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Research Article

ASSESSMENT OF GROUNDWATER POTENTIAL ZONES IN DINDIGUL DISTRICT, TAMIL NADU, USING GIS-BASED ON ANALYTICAL HIERARCHICAL PROCESS (AHP) TECHNIQUE

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ABSTRACT

The present study is an attempt to delineate the groundwater potential zones in Dindigul District, Tamil Nadu, India, using an integrated approach of geospatial techniques. The study is based on identifying the physical features that promote the groundwater potential and bringing it into the GIS platform. On the basis of corresponding contribution of each of these physical features towards groundwater potential the feature are identified as geomorphology, geology, slope, soil, land use and land cover, rainfall, drainage density and lineament density. These features are weighted and ranked depending on their capability to hold groundwater, using the integration method in GIS for calculating the groundwater potential index. Each weighted thematic layer is statistically computed to get the groundwater potential zones. The Analytic Hierarchy Approach (AHP) is used to determine the weights of various themes for identifying the groundwater potential zone based on weights assignment and normalization with respect to the relative contribution of the different themes to groundwater occurrence. The groundwater potential zones were obtained by overlaying all the thematic maps using the spatial analysis tools in ArcGIS 10.1. It is identified as five categories of groundwater potential zones i.e. Very Good, Good, Moderate, Poor and Very Poor groundwater potential zones. The result depicts the groundwater potential zones in the study area and found to be helpful in better planning and management of groundwater resources.

INTRODUCTION

Water is the only liquid naturally available on earth, that can be used for quenching the thirst to various day to day essential needs. The major source of water are surface water and groundwater that serves multi purpose viz., drinking, cleaning, washing, irrigation, industrial uses, etc. at various spatial locations in different forms. The groundwater potential zone assigned weights of thematic layers based on expert knowledge were normalized by eigen vector techniques of AHP method for the receiver operating characteristic curve was drawn in the groundwater potential map, and the area under curve was computed with the result obtained by other researchers used in groundwater probability assessment and various environmental studies (Jothibasu *et al*, 2016). The AHP method is used to determine the weights of various themes for identifying the groundwater potential zone based on weights assignment and normalization with respect to the relative contribution of the different themes to groundwater occurrence for classified into five categories low, medium, medium-high, high and very high potential zone identify and delineate groundwater potential zones through integration of various thematic maps with GIS techniques (Jhariya *et al*, 2016). The weights of each factor were computed statistically using multi-influencing factor technique followed by heuristic approaches driven method for assigning ranks to each sub-classes of factor maps at resulted for AHP model generated groundwater potential zones are validated with reported potential yield data of various wells (Raju Thapa *et al*, 2017). In this context, multi-criteria decision making (MCDM) is rather a simple, effective and reliable technique for AHP process for the identification of groundwater recharge mappinging and artificial recharge sites (Abdul Rahaman *et al,* 2016). A multi parametric data set comprising remote sensing data and conventional maps at the caterious wise all five different thematic layers were integrated with weighted overlay in GIS. For analysis result to different of thematic layers, namely, geomorphology, geology, soil type, slope, and land use/land cover, are prepared using satellite imageries, topographic maps, and secondary data set, and integrated with weighted overlay in GIS to generated groundwater potential zonation map (Pankaj Kumar *et al.,* 2016). To estimate the groundwater occurrence, there are

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different kinds of methodology in which devised, for past few decades Remote Sensing (RS) and Geographical Information Systems (GIS) can be considered as an essential tools in groundwater potential zone estimation (Balasubramani *et al*, 2011). Groundwater Potential zone is achieved by surveys, remote sensing and GIS techniques in the recent times help in precise identification of groundwater through analysing the various parameters (Venkatesan *et al,* 2017). Remote sensing and GIS technique facilitate time and cost effective, rapid assessment of groundwater resource, which otherwise through traditional method becomes very costly, laborious and time consuming work (Moore *et al*, 1991; Krishnamurthy *et al,* 2000; Jha *et al,* 2010; Arkoprovo *et al,* 2012; Hammouri *et al*, 2012; Lee *et al,* 2012a; Davoodi *et al,* 2015). The main objective of this study is to assess the competence of the AHP model for groundwater potential zone at Dindigul District, Tamil Nadu, India. Population growth and inadequate public water supply have led to increased demand for groundwater in Tamil Nadu during the few years. The present study sustainable development of the groundwater resources can be considered as the only viable alternative to support the community using remote sensing and GIS technique for the better planning, utilization, and management of groundwater resources.

Study Area

The total geographical area of the Dindigul District is 6,266.64 sq.km, which is about 4.82 percent of the total geographical area of Tamil Nadu State in India (Fig:1). The study area Dindigul lies between 10^{0} 05’ 00” N and 10^{0} 16’ 30” N latitudes and 77^{0} 16’ 30” E and 78^{0} 19’ 30” E longitudes it is bounded on the northwest by Coimbatore. North by Karur and Erode southeast by Madurai, southwest by Theni Districts and southwest Kerala State east by Tiruchirappalli District are the location of Dindigul District. In the District is bounded by Palani Hill ranges in the west, Sirumalai Hills in the south and in the east. The northern parts are covered by Plain terrains. The elevation ranges from about 2500 m above M.S.L. in the hill ranges of Kodaikanal to 100 m above M.S.L in the plains. In the main river of Cauvery basin, Vaigai basin and Pambar basin. The Northern part of the district fall in the Cauvery basin. The main river that detains this basin are Shanmuganagai, Nangangiar and Kodaganar River.

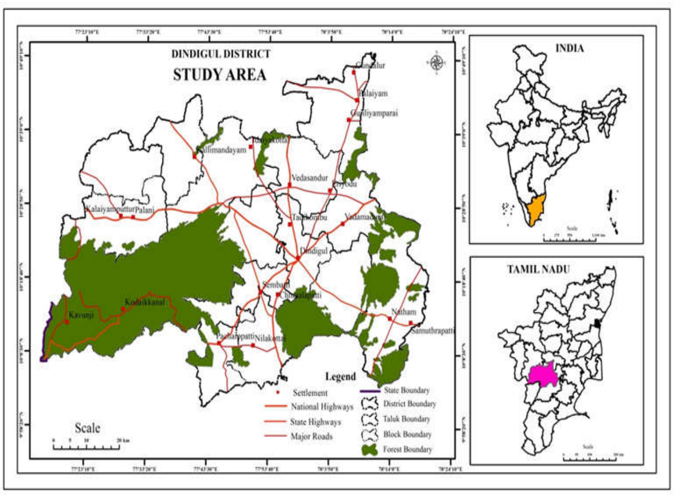


Fig 1 - Study Area

These rivers flow north and northeast ward and join Amaravathi river which finally confluence with river Cauvery. These river originate from the Palani Hill range of the western Ghats and Sirumalai Hills. They are all seasonal river. The southern part of the of the district falls under Vaigai basin. The main rivers that drain this basin are MadudhuNadhi, Manjalar and Vaigai River. These rivers are also seasonal in nature and receive flow during monsoon period only. The Pambar basin covers the part of this district. The minor rivers in this basin are Thirumanimuthar and Palar. They flow in the southeast direction and confluence with Pambar River. These rivers receive flows during monsoon period only.

MATERIALS AND METHODOLOGY

There are eight spatial parameters considered in conducting the study, they are Geomorphology, Land use/Land Cover, Geology, Slope, Drainage Density, Lineament Density and Soil Texture. The base map of Dindigul district prepared using the Survey of India topographic maps of 1:50,000 scale. The slope map was prepared from Aster DEM data using Arcgis Spatial Analyst Tool. The rainfall map was prepared using the data obtained from the Department of Economics and Statistics, Tamil Nadu. These data were then spatially interpolated using the IDW method to obtain the rainfall distribution map. The Bhuvan thematic service has been used for prepared the layer of lineament. The drainage density and lineament density maps were prepared using the line density analysis tool. The geomorphology map was prepared using the data obtained from the State Ground And Surface Water Resources Data Centre, Tamil Nadu.

Satellite images from NRSC, LISS-III sensor, on a scale of 1:50,000 (UTM projection, spheroid and datum WGS 84, Zone 44North) have been used for delineation of thematic layers such as land-use. The soil texture and geology layer is from NBSS and Geological Survey of India. The groundwater potential zones were obtained by overlaying all the thematic layers in terms of intersect methods using the analysis tool. During overlay analysis, the weights were given for individual parameter and rank for classes of each parameters.

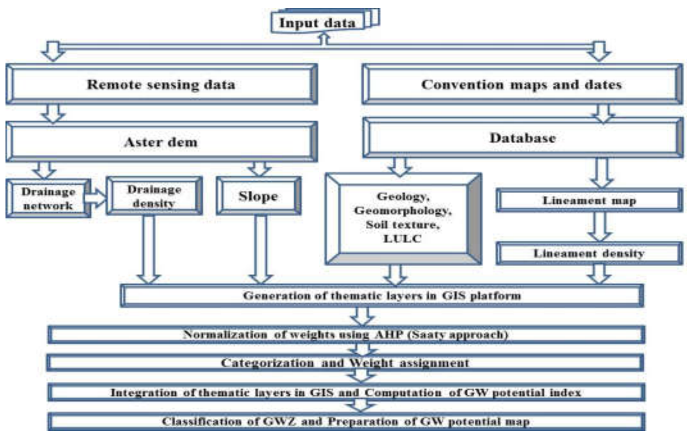


Fig 2 Methodology of the study

Analytical Hierarchy Process (AHP)

The analytical hierarchy process (AHP) are theory of measurement through pairwise comparison and relies on the judgment of experts to derive priority scales, the comparison was made on a scale of numbers 1-9 which indicates how many times, a layer is more important than the other factors (Saaty, 2008). Table1: measurement scale of AHP. The reciprocal matrix is called any matrix with this property.

Table 1 Saaty's 1-9 scale of relative importance

Intensity of relative importance	Definition
1	Equal importance
2	Weak or slight
3	Moderate importance
4	Moderate plus
5	Strong importance
6	Strong plus
7	Very strong
8	Very very strong
9	Extreme importance

The following steps were carried out to calculate in the normalized principal eigen vector. The values of the format were summed. All layers were divided by their corresponding sum of the column to form the relative weight matrix are shown in table 3. The normalized principal eigen vector is obtained by averaged across the rows are shown in table 4.

Saaty (1990) scale obtained by formulating on the following
CR=CI/RI
Where CI is the consistency index, RI is the random consistency index.
CI=λmax-n/n-1
Where λmax is the principal eigen value and n is the number if comparisons.
The Radom consistency index for calculating CR is shown in table 5.

thematic layers and their corresponding classes according to their relative influence on groundwater development. To differentiate groundwater potential zone, all the eight thematic layers after assigning weights and ranks were integrated (overlaid). The total weights and ranks of different polygons in the integrated layer were derived from the following equation to obtain groundwater potential index.

GWPI = {[(GMw)(GMr)] + [(GGw)(GGr)] + [(SLw)(SLr)] + [(LUw)(LUr)] + [(DDw)(DDr)] + [(LDw)(LDr)] + [(RFw)(RFr)] + [(STw) (STr)]} ………………...(1)

Where,
GWPI = Groundwater Potential Index
GM = Geomorphology GG = Geology
SL = Slope
LU = Landuse/Land Cover
DD = Drainage Density
RF = Rainfall
ST = Soil Texture
w = Weightage
r = Rank

Geology

Lithology is a very important factor in predicting groundwater potential zones. In the study area, five types of lithological characteristics were considered to understand the distribution and occurrence of ground water. The study area is mainly underlain by fissile hornblende biotite gneiss, Charnockite and granite. Garnet, Kankar, Laterite, Limestone, Pink Migmatite, Amphibolite, Anorthosite, Magnetite Quartzite is the dominant group of rocks covering major parts of the study area followed by the Charnockite and granite rocks. Limestone is porous and can be considered as favorable for groundwater storage. This rock and its associated combinations usually act as a favorable zone for groundwater (Fig.3).

Table 2 Pairwise comparison matrix – thematic layers

Thematic layers	Geomorphology	Geology	Lineament Density	Slope	Drainage Density	Landuse/ Land cover	Soil	Rainfall
Geomorphology	2.00	2.00	1.00	2.00	2.00	2.00	2.00	1.00
Geology	2.00	1.00	1.00	2.00	2.00	2.00	1.00	1/2
Lineament Density	4.00	1/2	2.00	3.00	2.00	1.00	1/2	1/2
Slope	1.00	1.00	1.00	2.00	1.00	1/2	1/2	1/2
Drainage Density	5.00	1/2	1/2	1.00	1/2	1/3	1/2	1/2
Landuse/ Land cover	3.00	1.00	1.00	2.00	1.00	1/2	1.00	1.00
Soil	2.00	1.00	1.00	2.00	1.00	2.00	1.00	1/2
Rainfall	1.00	1/2	1/3	1/5	1.00	1/4	1/2	1/2
Total	20.00	7.50	7.83	14.20	10.50	8.58	7.00	5.00

Table 3 Relative weight matrix – thematic layers

Thematic layers	Geomorphology	Geology	Lineament Density	Slope	Drainage Density	Landuse/ Land cover	Soil	Rainfall
Geomorphology	0.10	0.27	0.13	0.14	0.19	0.23	0.29	0.20
Geology	0.10	0.13	0.13	0.14	0.19	0.23	0.14	0.10
Lineament Density	0.20	0.07	0.26	0.21	0.19	0.12	0.07	0.10
Slope	0.05	0.13	0.13	0.14	0.10	0.06	0.07	0.10
Drainage Density	0.25	0.07	0.06	0.07	0.05	0.04	0.07	0.10
Landuse/ Land cover	0.15	0.13	0.13	0.14	0.10	0.06	0.14	0.20
Soil	0.10	0.13	0.13	0.14	0.10	0.23	0.14	0.10
Rainfall	0.05	0.07	0.04	0.01	0.10	0.03	0.07	0.10
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

RESULTS AND DISCUSSION

The weight age of the different parameters were assigned on a scale of Normalized principal eigenvector based on their influence on the groundwater development. Different classes of each theme were assigned rank on a Relative weight of various

Geomorphology

Geomorphology is a study of earth structures and also depicts the various landforms relating to the ground water potential zones and also structural features. Geomorphology of an area depends upon the structural evolution of geological formation.

Table 4 Normalized principal eigen vector-thematic layers

Thematic layers	Normalized principal eigen vector
Geomorphology	0.19
Geology	0.15
Lineament Density	0.15
Slope	0.10
Drainage Density	0.09
Landuse/ Land cover	0.13
Soil	0.13
Rainfall	0.06

Table 5 Random indices for matrices of various sizes

Matrixsize	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Shallow pediments (PFn and EFp) and pediments (PFe) are the result of denudational land forms. Flood plains of recent origin are found along the river side of Vaigai on the southern fringer of Dindigul District, in Nilakkottai taluk and the northwestern part in Palani taluk along Shanmuganadhi and Nallathangaiar river. The coalescence of alluvial cones and fans, formed after composite slopes boundary are Bazada zones. These formations are reported to occur on the northern part of Palanihills, Southern part of the Kodaihills and on the southern part of Nattam hills. An overall ground water occurrences in each geomorphic unit and the significance of its hydrogeological characters are furnished with groundwater potential (Fig.4).

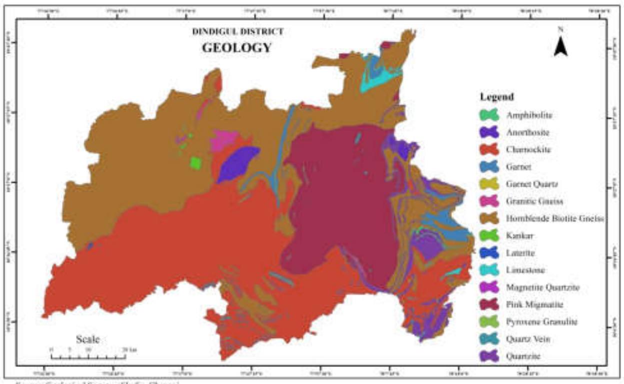
Table 6 Relative weight of various thematic layers and their corresponding classes

Sl.No	Influencing Factors	Category (Classes)	Rating	Weight
1	Geomorphology	Hydro-Geomorphological Unit, Hydro-Geomorphological Unit Province, Fragment of Fresh/Active Pediment, Residual Hill Complex	1	0.15
		Remnant of Planated Surface, Ridge and valley complex at the top of western ghats, Composite Slopes, Fragments of Dissected (Under Modification)	2	
		Fragments of Dissected (Under Modification) Pediment, Predominantly Black Soil Under Degradation, Basically PFn being Modified due to Anthropomorphic Process	3	
		High Moisture Zone	4	
		Bazada, Valley Fill, Younger Flood Plains	5	
2	Geology	Granite, Garnet, Garnet Quartz, Pink Migmatite, Amphibolite	1	0.15
		Anorthosite, Hornblende Biotite Gneiss, Granitic Gneiss,	2	
		Charnockite, Pyroxene Granulite, Laterite, kankar	3	
		Quartzite	4	
		Limestone	5	
3	Lineament density	< 0.5	1	0.15
		1.0 – 1.5	2	
		1.5 – 2.0	3	
		2.0 – 2.5	4	
		> 2.5	5	
4	Slope	< 5	1	0.10
		5 - 10	2	
		10 - 15	3	
		15 – 20	4	
		> 20	5	
5	Drainage Density	< 1.0	1	0.09
		1.0 – 1.5	2	
		1.5 - 2.0	3	
		2.0 - 2.5	4	
		> 2.5	5	
6	Land use/Land cover	Builtup rural, Builtup urban Bulitup mine industrial	1	0.13
		Agriculture fellow land, Forest deciduous, Forest evergreen, Forest scrup land	2	
		Forest plantation, Wasteland	3	
		Agriculture crop land, Salt affected land	4	
		Agriculture plantation, Water bodies	5	
7	Soil	Clay, Clayloam	1	0.13
		Loamysand, Loam	2	
		Sandyloam	3	
		Sandyclay, Sand	4	
		Sandyclayloam	5	
8	Rainfall	< 700	1	0.06
		701 – 800	2	
		801 – 900	3	
		901– 1000	4	
		> 1001	5	

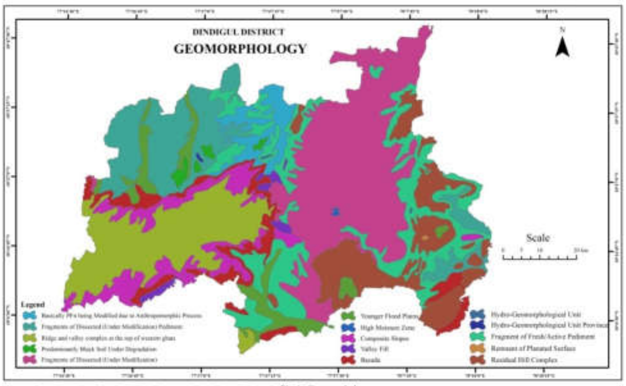
Geomorphological maps identify the various geomorphic units and groundwater occurrence in each units. The entire Kodaikkanal taluk comes under this category. Similarly structural hills are also found in parts of Nillakkottai, Nattam, Vadamadurai, Oddanchatram and Gujiliyamparai block areas.

Slope

The slope is one of the effective parameters which are explained by horizontal spacing of the contours. In general, the vector form closely spaced contours represent steep slopes and

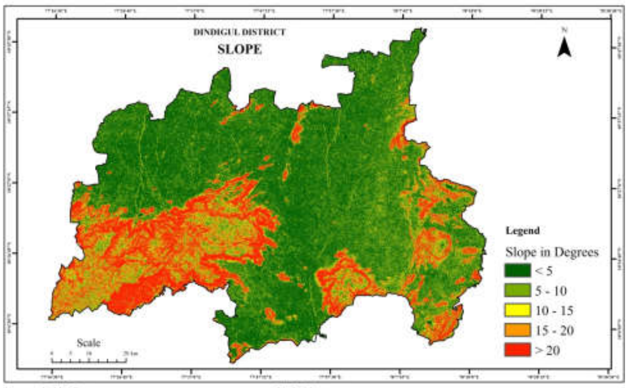


Source: Geological Survey of India, Chennai Fig 3 - Geology map



Source: State Ground and Surface Water Resources Data Centre, Chennai Fig 4 - Geomorphology

sparse contours exhibit very gentle slope, where as in the elevation output raster every cell has a slope value. The lower slope values indicate the flat terrain and higher slope values correspond to the steep slope of the terrain. The slope values are calculated either in percentage or degrees in both vector and raster forms. In the nearly level slope area >5 the surface runoff is slow, allowing more time for rainwater to percolate and consider good groundwater potential zone, whereas strong slope area <25% facilitate high runoff allowing less residence time for rain water hence comparatively less infiltration and poor groundwater availability (Fig 5).



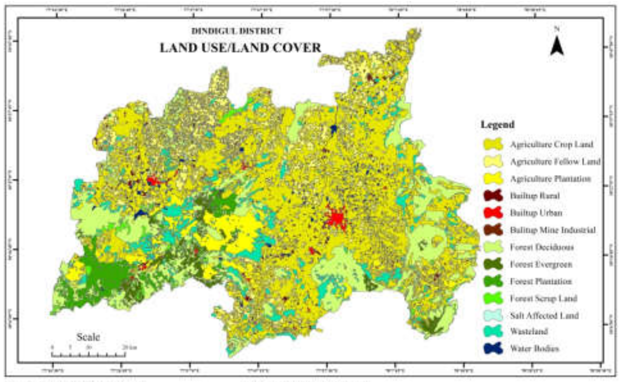
Source: ASTER Dem Fig 5 - Slope map

Land Use /Land Cover

The land use/land cover classification of Dindigul District for the year 2011-2012 is carried out using Bhuvan satellite data. The major classes are water bodies, Build up, Agriculture crop land, Agriculture Fallow, Agriculture Plantation, Evergreen Forest, Plantation Forest and Barren Land. Different land use/land cover classes were ranked based on its properties. Agriculture Crop Land and Fallow were given high ranks then the other land use features since its incessant recharge to ground, ensued by Agriculture Crop Land only, which pull maximum amounts of water from the deep root zone for sustaining, resulting the presence of water below the ground surface. Evergreen forest was ranked higher than Plantation forest. Next is the Built-Up Land and Barren Land, but the fallow land is ranked higher than the barren land (Fig 6).

Drainage Density

The drainage density is an important parameter for evaluating groundwater prospects. Drainage density is the closeness of spacing of stream channels. The less permeable a rock is, the less the infiltration of rainfall, which conversely tends to be concentrated in surface runoff. Drainage density of the study area is calculated as length of the stream flows per unit. The study area has been assigned with “very good’ (0-1 km/km2), “good’ (1-2 km/km2), poor (2-3 km/km2), and ‘very poor’ (3-4 km/km2) respectively. High drainage density (<4 km/km2) is part of the study area (Fig 7).



Source: Bhuvan, NRSC, Hyderabad Fig 6 - Land use /Land cover map

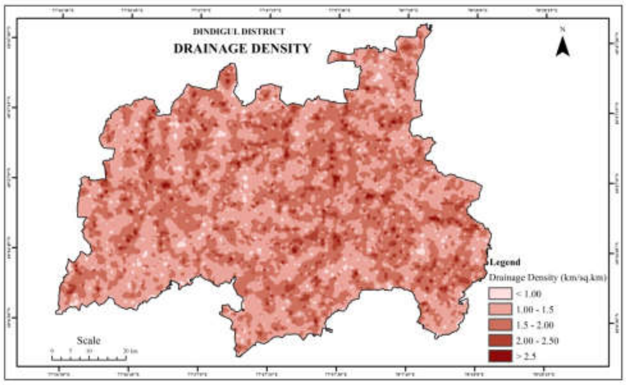


Fig 7 - Drainage density map

Lineament Density

Lineaments are straight linear factor visible at the Earth’s surface as a significant “Lines of landscape.” These are primarily a reflection of discontinuities on the Earth’ surface caused by geomorphic processes. Lineament density includes that give origin faults, shear zones, fracture, ridge, parallel, drainage parallel, axial trace of the fold. In present study lineaments feature are from an online geospatial service called Bhuvan thematic service. All lineament are associate with geomorphic lineament it is of major and minor lineament in nature, magnitude varies from km to km. In the study area with a very high lineament density more than 2.5 having good groundwater potential, whereas area with very less lineament density less than 0.5 having poor groundwater potential (Fig 8).

Rainfall

Rainfall is one of the main sources for ground water availability through the water cycle. The amount of rainfall is not same all the places it varies based on the environmental conditions of the place. The possibility of ground water is high if the rainfall is high and it is low if rainfall is low. The rainfall not only varies spatially it also varies temporally hence to determine the influence of rainfall in any region long time period study is necessary. The 15 rainfall stations receives rainfall from both southwest and northwest monsoons. The mean annual rainfall over the area varies from about <700 mm and >1001 mm. The rainfall on groundwater occurrence likely depends on the southwest and northwest monsoon. The highest mean annual rainfall north of Oddanchathiram and south part of Attur blocks (Fig 9).

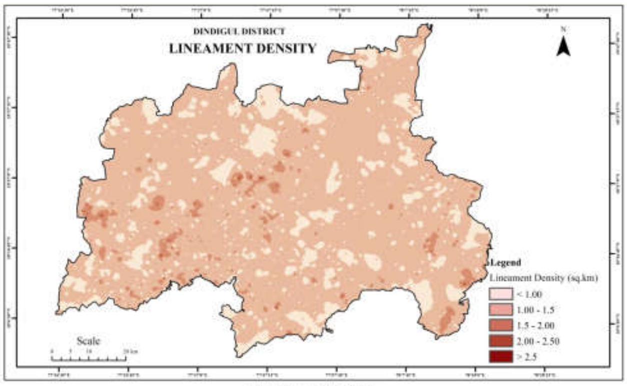


Fig 8 - Lineament density map

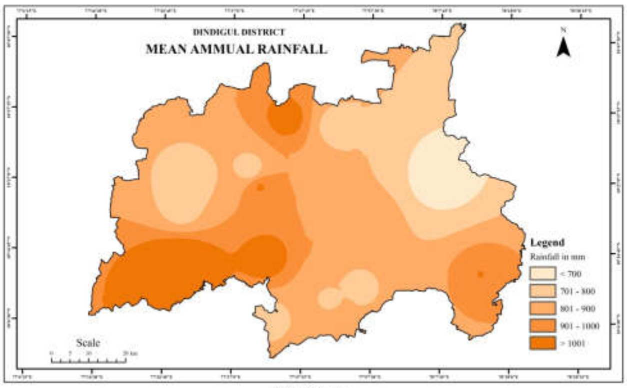


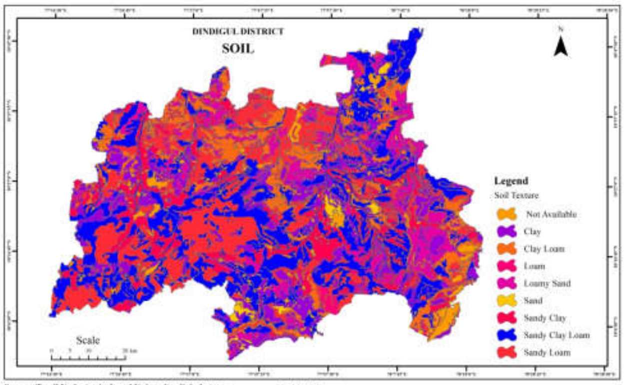
Fig 9 - Rainfall map

Soil Texture

Soils are the resultant product of weathering of parent rocks caused by temperature difference and hydration effect, consequently, the weathered rocks become angular fragment, fine rubble and sand. These fragmented rocks are transported during the rainy season by running water. During the process of transportation, fine materials are deposited as soil with various characteristics. Soil characteristics of a terrain are important aspect the basic needs of all agricultural products. Types of soil that are found in the study area are sandy clay, sand & sandy loam, sandy clay loam, clay loam, loamy sand (Fig 10).

Groundwater Potential Zones

The resultant map produced by analysis of AHP techniques on weighted parameters shows that groundwater potential of the Dindigul District is related mainly to lineament density, geomorphology, land use/land cover, rainfall, soil texture, drainage density, geology and slope. Based on this concept, the normalized weighted raster was classified into very high, high, moderate, low, and very poor categories to the unsuitable for groundwater recharge. The groundwater potential zone were identified in the district southeastern part and central part of the district having very good potential of 7.83 percent of the total area. Very good ground water potential is found in the district south and southeastern part which is of about 25.81percent of the total area. The moderate groundwater potential is found 34.78 percent total area which is mostly the plateau region. Poor groundwater potential is found in 25.36 percent of the total area which is mostly north and northwestern and west part of the district. They have very poor groundwater potential about 6.21 percent of the total area in the north, northeastern and eastern parts around the plain region (Fig 11).



Source: Tamil Nadu Agricultural University, Coimbatore Fig 10 - Soil map

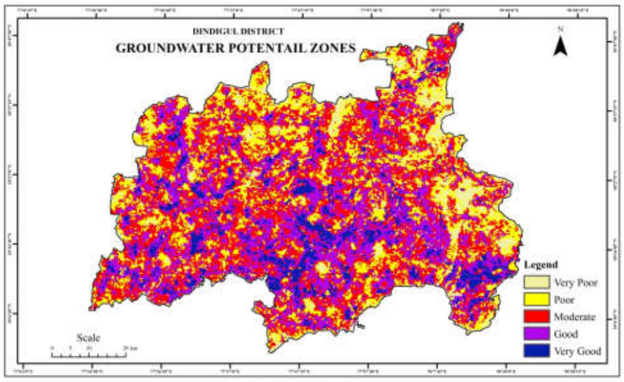


Fig 11 - Groundwater potential zones map

SUMMARY AND CONCLUSIONS

The groundwater potential zones were created by overlaying all the thematic layers in terms of weighted and rank overlay analysis using the spatial analysis tool in, Arc GIS and it is classified as the groundwater potential zones as Very Good potential, Good potential, moderately potential, poor potential and very poor potential occupying an area of 490.75sq.km (7.83 percent), 1617.63sq.km (25.81 percent), 2179.72sq.km (34.78 percent), 1589.26sq.km (25.36 percent), 389.28sq.km (6.21 percent) respectively of the total area of 6266.64 sq.km. It is evident from the resultant map that the influence of the physical features in the groundwater potential is really high reflecting the fact that the overlay analysis based on the weight age of the layers in nature that supports the promotion of groundwater are having high groundwater potential zone based on the physical nature of the region and those regions are having moderate and less groundwater potential zones where the influence of the physical feature is less in promoting the groundwater potential.

The application of integrated geoinformatics technology has to be a better tool for the identification of groundwater potential zones in Dindigul District. The present study demarcates the groundwater potential zones by analysing the influencing factors. These results suggest that the moderate potential zones will have a key role in the future expansion of drinking water and irrigation development in the study area. The results of the present study can function as guidelines for planning future in the study area in order to ensure sustainable groundwater utilization in the study area.

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