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RESEARCH ARTICLE

Integration of Remote Sensing, GIS, and AHP for Groundwater Potential Evaluation in İzmit, Türkiye

Abdirahman Mohamed Mohamud[1*], Ahmet Karakaş[2], Tekin Yeken[3], Şerafeddin Çakir[4]

[1, 3]Kocaeli University, Faculty of Engineering, Department of Geophysical Engineering, Izmit, Türkiye

[2, 4]Kocaeli University, Faculty of Engineering, Department of Geological Engineering, Izmit, Türkiye

ABSTRACT

This study presents the first systematic assessment of groundwater potential in İzmit, Türkiye, using an integrated approach combining Remote Sensing (RS), Geographic Information Systems (GIS), and the Analytic Hierarchy Process (AHP). Seven key factors geology, lineament density, slope, drainage density, land use/land cover, soil type, and rainfall were evaluated to delineate Groundwater Potential Zones (GWPZ). The analysis classified the study area into three potential categories: high (74 km², 16%), moderate (311 km², 66%), and low (88 km², 18%). High-potential zones were predominantly associated with permeable lithologies, dense lineament networks, and gentle slopes, whereas low-potential zones corresponded to impermeable formations, steep slopes, and urbanized areas. Geology and lineament density emerged as the most influential factors controlling groundwater distribution. The predictive capability of the model was confirmed with an AUC value of 0.756, demonstrating reliable performance. These results provide a scientifically validated tool for groundwater management, supporting sustainable extraction, targeted recharge initiatives, and conservation strategies in İzmit.

Keywords: Drainage Density, Geology, Groundwater Potential, Land use Land cover, lineament density, Remote sensıng.

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INTRODUCTION

Groundwater is a vital global resource, particularly in arid and drought-prone regions where it frequently represents the sole dependable source of domestic consumption, irrigation, and industrial use (1). Its importance has steadily grown over the decades due to the rising global population, intensified agricultural practices, and rapid urbanization. However, the combined impacts of climate change, erratic precipitation patterns, and unsustainable exploitation have placed severe stress on groundwater reserves, resulting in alarming depletion rates and challenges in water availability in many regions (2). As surface water resources continue to shrink and suffer degradation due to overuse, reliance on groundwater has become not only a necessity but also a critical factor in sustaining socio-economic development. Advances in geospatial technologies have significantly transformed water resource assessment. Remote sensing techniques, in particular, have emerged as indispensable tools for monitoring land surface dynamics, environmental change, and hydro-meteorological variability, providing valuable data that were previously difficult to obtain through conventional field methods (3). In addition, the distribution and availability of groundwater are not uniform; they are governed by a complex interplay of natural and anthropogenic factors including geomorphology, land use, topography, lithology, and climatic conditions, which collectively influence recharge, storage, and the movement of subsurface water (4). Recognizing these interdependencies is fundamental to delineating areas with higher groundwater potential and planning sustainable utilization strategies. In this regard, the integration of Remote Sensing and

Geographic Information Systems (GIS) with decision-support frameworks such as the Analytic Hierarchy Process (AHP) has proven to be an effective and scientifically robust approach for the delineation of Groundwater Potential Zones (GWPZ) (5). Previous studies applying similar methodologies have demonstrated their effectiveness in various regions. For instance, Aykut (2021) determined groundwater potential zones using GIS and AHP in northwestern Turkey, providing a systematic framework for weighting environmental parameters and validating the results with well data (6). Çelik, Kuşak, and Yakar 2024 applied GIS-based AHP along with multi-criteria decision-making techniques to assess groundwater potential in Mersin, Türkiye, showing the applicability of integrating multiple decision-support tools (7). Aslan 2024 combined GIS, AHP, and Fuzzy-AHP methods to identify groundwater potential zones in the Van Basin, demonstrating enhanced precision in heterogeneous terrains (8). Similarly, Ahmadi et al. 2020 employed GIS-based AHP and FR models in central Antalya to produce high-resolution groundwater potential maps, emphasizing the importance of multi-criteria weighting (9). These Turkish studies collectively provide a methodological foundation that can be adapted and applied to İzmit, ensuring scientific rigor and reproducibility. While numerous studies have assessed groundwater potential in other regions globally (10, 11, 12, 13, 14, 15, 16). No research to date has applied the combination of Remote Sensing, GIS, and AHP specifically to İzmit, Türkiye. This study addresses this research gap by considering the unique hydrogeological characteristics, land use patterns, and rapid urban expansion of İzmit, which significantly influence recharge zones and subsurface flow. Therefore, this study represents the first application of GIS, Remote Sensing, and AHP techniques for groundwater potential mapping in İzmit, building upon the established Turkish methodologies while providing original insights relevant to sustainable groundwater management. The final maps are intended to guide policymakers and water resource managers in identifying areas with higher groundwater potential and optimizing resource allocation in İzmit district.

2.MATERIALS AND METHODS

2.1 Study Area

İzmit is a rapidly urbanizing and industrial city in northwestern Türkiye, located along the Sea of Marmara (40°45′–40°55′ N, 29°55′–30°10′ E). The region faces rising water demand due to population growth, heavy industrialization, and agricultural needs. Groundwater is a critical resource, but overexploitation and pollution threaten its sustainability. The area's varied topography includes coastal plains, hills, and fractured aquifers, which influence groundwater recharge potential. Climate variability further stresses water availability, necessitating precise identification of groundwater zones. This study focuses on İzmit to support sustainable groundwater management using GIS, remote sensing, and AHP techniques.

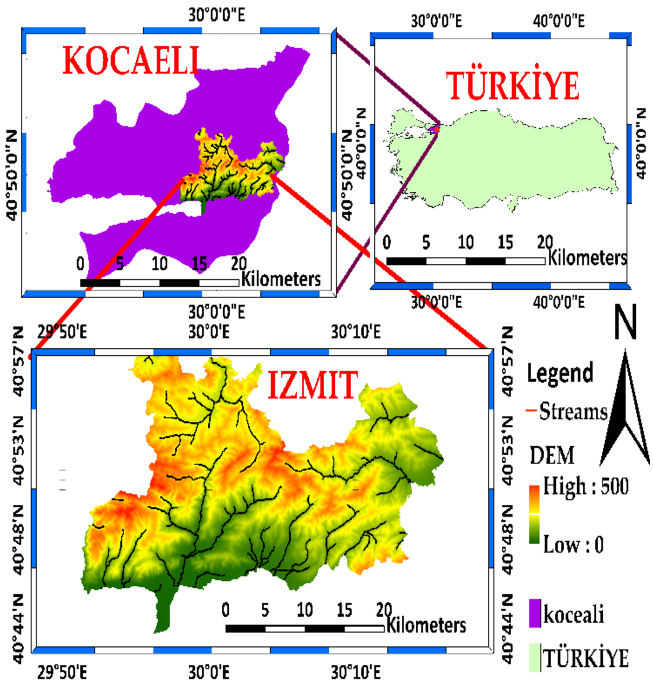

Figure 1. Locational map of Izmit district

2.2 Data Sources and Software Tools

This study integrated multiple geospatial datasets for groundwater potential assessment. Topographic data from USGS SRTM (30 m resolution), climate records from CRU, and soil properties from FAO databases were combined with land cover classification (10m Sentinel-2 imagery) and geological maps from Turkey's MTA. Lineament density extraction was exclusively performed using PCI Geomatica 2018, while all other spatial analyses including data processing, modeling, and mapping were conducted in ArcGIS 10.7. Model validation involved comparison of well yield data with groundwater potential zones, demonstrating satisfactory predictive accuracy (ROC AUC = 0.7). All datasets were standardized to WGS84 UTM Zone 35N coordinate system at 30m resolution.

Table 1. Sources of data used in İzmit Area

Data Type	Source of Data	Type of Data	Reference
STRM DEM	USGS	Raster 30m	earthexplorer.usgs.gov
Rainfall	CRU	Raster 30m	crudata.uea.ac.uk
Soil	FAO	Vector	fao.org/soils-portal
LULC	Sentinel-2	Raster 10m	sentinel.esa.int
Geological data	MTA	Vector	harita.mta.gov.tr
Well locations	Erdoğan Topçuoğlu (2022)	ROC validation	Hydrogeological Investigation and Groundwater Flow Modeling of the Izmit Basin (Ph.D. Thesis, Thesis No: 744383) (17).

Table 2. Scale of comparative importance proposed by Saaty (18)

Importance Value	Explanation
One	Both factors have identical influence
Three	One factors is noticeably favored
Five	One factor is clearly more influential
Seven	Nearly conclusive dominance
Nine	Complete dominance
Two, Four, Six, Eight	Balanced importance

Table3. Pairwise Comparison Matrix of Factors for groundwater Potential Assessment

Factor	Geology	Slope	LULC	Rainfall	Drainage Density	Lineament Density	Soil	Weights (Priority Vector)
Geology	1	1	3	5	5	5	7	32.48%
Lineament Density	1	1	3	3	5	5	5	28.86%
LULC	1/3	1/3	1	1	3	3	5	13.57%
Rainfall	1/5	1/3	1	1	1	2	3	9.33%
Drainage Density	1/5	1/5	1/3	1	1	1	3	6.83%
Slope	1/5	1/5	1/3	1/2	1	1	1	5.14%
Soil	1/7	1/5	1/5	1/3	1/3	1	1	3.79%

2.3 Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) was applied to assign relative weights to the seven thematic layers influencing groundwater potential: geology, lineament density, land use/land cover (LULC), rainfall, drainage density, slope, and soil. Pairwise comparisons were conducted based on expert knowledge and literature, and the resulting matrix was normalized to produce the final weights (Table 3).Geology received the highest weight (32.48%), followed by lineament density (28.86%), indicating their dominant role in groundwater occurrence. Soil had the lowest weight (3.79%), reflecting its limited influence in the study area. The consistency of the matrix was tested using the Consistency Index (CI) and Consistency Ratio(CR), calculated using the following equations: $CI=(\lambda max-n)/(n-1)$ and $CR= CI/RI$ Where $n = 7$ and $RI = 1.32$. The calculated values ($\lambda max = 7.12$, $CI = 0.02$, $CR = 0.03$) confirmed that the comparisons were consistent since $CR<0.10$.

Clarification**:** DEM= Digital Elevation Model LULC= Land Use/Land Cover.

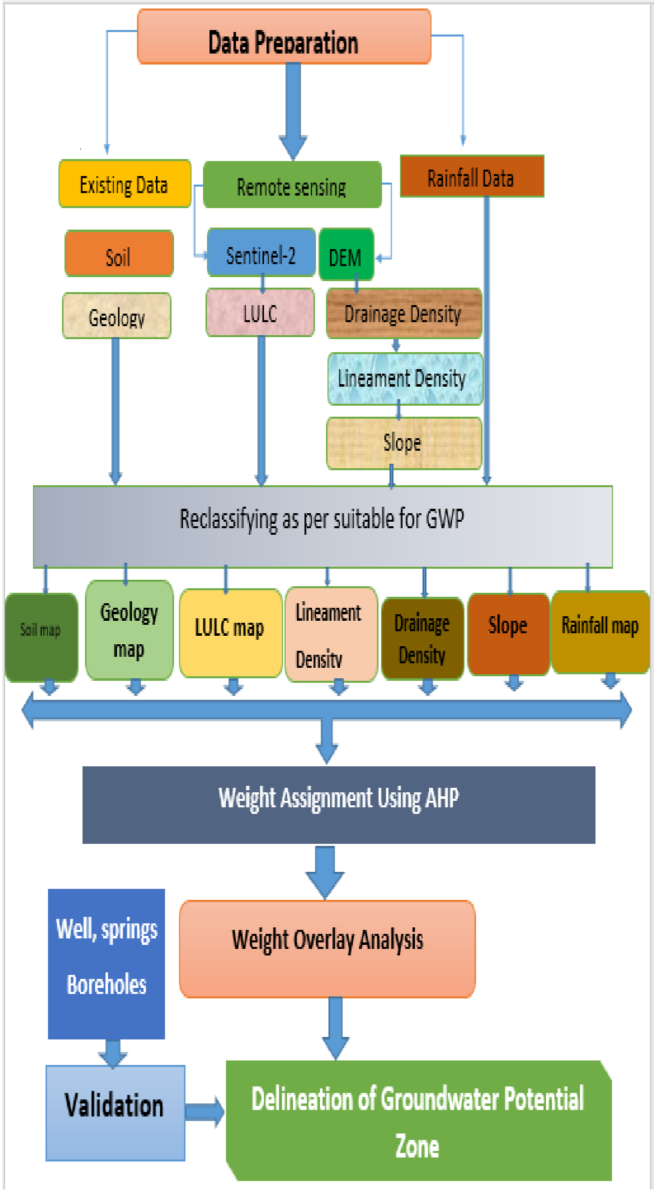

Figure 2. Study area Workflow showing groundwater potential zone analysis for İzmit District.

3. Results and Discussion

3.1 Drainage Density

The study linked drainage density to groundwater potential, finding that low-density areas favor recharge (higher potential) due to reduced runoff, whereas high density zones indicate lower potential owning to rapid drainage. It classified density into low, moderate, and high for GIS-based analysis.

This factor was weighted with other layers (e.g., slope, geology) in AHP to map groundwater zones (19). The drainage density (DD) in our study area ranges between 0 and 2.5 km/km², also divided into five classes. Low DD values (0–0.5 km/km²) indicate areas with high infiltration capacity and favorable groundwater recharge**,** as surface runoff is minimal and water has more time to percolate. On the other hand**,** high DD values (2.0–2.5 km/km²) suggest poor infiltration and high surface runoff**,** making these areas less suitable for groundwater accumulation. Moderate DD values reflect balanced conditions between runoff and infiltration.

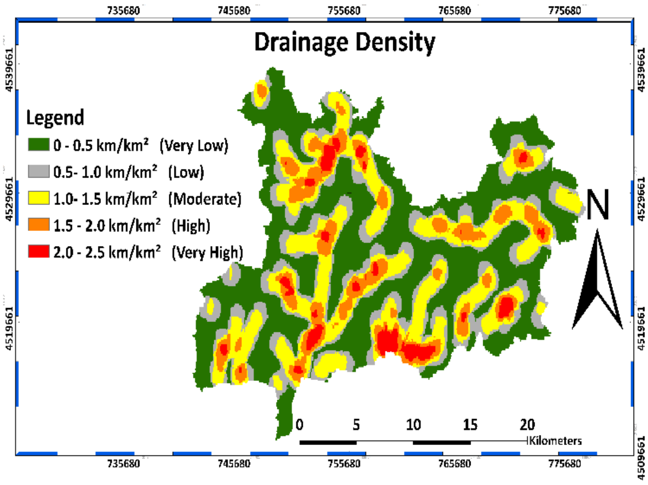

Figure 3.Drainage density map

3.2 Geology

The geological framework of any area is a key determinant in assessing groundwater potential, since it governs the porosity and permeability of underlying rock formations. Highly porous and permeable units, such as sandstones and fractured limestones, generally provide favorable conditions for groundwater storage and tend to produce higher well yields. In contrast, low-permeability rocks, including many volcanic, metamorphic, and certain sedimentary types, restrict the movement of water and are therefore considered poor aquifer materials(20).The geological characteristics of the İzmit study area exert a fundamental control on the distribution and availability of groundwater resources. Formations and units such as Recent Alluvium, Older Alluvium, Coastal Fill, and Arslanbey exhibit excellent zones due to their unconsolidated or loosely consolidated properties, which enhances porosity and permeability, thereby facilitating significant groundwater recharge and storage. In contrast, formations including Akveren, İzmit, Gözdağ, and Aydos are categorized as having moderate groundwater potential. These units are generally composed of semi-permeable sedimentary rocks, which allow limited infiltration and moderate aquifer development. On the other hand, Korucu, Peksimet, Acisu Formations and Tertiary Volcanics are considered to have low groundwater potential, because they are made up of compact and less permeable rocks which prevent groundwater from easily passing through or being stored. This geological framework plays a pivotal role in delineating the groundwater potential zones within the study area and underscores the importance of lithological variation in hydrogeological assessments.

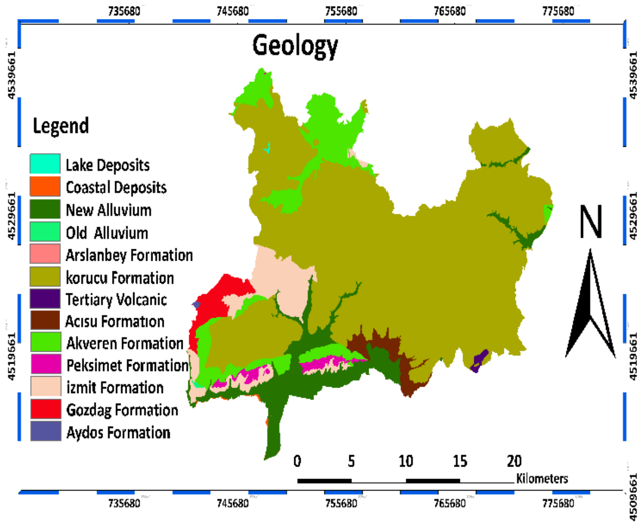

Figure 4. Geological map

3.3 Soil Classification

Soil distribution in a region is shaped by geomorphology, geology, and relief. Its permeability, influenced by infiltration, runoff, and soil properties, is a key factor in groundwater potential. FAO classifications show that the basin contains soil types affecting recharge.

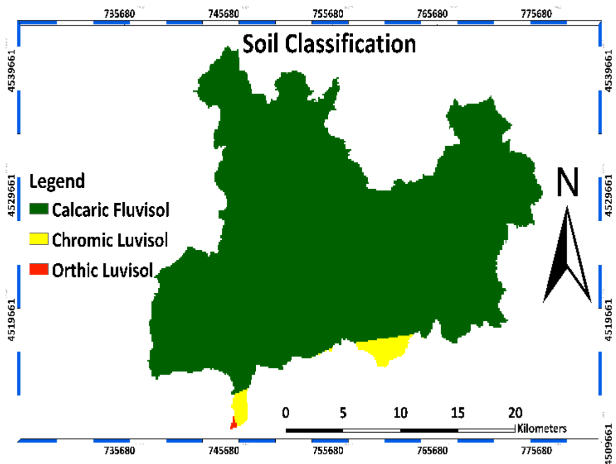

Figure 5. Soil classification map

3.4 Slope

Slope is one of the key geomorphological parameters influencing groundwater potential. It significantly affects water infiltration and the likelihood of groundwater recharge when considered alongside other terrain features (21). In the study area, slopes of less than 5 degrees cover approximately 18,007 km² (89.50%), indicating a generally flat or gently sloping terrain. Such conditions typically support higher infiltration rates and thus indicate strong potential for groundwater accumulation. Areas with slopes ranging between 5–8 degrees make up around 879 km² (9.30%), representing moderately inclined surfaces with moderate infiltration capacity. Slightly steep slopes between 9–20 degrees account for 195 km² (0.95%) of the land, while steeper areas exceeding 20 degrees occupy only 50 km² (0.25%). These steeper zones are less favorable for infiltration due to faster runoff, thereby offering limited groundwater recharge potential.

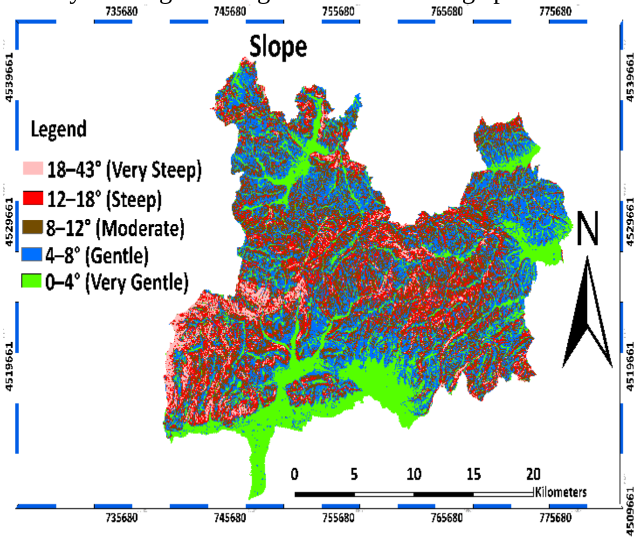

Figure 6. Slope map

3.5 Rainfall Distribution

Rainfall plays a crucial role in the hydrologic cycle as it directly influences groundwater potential. Being the primary source of both surface and groundwater in the study area, the amount and spatial distribution of rainfall strongly determine the basin's recharge capacity, as highlighted by numerous researchers (23).The study employed a geospatial approach to assess rainfall distribution patterns using annual precipitation data from 2012 to 2022. The kriging interpolation method was applied to generate a continuous rainfall surface, which was subsequently classified into five distinct categories: very low(7,479.92–7,965.20 mm), low (7,965.2–8,070.92 mm), moderate (8,070.92– 8,184.57 mm), high (8,184.57–8,316.73 mm), and very high (8,316.73–8,533.46 mm). These rainfall zones were integrated with slope characteristics and drainage density data within a GIS framework to delineate areas with high hydrological potential. Groundwater recharge is primarily controlled by rainfall, where increased precipitation significantly enhances recharge potential, while low rainfall restricts it.

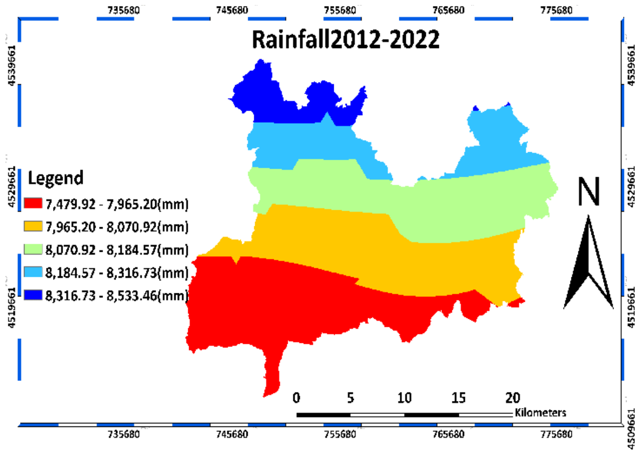

Figure 7. Rainfall map

3.6 Land use Land cover

The Assessment of groundwater potential is strongly

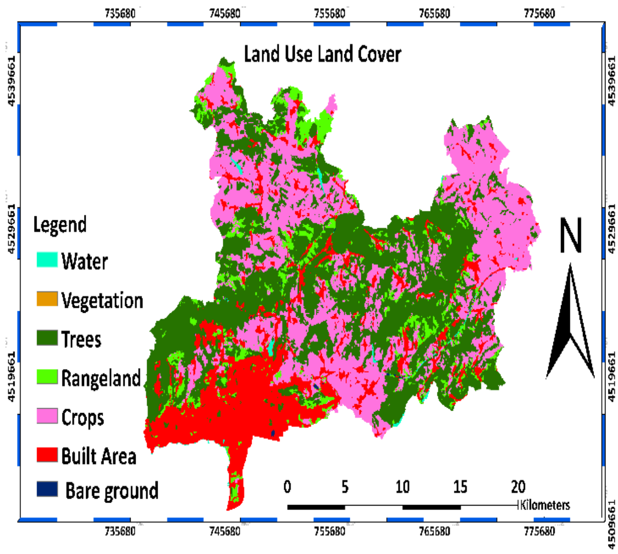

Figure 8. Land use land cover map

dependent on land use and land cover, which control the spatial distribution of recharge and influence the hydrological behavior of the basin. (22, 24, 25).The study area's LULC, derived from 2023 Sentinel-2 data, includes seven types. Vegetation, trees, grass, crops enhance groundwater recharge. Built-up and bare lands hinder infiltration, negatively affecting recharge zones.

3.7 Lineament Density

Lineament density is the quantity of linear geological structures on the surface that are expressions of underlying geological structures, such as faults and fractures. (22).Lineament density in the study area ranges from 0 to 3.2 km/km² and is divided into five classes. Very high densities (2.6–3.2 km/km²) indicate excellent groundwater potential, moderate densities (1.3–1.9 km/km²) suggest moderate potential, and low densities (0–0.6 km/km²) correspond to limited groundwater prospects.

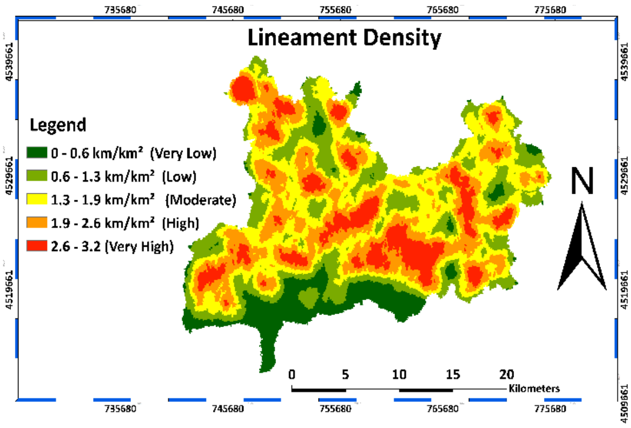

Figure 9. Lineament density map

3.8 Groundwater Prospectively Mapping

İzmit district was determined through integrated analysis of seven different factors, geology, lineament density, slope, drainage density, and land use/land cover, soil classification. The high- potential zones (74 km², 16%) predominantly occur within the Yeni and Old Alluvium units, where high permeability coincides with dense lineament networks (>1.5 km/km²), gentle slopes (<5°), and optimal drainage density (0.5–1.0 km/km²). These areas are further characterized by favorable LULC types (vegetated/agricultural land) that enhance infiltration. Moderately potential areas (310 km², 66%) typically overlay the Akveren andzmit formations, exhibiting moderate lineament density (1.0–1.5 km/km²), steeper slopes (5–20°), and mixed LULC patterns. The low-potential zones (88 km², 18%) correlate strongly with the Aydos Formation and Tertiary Volcanics, where poor geological permeability combines with scattered lineaments (<0.5 km/km²), steep slopes (>20°), high drainage density (>2.0 km/km²), and impervious LULC (urban/bare rock).

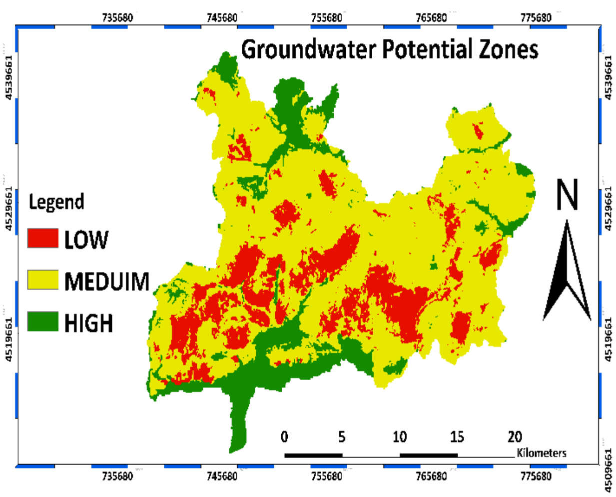

Figure 10. Groundwater potential zones in İzmit

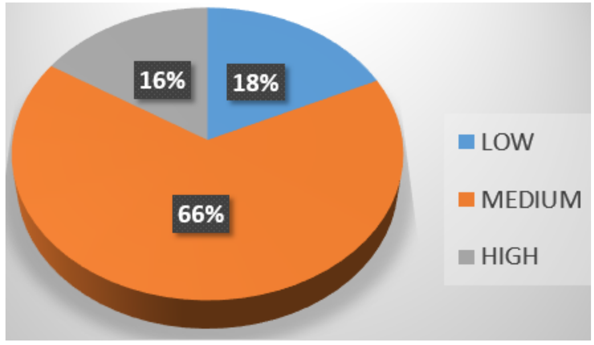

Figure 11. Distribution of GWPZ across the study area

This study delineated groundwater potential zones (GWPZ) in İzmit using an integrated approach combining Remote Sensing, Geographic Information Systems (GIS), and the Analytic Hierarchy Process (AHP). The results revealed spatial variations in groundwater potential across the district, largely influenced by geological formations, land use/land cover, soil type, slope, drainage density, lineament density, and precipitation patterns. Areas classified as having high groundwater potential were generally associated with permeable lithological units, lower slopes, and regions with moderate recharge potential. Conversely, zones with poor potential corresponded to impervious geological formations, steep slopes, and densely urbanized areas. When comparing these results with previous Turkish studies, clear similarities and distinctions emerge. Aykut 2021 applied GIS and AHP in northwestern Turkey and emphasized the importance of weighting environmental parameters to delineate GWPZ systematically (6). Similarly, Çelik et al. 2024 assessed groundwater potential in Mersin using GIS-based AHP and multi-criteria decision-making techniques, highlighting the utility of integrating multiple environmental factors (7). Aslan 2024 demonstrated the effectiveness of combining GIS, AHP, and Fuzzy-AHP in the Van Basin, particularly for heterogeneous terrains (8). Ahmadi et al. 2020 employed GIS-based AHP and FR models in central Antalya, producing high-resolution groundwater potential maps and reinforcing the importance of multi-criteria evaluation in groundwater studies (9).Building upon these foundational studies, this research provides the first application of GIS, Remote Sensing, and AHP for groundwater potential mapping specifically in İzmit. Notably, İzmit's rapid urban expansion and significant population growth have introduced additional stress on groundwater resources, affecting recharge zones and subsurface water flow. The analysis revealed that urbanized sectors, characterized by impermeable surfaces and dense construction, generally correspond to areas with low groundwater potential, whereas peri-urban and rural sectors exhibited higher potential due to natural recharge capacity. The findings underscore the practical implications for water resource management in İzmit. Identifying high-potential zones allows for targeted groundwater development and sustainable extraction practices, whereas recognizing low-potential areas can guide urban planning and conservation measures. Moreover, the study highlights the critical interplay between hydrogeological conditions and anthropogenic pressures, emphasizing the need for integrating scientific mapping techniques with policy and management strategies. Overall, this study not only validates the applicability of GIS, Remote Sensing, and AHP for groundwater potential assessment in Turkish contexts but also provides an original contribution by addressing the unique hydrogeological and socio-economic characteristics of İzmit. By comparing the findings with prior Turkish research, the study reinforces methodological rigor while demonstrating the necessity of localized assessments to guide sustainable groundwater utilization in rapidly growing urban regions.

3.9 Validation

ROC curve analysis was used to determine the accuracy of the groundwater potential map, with the AUC value indicating model performance; a score of 1.0 reflects ideal prediction, while 0.5 indicates random output. We adopted the classification framework of Naghibi et al. (22) to interpret results: Excellent (0.9-1.0), Very Good (0.8-0.9), Good (0.7-0.8), Satisfactory (0.6-0.7), and Unsatisfactory (0.5-0.6).This standardized approach enables objective performance assessment and comparison with similar hydrological studies.

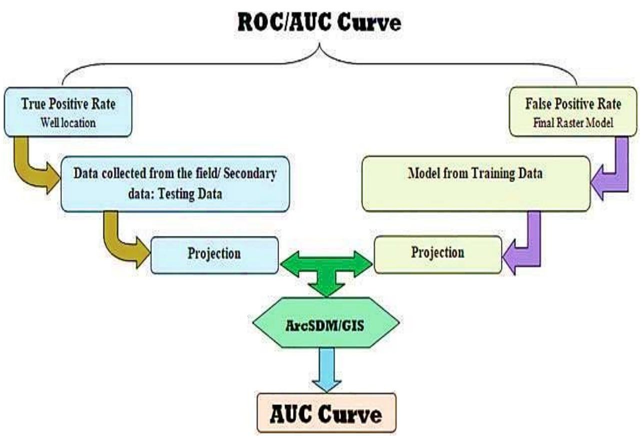

Figure 12. ROC/AUC curve for validation processes Yonas Hagos 2024 (26)

ROC analysis produced an AUC value of 0.756 figure13, classifying the model's predictive accuracy as "Good" according to the previous classification. This indicates a 75.6% probability of correctly identifying high and low groundwater potential zones.

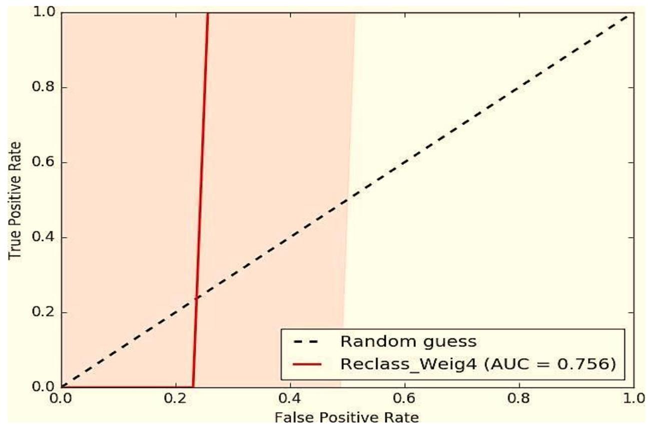

Figure 13. ROC curve for validation

Table 4. Factors, Weights, Degrees, and Ratings for Groundwater Potential Assessment

Factor	Weight (%)	Class/Range	Score (1–5)	Justification
Geology	32.48	Recent Alluvium, Older Alluvium, Coastal Fill and Arslanbey.	5	Highly permeable, excellent aquifers
		Akveren, İzmit, etc.	4	Moderate porosity/permeability
		Korucu,Acisu Tertiary Volcanics	2	Poor porosity, low recharge
Lineament Density	28.86	Very High	5	Highly fractured, enhances recharge
		High	4	Good fracture connectivity
		Moderate	3	Moderate structural influence
		Low	2	Fewer fractures
		Very Low	1	Poor structural control
LULC	13.57	Water,Vegetation Trees	5	High infiltration, direct recharg
		Crops/Rangeland	4	Moderate infiltration
		Built-up Area	2	Impervious surfaces reduce recharge
		Bare Ground	1	Low infiltration
Rainfall	9.33	130–133 mm/year	5	Intensive recharge
		127–130 mm/year	4	High recharge
		125–127 mm/year	3	Average recharge
		122–125 mm/year	2	Slight recharge
		117–122 mm/year	1	Minimal recharge
Drainage Density	6.83	>2.0 km/km² (Very High)	5	High runoff, low infiltration
		1.5–2.0 km/km² (High)	4	Reduced infiltration
		1.0–1.5 km/km²(Moderate)	3	Balanced recharge/runoff
		0.5–1.0 km/km² (Low)	2	Good infiltration
		0–0.5 km/km² (Very Low)	1	Excellent recharge (lowrunoff)
Slope(°)	5.14	0–4° (Very Gentle)	5	Highest infiltration
		4–8° (Gentle)	4	Good infiltration
		8–12° (Moderate)	3	Moderate infiltration
		12–18° (Steep)	2	Lower infiltration
		18–43° (Very Steep)	1	Lowest infiltration
Soil Type	3.79	Calcaric Fluvisol	4	High porosity/water-holding
		Chromic Luvisol	3	Moderate infiltration
		Orthic Luvisol	2	Poor infiltration

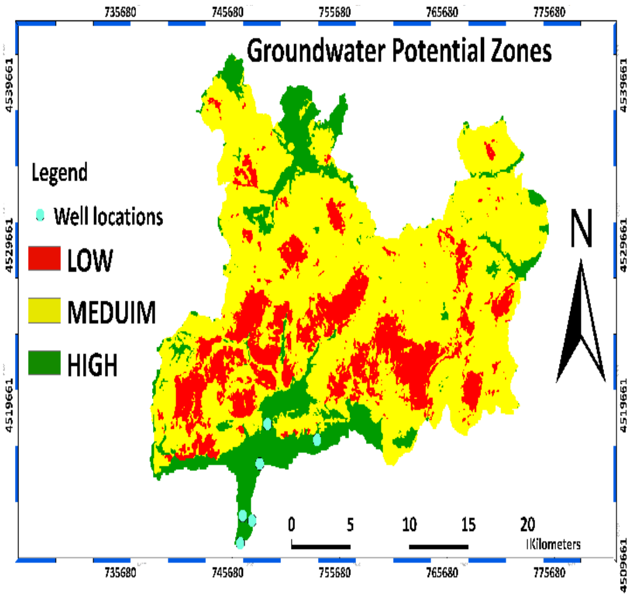

Figure 14. Validation map for GWPZ with well locations in mit district

CONCLUSION

Groundwater potential mapping in İzmit was successfully conducted using RS, GIS, and AHP by integrating seven critical factors: geology, lineament density, slope, drainage density, land use/land cover, soil type, and rainfall. The study area was classified into three categories: high (74 km², 16%), moderate (311 km², 66%), and low (88 km², 18%) potential zones. High-potential areas were mainly concentrated in the southern region and certain northern sectors, attributable to permeable geological formations, dense lineament and drainage networks, and gentle slopes enhancing recharge. Geology and lineament density emerged as the dominant controls on groundwater potential, highlighting the significance of structural and lithological characteristics. Model validation using an AUC value of 0.756 confirmed strong predictive accuracy. This research not only underscores the effectiveness of AHP based multi criteria analysis in groundwater potential mapping but also offers a practical framework for policy makers, urban planners, and water resource managers to guide sustainable groundwater utilization and conservation in İzmit, particularly under pressures from urban growth and climate variability.

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