Evaluating the Influence of Land Use Dynamics on Groundwater Potential Zones Dindigul West Firka using Satellite-Based Mapping

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Abstract
In the semiarid Dindigul West firka of Tamil Nadu, groundwater serves as a vital resource supporting both domestic consumption and agricultural activities across an area of approximately 127.56 km². Dindigul West Firka is experiencing gradual peri-urbanisation, with villages transforming into semi-urban settlements. The expansion of housing, roads, and public infrastructure has increased pressure on land and water resources. Small-scale industries, commercial establishments, and service activities have expanded along major roads and settlement clusters. Drainage is primarily seasonal, with small streams and tanks connected to the tributaries of the Kodaganar River, which flows near Dindigul town. Dindigul West Firka experiences a tropical semi-arid climate. Groundwater potential zones were delineated through the combined application of Remote Sensing (RS) and Geographic Information System (GIS) techniques, and the resulting spatial patterns were validated using Inverse Distance Weighting (IDW) interpolation. Satellite data and ancillary maps were employed to develop thematic layers of lithology, geomorphology, lineament density, slope, soil type, land use/land cover, elevation, drainage density, NDVI, NDWI, and rainfall. Relative weightages were assigned for GIS analysis to develop a composite Groundwater Potential Zone (GWPZ). The resulting groundwater potential map is classified into three zones: high (40%), moderate (35%), and low (25%). The central and southern parts of the Firka showed higher groundwater potential due to favourable lithology, dense lineament networks, and gentle slopes. In contrast, the southwestern rocky uplands exhibited low potential. The outcome is validated in groundwater prospecting and suggests sustainable water resource management in Dindigul West Firka. Multitemporal multispectral satellite imagery was used to generate LULC maps and detect land-use changes using supervised classification and post-classification comparison techniques. Higher weights were assigned to the LULC map. Future research should

integrate the study of long-term groundwater level trends, utilising high-resolution satellite data, artificial intelligence, and advanced machine-learning models to enhance the accuracy and sustainability of groundwater potential assessments.

Keywords: GWPZ, LULC, Remote Sensing (RS), GIS, and Lineament Density

Introduction

Water is a crucial component of the ecosystem and has been declining in both quality and quantity due to natural and human-induced interventions (Rajan et al., 2025). The water-bearing features of the Earth's crust (interconnected fractures, lineaments, etc.) serve as reservoirs and transmission conduits for water storage (Murugesan et al., 2025). Groundwater is a fundamental necessity for every human being to survive on Earth and to meet the drinking and irrigation needs in all areas with hard rock terrain (Kannan et al., 2025). Groundwater is a concealed natural resource found beneath the Earth's surface that fills all the pore spaces of soil and fractures of rock formations. It is universally accepted as the largest freshwater resource in the world. It is considered one of the most important natural resources that supports both human needs and economic development (Karung Phaisonreng Kom et al., 2018).

Water resources are an inevitable requirement in all sectors. The need to assess water resources increases every year due to declining water levels and changes in atmospheric water. Water resources are vital for all forms of life. Groundwater is particularly important for domestic and irrigation purposes in arid and semiarid regions (Phaisonreng Kom et al., 2023). A major portion of the world's population depends on groundwater for their daily needs. In regions such as arid and semiarid zones, it has become the primary water source for domestic, agricultural, and industrial activities (Kom et al., 2021). Numerous methods are available for water resource evaluation. Among them, evaluation using geospatial technology is significant due to its accuracy and timeliness of results. In the present study, an attempt was made to use satellite-based demarcation of water resources by analysing Lineaments and Lineament Density, Land Use/Land Cover, Normalised Difference Vegetation Index, Normalised Difference Water Index, and Normalised Difference Drought Index, all derived from high-resolution Sentinel satellite data. Surface water resources, such as drainage and surface water bodies, were also mapped using Survey of India toposheets and cross-verified with Google Map data. Changes in water bodies form another noteworthy outcome of this study. The appearance of new water resources and the disappearance of existing ones are key highlights.

Remote Sensing (RS) and Geographic Information Systems (GIS) are foundational tools for assessing groundwater potential zones (GWPZ) (Godif & Manjunatha, 2023; Tesfa & Sewnet, 2025). A major challenge in such assessments lies in the systematic identification and weighting of thematic layers that influence groundwater occurrence and distribution. Because geological settings and climatic regimes differ widely across regions, the relative importance of each factor also varies substantially (Guduru & Jilo, 2022). Earlier studies often relied on single parameters or isolated analytical approaches. For example, Duguma (2023) evaluated ten RS-derived thematic layers, including geomorphology, slope, soil depth, and rainfall, in the Upper Blue Nile Basin using an ArcGIS-based weighted overlay technique, with weights assigned based on expert knowledge. The study concluded that geomorphology and rainfall were the dominant determinants of groundwater potential.

Many researchers have attempted to map the water resources using many methods. The use of remote sensing data and digital elevation models in GIS and ERDAS enabled the determination of the spatial distribution of the parameters. An integrated remote sensing technique combined with GIS has proven to be an efficient tool for identifying groundwater potential zones (Boobalan (Boobalan.C et al., 2018) (Bagyaraj et al., 2012; Bagyaraj. M et al., 2014). GIS is an efficient tool for mapping and analysing spatial data sets (Nijagunappa et al., 2007) (Suresh. M et al., 2009). (Kalaivanan. K et al., 2019). GIS is a technology that enables many scholars worldwide to collect and process spatial and geographical information, which has been commonly used to map over the past four decades (Kom et al., 2021).

Groundwater potential zones of Natham taluk were identified using GIS and knowledge-based factor analysis of 10 layers of local data, including lithology, land use/land cover, lineament density, geomorphology, soil, slope, rainfall, and drainage density (Balasubramaniyan et al., 2025). The groundwater potential map for the Coimbatore district was generated by integrating thematic layers in a GIS environment using a weighted sum overlay analysis tool, and the author notes that it is noteworthy (Kom et al., 2024). Remote sensing and GIS are highly fruitful and useful for assessing groundwater potential zones (Arulbalaji & Gurugnanam, 2016).

The present study, titled "Evaluating the Influence of Land Use Dynamics on Groundwater Potential Zones in Dindigul West Firka Using Satellite-Based Mapping," aims to investigate how changing land use patterns affect groundwater availability and distribution. Using multi-temporal satellite data, GIS-based spatial analysis, and thematic layer integration, the study aims to delineate groundwater potential zones and assess the degree to which land use dynamics, such as agricultural expansion, urban growth, and surface modification, influence groundwater recharge processes. The specific objectives include: (i) mapping land use/land cover changes over time using satellite imagery, (ii) generating key hydro-geomorphic and environmental thematic layers relevant to groundwater occurrence, (iii) integrating these layers through a suitable multi-criteria evaluation approach, and (iv) identifying and analyzing zones with varying groundwater potential to support sustainable water resource management in Dindigul West Firka.

Study Area

The study area, Dindigul West Firka in Dindigul district, Tamil Nadu (127.56 km²), is located in a tropical, semiarid to sub-humid zone characterised by hot summers and a pronounced monsoon regime. Average annual temperature sits around the high 20s °C, with summer maxima often exceeding 38–40 °C. Annual rainfall is supplied mainly by the southwest and northeast monsoons and typically averages on the order of ~1,200–1,600 mm (Bagyaraj et al., 2015). The soils in this region are generally red, red-sandy, or black cotton soils, depending on localized variations. Groundwater serves as the primary source of water for both domestic and agricultural use. Surface water resources in the Firka include tanks, ponds, and small channels, but many of these have experienced siltation, pollution, or encroachment. (Fig. 1)

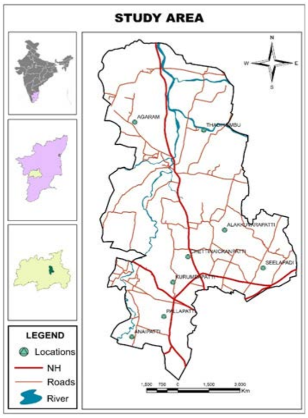

Figure 1 Study Area Map of Dindigul Firka

Methodology

In this study, groundwater potential zones (GWPZ) were delineated using an integrated Remote Sensing (RS) and Geographic Information System (GIS)-based multi-criteria decision analysis. First, various spatial datasets were collected from publicly available sources, such as Digital Elevation Model (DEM) data at 30 m spatial resolution from the United States Geological Survey (USGS) Shuttle Radar Topography Mission (SRTM) archive; satellite imagery such as Landsat 8 OLI/TIRS or similar, used for derivation of land-use/land-cover (LULC), vegetation and water-body indices (e.g. Normalized Difference Vegetation Index (NDVI) and Normalised Difference Water Index (NDWI)); hydrogeological and lithological maps from national geological dataset repositories such as the Geological Survey of India (GSI) or equivalent; soil maps from global or national soil databases such as the Food and Agriculture Organization (FAO) soils portal; rainfall or precipitation data from climatic databases (e.g. the Climatic Research Unit (CRU) dataset or national meteorological agencies). For example, in a recent study in the Sub-Himalayan Dooars region, the authors used SRTM DEM (30 m), Landsat 8 imagery (30 m), and rainfall data from CRU. The data information is provided in the table. 1.

All spatial data were preprocessed (georeferencing, projection to a common coordinate system, clipping to the study area, and rasterisation where necessary). From these datasets, thematic layers relevant to groundwater occurrence were derived in GIS: lithology, geomorphology, lineament density, slope, soil type, land use/land cover (LULC), elevation, drainage density, NDVI, NDWI, and rainfall distribution were prepared as raster layers.

Based on earlier research, relative weights and ranks were assigned to each thematic layer depending on their perceived influence on groundwater recharge and storage (e.g. geomorphology, rainfall, soil type, lineament density, slope). This weighted overlay analysis was implemented in GIS to integrate all thematic layers into a composite Groundwater Potential Zone (GWPZ) map. A similar methodology has been effectively applied in previous studies in India and elsewhere. Finally, to validate the GWPZ map, observed groundwater data (for example, well or bore-well yield, groundwater levels) were used. Spatial interpolation, specifically the Inverse Distance Weighting (IDW) method of well data points, was performed to generate a groundwater occurrence/level surface, which was then compared with the GWPZ classification to test how well the predicted zones matched the actual groundwater presence or yield. Use of well data for validation is a widely accepted practice in similar studies.

Table 1 Data Sources used in this Study

Data Type	Typical Source / Portal
DEM	USGS SRTM (30 m) — accessible via USGS EarthExplorer or similar archives.
Satellite imagery / LULC	Landsat 8 OLI/TIRS (USGS), or Sentinel-2 (European Copernicus), or national portals like Bhuvan (for India by Indian Space Research Organisation, ISRO).
Soil maps	FAO soils portal / FAO-UNESCO Soil Map / national soil survey data.
Hydrogeology / Lithology / Geomorphology maps	The Geological Survey of India (or equivalent national geological agency) published maps (hard-copy or GIS).
Rainfall / Precipitation data	CRU dataset (global gridded), national meteorological department records, and long-term rainfall station data. Example: CRU data used in recent GWPZ study.
Groundwater data for validation	Well / borewell yield records, groundwater level data from agencies like Central Ground Water Board (CGWB) or local/ state groundwater departments, collected through field surveys or from publicly available reports.

Results and Discussion

Surface water Body

Surface water bodies, including lakes and ponds, were delineated using toposheets and satellite imagery, as they exhibit a direct relationship with groundwater resources. A 20 m buffer was applied around the mapped water bodies for spatial analysis. A relatively higher weight was assigned to this thematic layer because of its significance in water resource assessment. The total area covered by water bodies in the study area was 9.83 km² (Fig. 2). The results of the output are listed in Table 2.

Table 2 Table Spatial Distribution Results of Surface Water Bodies

Surface water bodies	Weightage	Area in Km²
River	3	2.45
Canal	2	13.2 (length)
Tank	1	6.63

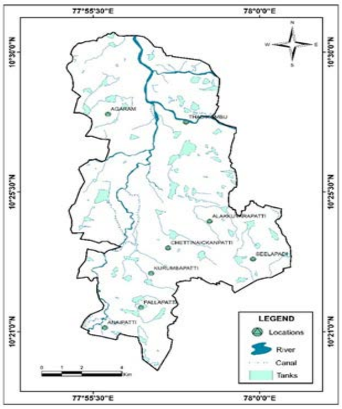

Figure 2 Spatial Distribution Map of Surface Water Bodies

Drainage and Drainage Density

Drainage is the surface movement path of rainwater. It is always moving towards a lower slope. This area is acting as a pathway to recharge groundwater. The drainage map of the study was prepared from the Topographic Sheet and is presented. The drainage density map is illustrated in Fig. 3. The results of this study are summarised in Table 3.

Table 3 Spatial Distribution Results of Drainage Density of Dindigul West Firka

Drainage Density	Weightage	Area (Km²)
Low	3	110
Moderate	2	16.84
High	1	0.72

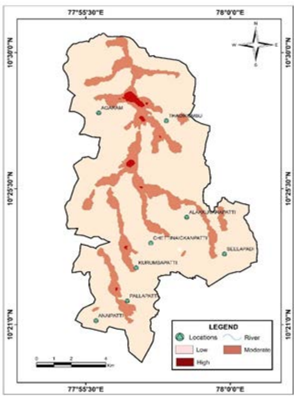

Figure 3 Spatial Distribution Map of the Drainage Density

Remote Sensing

Lineament and Lineament Density

The lineament map was prepared using satellite imagery (Fig. 4) by using its long linear natural feature. This is directly related to groundwater resources. The higher the lineament density, the higher the possibility of groundwater. Based on this characteristic, the lineament density zone weights were derived. The results of the lineament density output are given in Table 4.

Table 4 Spatial Distribution Results of Lineament Density of Dindigul West Firka

Lineament Density	Weightage	Area (Km²)
Very high	4	8.17
High	3	7.7
Medium	2	7.11
Low	1	104.55

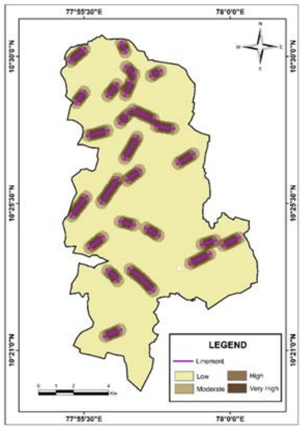

Figure 4 Spatial Distribution Map of Lineament Density

Land use/Land Cover

Land use changes were analyzed to understand their impact on groundwater recharge conditions. The land use/land cover (LULC) map was generated from satellite imagery downloaded from the USGS data repository. The imagery was processed in ArcGIS to create a false-colour composite (FCC). Supervised classification, supported by ground control information, was then applied to delineate the various LULC classes in the study area. The spatial distributions of these classes are described below.

Owing to rapid urbanisation and industrial expansion, a progressive decline in agricultural land, vegetation, forest cover, water bodies, and mineral resources has been observed (Arulbalaji & Gurugnanam, 2014b). Subsequently, relative weights were assigned to the LULC themes for groundwater potential zonation. The output (Fig. 5) and spatial details are listed in Table. 5.

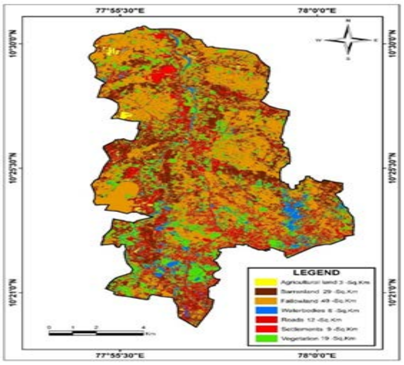

Figure 5 Spatial Distribution Map of Land use / Land Cover

Table 5 Spatial Distribution Results of Land use and Land Cover of Dindigul West Firka

LULC	Weightage	Area (Km^2)
Agricultural land	6	3
Vegetation	4	19
Waterbodies	7	6
Fallowlands	5	49
Settlements	2	9
Barrenlands	3	29
Roadways	1	12

Normalized Difference Vegetation Index

NDVI, or Normalised Difference Vegetation Index, is a remote sensing metric that measures vegetation health and density. It is calculated by comparing the amount of light that plants reflect in the visible (red) and near-infrared (NIR) bands of the electromagnetic spectrum. Healthy, green vegetation reflects more NIR light and absorbs more red light for photosynthesis. Geospatial technology, combined with a vegetation index, helps identify the water zone, and GIS helps demarcate it (Arulbalaji et al.,2014a).

Plants absorb red light for photosynthesis and reflect a large amount of near-infrared light due to the structure of their leaves.

Calculation: NDVI utilises these differences in reflectance to create a value that ranges from -1 to 1.

Formula: NDVI = (NIR - Red) / (NIR + Red)

Higher values indicate dense, healthy green vegetation (e.g., values between 0.5 and 1.0).

Lower values: Indicate areas with little to no vegetation, such as barren land, water, or snow (e.g., values close to 0 or negative). The results of the NDVI map are presented in Fig. 6 and Table 6.

Table 6 Spatial Distribution Results of NDVI of Dindigul West Firka

NDVI	Weightage for Water Resources	Area (Km^2)
Water body	1	22.82
0.1-0.2	2	39.9
0.2-0.3	3	29.24
0.3-0.4	4	21.57
0.4-0.7	5	12.31

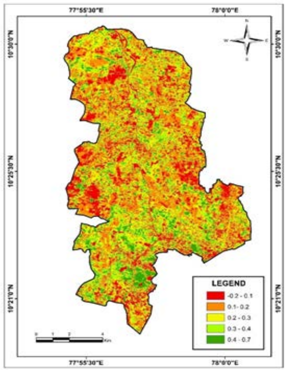

Figure 6 Spatial Distribution Map of NDVI of Dindigul West Firka

Normalized Difference Water Index

NDWI, or Normalized Difference Water Index, is a satellite-based index used to map open water bodies and monitor water content in vegetation and soil. It is calculated by subtracting the near-infrared (NIR) band from the green band and dividing the result by the sum of the NIR and green bands. Higher values typically indicate a greater presence of water. It is useful for,

Water body mapping: Delineates open water features, such as lakes, rivers, and oceans, from land.

Vegetation water content: Monitors the amount of water in plant leaves, which is useful for tracking plant health and stress

Agriculture: Enhances irrigation management by identifying areas that require water and minimising waste.

Drought monitoring: Supports monitoring of drought conditions and soil moisture.

Calculation and interpretation

Formula: $NDWI = (Green - NIR) / (Green + NIR)$

Bands: The formula uses the green and near-infrared bands from satellite imagery.

Value range: Values range from -1 to +1.

Interpretation

- **Water bodies**: Typically have values greater than 0.5.
- **Vegetation**: Has lower values, which helps differentiate it from water.
- **Built-up areas**: Show positive values between 0 and 0.2

The results of NDWI are given in Figure 7 and Table 7

Table 7 Spatial Distribution Results of NDWI of Thiruvattar Firka

NDWI	Weightage for Water Resources	Area (Km²)
Water body	3	5.58
0.5-1	2	66.6
Close to 0 and a negative value	1	53.61

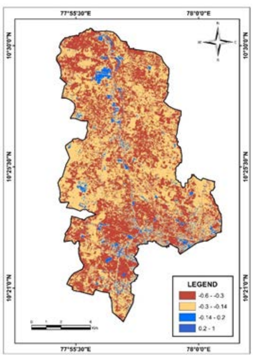

Figure 7 Spatial Distribution Map of NDWI of Dindigul West Firka

Multicriteria Weighted Overlay Index Map for Groundwater Potential Zones

In GIS, the relative weightings are given with respect to water resources. GIS is an efficient tool for integrating mapping to locate the groundwater zone (Gurugnanam et al., 2008).Using the Union analytical tool, the maps as shown in the methodology are integrated one over the other. All thematic maps on water were prepared and integrated into a comprehensive map. The results of the integration are again classified into three categories: High, Moderate and Low in terms of groundwater. The use of remote sensing and GIS is highly fruitful and useful for assessing groundwater potential zones (Arulbalaji & Gurugnanam, 2016). The spatial map of the output is presented in Fig. 8, and the results are summarised in Table 8.

Table 8 Spatial Distribution Results of Groundwater Potential Zones of Dindigul West Firka

Groundwater potential	Weightage for Water Resources	Area (Km²)
High	3	12.34
Moderate	2	83
Low	1	32.4
Fallowlands	5	49
Settlements	2	9
Barrenlands	3	29
Roadways	1	12

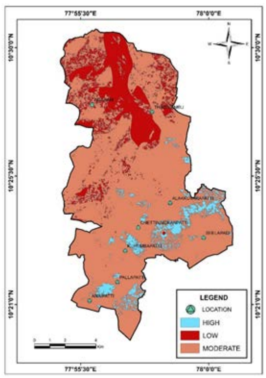

Figure 8 Spatial Distribution Map of Groundwater Potential Zones of Dindigul West Firka

Conclusion

The groundwater potential map (Figure 8) illustrates the spatial distribution of high, moderate, and low groundwater potential zones across the study area. The classification was derived from a weighted overlay analysis, with weights of 3 for high, 2 for moderate, and 1 for low potential zones. The results showed that the moderate groundwater potential zone dominated the study region, covering an area of approximately 83 km², and was widely distributed across the central and southern parts of the basin. These areas are characterised by gentle slopes, moderate lineament density, and mixed agricultural land use, which collectively support moderate ground water recharge.

The low groundwater potential zone, occupying around 32.4 km², is mostly concentrated in the northern and north-western portions of the map. These regions exhibit unfavourable hydro-geomorphic conditions, such as steep terrain, harder lithological units, and high drainage density, which hinder infiltration and reduce the potential for groundwater accumulation.

In contrast, the high groundwater potential zone, although limited in extent (approximately 12.34 km²), is scattered across the southeastern and central-eastern portions of the study area. As shown in the map, these zones correspond to areas with favourable characteristics, such as lower slopes, permeable soils, vegetated surfaces, and higher lineament density, which collectively enhance infiltration and subsurface storage.

Areas classified as very good and good potential zones were expected to exhibit shallower water table depths, while poor and very poor zones were associated with deeper groundwater levels. A statistical comparison between groundwater depth classes and potential zones was conducted to assess model consistency. As stated in the abstract, this study confirms that an integrated remote sensing and GIS-based approach effectively delineates groundwater potential zones and reveals the critical influence of land use dynamics on groundwater availability in the Dindigul West Firka.

Overall, the spatial variability observed in the groundwater potential map largely reflects the influence of land use and land cover patterns within the study region. The predominance of moderate zones suggests that groundwater development is feasible across much of the area, whereas the high-potential pockets represent priority zones for sustainable groundwater extraction. Conversely, the low-potential regions require careful management and may need artificial recharge interventions to improve groundwater availability.

Future Research Scope

1. The present study provides a foundational understanding of the influence of land use dynamics on groundwater potential in Dindigul West Firka.
2. High-resolution satellite imagery (e.g., PlanetScope, Cartosat-2) can improve the accuracy of land use classification and lineament extraction
3. Future research can integrate climate variability, that is changes in rainfall intensity and frequency, to assess their combined impact with land use dynamics on groundwater recharge.
4. Study can be done on the disappeared tanks and other water bodies their causes and solution on the firka
5. The effectiveness of existing and proposed artificial recharge structures (check dams, percolation ponds, recharge shafts) can be evaluated using pre- and post-implementation satellite and field data.

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