Assessing Groundwater Prospects through Terrain, Lithology, and Structural Controls in a GIS Environment in Kalvarayan Firka, Salem, Tamil Nadu, India

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Abstract
Groundwater is very important for keeping homes and farms in the semiarid area of Kalvarayan Firka, Salem, Tamil Nadu, which covers about 197 square kilometres. A combined Remote Sensing (RS) and Geographic Information System (GIS) method was used in this study to identify groundwater potential zones throughout the study area. Satellite images and other data were used to create thematic layers showing geology, lineament density, drainage density, land use/land cover (LULC), normalized difference vegetation index (NDVI), normalized difference water index (NDWI), and Normalized Difference Drought Index. The Analytical Hierarchy Process (AHP) integrated with the Weightage Overlay Method (WOM) was used to assign suitable weights to each thematic layer based on its hydrogeological significance. The resulting map classified the study area into three groundwater potential groups: the study area was predominantly characterized by moderate groundwater potential, covering 159 km² (80.71%) of the total 197 km² area. High-potential zones occupied 27 km² (13.70%), whereas low-potential zones accounted for only 11 km² (5.58%). Low-potential zones are found where there is a lot of water and solid rock present. High-potential zones were found where there was a lot of weathered or broken rock, low slopes, and good land use. Validation using existing well-yield data shows that the predicted zones and actual field conditions are very similar. However, this study was limited by the availability of temporal groundwater data, seasonal variations, limited field validation, and the resolution of the input datasets. An in-depth study could be conducted using geophysical interpretations. The results show that RS-GIS combined with AHP is a good method for identifying groundwater prospects. This provides scientists with a way to plan for groundwater growth, artificial recharge, and long-term resource management. Future research should focus on integrating temporal groundwater fluctuation data, climate change impacts, and machine learning techniques to improve the accuracy and reliability of groundwater potential assessments.

Keywords: Groundwater, NDWI, NDDI, GIS, Remote Sensing, Weighted Overlay Analysis.

Introduction

Water supply is essential for all industries. Due to changes in atmospheric water and decreasing water levels, evaluating water supplies is becoming increasingly important every year. Water supply is important for all purposes. In dry and semi-dry areas, groundwater is necessary for drinking and farming. Most people worldwide depend on groundwater for their daily needs. This type of water is now the main source of water for homes, farms, and factories in dry and semi-arid areas. Groundwater resources can be evaluated in several ways. The current results of the mapping technology evaluation make it stand out. In this study, higher-resolution Landsat Sentinel satellite data were used to determine how to divide water resources by examining lineament and lineament density, land use/land cover, the normalized difference vegetation index, the normalized difference water index, and the normalized difference drought index (Kanji & Das, 2025; Karimi-Rizvandi et al., 2021; Namous et al., 2021; Uddin et al., 2024). Survey of India Toposheet data were used to map surface water resources, such as drains and bodies of water. These data were then checked against Google Maps data. Many researchers have attempted to map water resources using various methods. The use of remote sensing data and GIS enabled the determination of the spatial distribution of these parameters. The feature class weights are easy to use and useful for overlay analyses. GIS is an efficient tool for mapping and analyzing spatial data (Chandra Roy et al., 2024a, 2024b; Rajan et al., 2025). GIS is a fast and accurate technology for mapping and integrating remote sensing datasets (Bagyaraj et al., 2014). GIS is a powerful tool that was used in the current study to detect favorable groundwater potential zones (Kalaivanan et al., 2019).

The spatial distribution and occurrence of groundwater in India are strongly influenced by the country's diverse physiography, complex geological framework, and monsoon-dominated climate. In hard rock terrains, which occupy nearly two-thirds of the Indian landmass, groundwater is predominantly controlled by secondary porosity developed through weathering, fracturing, and jostling processes.

Literature Review

Groundwater potential assessments have been conducted by several researchers using remote sensing and GIS techniques. Many authors have reported that factors such as geology, geomorphology, drainage density, slope, land use, and lineament density strongly influence groundwater occurrence. Recent studies have highlighted that multi-criteria decision analysis and weighted overlay methods are effective for groundwater potential assessment in both hard rock and sedimentary terrains. Productive aquifers generally occur in deeper fracture zones under semi-confined conditions and in shallow unconfined aquifers within the weathered mantle (Chatterjee and Dutta, 2022; Saha et al., 2024). However, increasing population growth, agricultural intensification, and urban expansion have significantly escalated the demand for both surface and groundwater resources, leading to declining water tables and localized water scarcity in several regions. Consequently, reliable and quantitative assessment of groundwater resources using scientifically robust approaches and advanced geospatial technologies, such as remote sensing, GIS-based modeling, and multi-criteria decision analysis, has become essential for sustainable groundwater development and long-term resource management (Adiat et al., 2024; Dandapat et al., 2024; Doke et al., 2021).

Some scholars have experimented with numerous approaches that have been utilized in mapping water resources (Murugesan et al., 2025; Pragadeeshwaran et al., 2026). The parameters were determined in space through the application of the remote sensing data and the digital elevation models as GIS and ERDAS (Arulbalaji & Gurugnanam, 2017). The weights of the feature classes facilitate and simplify their overlaying (Bagyaraj et al., 2012). GIS is an effective mapping and analysis software for spatial datasets (Kalaivanan et al., 2019; Nijagunappa et al., 2007). The specific objectives include the preparation and analysis of thematic layers such as geology, lineament density, drainage density, land use/land cover, Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), and Normalized Difference Drought Index.; assigning relative weights to these factors by integrating the weighted layers through Groundwater potential zones are identified using GIS-based overlay analysis, and the results are validated using current groundwater level and well yield data to provide groundwater development and conservation plans with a scientific foundation.

Although several studies have been conducted on groundwater potential mapping using RS and GIS techniques, few studies are available for the Kalvarayan Firka region of Salem District. Previous research has mainly focused on conventional hydrogeological factors and has given less importance to drought and water-related indices such as NDVI, NDWI, and NDDI, along with field validation using well yield data. Therefore, this study integrated these parameters with GIS-based weighted overlay analysis to improve groundwater potential zonation and support sustainable groundwater management.

Objectives of the Study

- Thematic layers such as geology, lineament density, drainage density, land use/land cover (LULC), NDVI, NDWI, and NDDI were prepared using Remote Sensing and GIS techniques.
- The relative weights of the groundwater influencing factors were assigned using the Analytical Hierarchy Process (AHP) and weighted overlay analysis.
- To delineate groundwater potential zones in the Kalvarayan Firka region using GIS-based spatial analysis.
- To validate the groundwater potential zones using existing groundwater level and well yield data.
- This study provides scientific information for sustainable groundwater development and resource management.

Study Area

Kalrayan Firka is located in the Kalrayan Hills of the Eastern Ghats, spread mainly across Salem and Kallakurichi districts of Tamil Nadu. The region has a hilly, undulating topography, with elevations ranging from approximately 600 to 1,200 m above mean sea level. It is covered by dense forests, valleys, and plateaus. The area is drained by several seasonal streams, which are tributaries of the Vellar and Cauvery River systems. The soils are mostly red, loamy, and lateritic, and are suitable for dry farming.

The climate of Kalrayan Firka is moderate and pleasant because of its higher elevation. Summers are mild compared to the surrounding plains, and winters are cool, especially at night. The region experiences fewer temperature extremes and has a generally healthier climate.

Kalrayan Firka receives rainfall from both the Southwest Monsoon (June–September) and the Northeast Monsoon (October–December). The average annual rainfall ranges between 900 and 1,200 mm, which supports rain-fed agriculture and forest cover. Most streams flow during the monsoon season and dry up during summer.

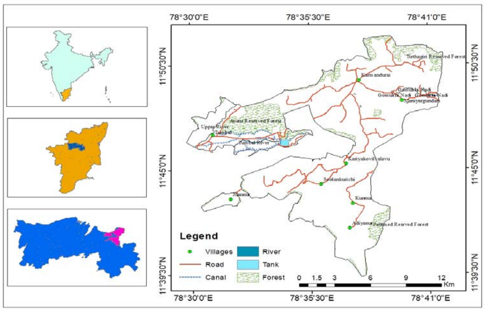

Figure 1 Study Area Map

Geology of the Study Area

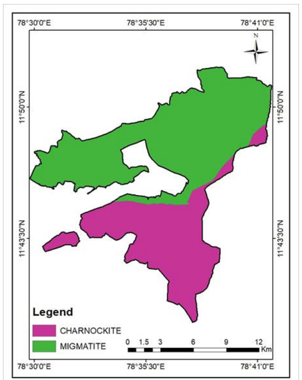

Figure 2 Geology

The geology of the area reflects an ancient crystalline basement terrain dominated by charnockite–migmatite lithology, which is typical of the Eastern Ghats high-grade metamorphic belt. Charnockite forms the major hard basement rock, which is typically dark grey to greenish in color, coarse-grained, and composed mainly of quartz, feldspar, and pyroxene, indicating formation under high temperature and high pressure (granulite facies conditions). Migmatite occurs in association with charnockite as a mixed light–dark banded rock, showing partial melting features and alternating felsic (light) and mafic (dark) layers. A geological map of the study area is shown in Figure 2.

Methodology

The methodology adopted for preparing the groundwater potential zone map integrated Survey of India toposheets, remote sensing datasets, and GIS-based spatial analysis. Initially, the toposheets were georeferenced and interpreted to extract the drainage network and major waterbodies, which are crucial for groundwater recharge and surface–subsurface hydrological interactions. Satellite data were geo-referenced in ArcGIS software with the UTM projection WGS 1984. Resampling was performed using a cubic interpolation strategy to reduce spatial distortion. By swiping one image over the other, the geocorrection accuracy was tested and confirmed through field inspection. Ground control points (GCPs) from the field were used to correct satellite data (Gurugnanam. B et al., 2022). Simultaneously, multispectral satellite imagery was processed to derive key thematic layers, including land use/land cover, lineaments and their density, and spectral indices such as the Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), and Normalized Difference Drought Index (NDDI). Landsat-8 and Sentinel-2 satellite datasets with spatial resolutions of 30 m and 10 m, respectively, were used for thematic layer preparation and groundwater potential analysis. Land use/land cover information helped assess infiltration characteristics, while lineament mapping provided insights into the structural controls on groundwater flow. Spectral indices were used to evaluate vegetation health, moisture availability, and drought-related factors that indirectly reflect groundwater conditions. All derived thematic layers were standardized, reclassified, and integrated in a GIS environment using weighted overlay techniques to delineate the groundwater potential zones. The weights and ranks assigned to each thematic layer were based on their influence on groundwater occurrence, as supported by previous studies and hydrogeological knowledge. Higher weights and ranks were assigned to favorable conditions, such as high lineament density, weathered formations, low drainage density, and dense vegetation cover. Geographic phenomena, together with their spatial dimensions and associated attributes (such as table analysis, classification, polygon classification, and weight classification), are well employed in GIS, and the results are then reclassified and assigned suitable weightage and spatial distribution (Gurugnanam et al., 2010).The results were obtained using a GIS platform. Contour Interpolation mapping with respect to all unsuitable numbers (Gurugnanam et al., 2009). Finally, the combined analysis yielded a spatially explicit groundwater potential map, enabling the systematic identification of areas with varying recharge rates and groundwater availabilities. The flowchart of the proposed methodology is shown in Figure 3.

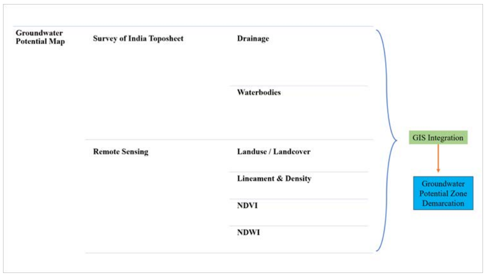

Figure 3 Detailed Methodology Flow Chart

Results and Discussion

Surface Waterbody

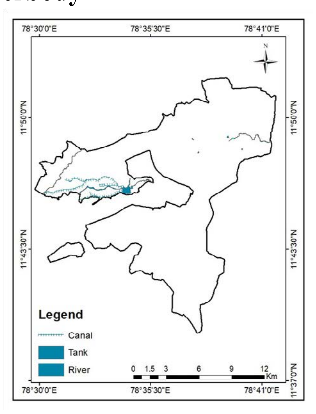

Figure 4 Spatial Distribution Map of Surface Waterbodies

Toposheets and satellite photos were used to create maps of surface bodies of water, such as Eri and Ponds. This is related to water supply. Twenty meters of buffering were placed around the waterbody zone. Maps of water resources were given a fair amount of weight. The tank and river in the study area cover an area of 0.64 and 0.7 square kilometers, respectively, and the canal in the study area is 18 kilometers long (Figure 4). In Table 1.

Table 1 Spatial Distribution Results of Surface Water Bodies

Surface Water Bodies	Weightage	Area in Km^2
River	3	0.7
Canal	2	18 (length)
Tank	1	0.64

Drainage and Drainage Density

Drainage is the process by which liquid moves across the ground. It is always going downhill. This place is a way for groundwater to return to normal. The most likely area for groundwater was approximately 30 m away from the drainage zone. Figure 5 shows the drainage for the study that was conducted using the Toposheet. The findings of this study are presented in Table 2.

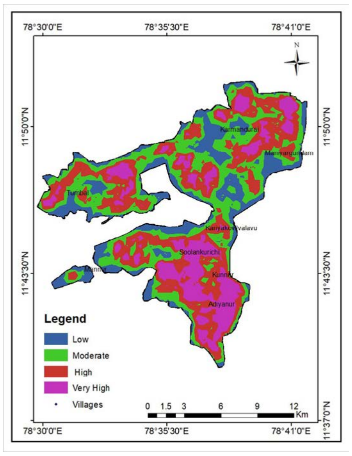

Figure 5 Spatial Distribution Map of the Drainage Density

Table 2 Spatial Distribution Results of Surface Water Bodies of Kalrayan Firka

Drainage Density	Weightage	Area (km^2)
Low	4	36
Moderate	3	60
High	2	66
Very high	1	35

Remote Sensing

Lineament and Lineament Density

A lineament is a natural, long, and weaker linear trait. Satellite images were used to produce the lineament map (Figure 6). Thematic maps were converted to raster form with a 30 m cell size to achieve considerable accuracy. GIS has been used for multicriteria analysis in resource evaluation (Prabhakaran et al., 2009). This is related to water supply. Satellite images were used to determine the lineament density. There is a greater chance of groundwater where the linear population is higher. The lineament density zone weights were determined based on this trait (Table 3).

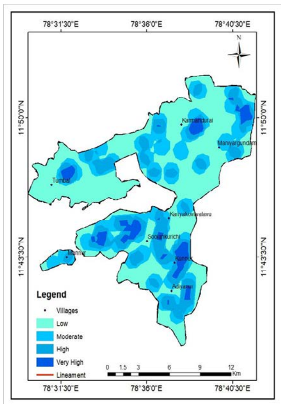

Figure 6 Spatial Distribution Map of Lineament Density

Table 3 Spatial Distribution Results of Lineament Density of Kalrayan Firka

Lineament Density	Weightage	Area (Km^2)
Low	4	99
Moderate	3	48
High	2	38
Very high	1	12

Land use/Land Cover

Satellite data were used to create land use and land cover maps. Satellite data were obtained from the USGS Explorer. The images are registered with their coordinates, and Geometric corrections are applied with the UTM-WGS 84 projection using ArcGIS (Chrisben Sam. S & Gurugnanam.B, 2022). The information was put into ArcGIS, and the FCC was created. Guided classification was used to separate the different land use and land cover areas in the study area using on-the-ground information. Here are more specifics about the spatial spread: Land for farming, plants, forests, water bodies, and minerals is being lost because of more people living in cities and more factories.

For groundwater potential mapping, themes are assigned relative weights.

Table 4 Spatial Distribution Results of Land use and Land Cover of Kalrayan Firka

LULC	Weightage	Area (Km^2)
Vegetation	4	84
Waterbody	5	14
Settlements	1	9
Agricultural land	3	50
Barren land	2	40

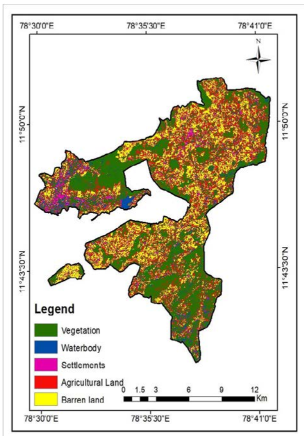

Figure 7 Spatial Distribution Map of Land use / Land cover

Normalised Difference Vegetation Index

The normalized difference vegetation index (NDVI) is a method for measuring the health and density of plants using remote sensing. The amount of light that plants reflect in the visible (red) and near-infrared (NIR) bands of the electromagnetic spectrum is used to determine it. Green and healthy plants scatter more NIR light and absorb more red light for photosynthesis. Geospatial technology on the plant index helps find the water zone, and GIS helps clarify the zone.

Because of the structure of their leaves, plants scatter much of the near-infrared light and absorb red light for photosynthesis. The NDVI uses these changes in reflectance to produce a value ranging from -1 to 1.To obtain the formula, the NDVI was divided by the NIR+Red value. Higher values indicate dense, healthy green vegetation (e.g., 0.5-1.0).

Lower values (values close to 0 or negative) show places with little to no plants, like bare land, water, or snow.

Find out what the NDVI map showed in Figure 8 and Table 5.

Table 5 Spatial Distribution Results of NDVI of Kalrayan Firka

NDVI	Weightage for Water Resources	Area (Km^2)
Waterbody	3	23
0.5-1	2	61
Close to 0 and a negative value	1	112
Agricultural land	3	50
Barren land	2	40

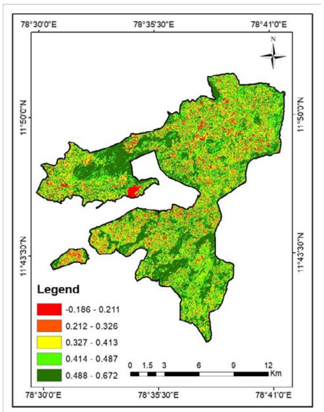

Figure 8 Spatial Distribution Map of NDVI of Kalrayan Firka

Normalized Difference Water Index

The Normalized Difference Water Index (NDWI) is a satellite-based tool used to map areas of open water and monitor the amount of water in plants and soil. To determine this, the green band was taken, and the near-infrared (NIR) band was removed. The result is then divided by the sum of the NIR and green bands. Higher numbers usually indicate that there is more water.

It is helpful for mapping bodies of water, such as lakes, rivers, and seas, which separate open water from land.

The formula is: $NDWI=(Green-NIR)/(Green+NIR)$

Bands: The method uses the green and near-infrared bands from satellite images.

Value range: -1 to +1 is the value range.

What it means:

In general, values for bodies of water are bigger than 0.5.

Vegetation: Its values are lower, which helps tell it apart from water.

Show values that are positive between 0 and 0.2 for built-up places.

Figure 9 and Table 6 show the NDWI findings.

Table 6 Spatial Distribution Results of NDWI of Kalrayan Firka

NDWI	Weightage for Water Resources	Area (Km^2)
Waterbody	3	23
0.5-1	2	61
Close to 0 and a negative value	1	112

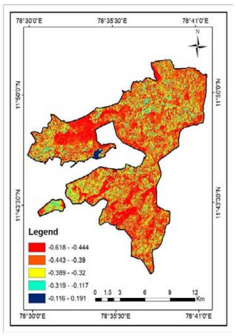

Figure 9 Spatial Distribution Map of NDWI of Kalrayan Firka

NDDI

NDDI can stand for Normalized Difference Drought Index, a remote sensing tool used to monitor and measure drought severity.

This is a remote sensing index used to assess drought by analyzing a satellite's spectral bands, primarily the Near-Infrared (NIR) and Short Wave Infrared (SWIR) bands.

It is calculated using the Normalized Difference Vegetation Index (NDVI) and the Normalized Difference Water Index (NDWI).

There are numbers from -1 to 1, and lower values mean that the drought stress is worse.

It helps in monitoring water stress in vegetation and is crucial for drought-related challenges in agriculture and water management.

The NDDI map is prepared using satellite data and are given in Figure 10.

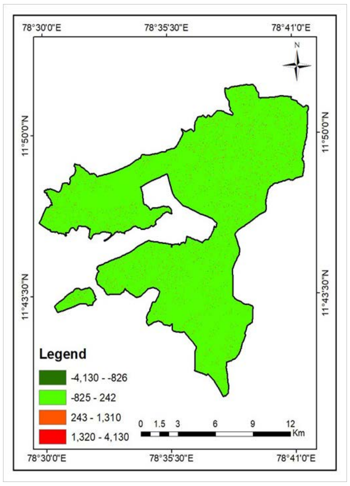

Figure 10 Spatial Distribution Map of NDDI

Weighted Overlay Index Map for Groundwater Potential Zones

All maps were digitized. Their attributes were edited and analyzed using ArcGIS. GIS overlay analysis is highly useful for identifying groundwater potential zones (Gurugnanam et al., 2008). With water supplies, GIS shows the value of each resource. When mapping is combined with GIS, it is easy to identify groundwater zones. The maps shown in the approach were combined using the Union analytical tool, one on top of the other. Five themed maps on water were created and combined. The results of the integration of groundwater were classified into three groups: good, medium, and bad. Remote sensing and GIS are useful tools for determining the presence of groundwater. Figure 11 shows the spatial plan of the output, and Table 7 presents the results.

Table 7 Overall Weightage Table for Each Layer

Thematic layer	Layer weight	Class	Rank (1-5)
Surface waterbody	6	River	3
		Canal	2
		Tank	1
Drainage Density	11	Low	4
		Moderate	3
		High	2
		Very High	1
Lineament Density	11	Low	4
		Moderate	3
		High	2
		Very High	1
Land use/ Land cover	15	Vegetation	4
		Waterbody	5
		Settlements	1
		Agricultural land	3
		Barren land	2
NDVI	6	Waterbody	3
		Vegetation	2
		Barren land	1
NDWI	6	Waterbody	3
		Vegetation	2
		Barren land	1
NDDI	6	Low	3
		Moderate	2
		High	1

Multicriteria Weighted Overlay Index Map for Groundwater Potential Zones

The relative weightings for water supplies are shown in GIS. The groundwater zone can be found quickly and easily with GIS. The maps from the approach are put together on top of each other using the Union analytical tool. All water-related theme maps were created and combined into one large map. Once more, the results of the merger were classified into three groups: High, Moderate, and Low for groundwater. Arulbalaji and Gurugnanam (2016) say that remote sensing and GIS are very helpful for figuring out where groundwater might be present. Figure 12 shows the spatial map of the output, and Table 8 lists the data as a whole.

Table 8 Spatial Distribution Results of Groundwater Potential Zones of Kalrayan Firka

Ground water potential	Weightage for Water Resources	Area (Km^2)	Area in Percentage (%)
High		27	13.70
Moderate	2	159	80.71
Low	1	11	5.58

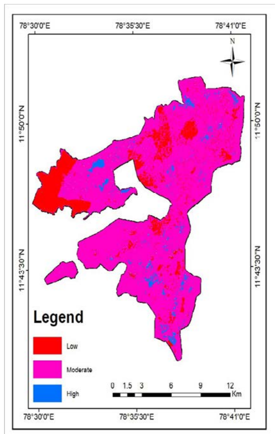

Figure 11 Spatial Distribution Map of Groundwater Potential Zones of Kalrayan Firka

The groundwater potential zonation map (Figure 12 and Table 8), derived through weighted overlay analysis in GIS, reveals that the study area is predominantly characterized by moderate groundwater potential, covering 159 km² (80.71%) of the total 197 km² area. High potential zones occupy 27 km² (13.70%), while low potential zones account for only 11 km² (5.58%). The dominance of the moderate class indicates generally favorable hydrogeological conditions controlled by moderate slopes, weathered and fractured formations, balanced drainage density, and mixed land use/land cover patterns that facilitate infiltration and subsurface storage. The high potential zones are spatially associated with low-slope regions, valley fills, structural lineaments, and permeable lithological units, which enhance groundwater recharge and storage capacity. In contrast, the low-potential areas are confined to regions with steep slopes, high runoff, and relatively impermeable formations, limiting infiltration. The spatial distribution pattern clearly demonstrated the strong influence of geomorphology, lithology, slope, drainage density, and lineament density in controlling groundwater occurrence in the study area.

The predominance of moderate groundwater potential zones indicates that groundwater occurrence is primarily controlled by moderately weathered and fractured hard rock formations. High potential zones are associated with high lineament density, gentle slope, vegetation cover, and favorable infiltration conditions, whereas low potential zones correspond to compact rocky terrain and high runoff areas with poor recharge capacity.

Suggestions

- Artificial recharge structures such as check dams and percolation ponds may be developed in high and moderate groundwater potential zones to improve groundwater recharge.
- Excessive groundwater extraction should be controlled in low potential zones.
- Rainwater harvesting practices should be encouraged in agricultural and settlement areas.
- Periodic monitoring of groundwater levels and water quality is necessary for sustainable groundwater management.
- Future studies may integrate machine learning and seasonal datasets for improving groundwater potential mapping accuracy.

Conclusion

The GIS-based weighted overlay approach effectively delineated groundwater potential zones and identified that the study area is largely suitable for groundwater development, with more than 94% of the area falling under moderate to high potential categories. The high potential zones (13.70%) represent priority areas for sustainable groundwater exploitation and recharge planning, whereas moderate zones can support controlled groundwater extraction with proper management practices. The limited extent of low-potential areas (5.58%) suggests minimal constraints but highlights the need for soil and water conservation measures in these regions. Overall, the study confirms that integrated geospatial techniques provide a reliable scientific framework for groundwater resource assessment and sustainable water resource management. Based on an analysis of different factors, the conclusion about the groundwater potential in a study area summarizes the results of the groundwater's location, availability, and projected yield. There are different groundwater potential zones in the study area, such as Low, Moderate, and High. Most of the time, this is the major quantitative result. The conclusion proves where and how large areas can be used for groundwater development. This provides scientists with a way to plan for future resource needs. The limitations of this study are based on the available seasonal groundwater data, field validation, and spatial resolution of the satellite datasets. The study outcomes were validated in the field.

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