Assessment of Groundwater Potential Zones and Well Yield Estimation Using GIS-Based Well Hydraulics Analysis

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Abstract: Groundwater is one of the most important freshwater resources supporting domestic, agricultural, and industrial activities. The increasing demand for groundwater and declining recharge rates necessitate the identification of potential groundwater zones for sustainable water resource management. This study aims to assess groundwater potential zones and estimate well yield in the Anjarakandy River Basin, Kerala, using Geographic Information System (GIS) and well hydraulics analysis. The study integrates thematic layers such as geology, geomorphology, slope, land use/land cover (LULC), and drainage density through the Analytical Hierarchy Process (AHP) in a GIS environment. The generated groundwater potential map classifies the study area into different groundwater potential zones. Vertical Electrical Sounding (VES) was conducted to validate the GIS-based groundwater potential map and identify suitable aquifer formations. Well hydraulics analysis was performed using field data to estimate well yield and evaluate aquifer performance. The results indicate that the integrated GIS–AHP approach effectively identifies suitable groundwater zones and provides reliable information for groundwater development and sustainable water resource planning.

***Keywords* - Groundwater Potential Zones, Geographic Information System (GIS), Analytical Hierarchy Process (AHP), Well Hydraulics, Vertical Electrical Sounding (VES), Well Yield Estimation.**

1. INTRODUCTION

Groundwater is a vital natural resource that plays a significant role in meeting domestic, agricultural, and industrial water requirements. Rapid urbanization, population growth, and irregular rainfall patterns have increased dependence on groundwater, leading to depletion of aquifers in many regions. Therefore, identifying groundwater potential zones has become essential for sustainable groundwater management.Recent advances in Geographic Information System (GIS) and Remote Sensing (RS) have provided effective tools for groundwater exploration by integrating spatial datasets. Various thematic layers such as geology, geomorphology, slope, land use/land cover, and drainage density influence groundwater occurrence and recharge. The Analytical Hierarchy Process (AHP) is widely used to assign weights to these parameters and generate reliable groundwater potential maps.The integration of Geographic Information System (GIS) with well hydraulics analysis provides a comprehensive approach for groundwater assessment. GIS enables efficient storage, analysis, and visualization of spatial data, while well hydraulics helps evaluate aquifer characteristics such as transmissivity, hydraulic conductivity, and well yield. The combined application of these techniques improves the accuracy of groundwater potential mapping and supports the identification of suitable locations for groundwater development. This integrated approach contributes to effective water resource planning, sustainable groundwater utilization, and long-term conservation of groundwater resources. Groundwater potential mapping has become an essential component of sustainable water resource management, particularly in regions experiencing increasing water demand and seasonal variations in rainfall. Accurate identification of groundwater-rich zones helps in locating suitable sites for borewell drilling, improving irrigation planning, reducing unnecessary drilling costs, and supporting artificial groundwater recharge measures. The use of modern geospatial and hydrogeological techniques enables researchers and planners to make informed decisions for the efficient utilization and conservation of groundwater resources. Geophysical techniques, particularly Vertical Electrical Sounding (VES), are useful for investigating subsurface formations and validating groundwater potential zones. The integration of GIS, AHP, and VES improves the accuracy of groundwater assessment and assists in identifying suitable locations for groundwater development.The present study focuses on the Anjarakandy River Basin in Kannur district, Kerala. The main objective is to delineate groundwater potential zones and estimate well yield using GIS-based well hydraulics analysis for sustainable groundwater management.

1.1 Groundwater and its importance

Groundwater is one of the most valuable freshwater resources and plays a vital role in supporting domestic, agricultural, industrial, and environmental needs. It serves as the primary source of drinking water for many rural and urban communities and contributes significantly to irrigation and economic development. In many parts of the world, especially in developing countries, groundwater is considered a reliable source of water because of its year-round availability and comparatively better quality than surface water. It also helps maintain the flow of rivers, lakes, and wetlands during dry seasons, thereby supporting ecological balance.

However, increasing population, rapid urbanization, climate change, and excessive groundwater extraction have resulted in declining groundwater levels and reduced aquifer recharge. In addition, factors such as land use changes, deforestation, and pollution from industrial and agricultural activities have further affected groundwater quality and availability. These issues pose serious challenges to water security and sustainable development.Therefore, effective groundwater assessment and management have become essential to ensure the sustainable utilization of this precious resource. The application of modern techniques such as Geographic Information System (GIS), Remote Sensing (RS), and geophysical investigations enables accurate identification of groundwater potential zones and supports scientific planning for groundwater conservation, recharge, and sustainable utilization.

1.2 GIS Based Groundwater Potential Mapping

Geographic Information System (GIS) has become an essential tool for groundwater potential mapping by integrating various spatial and non-spatial datasets. It enables the preparation, analysis, and visualization of thematic layers such as geology, geomorphology, slope, soil, drainage density, lineament density, land use/land cover (LULC), and rainfall, all of which influence groundwater occurrence and recharge. By combining these parameters, GIS helps in identifying areas with varying groundwater potential.

The use of GIS significantly improves the efficiency and accuracy of groundwater exploration compared to conventional methods. It allows large volumes of spatial data to be processed quickly and supports effective decision-making through map-based analysis. When integrated with multi-criteria decision-making techniques such as the Analytical Hierarchy Process (AHP), GIS can assign appropriate weights to different groundwater-controlling factors and generate reliable groundwater potential zone maps. These maps provide valuable information for groundwater exploration, well-site selection, artificial recharge planning, and sustainable management of groundwater resources.

2. METHODOLOGY

The procedure adopted to carry out a research study and achieve its objectives. It describes the methods and techniques used for data collection, data processing, analysis, and interpretation. A well-defined methodology ensures that the research is conducted in a logical, accurate, and reliable manner, allowing the results to be reproduced and validated. It provides a structured framework for conducting the research and ensures that every stage of the study is performed systematically. The selection of appropriate methods is essential for obtaining accurate and meaningful results that support the objectives of the study.In the present study, an integrated approach combining Geographic Information System (GIS), Analytical Hierarchy Process (AHP), Vertical Electrical Sounding (VES), and well hydraulics analysis was adopted to assess groundwater potential zones and estimate well yield. Various thematic layers influencing groundwater occurrence were prepared and analyzed in a GIS environment. The Analytical Hierarchy Process was used to assign weights to the thematic layers based on their relative importance, and a weighted overlay analysis was performed to generate the groundwater potential zone map. The GIS-generated results were validated using Vertical Electrical Sounding data, while well hydraulics analysis was carried out to estimate aquifer characteristics and well yield. The overall methodology adopted in this study provides a reliable, scientific, and cost-effective approach for groundwater exploration and sustainable groundwater resource management.

3.PREPARATION OF MAPS

The thematic maps were prepared for the Anjarakandy River Basin, located in Kannur district, Kerala, India, using Geographic Information System (GIS) techniques. The study area exhibits diverse geological formations, varying topography, different land use patterns, and a well-developed drainage network, all of which significantly influence groundwater occurrence and recharge. Spatial datasets required for the study were collected from reliable government organizations and satellite-based sources. These datasets were pre-processed, georeferenced, clipped to the study area boundary, and converted into suitable raster and vector formats using QGIS software. Each thematic layer was prepared individually to represent a specific groundwater-controlling factor. These thematic maps provide valuable spatial information regarding the hydrogeological characteristics of the watershed and form the basis for groundwater potential zone mapping. The integration of multiple thematic layers allows a better understanding of the spatial variability of groundwater resources and improves the accuracy of groundwater potential assessment.

The geology map was prepared to identify the different lithological formations present within the study area. Geological formations strongly influence groundwater occurrence because they determine the porosity, permeability, weathering characteristics, and storage capacity of rocks. Rocks with higher porosity and permeability allow greater infiltration and groundwater movement, whereas compact rocks restrict groundwater flow. Weathered and fractured rock formations generally possess high groundwater potential because they provide interconnected pathways for groundwater storage and movement. Therefore, geology is considered one of the most influential parameters in groundwater exploration and groundwater potential mapping.

The geomorphology map was prepared to identify various landforms such as valley fills, flood plains, pediments, structural hills, denudational hills, and plateaus. Geomorphological features directly control infiltration, runoff, groundwater recharge, and subsurface water movement. Valley fills and flood plains generally consist of unconsolidated sediments with high infiltration capacity and therefore exhibit excellent groundwater potential. Pediments provide moderate groundwater storage due to the presence of weathered materials. In contrast, structural hills and elevated terrains promote rapid runoff, resulting in comparatively lower groundwater recharge. Thus, geomorphology plays an important role in identifying favourable groundwater-bearing zones.

The slope map was generated from the Digital Elevation Model (DEM) to represent the terrain characteristics of the watershed. Slope controls the movement of surface runoff and the infiltration of rainwater into the ground. Gentle slope areas allow rainwater to remain on the surface for a longer duration, thereby increasing infiltration and groundwater recharge. Moderate slopes provide average recharge conditions, whereas steep slopes accelerate runoff, reduce infiltration, and decrease groundwater storage. Therefore, regions with low slope values generally exhibit higher groundwater potential compared to regions with steep terrain.

The Land Use/Land Cover map was prepared to assess the influence of different land cover types on groundwater recharge and water conservation. Different land use categories exhibit different infiltration characteristics. Agricultural land, plantations, forests, and water bodies generally promote groundwater recharge by allowing greater infiltration of rainwater into the soil. Vegetation also reduces soil erosion and surface runoff, thereby improving groundwater recharge. On the other hand, built-up areas, roads, and barren lands reduce infiltration because of impervious surfaces, leading to increased runoff and reduced groundwater recharge. Hence, LULC is an essential parameter in groundwater potential mapping.

The drainage density map was prepared from the drainage network extracted for the study area. Drainage density represents the total length of streams and rivers per unit area and reflects the runoff characteristics of the watershed. Areas with low drainage density usually indicate permeable soil and rock formations that favour groundwater infiltration and recharge. In contrast, areas with high drainage density indicate impermeable surfaces and rapid surface runoff, resulting in lower groundwater recharge. Therefore, drainage density serves as an important hydrological indicator for evaluating groundwater potential and identifying recharge zones.

Fig 1 – study area

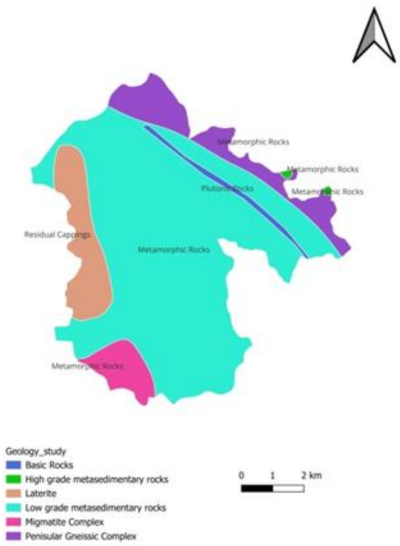

Fig 2 – geology map

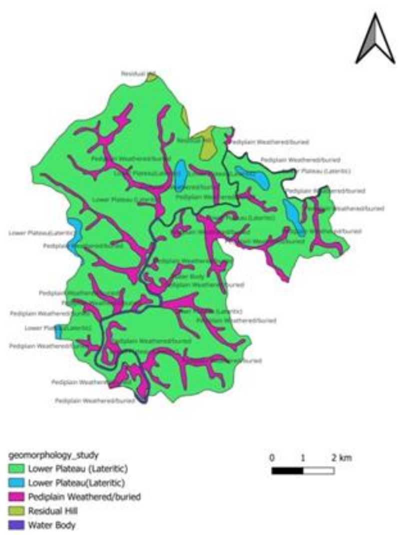

Fig 3 – geomorphology map

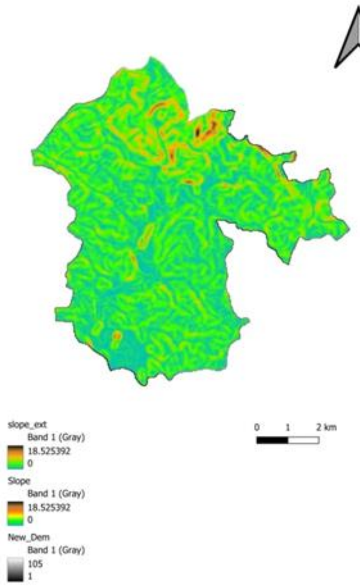

Fig 4 – slope map

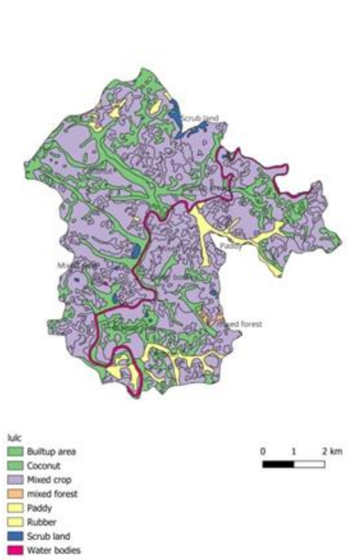

Fig 5 – lulc map

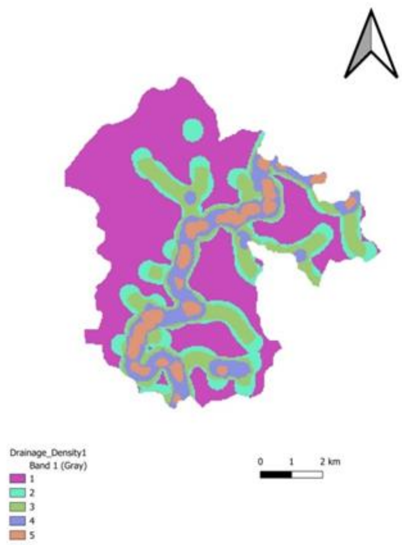

Fig 6 – drainage density map

4.ANALYSIS OF AHP

The Analytical Hierarchy Process (AHP) is a widely used Multi-Criteria Decision-Making (MCDM) technique developed by Thomas L. Saaty for solving complex decision-making problems involving multiple criteria. In groundwater potential mapping, AHP provides a systematic and scientific approach for evaluating the relative importance of different groundwater-controlling factors. Since groundwater occurrence depends on several interrelated parameters, it is essential to assign appropriate weights to each thematic layer according to its influence on groundwater recharge and storage. AHP facilitates this process by comparing each criterion with every other criterion using a pairwise comparison matrix, thereby reducing subjectivity in decision-making. In the present study, AHP was employed to determine the relative importance of the thematic layers, namely geology, geomorphology, slope, land use/land cover (LULC), and drainage density. These factors were selected because they significantly influence groundwater occurrence, infiltration, runoff, and aquifer recharge within the Anjarakandy River Basin. Each thematic layer was carefully evaluated based on its hydrogeological significance before assigning weights. The first step of the AHP analysis involved the preparation of a pairwise comparison matrix, in which each thematic layer was compared with every other layer based on its relative influence on groundwater potential. The comparison was carried out using Saaty's nine-point fundamental scale, where a value of 1 indicates equal importance, 3 indicates moderate importance, 5 indicates strong importance, 7 indicates very strong importance, and 9 indicates extreme importance. Intermediate values of 2, 4, 6, and 8 were used whenever the importance of one parameter lay between two adjacent scales. The reciprocal values were assigned when one parameter was considered less important than another. This systematic comparison ensured that all thematic layers were evaluated consistently and objectively. After constructing the pairwise comparison matrix, the values were normalized by dividing each element by the sum of its respective column. The normalized matrix was then used to calculate the priority weight of each thematic layer by averaging the normalized values across each row. These priority weights represent the relative contribution of each parameter to groundwater occurrence and were subsequently used in the weighted overlay analysis. To verify the reliability of the assigned weights, the Consistency Index (CI) and Consistency Ratio (CR) were calculated. The consistency test ensures that the pairwise comparisons are logically consistent and free from significant judgmental errors. A Consistency Ratio (CR) less than 0.10 indicates that the comparisons are acceptable and that the assigned weights are reliable for further analysis. If the CR exceeds 0.10, the pairwise comparison matrix should be revised until an acceptable consistency level is achieved. After obtaining the final weights, each thematic map was reclassified into different classes based on its contribution to groundwater occurrence. Suitable ranking values were assigned to each class according to its groundwater recharge potential. The weighted thematic layers were then integrated using the Weighted Overlay Analysis tool in the GIS environment. During this process, each thematic layer contributed to the final groundwater potential map according to its assigned weight, while each class contributed according to its ranking value. The weighted overlay analysis resulted in the generation of the Groundwater Potential Zone (GWPZ) map, which classified the study area into different groundwater potential categories such as very low, low, moderate, high, and very high groundwater potential. The generated map was subsequently validated using Vertical Electrical Sounding (VES) data and well hydraulics analysis. The integration of AHP with GIS significantly improved the accuracy and reliability of groundwater potential mapping by incorporating the influence of multiple hydrogeological factors in a systematic and scientifically justified manner.

Table 1 – AHP Nomralized pair wise matrix for GPZ

Criteria	Geomorphology (GM)	Geology (GL)	Slope (SL)	Drainage Density (DD)	LULC (LU)	Weightage
Geomorphology (GM)	1	2	3	5	5	37
Geology (GL)	1/2	1	2	3	4	24
Slope (SL)	1/3	1/2	1	2	3	17
Drainage Density (DD)	1/5	1/3	1/2	1	2	10
LULC (LU)	1/5	1/4	1/3	1/2	1	9

4.1.Vertical Electrical Sounding (VES)

Vertical Electrical Sounding (VES) is a widely used geophysical technique for groundwater exploration. It is based on the principle that different subsurface materials have different electrical resistivity values depending on their lithology, porosity, moisture content, and groundwater saturation. By measuring the variation in electrical resistivity with depth, VES helps identify groundwater-bearing formations, aquifer thickness, and subsurface geological conditions. It is a reliable, economical, and non-destructive method for groundwater investigation.In the present study, the VES survey was conducted at selected locations in the Anjarakandy River Basin to validate the groundwater potential zones identified through GIS analysis. The Half-Schlumberger electrode configuration was adopted for the field survey, where the spacing between the current electrodes was gradually increased to investigate greater depths. Apparent resistivity values were measured at different electrode spacings and recorded for further interpretation.The obtained resistivity data were analyzed to identify different subsurface layers and groundwater-bearing formations. Low to moderate resistivity values generally indicate weathered and fractured formations with good groundwater potential, whereas high resistivity values represent hard and compact rocks with comparatively lower groundwater potential. The interpreted VES results were compared with the GIS-generated groundwater potential map, and the results showed good agreement.

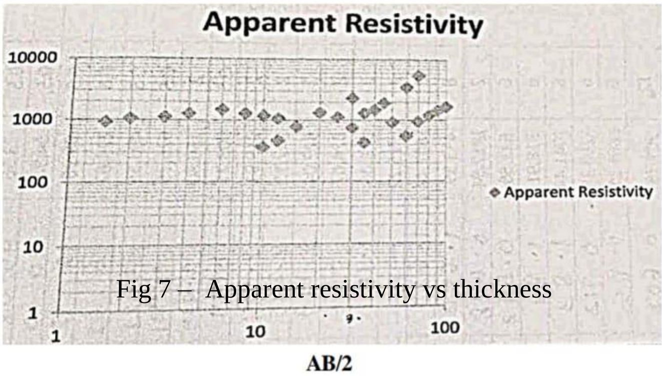

Fig 7 – Apparent resistivity vs thickness

4.1. Well yield estimation

Well yield estimation is an important part of groundwater assessment, as it determines the amount of groundwater that can be safely extracted from an aquifer. It helps evaluate the productivity of wells and provides useful information for groundwater development, irrigation planning, and sustainable water resource management.In this study, well yield estimation was carried out using field observations and well hydraulics principles. Data from selected wells in the Anjarakandy River Basin were collected and analyzed to evaluate groundwater availability. Hydraulic parameters such as discharge, drawdown, hydraulic conductivity, and transmissivity were considered to assess the performance of the aquifers.The estimated well yield values were compared with the groundwater potential zones generated using GIS and AHP analysis. Wells located in high groundwater potential zones generally showed higher yield and better aquifer performance, while wells in moderate and low potential zones produced comparatively lower yields. This comparison verified the accuracy of the groundwater potential map and demonstrated the effectiveness of the integrated methodology.

4.3 Results and discussions

The groundwater potential assessment of the Anjarakandy River Basin was carried out by integrating thematic layers, including geology, geomorphology, slope, land use/land cover (LULC), and drainage density, using the Analytical Hierarchy Process (AHP) and weighted overlay analysis in a GIS environment. The generated groundwater potential zone map classified the study area into Very Low, Low, Moderate, High, and Very High groundwater potential zones based on the combined influence of the selected parameters. The results indicate that areas characterized by favourable geological formations, valley fills, gentle slopes, agricultural land, and low drainage density exhibit higher groundwater potential due to increased infiltration and recharge. In contrast, regions with steep slopes, compact rock formations, built-up areas, and high drainage density showed comparatively lower groundwater potential because of increased surface runoff and limited infiltration. The groundwater potential map was validated using Vertical Electrical Sounding (VES) conducted at selected locations, and the interpreted resistivity values confirmed the presence of weathered and fractured aquifer formations in areas identified as having high groundwater potential. Furthermore, well yield estimation based on well hydraulics analysis indicated that wells located in high and very high groundwater potential zones produced comparatively greater discharge and better aquifer performance than wells situated in moderate and low potential zones. The close agreement between the GIS analysis, VES interpretation, and well yield estimation demonstrates the reliability of the integrated methodology. The study confirms that the combined application of GIS, AHP, geophysical investigation, and well hydraulics analysis provides an accurate and scientific approach for groundwater exploration, suitable well-site selection, groundwater recharge planning, and sustainable groundwater resource management in the Anjarakandy River Basin.

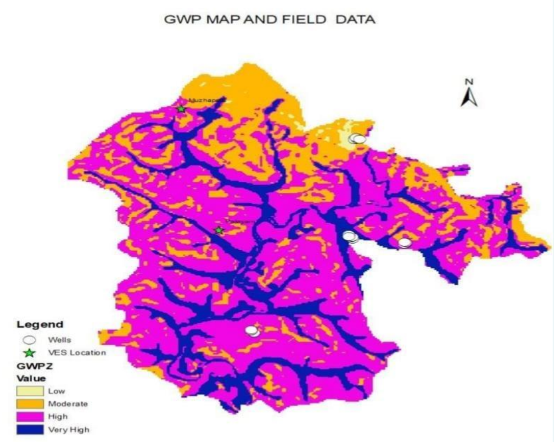

Fig 8 – Final Ground water potential zone map

5.CONCLUSION

The present study successfully assessed the groundwater potential zones of the Anjarakandy River Basin by integrating Geographic Information System (GIS), the

Analytical Hierarchy Process (AHP), Vertical Electrical Sounding (VES), and well hydraulics analysis. The thematic layers, including geology, geomorphology, slope, land use/land cover (LULC), and drainage density, were effectively integrated using the weighted overlay technique to generate the groundwater potential zone map. The generated map classified the study area into different groundwater potential zones and identified suitable locations for groundwater exploration and development.Validation using VES confirmed the presence of favourable groundwater-bearing formations in areas identified as having high groundwater potential, while well yield estimation demonstrated that wells located in these zones exhibited better aquifer performance and higher groundwater productivity. The close agreement between the GIS analysis, geophysical investigation, and field observations confirms the reliability and accuracy of the adopted methodology.The study demonstrates that the integration of geospatial techniques with hydrogeological investigations provides a scientific, cost-effective, and reliable approach for groundwater assessment. The generated groundwater potential map can serve as a valuable tool for groundwater exploration, scientific well-site selection, artificial recharge planning, irrigation management, and sustainable groundwater resource management in the Anjarakandy River Basin. The findings of this study highlight the importance of combining spatial analysis, geophysical methods, and field-based investigations to improve the accuracy of groundwater exploration and aquifer evaluation.Furthermore, the methodology adopted in this study can be applied to other watersheds with similar hydrogeological conditions to support efficient groundwater planning and long-term water resource conservation. The results of this research provide useful information for engineers, planners, and policymakers in formulating strategies for sustainable groundwater development and effective management of water resources. Continuous monitoring and the adoption of advanced geospatial technologies can further enhance groundwater assessment and contribute to the conservation of this valuable natural resource for future generations.

REFERENCES

[1] Abijith, D., Saravanan, S., Singh, L., Jacinth, J. J., Saranya, T., & Parthasarathy, K. S. S. (2020). GIS-based multi-criteria analysis for identification of potential groundwater recharge zones: A case study from Ponnaniyaru watershed, Tamil Nadu, India.

[2] Ahmed, A., et al. (2024). Application of AHP and GIS in groundwater potential mapping.

[3] Arunbose, S., Srinivas, Y., Rajkumar, S., Nair, N. C., & Kaliraj, S. (2021). Remote sensing, GIS and AHP techniques-based investigation of groundwater potential zones in the Karumeniyar River Basin, Tamil Nadu, Southern India.

[4] Arunbose, Y., Srinivas, Y., Rajkumar, S., Nair, N. C., & Kaliraj, S. (2021). Remote sensing, GIS and AHP techniques-based investigation of groundwater potential zones.

[5] Bera, A., Mukhopadhyay, B. P., Chowdhury, P., Ghosh, A., & Biswas, S. (2021). Groundwater vulnerability assessment using GIS-based DRASTIC model in Nangasai River Basin, India with special emphasis on agricultural contamination.

[6] Bhuvaneswaran, C., & Ganesh, A. (2020). Spatial assessment of groundwater vulnerability using DRASTIC model with GIS in Uppar Odai sub-watershed, Cauvery Basin, Tamil Nadu.

[7] Krishna Kumar, S., Ahmed, S. A., Karkala, J., & Kumar, S. (2025). Assessing the potential of hard rock terrain to store groundwater using AHP techniques in the Vedavathi River Basin, India.

[8] Lavanya, M., & Muthukumar, M. (2024). AHP and geospatial technologies for identifying groundwater exploration target regions in Dindigul, Southern India.

[9] Navaneeth, A., Sreeda, P., Vishnu Maya, T. M., Surendran, U., & Harikumar, P. S. (2024). Unlocking sustainable groundwater governance in secondary cities: Lessons from the assessment of groundwater vulnerability in a coastal city of India.

[10] Rashid, M., et al. (2012). Integrated approach for groundwater potential mapping using GIS and remote sensing.