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GROUNDWATER POTENTIAL ZONES DELINEATION IN OUED ZDIN BASIN – ALGERIA, USING GIS, RS AND HIERARCHICAL ANALYSIS PROCESS

Abstract: Water scarcity poses a significant challenge, particularly in regions with limited rainfall such as Algeria, where groundwater plays a crucial role in supporting both daily life and economic activities. This research aims to evaluate the groundwater potential in the Oued Zdin basin in northern Algeria by utilizing advanced geomatics methods, particularly the Analytic Hierarchy Process (AHP). Through the integration of Remote Sensing (RS) and Geographic Information Systems (GIS), the study incorporates multiple datasets, including rainfall patterns, topography, geology, drainage networks, land use, and hydrological data to assess areas with high groundwater potential. By applying AHP, the study assigns relative importance to these factors, creating a groundwater potential map that classifies the region into very high, high, low, and poor potential zones. The results indicate that 7% of the basin has very high potential for groundwater recharge, 33% has high potential, while 56% is categorized as low potential, and 4% falls under poor potential. The accuracy of the results is validated through comparison with existing well data, which aligns with the identified high-potential zones. The research demonstrates that combining GIS, RS, and AHP is an effective approach for mapping groundwater potential, offering valuable insights for sustainable water resource management in areas experiencing water scarcity. This methodology presents a scalable model that can be applied to similar regions facing groundwater challenges.

Keywords: underground water, geoinformatics, remote sensing, multi-criteria analysis, Oued Zdin

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Introduction

Water is the engine of life, and its scarcity inevitably leads to the disruption of daily human activities, affecting households, agriculture, and industry alike. All economic sectors depend, either directly or indirectly, on the continuous availability of water. In many regions, particularly in arid and semi-arid zones where rainfall is limited, groundwater has become an essential source for sustaining long-term water supply (Kamaraj et al., 2023a). As an integral yet hidden component of the hydrological cycle (El-Sayed & Elgendy, 2024), groundwater is stored beneath the Earth's surface (Godif & Manjunatha, 2023) and serves as a strategic reserve in times of surface water scarcity. However, its exploitation often remains limited, primarily due to insufficient understanding of its development processes and the technical and economic difficulties associated with its extraction (Kamaraj et al., 2023a).

Algeria ranks among the most water-stressed countries in the world, with renewable internal freshwater resources estimated at only 19 billion cubic meters per year - equivalent to about 295 cubic meters per capita annually (Negm et al., 2020). This limited availability places severe pressure on national water security. The Oued Zdin basin, a sub-basin of the Chelif basin, illustrates this challenge vividly, having experienced a significant decline in surface runoff since the 1970s. The reduction in rainfall has led to acute and recurring water shortages in the region (Zaibak & Meddi, 2022), forcing a greater reliance on groundwater resources to meet human and agricultural needs.

Delineating groundwater potential zones in such environments is a complex undertaking because it requires the integration of multiple geo-environmental factors, such as slope, drainage density, land use, rainfall, geology, and river network density, which influence groundwater formation and recharge deep within the Earth's crust (Danso & MA, 2023; Abaidia, Remini, & Ezziane, 2025). Modern geomatics technologies, particularly Remote Sensing (RS) and Geographic Information Systems (GIS), have emerged as powerful tools in groundwater assessment, offering higher precision and efficiency compared to traditional approaches (Ravichandran et al., 2022). The combined use of RS and GIS enables the systematic analysis of spatial data, the integration of multiple thematic layers, and the application of weighting techniques to assess groundwater potential.

Weight assignment plays a critical role in determining the accuracy of groundwater potential mapping because not all influencing factors have equal impact. To address this, various weighting methods have been proposed in the literature, including the multi-influencing factor (MIF) method (Nejad et al., 2017), the evidence belief function (EBF) applied by Pourghasemi & Beheshtirad (2015), and the frequency ratio (FR) used by Moghaddam et al. (2015). Among these, the Analytic Hierarchy Process (AHP), developed by Saaty (1980), has proven to be one of the most effective in groundwater studies (Seddiki & Dehimi, 2024) because it allows for structured pairwise comparison of parameters and the derivation of consistent weight values based on expert knowledge. This method has been successfully applied in multiple studies, such as those by Huang et al. (2013), Dwivedi & Nbsp (2016), Al-Manmi & Rauf (2016), Srinivasa Rao & Jugran (2003), Mukherjee et al. (2012), and Manap et al. (2013).

In the present study, RS and GIS tools are employed to process thematic layers of the Oued Zdin basin, with input parameters including slope, drainage density, land use, rainfall, geology, and network density. Each parameter is assigned an appropriate weight and rank using the AHP through the creation of a comparison matrix, followed by integration of the layers to generate a spatial map of groundwater potential (Kamaraj et al., 2023). The main aim of this research is to identify and map groundwater potential zones in the Oued Zdin basin in order to support sustainable water resource management in a region facing severe water scarcity. By combining advanced geomatics techniques with a robust weighting methodology, the study seeks to provide decision-makers and water managers with a reliable basis for strategic planning, resource allocation, and long-term water security in Algeria.

Study area

The Oued Zdin basin extends over an area of 891.5 square kilometers west of the city of Ain Defla and is located north of the large hydrographic basin of Chlef. the hydrographic network drains tertiary (Eocene, Pliocene) and quaternary lands. Its altitude ranges between 183 and 1786 meters. The maximum is in the south and the minimum is in the north. The mountainous terrain is found in the southern part and the far northeast, and is characterized by steep slopes exceeding 30%, covering 40 percent of the basin area. The majority of the area, which constitutes 60 percent, is characterized by weak slopes with a slope estimated at 2% and is located in the north of the basin.

The climate in the Oued Zeddine sub-basin is semi-arid, humid and cold in winter and hot and dry in summer.the basin receives between 300 and 500 mm of rain per year. The average annual precipitation of the watershed has been set at 461 mm/year.

The Oued Zeddine sub-watershed is characterized by a high density of the hydrographic network, which is justified by the existence of steeper slopes, and less permeable surface formations, increasing the large exports of land which are linked to runoff (Touahir e Colab., 2018) (Map. 1).

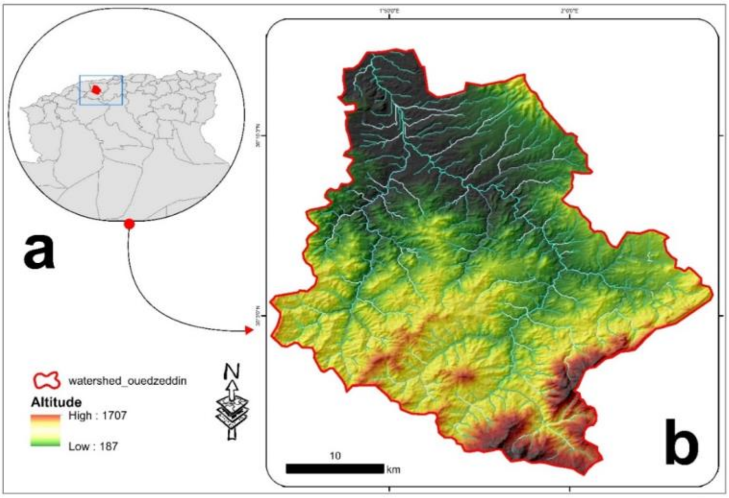


Fig. 1. Study Area of Oued ZDIN basin. Source: Authors

Data used

To conduct a thorough assessment of groundwater potential utilizing geomatics techniques alongside the Analytic Hierarchy Process (AHP), it is vital to incorporate a diverse range of data types and sources. Important hydrological data encompasses both monthly and annual rainfall figures as well as historical trends in runoff dating back to the 1970s. Geological information, including detailed maps of geological formations and soil type characteristics, is essential for comprehending the dynamics of groundwater movement and retention (US Geological Survey, 2020). Furthermore, land use and vegetation cover data play a significant role in evaluating how various land areas contribute to groundwater recharge (Food and Agriculture Organization, 2022). Topographic information, such as Digital Elevation Models (DEMs) and slope m jjkaps, provides insights into the influence of terrain on water flow patterns (National Oceanic and Atmospheric Administration, 2021). Additionally, drainage density maps and historical data on water tables are crucial for understanding hydrological networks in the area (International Water Management Institute, 2019). Remote sensing data, including satellite imagery and soil moisture assessments, enhances the analytical framework (NASA Earth Data, 2022). Software tools like QGIS and liberaGis are commonly employed for spatial data processing, while AHP assists in assigning appropriate weights to various factors involved in the analysis (Saaty, 1980). The sources of this data generally include national meteorological and geological agencies, academic research publications, and satellite data from providers such as NASA and the European Space Agency (European Space Agency, 2020). Moreover, field surveys and the examination of historical records are essential methods for monitoring changes in groundwater levels over time (International Union of Geological Sciences, 2021).

In the following table (Table 1) we find the type of data entered and its sources:

Table 1. Data used

Data Type	Source
Rainfall Data	National Meteorological Agency; FAO; García et al. (2014)
DEM	SRTM (30m resolution); Zhang et al. (2014)
Geological Maps	National Geological Services; Bjornerås et al. (2015)
LULC	Landsat 8 imagery (30m); Lillesand et al. (2015)
Drainage Network & Density	SRTM and GIS treatment
Lineament Data	Remote Sensing interpretation; Geological surveys
Hydrogeological Data	Field surveys; well data; IWMI (2019)

Methodology

To evaluate groundwater potential in the Oued Zeddin region, a methodical approach employing GIS, remote sensing, and the Analytic Hierarchy Process (AHP) is adopted. This process begins with the collection of diverse data sources, including satellite imagery for land use classification (Lillesand et al., 2015), a Digital Elevation Model (DEM) for slope analysis (Zhang et al., 2014), geological maps to obtain lithological information (Bjornerås et al., 2015), meteorological data on rainfall patterns (García et al., 2014), and details regarding existing hydrological networks (Fisher et al., 2015). Following data collection, preprocessing steps are undertaken, involving image processing techniques, manipulation of the DEM to derive slope and drainage density, and vectorization of hydrological data (Jiang et al., 2018).

The next phase focuses on analyzing key factors, which include calculating slope percentages, measuring drainage density, classifying lithological types based on permeability, categorizing land use types affecting groundwater recharge, evaluating rainfall contributions, and assessing the density of water networks (Sener et al., 2010; Jha et al., 2022) (Map 2).

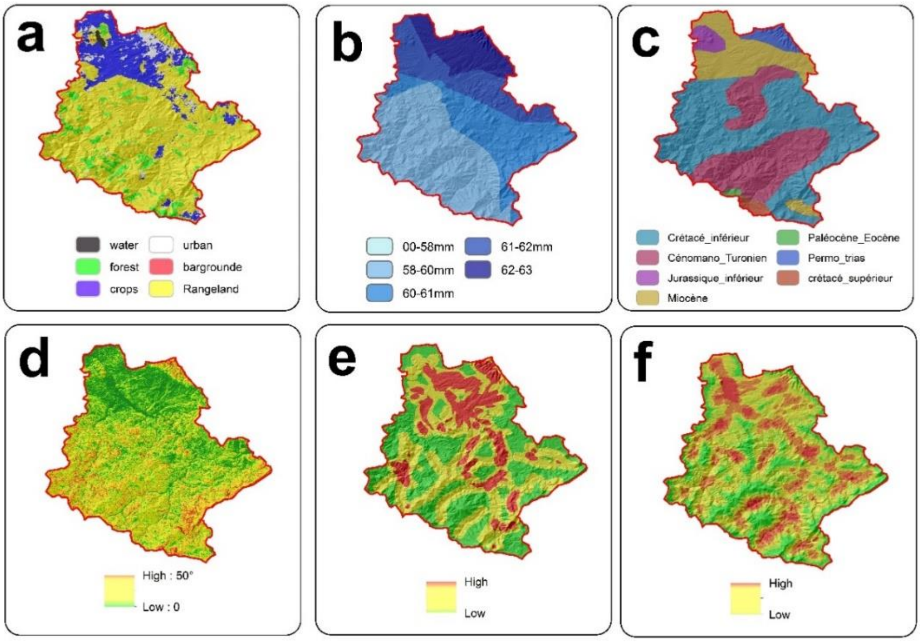


Fig. 2. Factors: a) landuse, b) rainfall, c) lithology, d) slope, e) drainage density, f) network densit

In the following table (table 2) we find the factors and how they affect groundwater:

Table 2. Factors and their purpose of use in the study

Factor	Purpose / Application
rainfall	Assess annual and seasonal precipitation influencing groundwater recharge
lythology	Identify lithological units and their permeability for recharge potential
LULC	Evaluate surface cover types and their impact on water infiltration
Drainage and network density	Understand surface water movement and influence on recharge zones
Lineament density	Assess structural features like fractures and faults enhancing groundwater flow
Slope	determining the infiltration and runoff characteristics of the terrain.

Source: Authors

These factors are then standardized for comparability (Rossi et al., 2015). AHP is utilized to weight the factors through pairwise comparisons, ensuring consistent ranking of their importance (Saaty, 1980). Subsequently, the weighted factors are combined using overlay analysis in a GIS environment, leading to the creation of a groundwater potential map, categorized into high, medium, and low potential areas (Kumar et al., 2021; Basharat et al., 2021). Finally, the resultant map is validated against existing groundwater data, and a sensitivity analysis is performed to understand the impact of variations in the input factors (Duncan et al., 2015; Zhou et al., 2021).

For this we followed the following steps:

Constructing the Comparison Matrix: Parameters influencing groundwater are systematically compared, creating a matrix that captures their relative significance.

$$A = \begin{bmatrix} 1 & P_{12} & P_{13} & \cdots & P_{1n} \\ \frac{1}{P_{12}} & 1 & P_{23} & \cdots & P_{2n} \\ \frac{1}{P_{13}} & \frac{1}{P_{23}} & 1 & \cdots & P_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \frac{1}{P_{1n}} & \frac{1}{P_{2n}} & \frac{1}{P_{3n}} & \cdots & 1 \end{bmatrix} \tag{1}$$

Matrix Normalization: Each entry is divided by the sum of its respective column to standardize the values across parameters.

$$N_{ij} = \frac{A_{ij}}{\sum_{i=1}^{n} A_{ij}} \tag{2}$$

Weight Derivation: The average of the normalized row values is computed, yielding a weight for each parameter that indicates its relative importance.

$$W_i = \frac{\sum_{j=1}^{n} N_{ij}}{n} \tag{3}$$

Assessing Consistency: The logical coherence of the comparisons is evaluated through the Consistency Index (CI) and the Consistency Ratio (CR).

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{4}$$

The CR is calculated by comparing CI with a random consistency index (RI):

$$CR = \frac{CI}{RI} \tag{5}$$

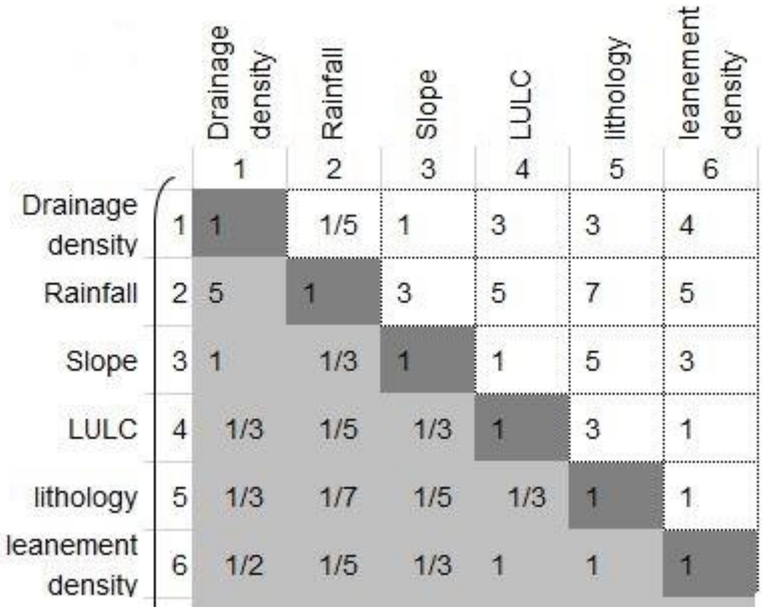
A CR of 0.1 or less is considered acceptable for consistency.

Where **λmax** is the largest or principal eigenvalue of the matrix and can be easily calculated from the matrix and **n** is the order of the matrix. When the Consistency Ratio

(CR) exceeds 0.1, it suggests that the comparison matrix lacks consistency and needs to be revised. As shown in Table 3, all CR values in this study are below the 0.1 threshold, indicating that the judgments used to construct the comparison matrices are consistent and reliable. The Analytical Hierarchy Process (AHP) was employed to assign weights and determine the hierarchical levels of the conditioning factors and their respective categories.

Table 3. Scale of preference between two parameters in AHP

Scales	Degree of preferences	Explanation
1	Equally	Two activities contribute equally to the objective.
3	Moderately	Experience and judgment slightly to moderately favor one activity over another.
5	Strongly	Experience and judgment strongly or essentially favor one activity over another.
7	Very strongly	An activity is strongly favored over another and its dominance is showed in practice.
9	Extremely	The evidence of favoring one activity over another is of the highest degree possible of an affirmation.
2, 4, 6, 8	Intermediate values	Used to represent compromises between the preferences in weights 1, 3, 5, 7 and 9.
Reciprocals	Opposites	Used for inverse comparison.



		Drainage density 1	Rainfall 2	Slope 3	LULC 4	lithology 5	leanement density 6
Drainage density	1	1	1/5	1	3	3	4
Rainfall	2	5	1	3	5	7	5
Slope	3	1	1/3	1	1	5	3
LULC	4	1/3	1/5	1/3	1	3	1
lithology	5	1/3	1/7	1/5	1/3	1	1
leanement density	6	1/2	1/5	1/3	1	1	1

Fig. 3. Comparison matrix

After creating the comparison matrix between the factors, we calculate the weight of each criterion using a tool developed specifically for creating the matrix and calculating the weights. We obtained the following weights for each criterion table 4 and figure 4:

Table 4. Relative Weights of Factors Influencing groundwater Potential

Factors	Wheights (%)
Drainage density	17.4
rainfall	46.5
Slope	16.3
LULC	08
lythology	4.8
Lineament density	6.9
RC= 4%	

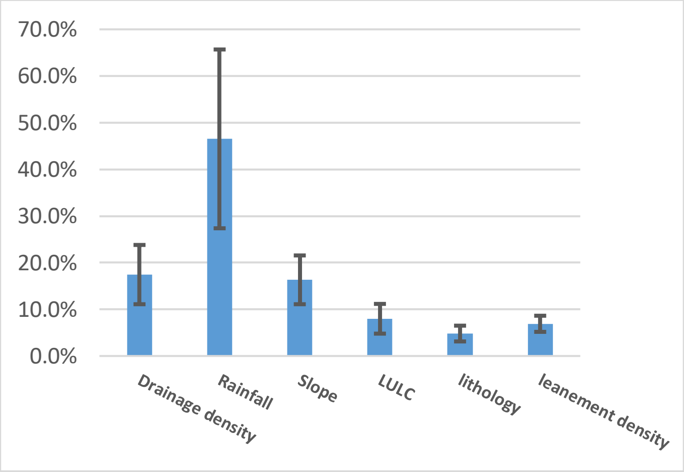


Fig. 4. Relative Weights of Factors Influencing groundwater Potential

Geographic Information Systems (GIS) and Remote Sensing technologies play a crucial role in this study by enabling the efficient collection, analysis, and visualization of spatial data related to groundwater potential. GIS allows researchers to integrate various data layers, such as soil type, land use, topography, and hydrogeological features, to create detailed maps highlighting areas with different levels of groundwater availability. Specifically, GIS is used to assign weights to these layers based on their influence on groundwater potential, and then perform spatial overlay analysis to combine them. This process results in a comprehensive groundwater potential map that accurately reflects the spatial distribution of groundwater resources. Remote sensing provides up-to-date satellite imagery and aerial data, which assist in monitoring environmental changes and identifying surface indicators of groundwater presence. Together, these technologies enhance the precision of groundwater potential assessment, support informed decision-making for water resource management, and facilitate sustainable planning in the region (Adugna & Awoke, 2024).

Results and Discussion

The integration of GIS, remote sensing, and the Analytic Hierarchy Process (AHP) enabled the production of a detailed groundwater potential map for the Oued Zeddin watershed. The results classify the area into four potential categories: very high (7%), high (33%), low (56%), and poor (4%) (Table 5).

Very high potential zones, concentrated in flat or gently sloping areas with permeable lithology and well-developed drainage networks, present optimal conditions for groundwater recharge. Similar to findings by Huang et al. (2013) and Manap et al. (2013), these areas represent prime targets for sustainable groundwater development. High potential zones share favorable recharge characteristics but occur in moderately sloping terrains with slightly less optimal geological conditions, aligning with the recharge patterns reported by Al-Manmi & Rauf (2016).

Low potential areas dominate more than half of the basin (56%), primarily due to steep slopes and low-permeability formations that favor runoff over infiltration, patterns also observed in semi-arid basins by Dwivedi (2016) and Nejad et al. (2017). Poor potential zones (4%) are mostly steep or urbanized lands with impervious surfaces, where infiltration is severely restricted; comparable limitations have been noted in urban catchments studied by Pourghasemi & Beheshtirad (2015).

Sensitivity analysis identified slope, lithology, and drainage density as the most influential factors in groundwater potential, in agreement with studies by Seddiki & Dehimi (2024). Validation against known productive wells confirmed the accuracy of the classification, supporting the method’s applicability to other semi-arid watersheds.

These results not only refine the understanding of recharge dynamics in Oued Zeddin but also offer a decision-making framework for targeted groundwater development. Prioritizing high and very high potential zones while applying recharge-enhancing measures, such as contour farming or reforestation, in low potential areas could significantly improve water availability in the region under current climate variability and growing demand.

Table 5. Groundwater Potential Level

Groundwater Potential Level	Description	%
Very High	Strong potential for groundwater availability	7
High	Good groundwater availability	33
Low	Limited groundwater resources	56
Poor	Very low groundwater availability	4

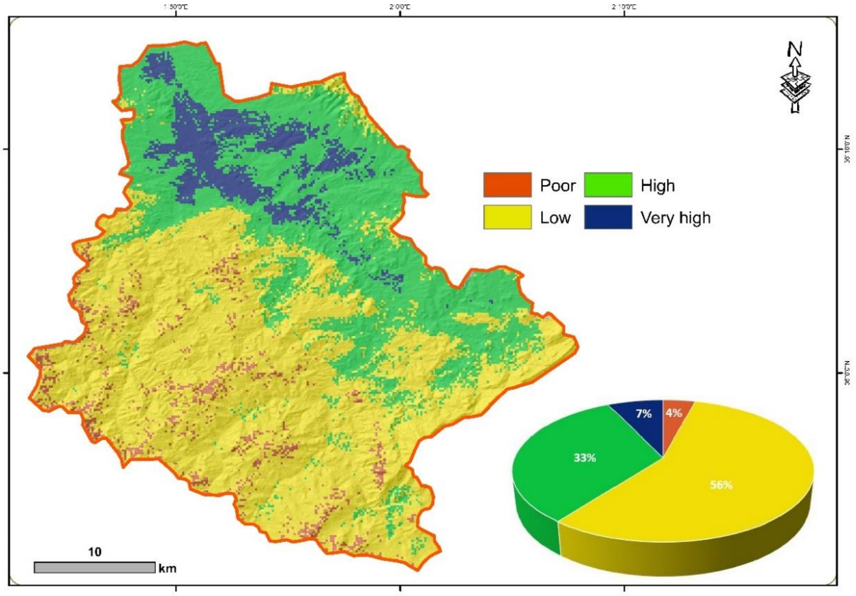


Fig. 5. Groundwater potential zones delineation in Oued Zdin. Source: Authors

Validation

To verify the reliability of the groundwater potential map for the Oued Zeddin watershed, a comprehensive validation procedure was carried out. This process involved overlaying the classified groundwater potential zones with the geographic coordinates of existing productive wells in the study area. The spatial comparison revealed a strong correspondence between the predicted zones and actual well locations, particularly within the very high (7%) and high (33%) potential categories, where the majority of productive wells are concentrated. This spatial alignment indicates that the areas identified through the model are indeed capable of supporting significant groundwater yields.

In addition to spatial verification, historical records of groundwater levels and recharge rates were analyzed and cross-referenced with the classified potential zones. The analysis showed that zones categorized as very high and high potential not only host more wells but also exhibit higher average groundwater levels and recharge rates compared to low and poor potential zones. These observations provide further evidence of the model's accuracy.

The combination of these validation steps, spatial matching with well locations and temporal consistency with historical hydrological data, confirms the robustness of the integrated approach used in this study, which merges GIS, remote sensing, and the Analytic Hierarchy Process (AHP). The close agreement between predicted potential and observed groundwater productivity underscores the model's applicability for guiding exploration, sustainable extraction, and long-term water resource management in the watershed.

For visual representation, a validation map was produced by overlaying the classified groundwater potential map with the validation points representing existing productive wells (Figure 6). This map serves as a clear, practical tool for both assessing the model's performance and aiding decision-makers in future groundwater planning.

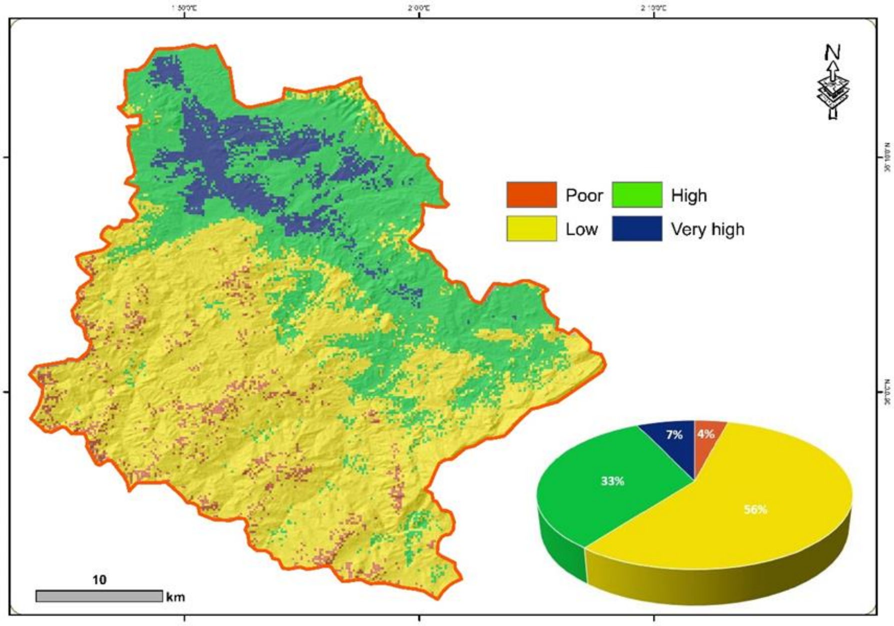


Fig. 6. Validation map

Conclusion

This research demonstrates a significant advancement in groundwater potential assessment for the Oued Zeddin watershed by integrating GIS, remote sensing, and the Analytic Hierarchy Process (AHP). Building upon earlier studies that relied predominantly on single-source datasets or qualitative interpretations, the present work leverages a multi-source approach, combining satellite imagery, DEM, geological maps, and rainfall data, to produce a spatially explicit and quantitatively validated groundwater potential map.

Compared to the current state of knowledge, this study advances methodological rigor in two main ways. First, it applies a structured weighting system through AHP, reducing subjectivity in factor prioritization and improving reproducibility, an improvement over earlier groundwater mapping efforts that often assigned weights based solely on expert judgment without formal consistency checks.Second, it incorporates a sensitivity analysis to evaluate the influence of key parameters such as slope, lithology, and drainage density, providing transparency on model robustness, an element still missing in many regional assessments.

The results not only confirm patterns observed in similar semi-arid watersheds but also refine them for the specific geological and climatic context of northwestern Algeria. The identification of very high and high potential zones offers strategic opportunities for targeted groundwater development, while the mapping of low and poor potential areas supports better land-use planning to mitigate recharge limitations.

By validating the model against known productive wells, the study enhances the reliability of its recommendations, paving the way for its application in other water-stressed basins. Ultimately, this work contributes to the evolving toolkit of groundwater resource assessment, demonstrating how the integration of modern geomatics techniques with robust decision-support methods can move beyond traditional mapping toward adaptive, data-driven water management strategies in the face of climate variability and growing demand.

Conflicts of Interest: The authors declare no conflict of interest.

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