

AHP-Based Mapping of Optimal Groundwater Recharge Sites in Tirupathur District, Tamil Nadu, India

A. Muthamilselvan¹, A.L. Mathumitha¹, S. Irfan Batsha¹, S. Aadhavan¹ and J. Jyothirmayi²

¹Department of Remote Sensing, Bharathidasan University, Trichy, Tamil Nadu, India

²Department of Geography, Nirmala College, Coimbatore, Tamil Nadu, India

*Corresponding Author: muthamilselvan.a@bdu.ac.in

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Abstract: A study was conducted in the Tirupathur district of Tamil Nadu, India to identify suitable sites for groundwater recharge and to suggest appropriate site specific recharge mechanisms. The potential of groundwater depends on topography, lithology, geological structure, depth of weathering, slope, drainage pattern, land use land cover, soil, rainfall, lineament density, drainage density, magnetic breaks and topographic wetness index. All thematic layers were prepared and assigned comparative weights using Saaty's 9-point scale and then normalized using the Analytical Hierarchy Process. According to the investigation, groundwater recharge zones are categorised into five classes; very low, low, moderate, high, and very high. The study found the region of Vaniyambadi and Natrampalli had very high and high potential zones, respectively, covering 6.22% (128.75km²) and 15.2% (312.79km²) area. Conversely, the region of south Natrampalli, Tirupathur, and eastern Ambur had moderate, low, and very low potentials, covering 29.31% (607.06km²), 24.35% (518.30km²), and 25.02% (504.41km²) area. The study mainly focused on moderate to very low potential zones for artificial recharge. High and very high zones were not considered as priority due to their high infiltration rates. This approach helped to identify 46 potential sites for artificial recharge based on the best execution of AHP to boost groundwater conditions and meet the shortage of water resources in agriculture and domestic use. This study reveals that Remote Sensing and GIS with AHP provide an efficient and effective platform for convergent analysis of various data for groundwater management and planning.

Keywords: Artificial groundwater recharge, Remote sensing, GIS, Analytical Hierarchy process

1. Introduction

Groundwater is a vital resource for domestic, agricultural, and industrial use, particularly in semi-arid regions such as Tamil Nadu, where surface water availability is limited and seasonal. In recent years, the integration of Remote Sensing (RS) and Geographic Information Systems (GIS) with multi-criteria decision-making techniques such as the Analytical Hierarchy Process (AHP) has become a widely accepted approach for groundwater potential mapping and recharge site selection. Several studies have demonstrated the effectiveness of RS, GIS & AHP techniques in identifying groundwater potential zones and recharge site selections (Abdalla, 2012; Aydi et al. 2016; Brunner et al. 2004; Bouwer, 2002)

Studies on groundwater potential in Tamil Nadu have been extensively carried out in over-exploited districts of Dharmapuri, Dindigul, Salem, and Vellore etc. where researchers have utilized various environmental and geological factors such as rainfall, soil type, slope, land use, drainage density, and lithology to identify areas with high groundwater potential and to suggest appropriate remedial measures. These studies have contributed significantly to effective water resource planning, particularly in drought-prone regions. However, most of these studies were lack the incorporation of important geophysical parameters such as magnetic breaks, gravity anomalies, and resistivity data, which provide critical insights into subsurface conditions. When focusing specifically on Tirupattur district, existing research also shows similar limitations, including the absence of

geophysical data integration, the use of outdated satellite imagery with varying spatial resolutions, and insufficient validation using groundwater level data. Therefore, the present study aims to address these limitations by utilizing recent and high-resolution datasets, along with the integration of both geological and geophysical parameters, to accurately delineate groundwater potential zones and identify suitable sites for artificial recharge.

In addition, recharge site selection has gained considerable attention in recent research. Many studies have employed GIS-based multi-criteria decision analysis to identify appropriate locations for artificial recharge structures such as check dams, percolation tanks, and recharge wells. These studies consistently indicate that areas characterized by low slope, high infiltration capacity, and close proximity to drainage networks are the most suitable for effective groundwater recharge. (Chenini et al. 2010; Da Costa et al. 2019)

Groundwater is an extremely valuable and highly important resource with manifold uses (Todd and Mays, 2005). As a result of its wide global demand, groundwater has been overexploited in many areas around the world, leading to ecological and environmental problems. Therefore, groundwater recharge is an important factor for sustainable groundwater management. The recharge of natural and artificial aquifers has gradually become a prospective mechanism for managing groundwater resources (Bouwer, 2002; Singh et al. 2019). The ecological and environmental problems associated with the overexploitation of groundwater can be overcome

using artificial groundwater recharge technology (Asano, 1985; Oaksford, 1985). Groundwater recharge from the unsaturated zone into the saturated zone (Freeze and Cherry, 1979) occurs only when water flows and seeps into the saturation zone (Yeh et al. 2016).

There are numerous advantages to artificially replenishing groundwater. It uses wastewater, avoids saltwater intrusion from degrading water quality, and helps to raise groundwater levels. It also aids in secondary oil recovery, encourages crop growth, improves stream flow, prevents soil subsidence, and stores freshwater. Numerous scholars and institutions, including Asano (1985); Oaksford (1985); and UNEP (2011), have recognized these advantages. The Geographic Information System (GIS) and remote sensing (RS) are promising technologies for effective groundwater resource planning and management (Pazhuparambil et al. 2022; Mahmoud and Alazba, 2014; Mogaji et al. 2016; Mukherjee et al. 2012; Senanayake et al. 2016). Additionally, this tool along with geophysical approaches facilitates the process of identifying locations with favorable water quality, storage, and infiltration characteristics all of which are critical for artificial groundwater recharge projects (Srivastava and Bhattacharya, 2006). Groundwater potential zones in a tropical river basin in Kerala, India, are identified using remote sensing and GIS approaches.

Recent advancements in groundwater studies have introduced the use of fuzzy AHP and hybrid models, which help reduce uncertainty in decision-making and significantly improve spatial prediction accuracy. These approaches combine traditional AHP with advanced computational techniques, making them more robust and reliable for analyzing complex hydrogeological conditions (Gdoura et al. 2015; Thapa et al. 2017). However, such advanced methodologies are largely lacking in previous studies conducted in the study area.

The most prevalent and efficient use of AHP technology is assessing groundwater potential and identifying appropriate locations for artificial recharge (Pazhuparambil et al. 2022; Kaliraj et al. 2014; Navane and Sahoo, 2020). A number of attributes have been taken into account in order to identify a GWPZ (Allafta et al. 2021; Rahimi et al. 2014). When choosing where to find the groundwater, their proportional weights are taken into consideration. Each attribute was given a weight based on its proportional importance in the process of determining the location of the groundwater zone. A hierarchical model comprising goals, criteria, sub-criteria, and choices is employed for every problem in the AHP technique (Saaty, 2008). Problems with AHP are resolved by using the weights or priority of the pairwise comparisons. The AHP technique is relatively prone to inconsistencies when comparing the criteria in pairs. The present study employs an Analytical Hierarchy Process (AHP) integrated with

GIS and remote sensing methods to accurately identify suitable groundwater potential zones in the Tirupathur District of Tamil Nadu. By combining these advanced tools and techniques, we aim to enhance sustainable groundwater management practices and contribute valuable insights for addressing water scarcity and environmental challenges.

2. Study Area

2.1 Geography of the Study Area

Tirupathur district is in state of Tamil Nadu, India, formed by trifurcating the Vellore district. Geographically, it lies between 12°29'21.77'' and 12°49'83.51'' North latitude and 78°34'45'' and 78°56'41'' East longitude, covering an area of 2,114.29 square kilometers. Tirupathur is situated approximately 89 km from Vellore, 210 km from Chennai, and 125 km from Bangalore, with excellent road and rail connectivity to these major cities (Figure 1). The district comprises of four taluks Tirupathur, Natrampalli, Vaniyambadi, and Ambur and includes 208 village panchayats. It is surrounded by the Javadhu and Yelagiri Hills, notable for scenic waterfalls, streams, and forests that attract visitors. The Javadhu Hills feature key attractions like Beema Falls and Amirthi Biological Park, along with rivers such as Cheyar, Arani, Kamandala Naganadhi, and Miruganda. The hills are primarily inhabited by Malayali tribes, who rely on agriculture as their main livelihood. The district also has significant mineral resources, including vermiculite, a yellow-brown, mica-like mineral used as a soil conditioner in agriculture.

2.2 Geological and Geomorphological Settings of the Study Area

The geological framework significantly influences groundwater presence and distribution throughout any region. The lithological units of the research region were identified using a geological map released by the Geological Survey of India. Metamorphic rocks predominantly cover the area, followed by igneous formations. In the west, Neoproterozoic-age Gabbroic Anorthosite from the Kadavur-Oddanchatram Complex is prevalent. The northern and southeastern sections are composed largely of Charnockite from the Archean Proterozoic age, while the central and part of the southern areas feature Epidote hornblende gneiss of Proterozoic origin. Additionally, Amphibolites, hornblende syenite, Quartzite, and Garnet gneiss are present in specific locations (Figure 2).

The area's primary geomorphological features include the pediment-piedplain complex, moderately dissected structural hills, active flood plains, bajadas, dissected hills and valleys, and piedmont slopes. The pediment-piedplain complex, a significant runoff zone, covers much of the area and plays an essential role in groundwater conservation. (Figure 3).

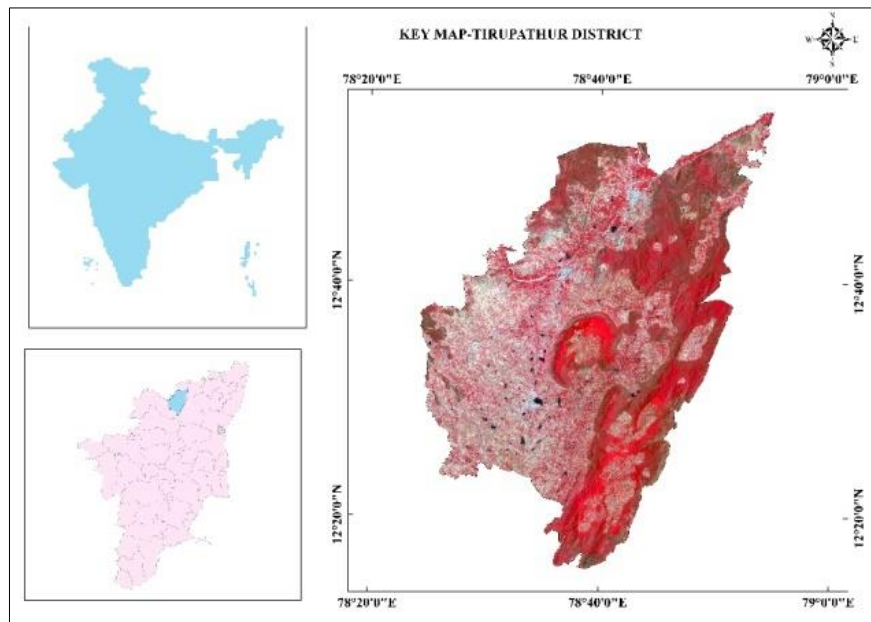


Figure 1: Location Map of the Study Area

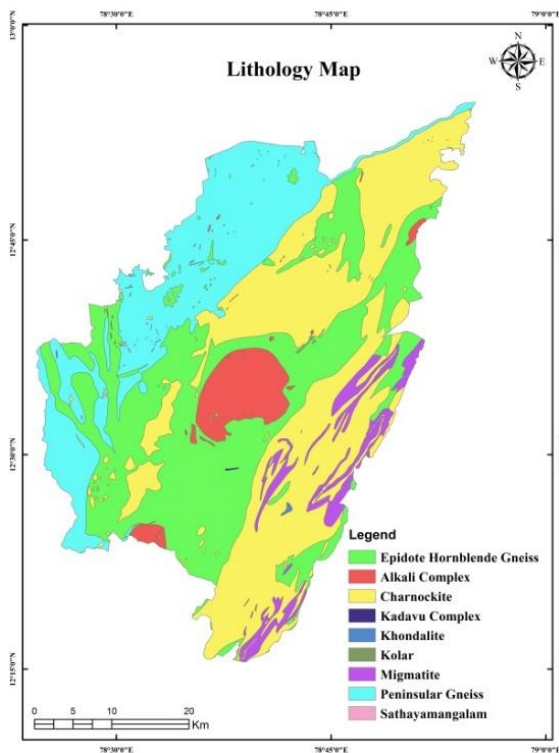


Figure 2: Lithology Map

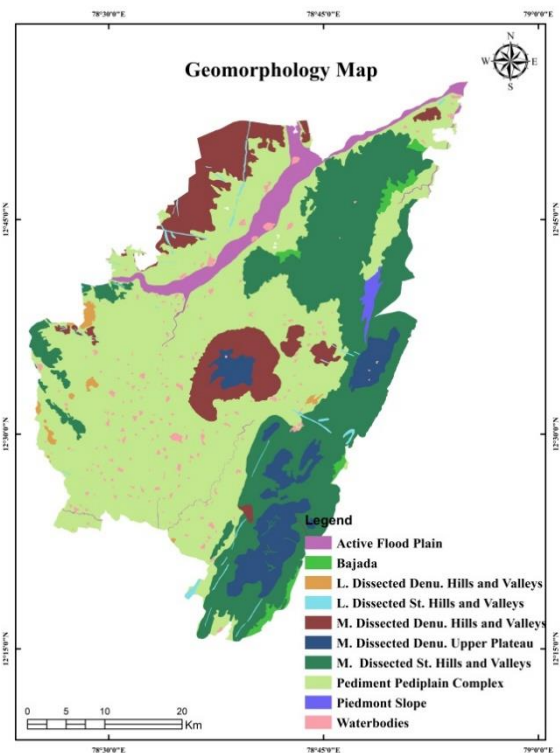


Figure 3: Geomorphology Map

3. Materials and Methods

3.1 Data Acquisition

This study utilized a combination of primary and secondary data sources, including Landsat, SRTM, topographical sheets, district resource maps, soil maps, and groundwater level maps. Landsat satellite imagery with a spatial resolution of 30m was obtained in April 2023 (<https://usgs.com>). Slope and aspect maps were generated from the SRTM Digital Elevation Model (DEM), sourced in April 2023 (<http://www.gscloud.cn>). Topographic sheets (57L/6, 57L/7, 57L/9, 57L/10, 57L/11, 57L/13, 57L/14, 57L/15) were used to construct base and drainage maps of the area. Groundwater depth data was sourced

from the Water Resource Information System (WRIS) (<https://indiawriss.gov.in/wris>). Additionally, rainfall data from CHIRPS was used to develop a rainfall map for the area. Magnetic anomaly and magnetic breaks maps were created using magnetic data from the Bhukosh portal of the Geological Survey of India (GSI), processed with OASIS MONTAJ software. The data were prepared and integrated using ARC GIS.

3.2 Multi Criteria Decision Analysis using GIS Techniques

The Analytical Hierarchical Process (AHP) is a widely used GIS-based approach for delineating groundwater potential zones through multi-criteria decision analysis.

The methodology, as depicted in the flowchart (Figure 4), illustrates the process for identifying both groundwater potential and artificial recharge sites. Various data sources were utilized to generate thematic maps, a total of 12 layers, including lithology, geomorphology, soil, land use, land cover, drainage density, lineament density, slope, aspect, Topographic Wetness Index (TWI), rainfall, magnetic data, and groundwater levels. These layers are considered critical in controlling water flow and storage within the area.

The significance of these factors was weighted based on their influence on groundwater occurrence and expert opinion. Parameters with higher weights reflect layers that have a stronger impact, while those with lower weights indicate a lesser effect on groundwater potential. Each parameter was weighted using Saaty’s scale (1–9) of relative importance, where 9 represents extreme

importance, 8 very, very strong importance, 7 very strong to extreme importance, down to 1 for equal importance. Weights were assigned based on the thematic layers’ relevance to groundwater retention, informed by past studies and field observations. Accordingly, thematic layers were compared in a pairwise comparison matrix (Table 1). The thematic layers’ sub-classes were reclassified on the GIS platform using the natural breaks classification method to assign ranks. Sub-classes within each layer were ranked corresponding to their relative influence on groundwater development, as shown in Table 2.

To ensure consistency, the consistency ratio (CR) was calculated through the following steps: (1) The principal eigenvalue (λ) was derived using the eigenvector method (Table 3), and (2) the Consistency Index (CI) was computed using a standard formula.

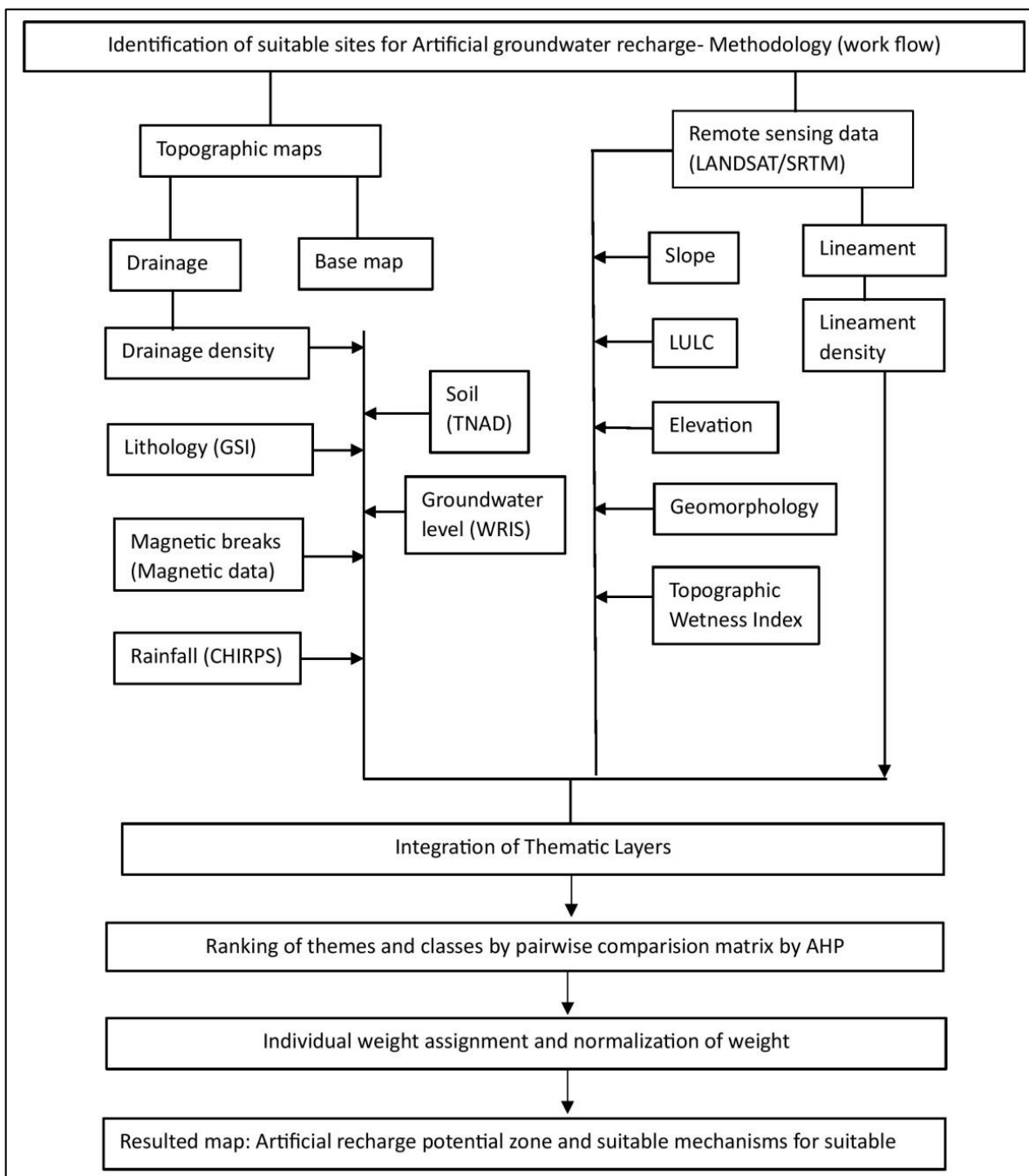


Figure 4: Methodology Flowchart

Table 1: Pairwise Comparison Matrix for Calculating Scale Weight

PARAMETERS	LD	MB	GMY	ST	GWL	S	EL	TWI	DD	RF	LI	LULC
LD	1	1	2	2	3	3	4	2	1	3	4	5
MB	1	1	2	2	3	3	4	2	1	3	4	5
GMY	0.5	0.5	1	2	1	2	3	3	2	4	3	4
ST	0.5	0.5	0.5	1	2	3	3	2	2	3	3	4
GWL	0.33	0.33	1	0.5	1	2	2	1	2	2	3	3
S	0.33	0.33	0.5	0.33	0.5	1	1	3	2	2	3	4
EL	0.25	0.25	0.33	0.33	0.5	1	1	2	1	2	3	3
TWI	0.5	0.5	0.33	0.5	1	0.33	0.5	1	2	1	2	3
DD	1	1	0.5	0.5	0.5	0.5	1	0.5	1	2	2	3
RF	0.33	0.33	0.25	0.33	0.5	0.5	0.5	1	0.5	1	2	3
LI	0.25	0.25	0.33	0.33	0.33	0.33	0.33	0.5	0.5	0.5	1	2
LULC	0.2	0.2	0.25	0.25	0.33	0.25	0.33	0.33	0.33	0.33	0.5	1
SCALE WEIGHT	6.2	6.2	9	10.08	13.67	16.92	20.67	18.33	15.33	23.83	30.5	40

Note: LD- lineament density; MB – magnetic breaks; GMY- geomorphology; ST- soil type; GWL-groundwater level; S- slope; E- elevation; TWI- topographic wetness index; DD- drainage density; RF- rainfall; LI- lithology; LULC- land use land cover

Table 2: Rank and Weightage

S.NO	PARAMETERS	FEATURE CLASS	RANK (R)	WEIGHTAGE (Wt) %
1	Lineament Density	Very Low	5	15.7
		Low	4	
		Moderate	3	
		High	2	
		Very High	1	
2	Magnetic Breaks	500	1	15.7
		1000	2	
		1500	3	
3	Geomorphology	Active floodplain	1	12.2
		Bajada	2	
		Low Dissected Denudational hill	5	
		Low Dissected Structural hill	5	
		Moderately Dissected Denudational hill	5	
		Moderately Dissected Denudational Upper Plateau	5	
		Moderately Dissected Structural hill	5	
		Pediment Pediplain complex	3	
		Piedmont Slope	2	
Waterbodies	1			
4	Soil Type	Calcareous Clay Soil	3	11.2
		Clayey Soil	5	
		Loamy Soil	4	
		Gravelly Clay Soil	3	

		Gravelly Loamy Sod	1	
5	Groundwater Level (m bgl)	2 – 5	1	8.3
		5 – 10	2	
		10 – 20	3	
6	Slope (%)	Gentle sloping	1	7.6
		Moderate sloping	2	
		Strongly Sloping	3	
		Moderate steep to Steep Sloping	5	
		Steep Sloping	4	
7	Elevation (m)	<300	1	6.1
		300-600	2	
		600-900	5	
		900-1200	5	
		>1200	5	
8	TWI	(-0.83) – 2.8	5	6.1
		2.9 – 4.8	4	
		4.9 – 7.3	3	
		7.4 – 11	2	
		12 – 20	1	
9	Drainage density	Very low	1	7.2
		Very low	2	
		Moderately	3	
		High	4	
		Very High	5	
10	Rainfall (mm)	1084 – 1225	2	4.4
		1226 – 1374	2	
		1375 – 1502	1	
		1503 – 1618	1	
		1619 – 1789	3	
11	Lithology	Epidote Hornblende Gneiss	3	3.1
		Hornblende Syenite	5	
		Charnockite	3	
		Gabbroic Anorthosite	5	
		Garnet – Siliminate – Gneiss	3	
		Amphibolite	5	
		Garnet Gneiss and Hornblende Gneiss	3	
		Grey Hornblende Biotite Gneiss	3	
Quartzite	3			
12	Landuse Landcover	Built-up	5	2.2
		Agricultural Land	1	
		Forest Land	5	
		Waterbodies	1	
		Wastelands	3	

Table 3: Normalized Weight Table (NWt)

PARAMETER	LD	MB	GMV	ST	GWL	S	EL	TWI	DD	RF	LI	LU/LC	NWt
LD	0.170	0.169	0.227	0.203	0.232	0.178	0.188	0.110	0.065	0.184	0.141	0.14	0.167
MB	0.170	0.169	0.227	0.203	0.232	0.178	0.188	0.110	0.065	0.184	0.141	0.12	0.165
GMV	0.085	0.085	0.113	0.203	0.077	0.119	0.150	0.164	0.130	0.153	0.085	0.1	0.122
ST	0.085	0.085	0.057	0.101	0.154	0.178	0.113	0.110	0.130	0.122	0.113	0.1	0.112
GWL	0.057	0.056	0.113	0.051	0.077	0.119	0.188	0.055	0.130	0.092	0.113	0.12	0.098
S	0.057	0.056	0.057	0.034	0.039	0.059	0.038	0.164	0.130	0.061	0.085	0.1	0.073
EL	0.034	0.034	0.028	0.034	0.015	0.059	0.038	0.110	0.065	0.061	0.085	0.06	0.052
TWI	0.085	0.085	0.038	0.051	0.077	0.020	0.019	0.055	0.130	0.031	0.056	0.08	0.061
DD	0.170	0.169	0.057	0.051	0.039	0.030	0.038	0.027	0.065	0.061	0.056	0.06	0.069
RF	0.028	0.028	0.023	0.025	0.026	0.030	0.019	0.055	0.033	0.031	0.085	0.06	0.037
LI	0.034	0.034	0.038	0.025	0.019	0.020	0.013	0.027	0.033	0.010	0.028	0.04	0.027
LULC	0.024	0.028	0.023	0.020	0.013	0.012	0.013	0.014	0.022	0.010	0.014	0.02	0.018
													1.000

4. Results and Discussions

4.1 Lineament Density

The total length of lineaments per unit degree is known as lineament density, and it offers important information about groundwater potential, shearing, fracture, and structural deformation.

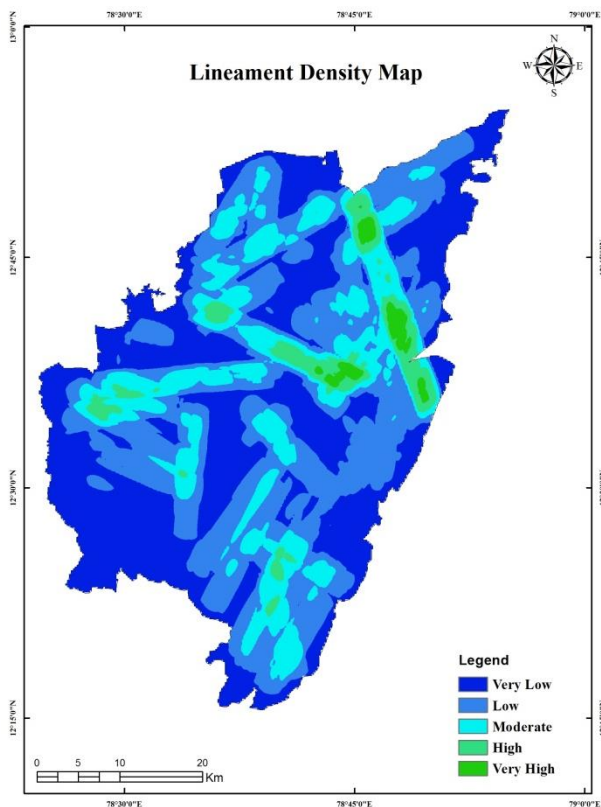


Figure 5: Lineament Density Map

Careful observation can improve the accuracy of determining lineament concentrations in a region, and

lineament density analysis is an advantageous method for capturing a variety of geological features. The lineament density ranges from 0 to 19 (Figure 5) in the study area and is classified into five levels: very low (0-3.9), low (4-7.7), moderate (7.8-12), high (13-15), and very high (16-19). Greater groundwater resource potential is indicated by areas with higher lineament density scores.

4.2 Drainage Density

Drainage density is a crucial factor in evaluating groundwater potential, as it measures the ground's porosity. It reflects the proximity of stream channels within a specific area. The drainage density of a region is influenced by its topography, geomorphology, subsurface geology, and land use/cover. Values are categorized into five levels, ranging from very low to very high. Higher drainage density typically leads to increased runoff and reduced infiltration, which directly impacts groundwater recharge capacity. Consequently, drainage density is an essential parameter for assessing groundwater prospects, as it is closely related to both porosity and permeability (Figure. 6).

4.3 Soil

The amount of water that may percolate into subterranean formations is greatly influenced by soil types, which in turn affects groundwater recharge. When determining the infiltration rate, the soil's texture and hydraulic properties are crucial. Using information from the Tamil Nadu Agricultural Department (TNAD), a soil map was created (Figure 7). Calcareous clay, clayey, gravelly clay, gravelly loamy, and loamy soil are the five types of soil found in the research region. Loamy soil has the highest infiltration rate of all of these, which raises its Analytical Hierarchy Process (AHP) score. On the other hand, clayey soil received a lower grade because it has the lowest infiltration rate.

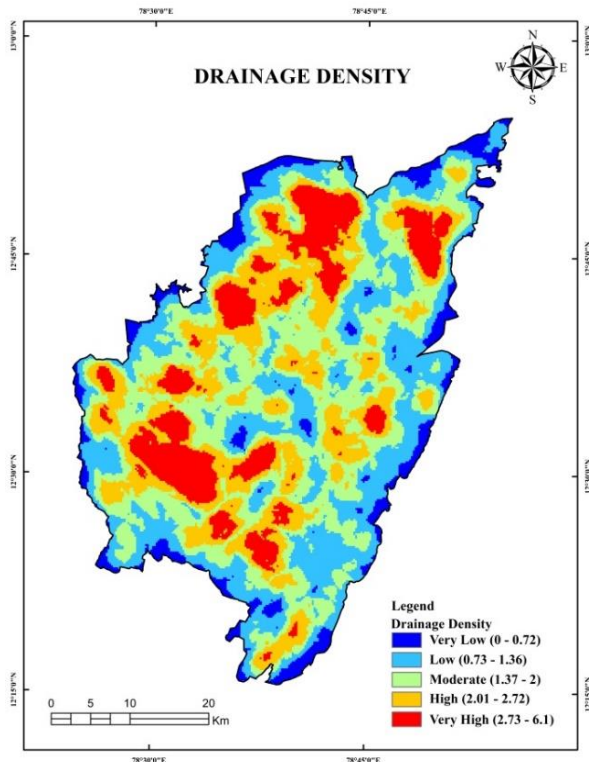


Figure 6: Drainage Density Map

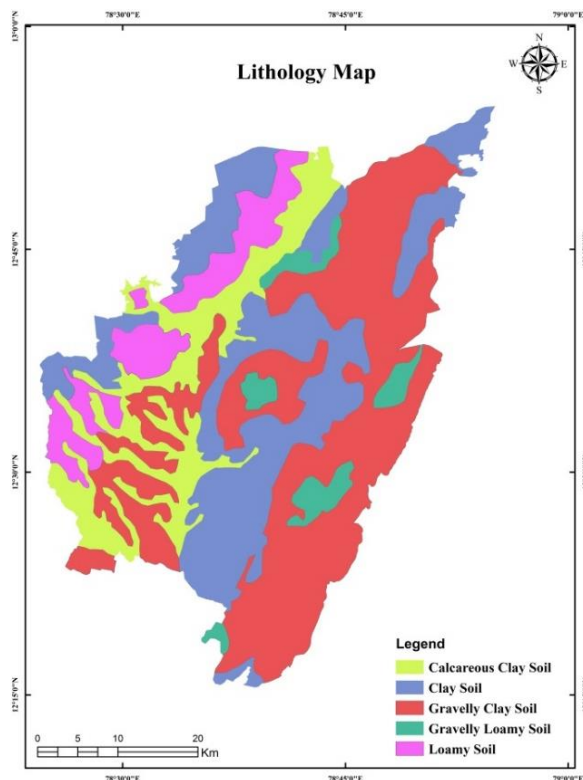


Figure 7: Soil Map

4.4 Groundwater Level

Groundwater depth refers to the distance from the surface to the groundwater table, and many researchers use this measurement as an indicator of groundwater storage capacity. In the study area, groundwater depth has been categorized into three levels: low, moderate, and deep. The depth ranges from 2 to 20 meters below the surface, with most areas falling between 5 and 20 meters (Figure 8). As the depth of the water table increases, the potential for

water addition to the groundwater also rises, due to the greater storage capacity of underground water reservoirs.

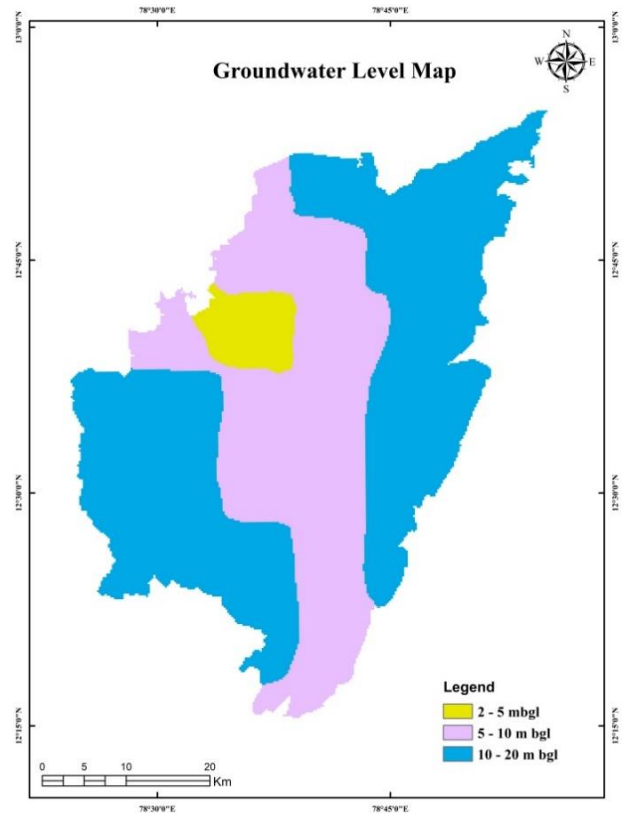


Figure 8: Ground Water Level Map

4.5 Slope

The slope of an area significantly influences water flow rates, affecting how much water infiltrates subsurface layers and, consequently, the groundwater availability also. In regions with gentle slopes, moderate surface runoff, facilitates better infiltration, while steep slopes lead to high runoff and reduced infiltration. To analyze the slope of the region, a slope map was generated using SRTM DEM imagery in the ArcGIS 10.8 environment. This map categorized slopes into five classes based on IMD classification: gentle sloping (3-5%), moderately sloping (5-10%), strongly sloping (10-15%), moderately steep to steep sloping (15-30%), and steep sloping (>35%). The study reveals that areas with gentle to moderately sloping terrain (3-10%) are particularly suitable for water recharge (Figure 9).

4.6 Aspect

In flat areas, there are no slopes or aspects, whereas mountainous regions feature slopes oriented in all directions—north, west, south, and east. Aspect indicates the compass direction that a slope faces. A map displaying both aspect and slope degree (Figure 10) can be instrumental in predicting water infiltration rates and runoff patterns. These microclimate differences can influence soil moisture levels and the overall hydrological balance. By recognizing these variations, it becomes possible to design effective artificial recharge systems that capitalize on local microclimates.

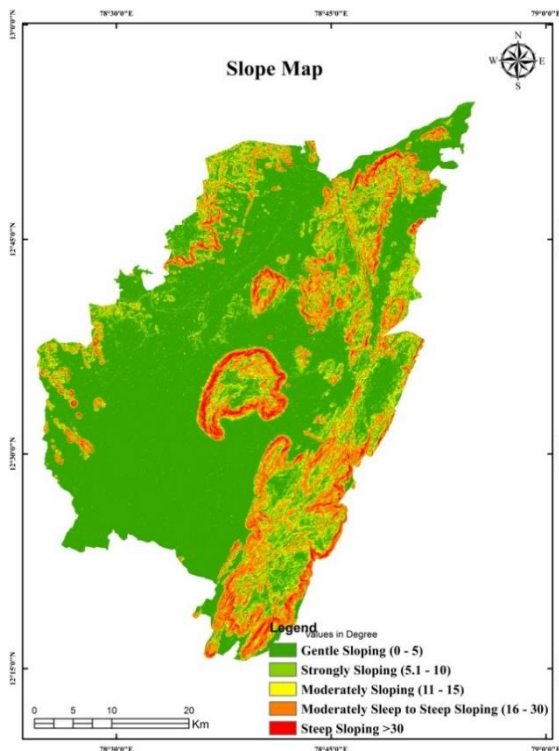


Figure 9: Slope Map

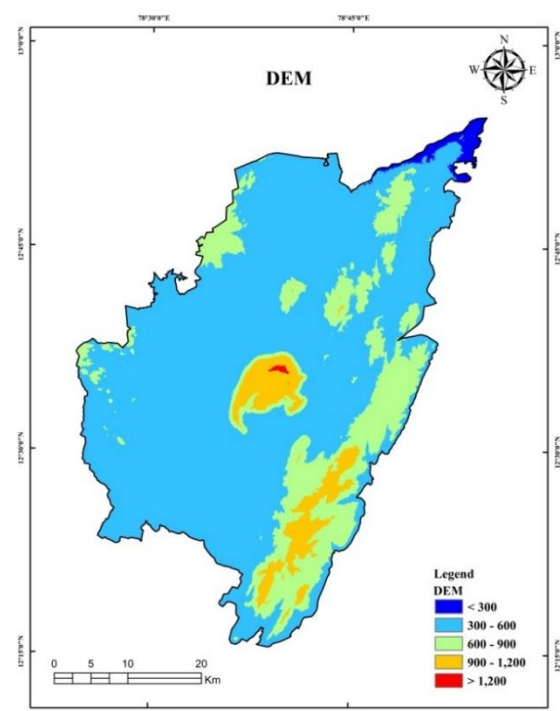


Figure 11: Elevation Map

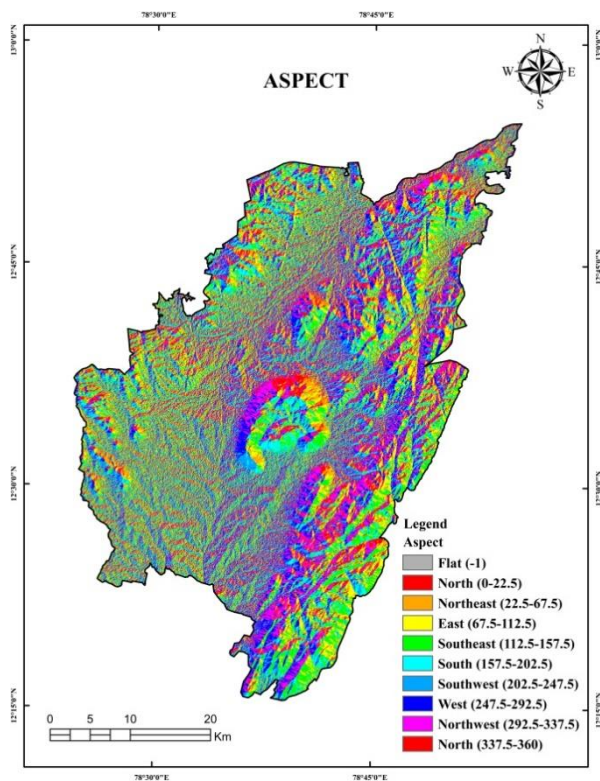


Figure 10: Aspect Map

4.7 Elevation

The elevation map, created using SRTM DEM data, categorizes elevations in the study area into five ranges: below 200m, 200–600m, 600–1000m, 1000–1200m, and above 1200m. The majority of the area lies between 200m and 600m. Some regions, such as the reserved forest, are located between 600m and 1000m, while the Yelagiri Hills are situated in areas above 1000m (Figure 11).

4.8 Magnetic breaks

Magnetic breaks are linear features in the Earth's magnetic field that are commonly linked to subsurface geological structures. These breaks can indicate faults, fractures, or other underground formations that may influence groundwater flow. To identify these magnetic breaks, point data collected by the GSI were transformed into a magnetic image using OASIS MONTAJ software. In the ArcGIS environment, these magnetic breaks were digitized (Figure 12) for integration. Study area has predominantly displaying a NE-SW orientation, with some minor breaks trending SW-NE.

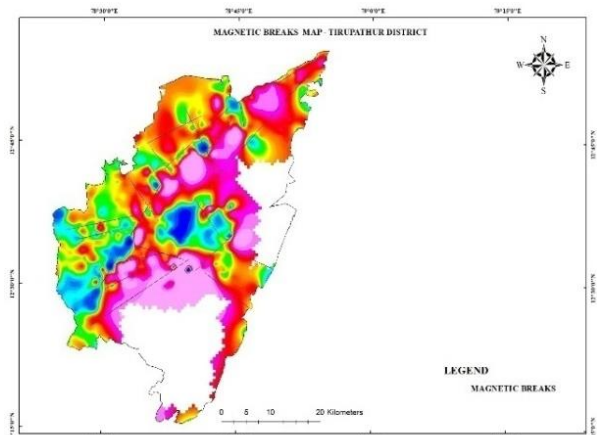


Figure 12: Magnetic Breaks Map

4.9 Rainfall

Variations in rainfall are the primary factor influencing recharge rates (Musa et al. 2000; Magesh et al. 2012; Shekhar and Pandey, 2014), significantly impacting groundwater potential. Monthly rainfall data collected from CHIRPS over one year (2022-2023) was analyzed. The rainfall map was reclassified into five categories: 1084–1225mm, 1226–1374mm, 1375–1502mm, 1503–1618mm, and 1619–1789mm/year (Figure 13).

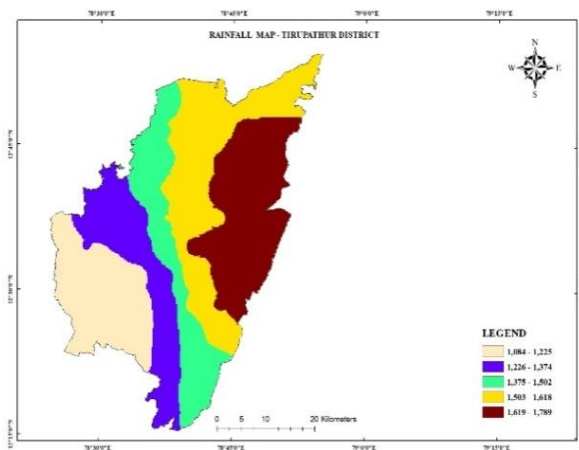


Figure 13: Rainfall map

4.10 Land use Land Cover

Land use refers to the activities and various uses humans engage in on the land, while land cover pertains to the natural vegetation, water bodies, rock/soil, artificial surfaces, and other outcomes of land transformation. The standard land use/land cover classification is developed by NRSC. A land use map was created from satellite data using supervised classification under ArcGIS environment and was validated through a limited field check. According to NRSC level 1 classification, the different land use/land cover classes in the study area include built-up areas, agricultural land, forest land, water bodies, and wastelands. Agricultural land and water body regions are considered suitable for recharge and hold a high ranking in the AHP analysis (Figure 14).

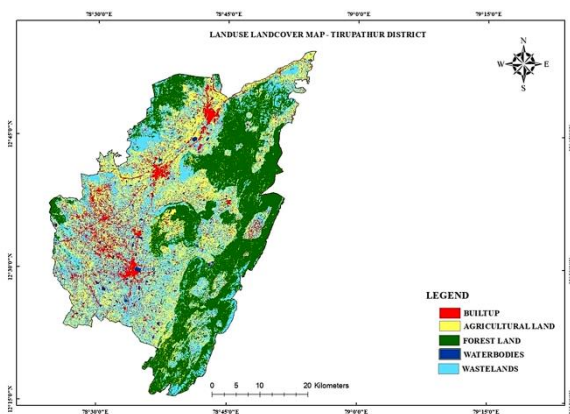


Figure 14: Land Use Land Cover Map

4.11 Topographic Wetness Index

The Topographic Wetness Index (TWI), introduced by Beven and Kirkby (1979) within the runoff model, is used to estimate the potential for water accumulation in a landscape based on topography. It is commonly applied to evaluate area suitability for hydrological processes, including artificial groundwater recharge. TWI is calculated using the terrain slope and the upstream contributing area for each cell in a digital elevation model (DEM) (Figure 15).

Topographic Wetness Index (TWI) is usually used to compute topographic control of hydrological processes and reflects the potential groundwater infiltration caused by the effects of topography. The TWI was prepared using “TOPMODEL”- a model that stimulates the hydrologic

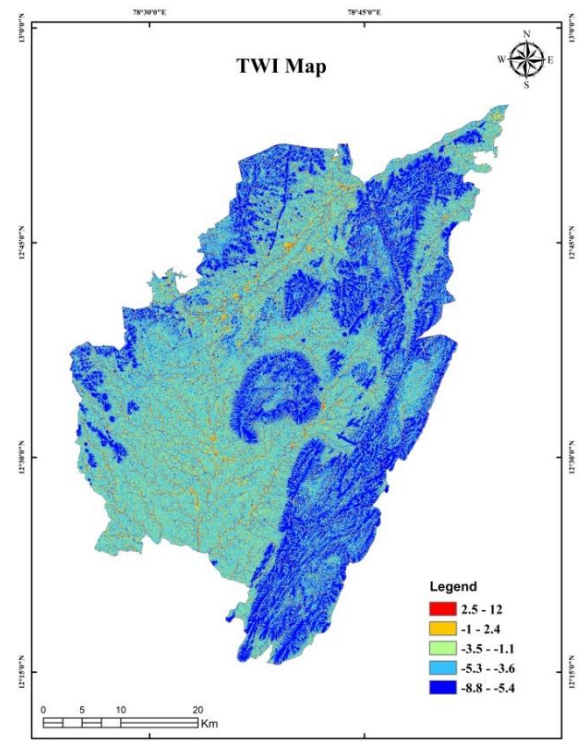


Figure 15: TWI Map

fluxes of water throughout watershed. Equation given below was used for the estimation of TWI.

$$TWI = \ln \frac{a}{\tan b}$$

Where a is the local upslope area draining through a certain point per unit contour length and tan b is the local slope in the radians.

5. Analytical Hierarchy Process

The use of the Analytic Hierarchy Process (AHP) technique for artificial groundwater recharge in hard rock terrain is a strategic and effective approach. This method enables the identification of the most suitable recharge techniques tailored to the unique challenges and opportunities presented by hard rock environments, ultimately improving water availability and resilience in these areas. A GIS-based AHP technique, as proposed by Saaty (1970), was employed to analyze multiple parameters and delineate potential quality zones for artificial recharge in the study area. The steps involved in the AHP process were detailed earlier. A preference scale was utilized in a pairwise comparison matrix (Table 1) to assess the relative importance of each criterion for artificial recharge (Table 2: Normalized weight matrix).

The Pairwise Comparison Matrix created by the decision-maker must meet Saaty's consistency condition, given as $R=CI/RI$, (where $CR < 0.1$). Here, CI is the Consistency Index, and RI is the Random Inconsistency. To test for consistency, a matrix is generated by multiplying the pairwise comparison matrix with the geometric mean ($P_{ij} * GM$) (Table-4). The sum of each row is calculated, and each sum is multiplied by its respective geometric mean. Adding these values yields λ_{max} , which is then used to determine the Consistency Index (CI).

$$CI = (\lambda_{max} - n) / (n - 1)$$

Where, λ_{max} is highest Eigen value of matrix and n is number of parameters. For this study, $CI = 0.089$.

The Random Inconsistency value for 12 parameters is 1.54. (Table 5) Substituting these values into the consistency ratio formula gives $CR = 0.06$.

Table - 4 : Geometric Mean and λ_{max} Values

Scale Weight	Geometric Mean	λ_{max}
6.2	0.157	0.976
6.2	0.157	0.976
9	0.122	1.101
10.08	0.112	1.133
13.67	0.083	1.137
16.92	0.076	1.292
20.67	0.061	1.251
18.33	0.061	1.119
15.33	0.072	1.098
23.83	0.044	1.049
30.5	0.031	0.952
40	0.022	0.892
λ_{max}		12.978

Since the Consistency Ratio of 0.06 is below 0.1, the pairwise comparison matrix satisfies the consistency requirement. Following this validation, the parameters are reclassified and assigned weights (Table 3) based on their positive or negative impact on groundwater recharge. For instance, areas with low drainage density, which have low runoff and high infiltration potential, are given a high rank (1). To obtain normalized weighted layers, each reclassified raster layer is divided by its respective geometric mean. The 12 normalized weighted layers are then averaged in the raster calculator to generate the final artificial groundwater recharge site map.

5.1 Groundwater Potential Zone

The quintile process classified potential groundwater zones into five categories: very low, low, moderate, high, and very high. The findings revealed that 24.35%, 25.02%, and 29.31% of the Natrampalli, Tirupathur, and eastern Ambur regions fall into the very low, low, and moderate potential categories, respectively. In contrast,

Vaniyambadi and northern Natrampalli exhibit high and very high potential zones. Figure 16 show that these high

and very high potential areas have good infiltration rates. Since these zones are designated as reserved forest areas, they are not suitable for artificial recharge sites (Figure 16).

5.2 Artificial Recharge Zone

Artificial recharge zones were identified by analyzing the correlation between groundwater level data obtained from the Tamil Nadu Groundwater Board and groundwater potential zones derived through AHP analysis. The correlation study indicates that moderate and deep groundwater levels are predominantly observed in low and moderate groundwater potential zones, respectively. Based on this interpretation, areas with moderate and low groundwater potential are considered suitable for artificial recharge. In contrast, high and very high potential zones exhibit greater infiltration and lower runoff, resulting in shallow groundwater levels. Meanwhile, moderate and low potential zones experience reduced infiltration, making them more appropriate targets for artificial recharge planning.

Additionally, factors such as steep slopes, high drainage density, and low-porosity lithology contribute to the classification of certain regions as very low artificial groundwater recharge zones (Figure 17).

6. Conclusions

The Analytical Hierarchy Process based approach has been utilized to identify artificial groundwater recharge zones and suitable structures for enhancing groundwater in Thirupathur district. This strategy emphasizes the importance of various thematic maps and their subclasses that impact groundwater recharge potential. The study yielded a Consistency Ratio (CR) of 0.06, which is below the threshold of 0.1, thereby meeting Saaty’s criteria. Suitable rankings and weightings were then assigned based on their influence on groundwater replenishment rates. Approximately 6.22% of the area was classified as very high potential, and 15.10% as high potential for potential groundwater. In contrast, 29.3%, 24.3%, and 25.02% of the areas were categorized as having moderate, low, and very low groundwater potential, respectively. The moderate and low potential zones were selected for the implementation of artificial recharge structures, as the high and very high potential zones exhibit greater infiltration. Recharge structures were determined based on construction needs and environmental sustainability. For percolation ponds, areas with shallow slopes and micro drainage catchments were prioritized, resulting in the identification of 20 percolation ponds, 5 check dams, and 13 pitting sites. Additionally, 8 sites were chosen for well batteries based on.

Table 5: Random Inconsistency Value

No. of Parameters	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI Values	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.54	1.56	1.57	1.59

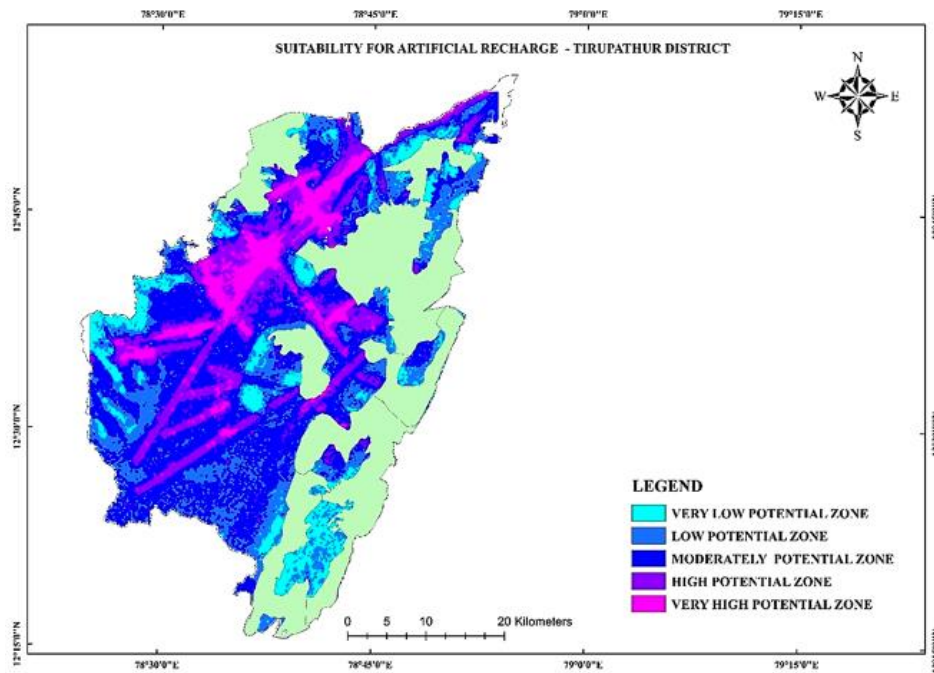


Figure 16: Groundwater Potential Zone

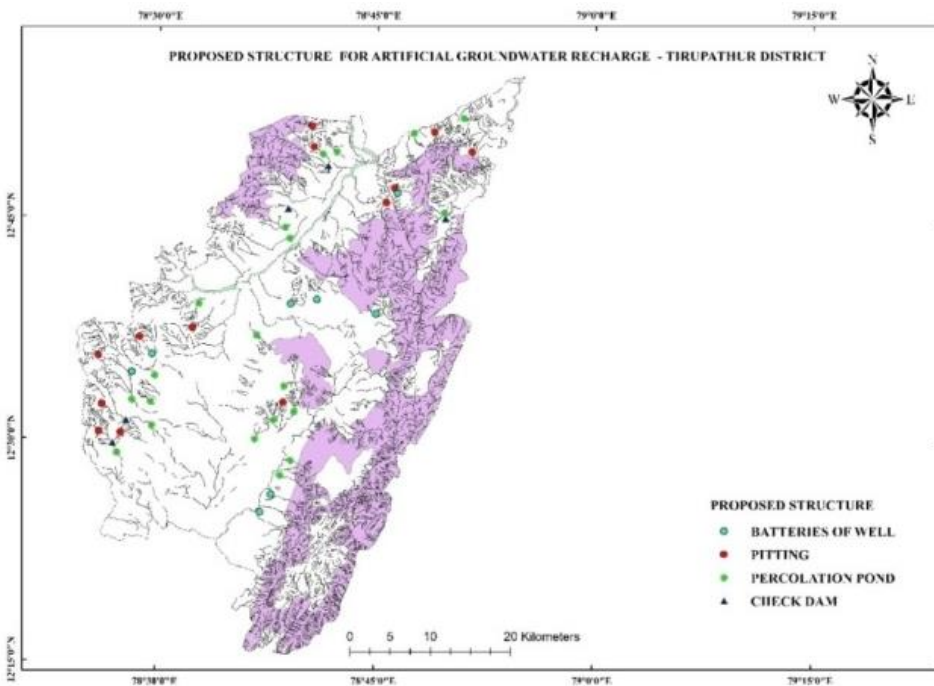


Figure 17: Proposed Structure for Artificial Recharge

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