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Optimizing Groundwater Exploration Using Geomorphic and Lineament Analysis in Urban Area - Tiruchirappalli West: A Geospatial Approach

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Abstract
Groundwater is a vital resource for domestic and irrigation needs in rapidly urbanising regions such as Tiruchirappalli West in Tamil Nadu. This study aimed to delineate groundwater potential zones using an integrated Remote Sensing (RS) and Geographic Information System (GIS) approach. Multiple thematic layers, including drainage density, lineament density, land use/land cover (LULC), and spectral indices, such as the normalised difference vegetation index (NDVI) and normalised difference water index (NDWI), were generated from Resources at LISS-IV satellite data and ancillary sources. These layers were integrated using the Weighted Overlay Method to compute the Groundwater Potential Index (GWPI). The results classified the study area into three groundwater potential zones: high (33%), moderate (43%), and low (24%). High potential zones were primarily associated with high lineament density, low drainage density, and favourable surface moisture conditions, as indicated by the NDVI and NDWI. Validation using well-yield data through Inverse Distance Weighting (IDW) interpolation showed a strong spatial agreement with the predicted zones, confirming the reliability of the model. This study demonstrates that the integration of RS–GIS techniques provides an effective framework for groundwater assessment and supports sustainable groundwater management and artificial recharge planning in urban environments.

Keywords: Groundwater, NDWI, NDDI, NDVI, GIS, Satellite Imagery

Introduction

Groundwater is a vital freshwater resource that supports domestic, agricultural, and industrial needs, particularly in rapidly urbanising regions, where surface water availability is limited. In many parts of India, increasing population growth, unplanned urban expansion, and climate variability have significantly intensified the pressure on groundwater resources, leading to declining water levels and increasing resource stress. Therefore, effective management of groundwater resources requires accurate identification of potential zones for exploration and recharge.

Literature Review

Remote Sensing (RS) and Geographic Information Systems (GIS) techniques have emerged as powerful tools for groundwater potential mapping because of their ability to efficiently integrate multi-source spatial datasets. Several studies have successfully applied multi-criteria decision-making approaches, such as the Analytical Hierarchy Process (AHP) and Weighted Overlay Method (WOM), to delineate groundwater potential zones. These approaches commonly utilise thematic layers, such as lithology, geomorphology, slope, drainage density, land use/land cover, and lineament density, which play a significant role in controlling groundwater occurrence and movement (Balasubramaniyan et al., 2025; Garg et al., 2020; Parween, 2026).

Previous research has demonstrated that lineament density enhances secondary porosity and groundwater movement in hard-rock terrains, whereas drainage density influences infiltration and runoff characteristics. Similarly, land use/land cover and vegetation indices such as NDVI and NDWI provide insights into surface conditions that indirectly control groundwater recharge (Bagyaraj et al., 2012; Ganesan & Subramaniyan, 2024; Murugesan et al., 2025; Sulaiman & Mustafa, 2023)

Despite these advancements, several limitations remain to be addressed. Many studies rely on expert-based weighting schemes, which introduce subjectivity in assigning weights to thematic layers, and there is a lack of standardised approaches for Groundwater Potential Index (GWPI) generation (Hagos et al., 2024; Islam et al., 2025). In addition, the validation of groundwater potential maps using field-based data, such as well-yield information, is often limited, reducing the reliability of model outputs. Although advanced techniques such as machine learning have been introduced, their application in localised urban-scale studies remains limited.

Another important gap is the lack of focused studies in rapidly urbanising regions of Tamil Nadu, where groundwater stress is increasing owing to land-use changes and growing water demand. In particular, the integration of hydrological validation methods with geospatial modelling has not been adequately explored in regional studies.

This study aimed to delineate groundwater potential zones in Tiruchirappalli West, Tamil Nadu, using an integrated RS–GIS approach combined with weighted overlay analysis. The study incorporates multiple thematic layers, including lineament density, drainage density, land use/land cover, NDVI, and NDWI, and validates the results using well-yield data through Inverse Distance Weighting (IDW). The outcomes of this study provide a reliable scientific basis for groundwater exploration, artificial recharge planning, and sustainable water resource management in urban areas.

Study Area

Tiruchirappalli West lies in Tamil Nadu, 42 sq.km, and experiences a tropical semi-arid climate, characterised by high temperatures and moderate seasonal rainfall. The region receives most of its precipitation from the Northeast Monsoon (October–December), whereas the Southwest Monsoon (June–September) contributes comparatively less. Summers are typically hot, with temperatures often exceeding 38–40°C, and winters are mild and dry. The geology of Tiruchirappalli is dominated by Archaean crystalline rocks, including charnockite, granite gneiss, and quartzite, overlain in some areas by sedimentary formations such as sandstone, clay, and limestone belonging to the Cretaceous–Tertiary sequences. This geological setup, combined with limited monsoon recharge and increasing urbanisation, makes groundwater highly dependent on fractures, lineaments, and weathered zones, influencing both its availability and sustainability in the region. (Fig. 1)

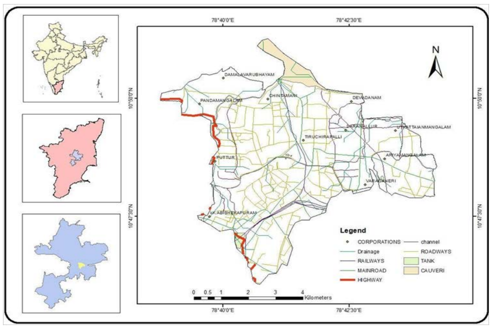

Figure 1 Study Area Map of Tiruchirappalli West

Methodology

The methodology adopted for delineating groundwater potential zones integrates geospatial datasets, remote sensing techniques, and GIS-based multicriteria analysis. The overall workflow is illustrated in Fig. 2. Survey of India toposheets were initially georeferenced using the WGS 84 coordinate system and were used to extract drainage networks and surface water bodies. These features are critical for understanding surface–subsurface hydrological interactions and groundwater recharge processes. Multispectral satellite data from Resourcesat LISS-IV (spatial resolution: 5.8 m) were processed to generate the thematic layers. Image processing and analysis were performed using ERDAS Imagine and ArcGIS 10.6 software. Land Use/Land Cover (LULC) maps were prepared using supervised classification techniques supported by ground-truth data. Lineaments were identified through the visual interpretation of satellite imagery, and lineament density maps were generated using spatial analysis tools in GIS.

Spectral indices, including the Normalised Difference Vegetation Index (NDVI), Normalised Difference Water Index (NDWI), and Normalised Difference Drought Index (NDDI), were derived from the satellite data using standard band ratio techniques. These indices provide information on vegetation health, surface moisture conditions, and drought characteristics, which indirectly influence the groundwater recharge potential. Each thematic layer, including drainage density, lineament density, LULC, NDVI, NDWI, and NDDI, was standardised and reclassified into suitable classes based on its influence on groundwater occurrence. Weights were assigned to each layer according to their relative importance using the Weighted Overlay Method (WOM). The integration of all thematic layers was performed in the GIS environment to compute the Groundwater Potential Index (GWPI). Finally, the resulting groundwater potential map was classified into high-, moderate-, and low-potential zones. The model was validated using well-yield data, which were spatially interpolated using the Inverse Distance Weighting (IDW) method with a power parameter of 2. This validation step ensured the reliability and accuracy of the generated groundwater potential zones.

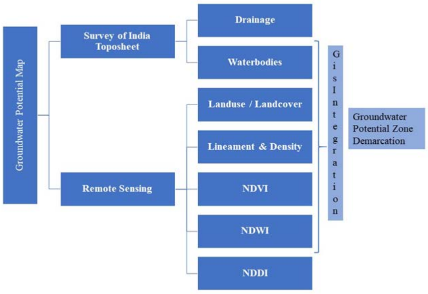

Figure 2 Detailed Methodology Flow Chart

Results and Discussion

Surface Water Bodies

Surface water bodies play a significant role in groundwater recharge by enhancing infiltration through prolonged retention. The spatial distribution of lakes and ponds and their buffer zones indicates areas with increased recharge potential. Regions located in close proximity to these water bodies exhibit higher groundwater potential owing to continuous surface–subsurface interaction. This highlights the importance of conserving surface water bodies for sustainable groundwater management in the region. The spatial distribution of surface water bodies is shown in Fig. 3, and their areal extent and influence are summarised in Table 1.

Table 1 Table Spatial Distribution Results of Surface Water Bodies

Surface water bodies	Buffered Zone	Weightage	Area
Surface water bodies	10 Mts buffered zone	2	53 km -length

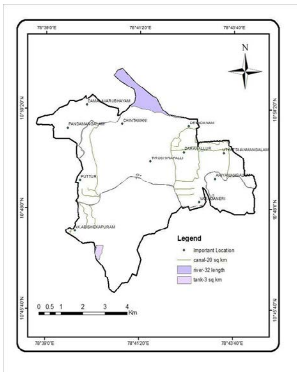

Figure 3 Spatial Distribution Map of Surface Waterbodies

Drainage Density

Drainage density is a key parameter that influences groundwater recharge. Areas with low drainage density allow greater infiltration due to reduced surface runoff, thereby enhancing the groundwater potential. In contrast, regions with high drainage densities promote rapid runoff, limiting infiltration and reducing groundwater recharge. The results indicate that low-drainage-density zones correspond to moderate-to-high groundwater potential areas. This inverse relationship between drainage density and groundwater availability supports the weight assigned in the overlay analysis. The spatial distribution of the drainage density is shown in Fig. 4, and the classification details are provided in Table 2.

Table 2 Spatial Distribution Results of Drainage Density of Tiruchirappalli West

Drainage Density	Weightage	Area (Km^2)
Low	3	12.76
Moderate	2	16.18
High	1	12.76

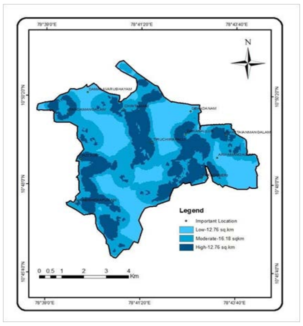

Figure 4 Spatial Distribution Map of the Drainage Density

Lineament Density

Lineament density is one of the most critical factors controlling groundwater occurrence in hard-rock terrains. A high lineament density indicates the presence of fractures and faults, which enhance secondary porosity and permeability, facilitating groundwater movement and storage. The results showed a strong spatial correlation between high lineament density and high groundwater potential zones. This confirms the structural control on groundwater occurrence in the study area. The lineament density map is shown in Fig. 5, and its spatial distribution is presented in Table 3.

Table 3 Spatial Distribution Results of Lineament Density of Tiruchirappalli West

Drainage Density	Weightage	Area (Km^2)
Low	3	12.76
Moderate	2	16.18
High	1	12.76

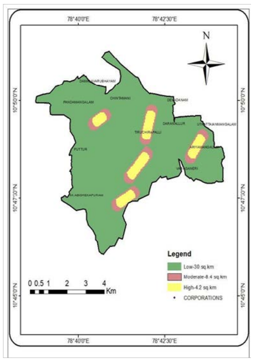

Figure 5 Spatial Distribution Map of Lineament Density

Land Use/Land Cover

Land use/land cover significantly affects groundwater recharge by influencing infiltration characteristics. Vegetated areas and water bodies promote infiltration and moisture retention, thereby enhancing groundwater potential. In contrast, built-up areas reduce infiltration due to impervious surfaces, resulting in lower groundwater recharge. The results indicate that regions dominated by vegetation and water bodies correspond to higher groundwater potential, whereas urbanised areas show a reduced recharge capacity. The spatial distribution of land use/land cover is illustrated in Fig. 6, and the classification details are presented in Table 4.

Table 4 Spatial Distribution Results of Land use and Land Cover of Tiruchirappalli West

Lineament Density	Weightage	Area (Km^2)
High	3	12
Medium	2	9.5
Low	1	28.5

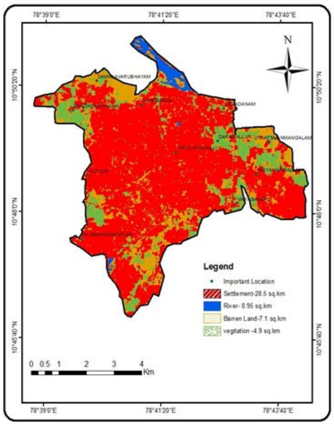

Figure 6 Spatial Distribution Map of Land use / Land Cover

NDVI Analysis

The normalised difference vegetation index (NDVI) provides information on vegetation density and health, which indirectly reflects soil moisture conditions. Higher NDVI values indicate dense vegetation and favourable moisture conditions, which contribute to increased groundwater recharge. The analysis showed that areas with higher NDVI values corresponded to moderate-to-high groundwater potential zones, emphasising the role of vegetation in enhancing infiltration. The NDVI distribution is shown in Fig. 7, and its classification is listed in Table 5.

Table 5 Spatial Distribution Results of NDVI of Tiruchirappalli West

NDVI	Weightage for Water Resources	Area (Km^2)
Vegetation	3	10.39
0.5-1	2	14.37
Close to 0 and a negative value	1	10.39

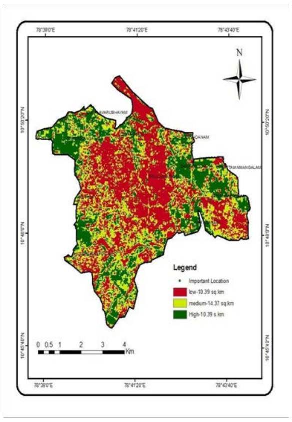

Figure 7 Spatial Distribution Map of NDVI of Tiruchirappalli West

NDWI Analysis

The normalised difference water index (NDWI) was used to identify water bodies and surface moisture conditions. Areas with high NDWI values indicate the presence of water or moist soil, which enhances the groundwater recharge potential. The results demonstrated a strong spatial agreement between high NDWI values and high groundwater potential zones, highlighting the importance of surface moisture availability. The NDWI map is shown in Fig. 8, and the corresponding data are listed in Table 6.

Table 6 NDWI Results of Tiruchirapalli West

NDVI	Weightage for Water Resources	Area (Km^2)
Water body	3	13.91
0.5-1	2	16.17
Close to 0 and a negative value	1	13.91

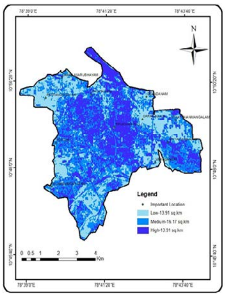

Figure 8 Spatial Distribution Map of NDWI of Tiruchirappalli

Weighted Overlay Assessment for Groundwater Potential Zones

In GIS, the relative weightings are assigned with respect to water resources. GIS is an efficient tool for integrating mapping to locate groundwater zones (Bagyaraj et al., 2012; Kom et al., 2024; P & B, 2016). Using the Union analytical tool, the maps shown in the methodology were integrated. Six thematic maps on water were prepared and are integrated in Table 7.

Table 7 Overall Weightage Table for Each Layer

Thematic layer	Layer weight	Class	Rank
Surface waterbody	20	River	3
		Canal	2
		Tank	1
Drainage Density	25	Low	4
		Moderate	3
		High	2
Lineament Density	12	Low	1
		Moderate	2
		High	3
Land use/ Land cover	18	River	7
		Vegetation	5
		Waterbodies	6
		Barren lands	4
		Settlements	2
		Barren lands	1
		Roadways	3
NDVI	10	Moderate - water	3
		High- Vegetaion	2
		Low- Barren land	1
NDWI	8	High-Water body	3
		Moderate -Vegetation	2
		Low-Barren land	1

Groundwater Potential Zones

The integration of all thematic layers using the Weighted Overlay Method resulted in the classification of groundwater potential into three categories: high (33%), moderate (43%), and low (24%).

High groundwater potential zones are primarily associated with the following:

- High lineament density
- Low drainage density
- Moderate to high NDVI and NDWI values

Moderate zones represent areas with balanced conditions, whereas low-potential zones are associated with unfavourable factors such as high drainage density, low structural influence, and increased urbanisation. This demonstrates that groundwater occurrence is controlled by the combined influence of multiple parameters rather than by a single factor. The groundwater potential map is shown in Fig. 9, and the spatial distribution is summarised in Table 8.

Table 8 The Spatial Distribution of Groundwater Potential Area

Groundwater potential	Weightage for Water Resources	Area (Km^2)	Area%
High	3	14 sq.km	33
Moderate	2	18 sq.km	43
Low	1	10 sq.km	24

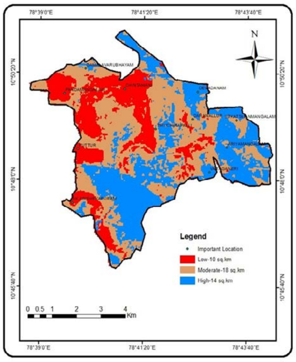

Figure 9 Spatial Distribution Map of Groundwater Potential Zones of Tiruchirappalli West

Validation Using Well-Yield Data

Validation of the groundwater potential zones was carried out using well-yield data interpolated through the Inverse Distance Weighting (IDW) method, field visits, and depth of water level assessment. The results showed a strong agreement between the high groundwater potential zones and areas with higher well yields.

Conclusion

This study successfully delineated groundwater potential zones in Tiruchirappalli West using an integrated RS–GIS approach. The results revealed that the study area is dominated by moderate groundwater potential (43%), followed by high (33%) and low (24%) potential zones.

The analysis demonstrated that groundwater occurrence is controlled by the combined influence of geomorphic, structural, and hydrological factors. High groundwater potential zones are strongly associated with high lineament density, which enhances subsurface permeability, and low drainage density, which promotes the infiltration. Additionally, moderate to high NDVI and NDWI values in these regions indicate favourable vegetation cover and surface moisture conditions that further support the groundwater recharge.

In contrast, low-potential zones are linked to high drainage density, reduced structural features, and increased built-up areas, which limit infiltration and groundwater storage. These findings clearly establish the relationship between the thematic parameters and groundwater distribution observed in the Results and Discussion sections.

Furthermore, validation using well-yield data showed a strong agreement with the predicted groundwater potential zones, confirming the accuracy and reliability of the model.

Overall, this study highlights the effectiveness of integrating RS–GIS techniques for groundwater potential mapping and provides a scientific basis for groundwater exploration, artificial recharge planning, and sustainable water resource management in rapidly urbanising regions.

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