of sun's rays) of the surface can affect rates of evaporation, humidity levels and cloud formation also greatly influenced by the land use/ land cover. Natural hazards like drought and flood have occurred based on the land use/land cover of a region. Surface and subsurface water flows are being regulated by the land cover properties and its variability. Land use/land cover is the main factor for soil erosion and landslides.

The amount of precipitation is similar in a single basin but, the yield of runoff and infiltration is different upon based on land use/land cover. The areas of forest cover and lineament density have controlled the runoff yield to the river (Anbazhagan *et al*. 2005). The area with high lineament density is having low infiltration and high stream flow. Vegetation cover increased the infiltration. Steep slope areas have low infiltration, and gentle slope has high infiltration. The area with less vegetation cover is prone to the sheet, rill and gully erosion (Field, 1997). These erosion result in high stream flow and low groundwater level. Mountains and uplands are called as the water towers of the world that are promising reliable supplies of freshwater to lowland areas (Becker and Bugmann, 2001).

Geospatial is a useful tool in land use and land cover mapping because it provides synoptic view and multi-temporal data. The effectiveness of moderate resolution satellite data and computer-aided GIS techniques were evaluated through this study. The land cover classes are derived from tone, colour, pattern and association of the elements. Computer-assisted image classification techniques are used for the study (Rosenfield and Fitzpatrick-Lins 1986; Foody 1992; Burrough 1996; Congalton 1996). Unsupervised image classification is a method in which the image interpreting software separates the pixels in an image based upon their reflectance values into classes or clusters with no direction from the analyst. Once this process is completed, the image analyst determines the land cover type for each class based on image interpretation, ground truth information, maps, field reports, etc. and assigns each class to a specified category by aggregation (ERDAS, 1999).

The LU/LC for the study area interpreted from satellite data by adopting NRSA classification system (NRS 2001). Figure 2.7 shows the land use/ cover map the study area.

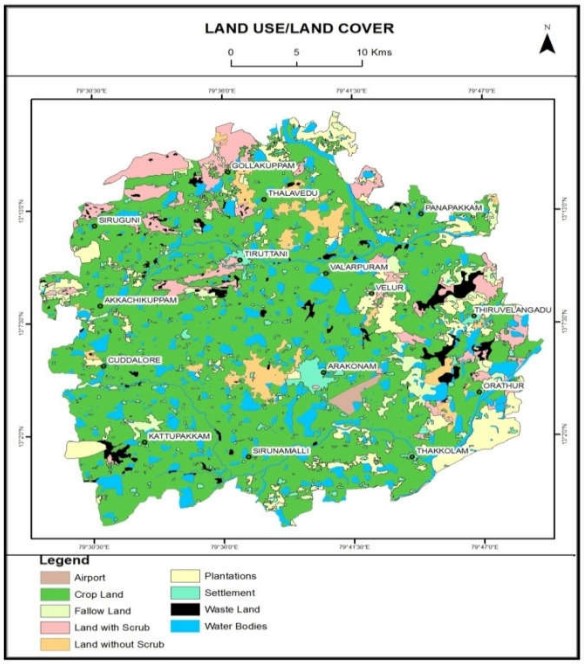


Fig 4 Land use / Land cover map

Majority of the study area covered by cropland (598.74 sq.km) next 107.95 sq.km area covered by water bodies, 33.43 sq.km area covered by fallow land and 22.97 sq.km area covered by a wasteland. Built-up land covers 31.70 sq.km area and 63.19sq.km area covered by landwith scrub and 33.56sq.km area covered by land without scrub and plantations covered 78.69sq.km.

Spatial distribution of Land use/Land cover features

Category	AREA (sq.km)
Airport	4.74
Crop land	598.74
Fallow land	33.43
Land with scrub	63.19
Land without scrub	34.56
Plantations	78.69
Settlement	31.70
Waste land	22.97
Water bodies	107.95

Soil

Varieties of soils that occur in the study area are derived from a wide range of geological formations. A soil map (Fig. 1.5) generated for the study area based on the data collected from Soil Survey and Land use Organization (SSLU) of the Agricultural department. The area covered by four different varieties of soils such as Inceptisols, Entisols, Alfisols and Vertisols. Alfisols cover the district with Entisols patches in the eastern part of the study area. Most of the area is covered with by Inceptisols almost 47%. Vertisols are also noticed at four patches of the study area.

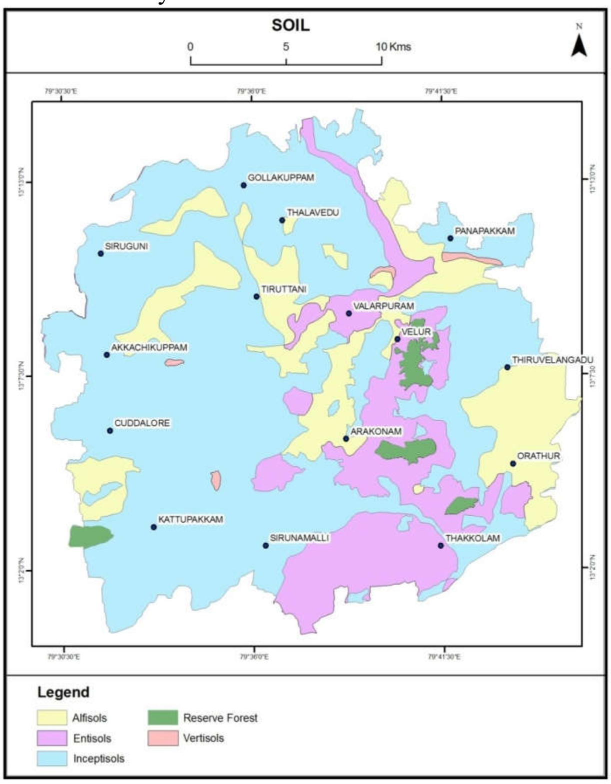


Fig 5 Soil map of the Study area

Soil Cover of the Study area

Soil Order	Area (sq.km)
Alfisols	172.81
Entisols	167.55
Inceptisols	615.03
Reserve forest	16.57
Vertisols	3.57

Lineament

Simple or composite linear features on the terrain surface are termed as lineaments. Lineaments are aligned in a rectilinear or slightly curvilinear relationship with the surrounding features. They have a distinct trend and pattern explained by O'Leary *et al*. (1976). Structured hills, rivers and streams have a curvilinear trend. Dykes and faults zones have a linear trend. Both have the great influence on the movement of groundwater in the subsurface.

The structural lineaments can be identified through relief maps that derived from contours and SRTM images. The joints, fractures, faults and dykes also can be identified through the satellite images. Vegetation growth, distribution, abrupt change of river course, soil cover changes and slope are the tools to demark the fault and dykes. Fractures are the good traces for groundwater accumulation.

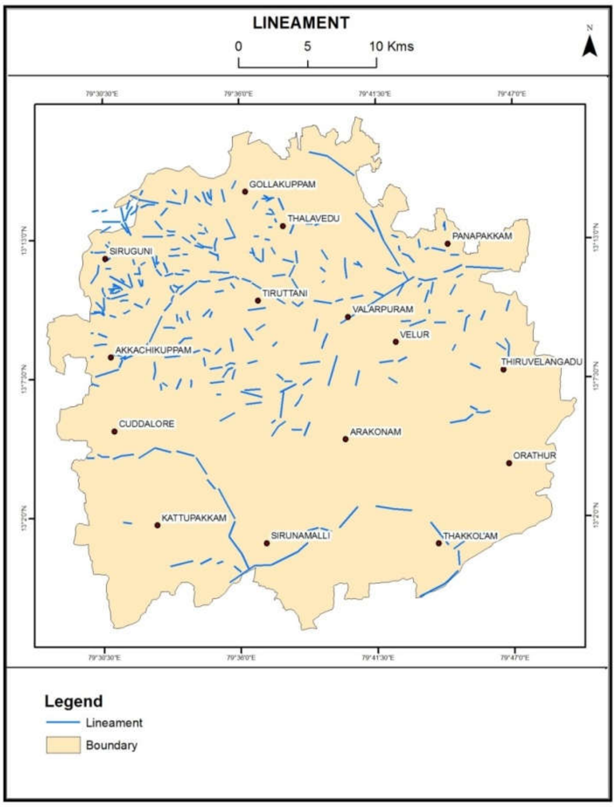


Fig 6 Lineament map of the study area

Lineament Density

From the lineament map, lineament density map was prepared to classify the study area and relate with groundwater potential (Krishnamurty *et al*. 1996; Subba Rao *et al*. 2001; Sener 2005; Subba Rao 2006). Total length per km of each lineament was measured and plotted. Each unit length plots were converted into contour map. Using Surfer 8.0 software lineament density map was prepared. Kriging method was adopted for the generation of lineament density map. This map was imported to ArcGIS software for the further integration and interpretation of maps. Lineament density was classified into three classes; high lineament density, medium lineament density and low lineament density. The high lineament density observed in the study area is 325.48 sq.km, medium lineament density area observed in 325.55 sq.km and low lineament density observed in 325.50 sq.km.

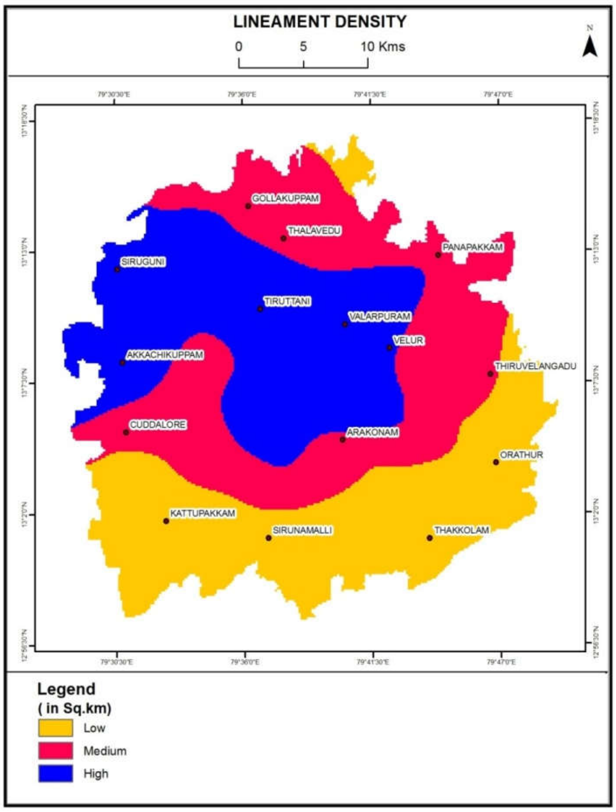


Fig 7 Lineament Density map of the study area

Spatial distribution of Lineament Density

Lineament Density	Area (Sq.km)
High	325.48
Moderate	325.55
Low	325.50

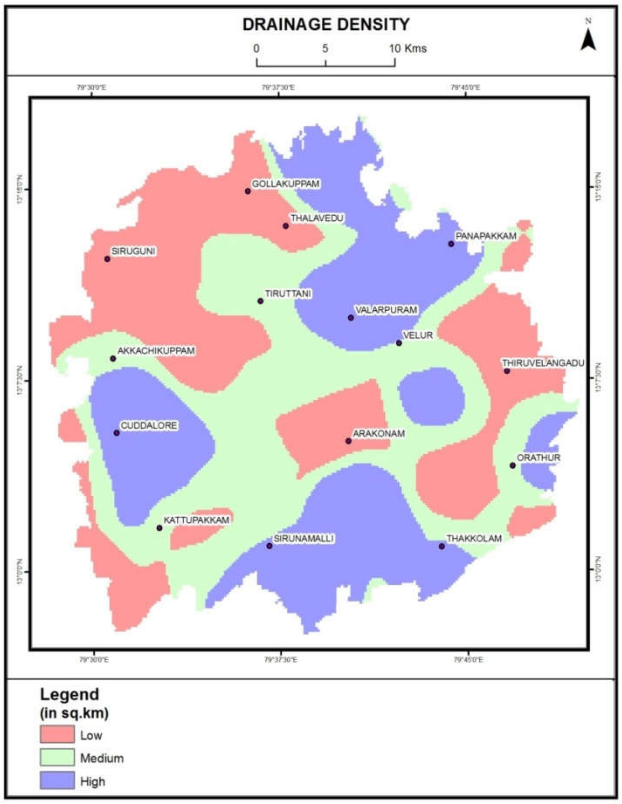


Fig 8 Drainage Density map

Spatial distribution of Drainage Density

Drainage Density	Area (Sq.km)
High	325.35
Moderate	325.48
Low	325.43

Drainage

The drainage pattern of an area is very important in hydrogeological studies. Groundwater condition of an area can be inferred through the drainage pattern and density. A drainage basin is called the area that collects rainwater and form channels and streams (Kale and Gupta, 2001). The small tributaries and mainstream network are called drainage network. The drainage pattern in the study area is mapped using Survey of India toposheet, and all drainage patterns are visible in the satellite images, and it is overlapped with toposheets for the verification and digitization (Fig.1.2).

Drainage Density

Drainage density is defined as the total length of the drainages present in a unit area. It is an important parameter for groundwater exploration. The drainage density of the area is calculated by measuring the total length of drainages for each sq.km area, plotted in the respective grid centres. The maximum drainage density observed in the study area is 325.35 sq.km area. The measured drainage density value considers as point data were imported to surfer 8.0 and kriging method was used to prepare the contour map. This map is taken into Arc GIS 9.3 environment. Drainage densities were classified into three classes as high, medium and low drainage density area (Fig. 2.8). The moderate to low drainage density areas are having more surface infiltration and permeability. This factor is an indirect sign of groundwater potentiality.

Slope

Digital Elevation Model (DEM) is the representation of elevation of the terrain, slope gradient and aspect. It can be used for finding features on the terrain, such as drainage basins and watersheds, drainage networks and channels, peaks and pits and other landforms, modelling of hydrologic functions, energy flux, forest fires etc. DEM is in raster format, and each pixel is having the x, y values and elevation (Z) value. Digital elevation model is developed from the contour map, and stereo corrected aerial photographs or other images (Vieux, 2001). Contour map was developed from the topomap. The scanned and georeferenced topomap of 1:50,000 scale was taken into GIS environment, and 20 m contours were digitized. Contour shapefiles were imported to ERDAS Imagine software was used to generate the DEM. The DEM of the study area is overlapped with the IRS 1D LISS III satellite image.

The slopeis defined as the inclined surface of a part of the Earth's crust. The term is used to indicate the level of inclination. The surface of the earth has a different range of slopes at various percentages 0% and 1% (horizontal) to >35% (Vertical), and in rare cases, even vertical (NRSA, 1995). There are three geometric components of a slope; gradient, slope length, and slope width. All above three measures are necessary to describe a slope accurately.

A land with 5m of vertical drop over a horizontal distance of 100 meters has 5% slope. Accordingly, 10m or 20m vertical drop for every 100m of horizontal distance has 10% or 20% slope respectively. The vertical drop can be estimated from the contour intervals, and the horizontal distance between the contours can be measured from maps by multiplying the map distance with the scale factor. The following formula is used to calculate and classify the slope categories.

$$\text{Slope percentage} = \frac{V}{D} * 100$$

Where;

V = Vertical Distance (m)

D = Horizontal Distance (m)

The slope map in the study area was then classified into three groups according to the scheme of NRSA classification, shown the Table 2.3 and themapshowed the Figure 2.14.

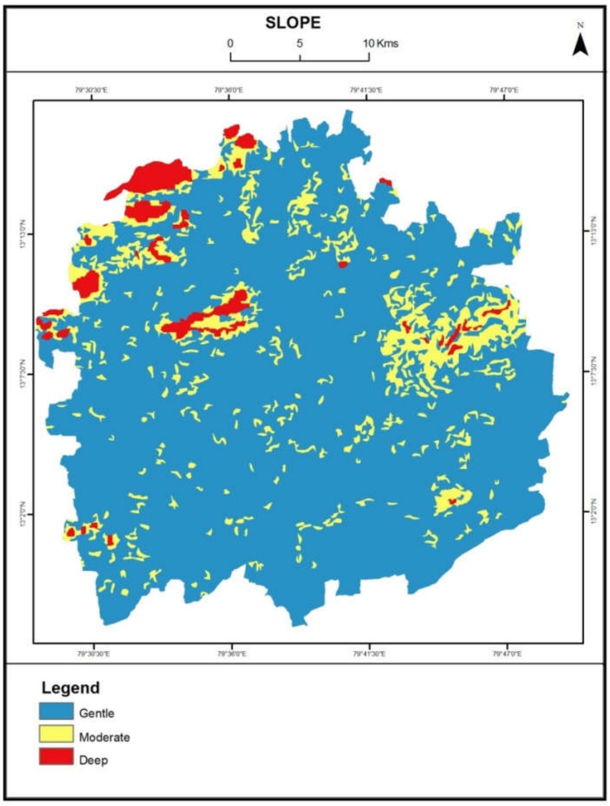


Fig 9 Slope map

Spatial distribution of the slope

Slope	AREA (in Sq.km)
Gentle	830.50
Moderate	111.94
Deep	32.72

ANP method and analyses

The Multi Criteria Decision Analysis (MCDA) is a qualitative analyses method which provides a structured way to deal with the complex problem. It has been applied in the fields of engineering, business, and social sciences and proved that MCDA is are liable method. There are many MCDA methods have developed for analysis. Selecting an appropriate MCDA method depends on the input parameters, modeling and outcome of the analysis. The input parameters are the ideal value, relative value and values with threshold. Consequently in the modeling component, if the input value is a known ideal value, then direct ranking will be given to parameters. If it is a relative value, then outranking method is adopted derive the overall rank of the parameters through a pair-wise comparison. That means, two parameters are compared at a time to derive their influence over groundwater potential zone. Since actual importance (ideal value) of each parameter influencing the goal is not known, the relative importance (relative value) of the parameters is derived. Since multiple parameters were used in the present study, for identifying groundwater resources, the relative influences technique was adopted.

ANP Model

The ANP model consists of the control hierarchies, clusters, elements, interrelationship between elements and clusters. The modeling process can be divided into four steps for the ease of understanding which are described as follows:

ANP Surface Groundwater Parameters

In the present ANP model, the control criterion is groundwater potential zone. The main parameters / elements that influence the occurrence of groundwater are geomorphology, land use/ land cover, lithology, lineament, drainage and slope forms the "criteria cluster". The categories / classes of the above parameters are grouped under "alternative cluster". For example, in the study area, the geomorphic landforms / elements criteria contains five sub criteria elements - flood plain, pediplain, pediment, dyke and structural hill, thus grouped under "alternative cluster". Similarly the elements / classes of other influencing parameters were also grouped under their respective "alternative cluster".

Super matrix formation

The supermatrix serves as a unifying framework and the values derived through the supermatrix represent the overall relative dominance of one element over another in the network. In the present study 361 inner and inter dependency computations were made amongst various surface parameters. The Computations command in the software is used to obtain results. All of the subcommands under the computations command may be used to display results in a simple network that occupies a single window. There are three supermatrices: 1) The unweighted supermatrix, 2) The weighted supermatrix and 3) The limit supermatrix Since the present ANP model comprises only two clusters, no cluster comparisons was done, therefore the unweighted supermatrix will be same as the weighted supermatrix. Hence the other two supermatrices were not determined.

Groundwater potential map

The main results of an ANP model are the overall priorities of the alternatives obtained by synthesizing the priorities of the alternatives from all the subnetworks. As discussed earlier the ideal values are the numerical values representing the influence of the respective parameter in terms of groundwater prospect with respect to all other parameters in the study area. Thus amongst 27 parameters, the floodplain gains an ideal value of 1 implying the most promising parameter in terms of groundwater prospect followed by cropland and so on (Table 4.4). Using ArcGIS software, the thematic layers of six surface parameters were converted into raster datasets. The derived ideal values were assigned to their respective parameters.

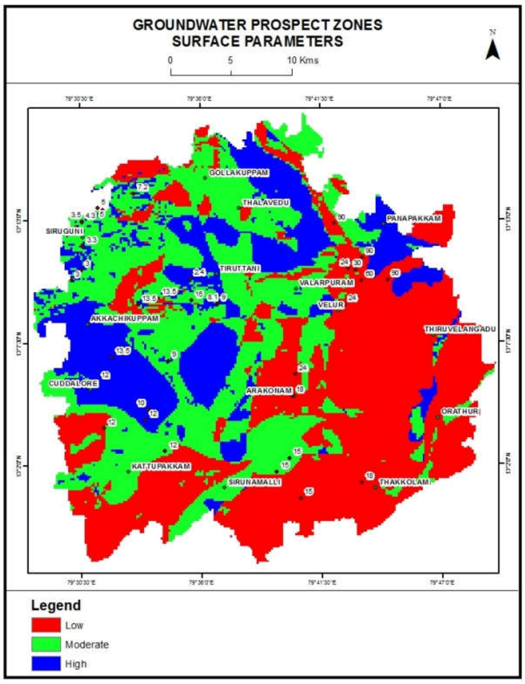


Fig 10 Groundwater prospect Zones

Later all the layers were integrated using raster calculator tool thereby surface parameters based groundwater potential zone map was prepared. Subsequently based on the derived values the map was categorized into three categories as high, moderate and low potential zones.

The above map has shown that 210.92 sq.km of the area was classified to have high groundwater potential and 341.2 sq.km of the area was classified as moderate groundwater potential, 423.84 sq.km of the area is of low groundwater potential.

CONCLUSION

The surface parameters of the study area has been analysed through remote sensing and GIS techniques. The thematic layers of surface parameters such as geology, geomorphology, soil, lineament, drainage, slope and land use/cover have prepared and analysed. The groundwater potential zone exploration have done using all surface thematic layers in Super Decision Software specially designed for Analytical Networking Process. This technique is highly efficient in decision making in multiple criteria scenario. The ANP have done and the groundwater potential zones have identified. The map shows that 210.92 sq.km of the area was classified to have high groundwater potential and 341.2 sq.km of the area was classified as moderate groundwater potential, 423.84 sq.km of the area is of low groundwater potential.

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