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# Identification of Groundwater Potential Zone in the Region of Tiruvallur using Remote Sensing and GIS Technique

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**ABSTRACT:** An assessment of groundwater potential is crucial for sustainable water resource management. In fact, traditional methods lack spatial coverage and precision, which hinders the accurate delineation of groundwater potential zones (GWPZs). So, incorporating remote sensing and GIS enables comprehensive mapping by integrating diverse geospatial data for enhanced analysis. However, this approach enhances the efficiency of identifying groundwater potential zones and aids in decision-making for optimal resource utilization and conservation strategies. This study mainly focused on describing the groundwater potential zones in the Tiruvallur district of Tamil Nadu. The study utilized Landsat data from the USGS to generate the LULC (Land Use Land Cover Change), CRU TS 4.07 Global Climate Database for rainfall, SRTM 30m DEM for slope analysis & hydrology, and Geological Survey of India's Bukhosh portal for geology data. Additionally, soil maps from the FAO and groundwater levels from the Central Ground Water Board (CGWB) were utilized for validation. A comprehensive methodology was implemented in this study, which includes weighted overlay techniques using a spatial analysis tool for delineating the GWPZs. Parameters such as drainage density, slope, geology, geomorphology, soil, rainfall, and LULC were ranked and weighted based on their influence. The scores ranged from 1 to 5, and the layers with matching scores were merged into one. Finally, the zones were classified ranging from excellent to extremely poor. The results indicated that the excellent groundwater potential zones cover an area of 0.1647 km<sup>2</sup> (near water bodies), whereas poor groundwater potential zones encompass approximately 5.1705 km<sup>2</sup> (including settlements and agricultural areas). However, this information aids in locating optimal water extraction sites and provides a model for future water resource management studies. The validation was done using the Receiver Operating Characteristics (ROC) and Area Under the Curve (AUC) approach, which yielded a value of 0.711 corresponding to a moderate GWPZ. Since Tiruvallur district is a moderate GWPZ and highly potent for agriculture, even minor deviation in the seasonal rainfall amount can lead to significant water scarcity because of its high vulnerability to seasonal rainfall pattern variation. So, as a result, agricultural productivity may be hampered due to the unavailability of optimum water requirements during the critical crop growth stages. Therefore, it is necessary to monitor the GWP for efficient crop selection and planning using remote sensing and GIS.

**KEYWORDS:** AUC, GWPZ, LULC, ROC, Weighted overlay

## I. INTRODUCTION

Groundwater is a vital natural resource, constituting 99% of the Earth's liquid freshwater and supporting approximately 50% of the river flow (Cherry, 2023). It is stored in underground aquifers, moving slowly through soil, sand, and rocks, providing a source of fresh water that is crucial for various uses (Groundwater Management, United Nations World Water Development Report (2022). Groundwater management involves operational decisions and practices aimed at the sustainable abstraction and protection of aquifers, guided by local system knowledge (McNabb and Swenson, 2023). Approximately one-third of the global population relies on groundwater for drinking water, making it essential for human health and sustainable development (Karunanidhi et al., 2022). Despite its significance, challenges, such as pollution from urbanization, agriculture, and industry, threaten groundwater quality, necessitating continuous monitoring and regulation to ensure safe usage (Reinecke, 2022). The groundwater in India plays a vital role in various sectors, particularly agriculture (Deepratan, 2022). It is the primary source for irrigation and domestic

International Journal of Innovative Research in Science, Engineering and Technology & Mobile No 7025571641 use, facing challenges like depletion due to climate change and increasing demand (Swaraj and Maheshwari, 2022). Furthermore, the agricultural sector uses more than 60% of groundwater (Hoekstra, 2017).

India is one of the world's largest consumers of groundwater, with an estimated annual groundwater extraction of approximately 230 km<sup>3</sup>. According to the yearly water withdrawal-to-availability ratio, the majority of India's land regions are significantly water-stressed (Saha and Ray, 2019). Notably, India's water demand is projected to surge by over 75% owing to population growth and economic activities, leading to visible consequences such as water quality deterioration and aquifer over-exploitation (Shiferaw et al., 2023). In the semi-arid crystalline aquifers of Central and Southern India, groundwater fluctuates dynamically. During the monsoon season (October to January) the land is replenished with rainfall, whereas in summer (February to May) excessive evaporation is observed. In addition to rainfall, topographical depressions largely promote infiltration, whereas high relief and steep slopes boost runoff. For instance, a location with high drainage density encounters more surface runoff than a low drainage density area.

In Tamil Nadu 108719.68 sq. km of recharge-worthy land is present, out of which 29.8% fall under the category of over-exploited, followed by critical and semi-critical (20.22%), and the remaining 40.14% fall under the category of safe. Therefore, efficient management strategies are crucial, including decoupling groundwater rights from land ownership, aquifer-based storage plans, and participatory irrigation management (Gupta and Sharma, 2023). The governance of groundwater in India is complex, with a multilayered legal framework involving both central and state governments (Pandey et al., 2022). So, understanding societal and gender aspects related to groundwater access is essential, especially for rural women, who are often impacted by water scarcity and gender inequality. Global research efforts are also ongoing to understand the distribution, availability, and interactions of groundwater with surface water, particularly in the context of climate change. Given these circumstances, a systematic approach was formulated to assess the groundwater potential and the Ground Water Potential Zones (GWPZ) were delineated for the study area.

## II. METHODOLOGY

### Study area

The Tiruvallur district is located in the Northeastern part of Tamil Nadu, India between 12°15' N - 13°15' N (latitude) and 79°15' E - 80°20' E (longitude). The geographical area of the district is 3,422 square kilometers (Fig. 1). Like other parts of Tamil Nadu, Tiruvallur district experience hotness in April to May, and humid for the rest of the year, except in December, January, and February, which are significantly colder. The average normal rainfall is 1104 mm, wherein 50% is received during the northeast monsoon period, and approximately 40% is received during the southwest monsoon period. The average maximum temperature of the district is 37.9°C, with an average minimum of 18.5°C.

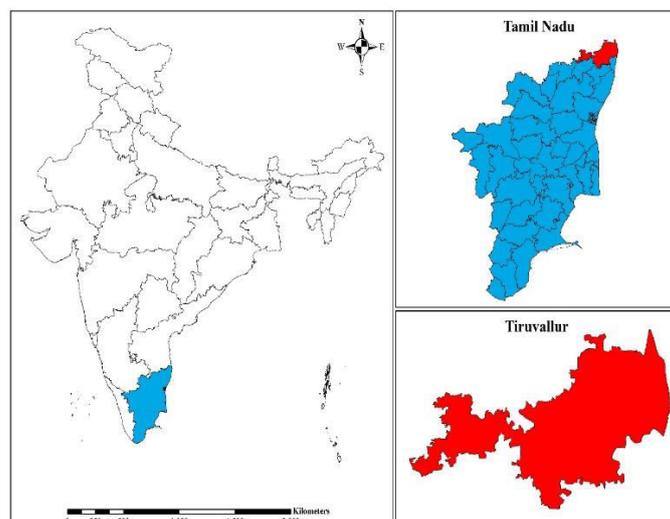


Fig. 1 Study area

**Data sets and sources**

For this study, Landsat 8 and 9 (summer data, 2022) datasets were preprocessed and downloaded from the USGS Earth Explorer website. The Climatic Research Unit (CRU) at the University of East Anglia established the CRU TS 4.07 Global Climate Database from which the rainfall data were obtained in gridded format, whereas slope and relief

International Journal of Innovative Research in Science, Engineering and Technology & Mobile No 7025571641 analysis was performed using SRTM 30m Digital Elevation Model (DEM) data, obtained from USGS Earth Explorer. Further, the soil map was obtained from the Food and Agriculture Organization (FAO) website including the geology and geomorphology data from the Geological Survey of India's Bukhosh portal. Additionally, groundwater level data was obtained from the Central Ground Water Board website for validation purpose.

**Experimental Design**

The analysis proceeds with the generation of Land Use Land Cover (LULC) map using Landsat 8 and 9. The SRTM 30m DEM was used to build the drainage network and slope map. A density map of the drainage system was created using the density analysis tool in ArcGIS. Further, the average yearly rainfall distribution map was created based on the inverse distance weighted (IDW) interpolation for point rainfall data across the study period. However, in this study different thematic maps were considered for the identification of groundwater potential viz., Geomorphology, Slope, Drainage density, LULC, and Geology maps. Most significantly, each layer was assigned a rank and weight. To further integrate these layers, a weighted overlay analysis (WOA) was used. Finally, all thematic layers were overlaid using GIS to determine the integrated output of groundwater potential zones (Fig. 2).

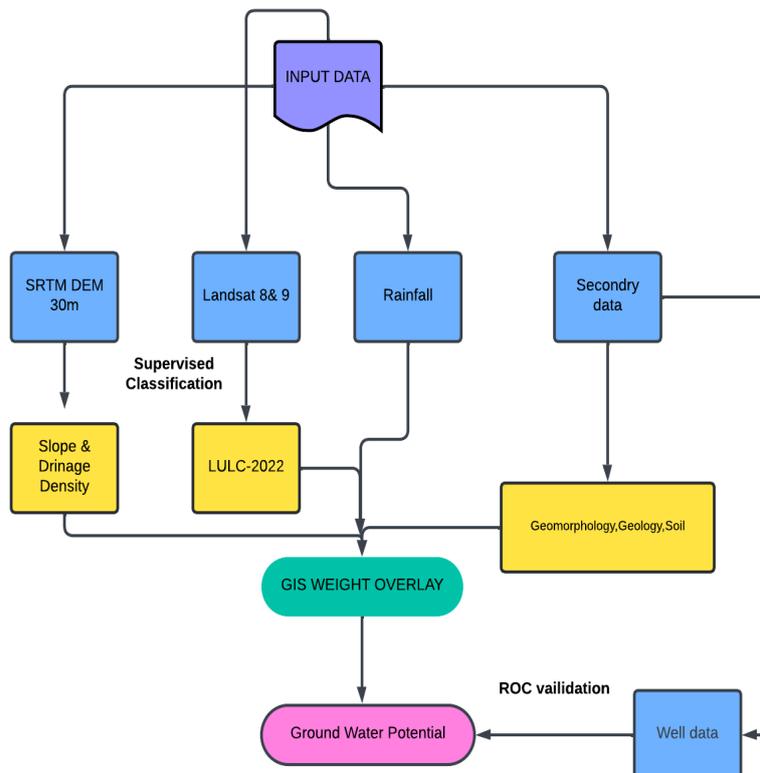


Fig. 2 Flowchart for the delineation of Groundwater Potential Zones

The weight of the specified thematic layer was computed using Saaty's (1980) scale approach. The areas with high weighted values were identified as strong groundwater potential zones. In this approach, each layer and class are assigned as weight and ranked from 1 to 5 (Low GWPZ - High GWPZ), viz., Very poor, Poor, Moderate, Good, and

Very good. This categorization was performed using a Cumulative Score Index (CSI) approach, and the CSI equation is as follows:

Cumulative Score Index (CSI) =  $\Sigma$  (Drainage density rank  $\times$  weight + Geology rank  $\times$  weight + Geomorphology rank  $\times$  weight + LULC rank  $\times$  weight + Rainfall rank  $\times$  weight + Soil rank  $\times$  weight + Slope rank  $\times$  weight)  
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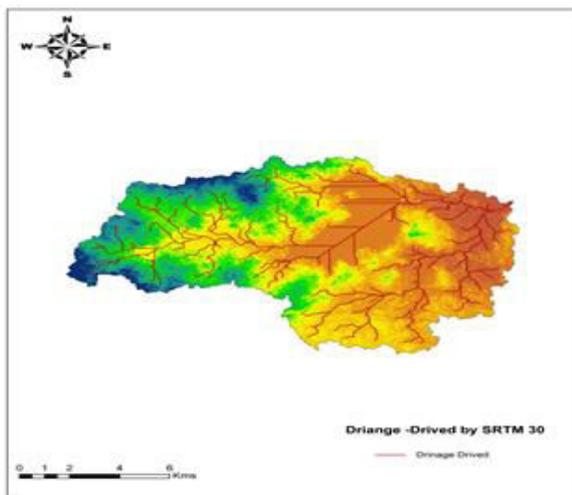
### III. EXPERIMENTAL RESULTS

#### Drainage density

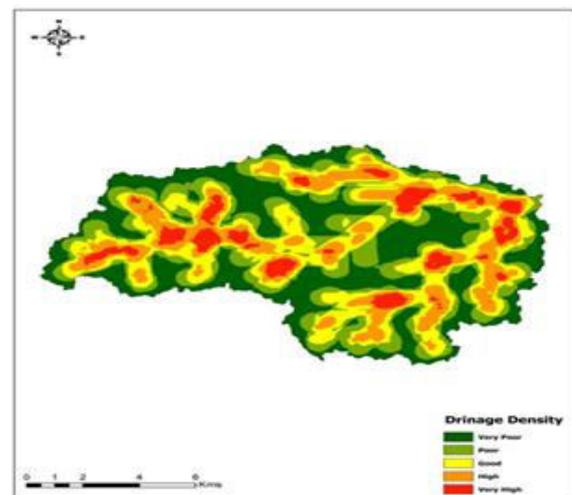
The density and type of drainage determine the runoff, infiltration relief, and permeability. In GWPZ delineation natural drainage systems are used. The classification of drainage density (Table 1) categories provides a structured framework for assessing the density of drainage networks within a given area ranging from Very poor to Very high. However, each category delineates specific thresholds of drainage density. The very poor category represents areas with the lowest drainage density, characterized by minimal water flow and sparse drainage networks, typically ranging from 0 to 0.50 Km/Km<sup>2</sup>. In contrast, the Very high category denotes regions with the highest drainage density, indicating abundant water flow and well-developed drainage networks, with values ranging from 2.95 to 5.20 Km/Km<sup>2</sup> (Fig. 3a and 3b).

Table 1 Classification of Drainage density

Class	Drainage density category	Km/Km <sup>2</sup>
1	Very poor	0 - 0.50
2	Poor	0.50 - 1.30
3	Good	1.30 - 2.08
4	High	2.08 - 2.95
5	Very High	2.95 - 5.20



(a)



(b)

Fig. 3 (a) Drainage network (b) Drainage density

**Slope map**

Slope is an essential topography feature, which is described by the horizontal separation of contours. In the vector form, tightly spaced contours indicate steeper slopes, whereas sparse contours show gentle slopes. In the output raster, each cell has a slope value, wherein the lower slope values suggest smoother terrain (gentle slope), whereas larger slope values correspond to steeper terrain. Further, slope determines the rate of rainfall infiltration and percolation into the ground. The degree of slope category classification (Table 2), offers a systematic approach for categorizing the terrain steepness within a given area, ranging from Nearly level to Strongly sloping. However, each class delineates specific thresholds for slope angles. The Nearly level category represents areas with the gentle slopes, characterized by minimal inclines ranging from 0° to 0.78°. Conversely, the Strongly sloping category denotes regions with the steepest terrain, featuring significant inclines ranging from 6.16° to 22.15°. Between these extremes, the Very gently sloping, Gentle sloping, and Moderate sloping categories encompass progressively increasing degrees of slope (Fig. 4).

Table 2 Classification of Slope

Class	Degree	Slope category
1	Nearly level	0 - 0.78
2	Very gently sloping	0.78 - 1.91
3	Gently sloping	1.91 - 3.38
4	Moderately sloping	3.38 - 6.16
5	Strongly sloping	6.16 - 22.15

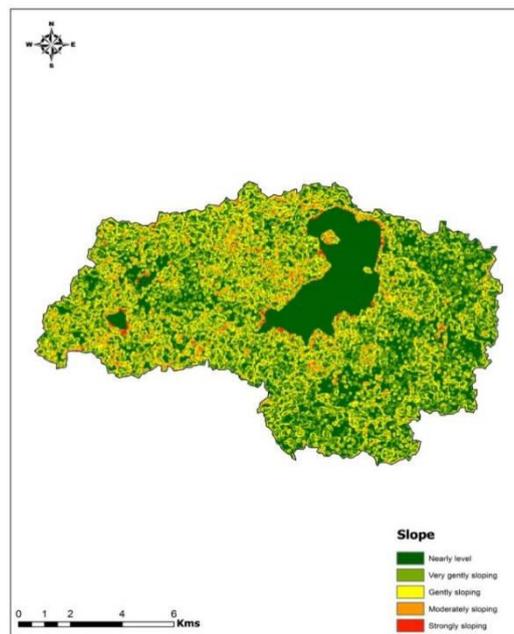


Fig. 4 Slope in degree

**Rainfall**

Rainfall is a crucial factor in determining prospective groundwater zones. The distribution map was divided into five categories based on the average annual rainfall (score from 1 to 5). The classification of rainfall levels into distinct categories based on millimeters of precipitation provides a structured framework for evaluating the intensity and distribution of rainfall within a specific area (Fig. 5). Each category delineated a specific range of rainfall amounts, wherein, class 1 represents areas experiencing the lowest levels of rainfall, precipitation ranging from 1,874.90 mm -

International Journal of Innovative Research in Science, Engineering and Technology & Mobile No 7025571641 1,888.75 mm. On the other hand, class 5 encompasses regions with the highest levels of rainfall, with precipitation ranging from 1,920.68 to 1,934.77 millimeters.

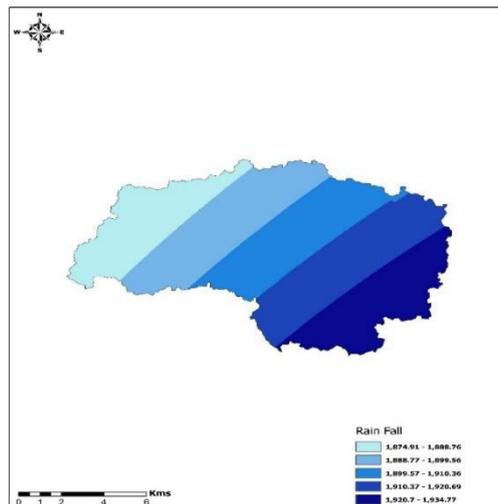


Fig. 5 Rainfall

**Geology and Geomorphology**

The geomorphology of an area is determined by the structural development of its geological formation. Numerous structural elements and terrain forms are reflected in geomorphology. Many of these characteristics are categorized according to the potential of groundwater and are favorable for the presence of groundwater. The geological map and different geomorphological categories were represented in Figure 6 (a) and 6 (b).

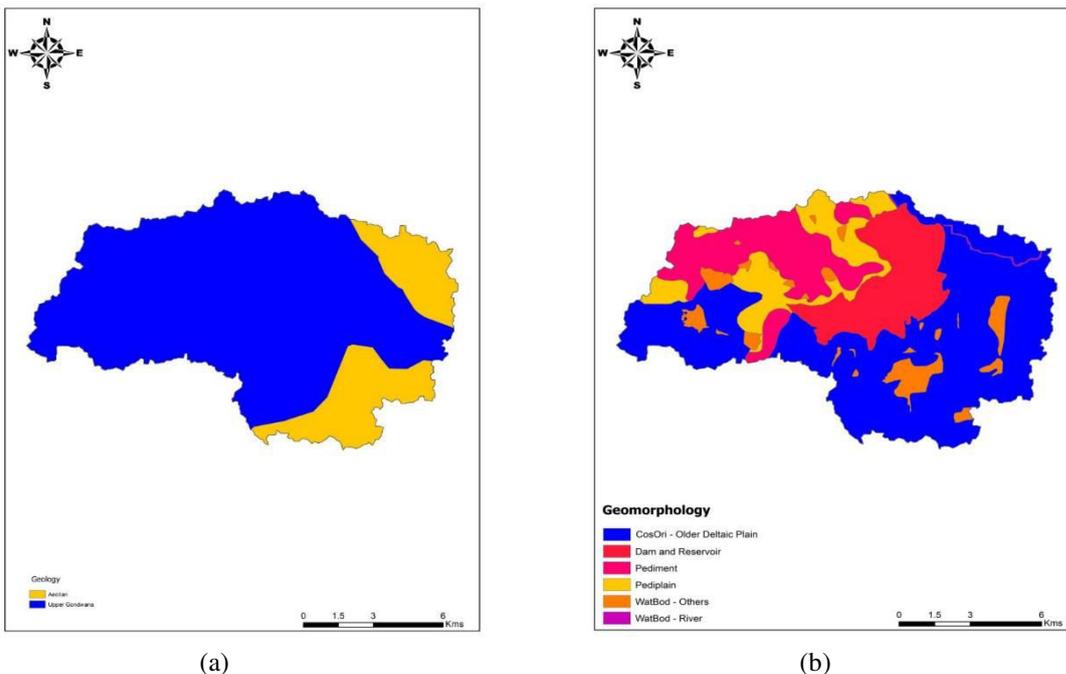


Fig. 6 (a) Geology (b) Geomorphology

**Land Use Land Cover (LULC)**

The LULC of the research area was examined using the supervised classification method. The findings (Table 3 and Fig. 7) showed that the major area is covered by Settlements (62.476 sq.km), followed by Agricultural lands (39.211 sq.km).

Table 3 Classification of LULC

Class	LULC	Area (sq.km)	Area (%)
1	Settlement	62.4762	46.60
2	Water bodies	18.6552	13.909915
3	Forest	3.9834	2.970151
4	Baren land	9.7884	7.298545
5	Agriculture crop	39.2112	29.247129

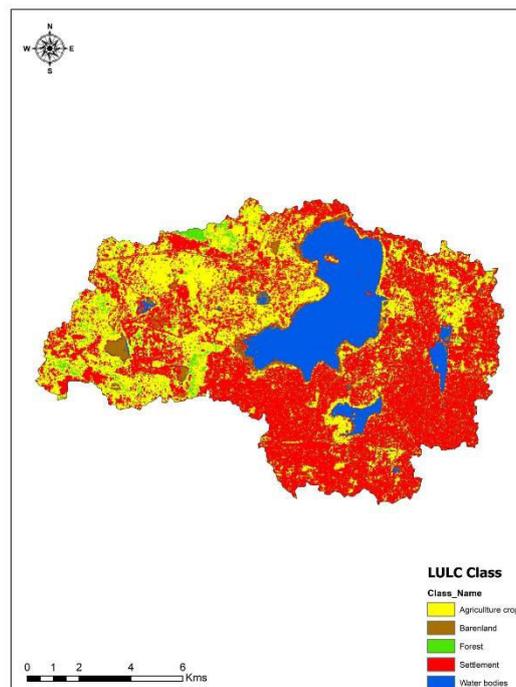


Fig. 7 LULC

**Weighted Overlay Analysis (WOA)**

To identify groundwater potential zones, a spatial analysis tool was used to overlay all thematic maps using the weighted overlay approach. All layers were assigned a score between 1 and 5, as all layers had to be on the same scale for the WOA (Table 4). After awarding the scores, all layers with the same index were combined into one.

**Identification of Groundwater Potential Zones**

$$GWPI = \sum (W) \times X_i \quad w=1 \quad j=1$$

where W represents the normalized weight of parameter j, X refers to the weight of class I of the parameter, m denotes the number of parameters, and n denotes the number of classes within a specific parameter. For each grid, the GWPI was computed (Table 5) and represented in Figure 8.

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Table 4 Weighted Overlay Analysis

Parameter	Class	Groundwater prospect	Weight %	Rank
Slope Classes	Nearly level - (0 <sup>0</sup> -0.78 <sup>0</sup> )	Very good	5	5
	Very gently sloping - (0.78 <sup>0</sup> -1.91 <sup>0</sup> )	Good		4
	Gently sloping - (1.91 <sup>0</sup> -3.38 <sup>0</sup> )	Moderate		3
	Moderately sloping - (3.38 <sup>0</sup> -6.16 <sup>0</sup> )	Poor		2
	Strongly sloping - (6.16 <sup>0</sup> -22.15 <sup>0</sup> )	Very poor		1
Drainage Density (Km/Km <sup>2</sup> )	0 - 0.50	Very poor	30	1
	0.50 - 1.30	Poor		2
	1.30 - 2.08	Good		3
	2.08 - 2.95	High		4
	2.95 - 5.20	Very high		5
Rainfall (mm)	1,874.90 - 1,888.75 mm	Very less	15	1
	1,888.75 - 1,899.55 mm	Less		2
	1,899.55 - 1,910.35 mm	Moderate		3
	1,910.35 - 1,920.68 mm	High		4
	1,920.68 - 1,934.77 mm	Very high		5
Soil		Red soil	10	1
		Loamy soil		2
LULC	Settlement		10	3
	Water bodies			5
	Other crops			4
	Baren land			1
	Agriculture crop			2
Geomorphology	Deltaic Plain	Very Good	20	5
	Pediment Pedi plain	Good		4
	Dam and Reservoir	Good		4
	Complex	Poor		1
	Waterbodies-Other	Moderate		2
Waterbody - River	Moderate	2		
Geology		Aeolian	10	1
		Upper Gondwana GP		2

Table 5 Groundwater potential zones of the study area

S. No.	Potential zones	Area (sq.km)
1	Very poor	5.1705
2	Poor	31.4316
3	Good	58.959
4	Very Good	36.4797
5	Excellent	0.1647

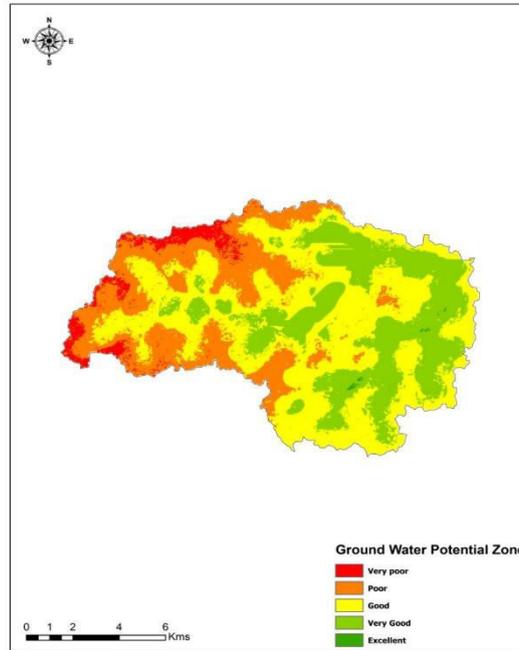


Fig. 8 Ground Water Potential Zone

### Validation of GWPZ

The GWPZ map was verified using the receiver operating characteristic (ROC) or Area Under the Curve (AUC) approach (Naghibi et al., 2018). Data from the watershed was overlaid on the GWPZ and the graphical representations showed the values on the X and Y axes. Notably, the ROC curve had values ranging from 50% (average) to 100% (excellent). The model predicted the existence of groundwater zones using the AUC would be 0.711 (Fig. 9), indicating moderate groundwater potential zone.

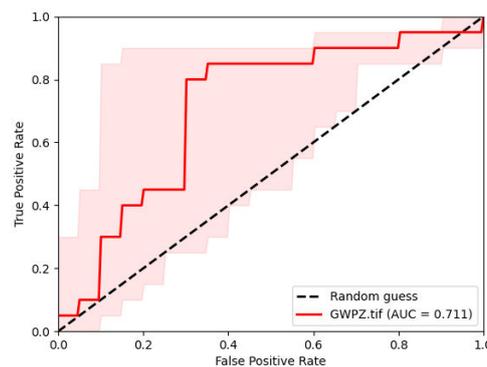


Fig. 9 ROC Curve

### IV. CONCLUSION

In certain areas of the Tiruvallur district, groundwater potential can be found using remote sensing and geographic information systems, which are effective and affordable. The local governments and planners should focus on obtaining the first-hand knowledge about the places that are suited for groundwater exploration by integrating six thematic maps,

including those that show drainage density, slope, geology, geomorphology, soil, rainfall, and land use/land cover. In this method, the study area was divided into different groundwater potential zones, ranging from excellent to poor. The excellent groundwater potential area was located over the water bodies and settlements showed a very poor groundwater potential. Therefore, identifying appropriate sites for water extraction can be made easier with the help of groundwater potential information. Additionally, it is believed that the current technique can serve as a model for future research.

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