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Groundwater potential mapping using the integration of AHP method, GIS and remote sensing: a case study of the Tabelbala region, Algeria

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Research Article

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ABSTRACT

Recently, groundwater resources are assessed and evaluated using Geographic Information System (GIS) and remote sensing technologies due to their effectiveness and wide spatial coverage. This work aims to identify groundwater potential areas in the Tabelbala region which lies in the Algerian desert in order to help for the solution of water resources shortages. GIS and remote sensing are employed in the preparation of the controlling factors such as lithology, lineaments, drainage network, slope, land use/land cover, topographic wetness index, and elevation. Statistical Analysis, as well as interpretation of remote sensing data, allow the extraction of important features about the study area and its characteristics. The prepared layers are combined with multicriteria analysis to identify the groundwater potential zones (GWPZs) based on their statistical weights. To validate the conducted work, 222 wells/boreholes are collected and prepared to assess the potential areas. Results reveal that the very good potentiality class covers approximately 8.81% of the total area while 6.47% shows very poor potentiality. In addition, the application of the ROC curve shows an AUC of 89% which reveals the effectiveness of the proposed approach. The final resulting map can be used for the identification of suitable sites for wells implantation.

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1. Introduction

In arid regions, groundwater is one of the essential natural resources for agricultural, domestic, and industrial needs (Kumar et al., 2021). A significant part of the world's population uses groundwater as a source for their daily supply (Kemper, 2004). The Saharan region's development is related to the water-resource availability. Agriculture is the main activity in such regions and an important factor for stabilizing the population. Region development is not limited to enlarging the irrigated surfaces and extending the flow from the wells but mainly it is concerned with the improvement of agricultural productivity. The development success based on a coherent and appropriate definition of water-agriculture-environment policies implies the implementation of suitable technical and organizational actions so that the expected effects are not compromised by uncontrolled and inefficient management.

In the data-scarce region (well data, geophysical data, geomorphology, and geology), GIS and remote sensing techniques are considered effective for water resources prospection and evaluation of groundwater resources. Investigating water resources through

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classical methods (ex. geophysical, hydrogeological surveys, mapping of outcrops, and logging) is the most adopted approach but they remain expensive and time-consuming (Jha et al., 2010). Although remote sensing applications are numerous, the integration of satellite data with different groundwater layers remains a challenging problem in terms of results reliability. Thus, the integration of such data, as sources of information, in the Saharan region is an effective and promising solution provided that reliability is assured. On the other hand, groundwater prospection maps require the use of spatial techniques (GIS and remote sensing (RS) technique) as well as multi-decision criteria (ex. Analytical Hierarchy Process, AHP) as tools for identifying groundwater potential areas before detailed exploration based on drilling, geophysical techniques and hydrogeological data (Fenta et al., 2015). The created maps can be used for rational and sustainable management based on the estimated groundwater areas (Dar et al., 2011; Thapa et al., 2017; Nasir et al., 2018).

Examining the literature, several decision-making methods (heuristic, deterministic, statistic, index overlay …) allow the decision-maker to formalize the problem and explain the decisional context before proceeding to the evaluation and comparison of the solutions. The AHP aggregation method is one of the simplest to implement, it makes it possible to calculate a synthetic score on the basis of a hierarchy and a weighting of all the criteria relating to the process. Several studies delineate groundwater potential by the use of spatial techniques and conventional classical methods. Multi-Criteria Decision-Making (MCDM) techniques to assess groundwater potential zones is used for potentiality maps that are prepared by assigning weights to variables based on their calculated influences (Kaur et al. 2020). Other authors succeeded in evaluating the groundwater potential by showing the effectiveness of geology and geophysics through the extraction and analysis of the lineaments network and its role in identifying recharge areas (Mpofu et al. 2020). In Panipat (India), two multi-criteria analysis methods (AHP, CT catastrophe multi-criteria technique) are applied by Kaur et al. (2020) to delineate the groundwater potential where the obtained maps are validated using field data. To exploit the importance of remote sensing Saadi et al. (2021) delineated groundwater storage zones by using RS and GIS based on the integration of several influencing factors like geology, rainfall, slope and TWI. These works confirm the importance of remote sensing and GIS when combined with multi-criteria decision methods.

The conducted study aims at the identification of the groundwater potentiality areas by the integration of satellite data, GIS, as well as the AHP method. According to recent works, it can be seen that multi-criteria decision analysis is widely used for groundwater modelling (Islam et al., 2017) and groundwater storage evaluation (Jha et al., 2010; Nag and Kundu, 2018). The combination of information obtained by the processing and analysis of satellite data and conventional statistical data facilitates the elaboration of information related to groundwater potential areas (Rashid et al., 2012; Selvam et al., 2015; Nasir et al., 2018). It is, furthermore, useful for extracting morpho-structural information (lineaments, and drainage patterns) contributing to delineating the recharge areas (Magesh et al., 2012). In addition, the analysis of the controlling factors (ex. lithology, structures, slope, aspect and drainage density) in the GIS framework through the AHP can lead to better performance as all the factors are brought into consideration. To increase the reliability of the conducted study, field data (222 wells/boreholes) are collected and used to assess the obtained results based on the ROC curve. The final map has the objective of identifying sites for wells implementation to satisfy the water demands. For the first time, remote sensing and GIS technique is used in this Saharan region (Tabelbala) which has not known any hydrogeological study before. The result of the present study can give an idea about the potential zones in the Tabelbala region. The first part of this paper is to elaborate the influencing parameters (lithology, lineaments, LULC, drainage network, slope, elevation, and TWI) at an appropriate scale allowing a hydrogeological study, and update the lineament (structural study) and lithological maps from the interpretation of satellite images (optical images and DEM). The second part of this work presents the groundwater potential zone's locations, using the AHP technique as an illustration of how to use the digital maps created as part of this study and it is the first method to delineate the groundwater potential zones in this region (Tabelbala).

2. Description of the Study Area

The study area is situated in southern west Algeria and lies between 3° to 4° W longitude and 29° to 30°N latitude (Figure 1). Its elevation varies from 398 m to 909 m above mean sea level. The Tabelbala region borders the Marocain Anti Atlas in the North, the Réguibat shield in the South, the Ougarta range in the East and the Tindouf basin in the West. It has an area of 10705.09 km^2, an average temperature of 25°C and an arid continental climate.

The geological structures of the region are characterized by different geological domains that are: Erg Er Raoui in the North-East, Djebel Kahal Tabelbala in the East, Djebel Ben Tadjine in the South, and Erg El Atchane in the South.

The precipitation is very low as reported by the average monthly precipitation distribution data acquired from Data Access Viewer-Nasa Power (DAV) in the period 1981 to 2020 (https://power.larc.nasa.gov/data-access-viewer/). Figure 2 shows that the Tabelbala region is located in the areas of isohyets which have values below 10 mm. In addition, the average monthly precipitation histogram shows clearly that the rainiest month is October (0.4 mm) whereas July is the driest month (0.02 mm).

The drainage network characterizing the study area seems well developed in the landscape, dry for the most part, the main river in the region is that of the Daoura (Oued Daoura) in the North coming from Morocco (Figure 3).

Except for some existing reliefs (Djebel Kahal Tabelbala in the East, Djebel Ben Tadjine in the South-West), the Tabelbala region consists of Erg Erraoui, Erg El Atchane, Erg Atimine and Hamada of Manda. The geological structures characterizing the considered area are of medium complexity, noting the complexity of the Lower Cambrian deposits. This entity as it appears to us today is actually infinitely more complex than the presented maps. Indeed, each new cycle modifies the state of the previous cycle. The sediments of the recent cycle partly mask the oldest deposits and each orogenic phase partially deforms and breaks the pre-existing architectures and structural pre-dispositions that guide the new structures. Based on the previous work (Menchikoff, 1930; Mekkaoui et al., 2017), it appears that the mountains of the

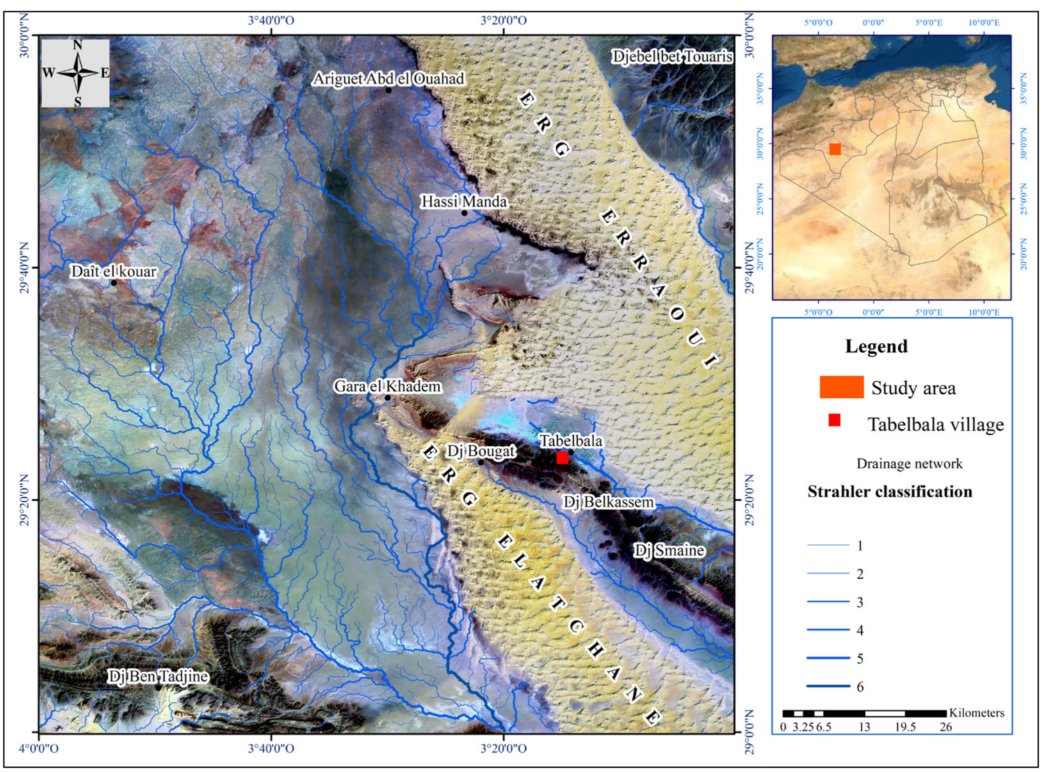

Figure 1- Study area location.

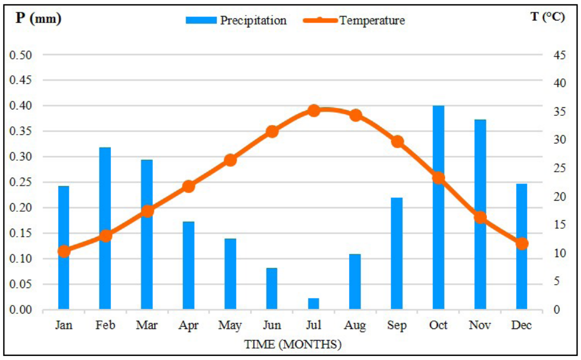

Figure 2- The average monthly precipitation and temperature from 1981 to 2020.

considered area (Tabelbala) form a succession of anticlines and synclines of NW-SE direction and they are sometimes intersected by accidents of the same direction (Ougartian accident), as well as by major accidents of direction NE-SW (main tectonic accidents). The age of the folding's cannot be specified (Menchikoff, 1930) but the author explains that by their tectonic style, the mountains of Tabelbala would be linked well to the Hercynian folding's of Morocco, which does not appear in the south of the region. The drainage pattern of the study area is controlled by the second direction NW-SE.

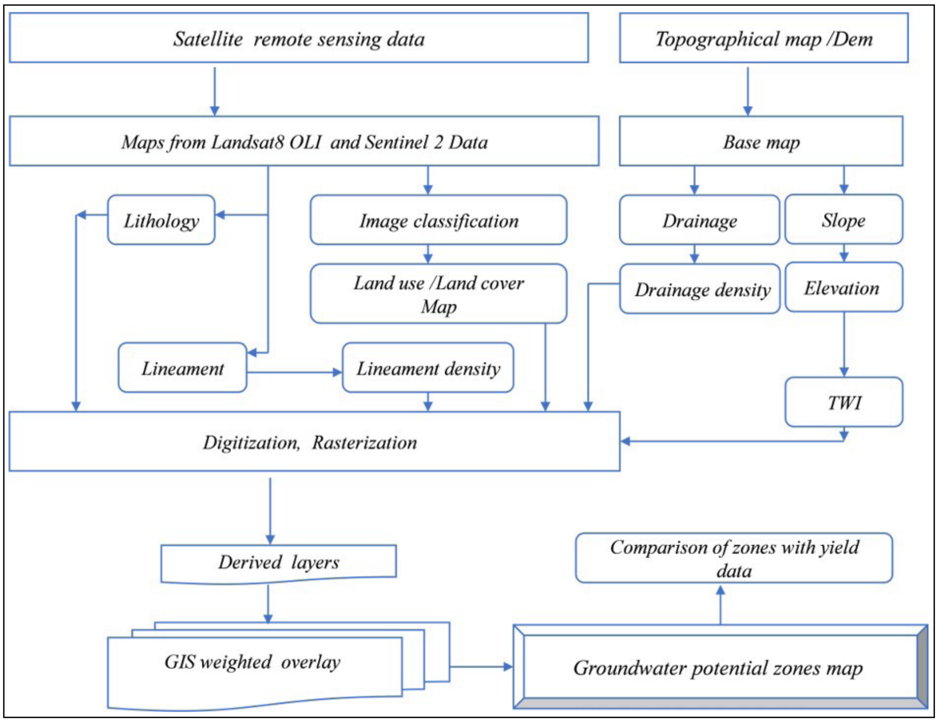

Figure 3- Conceptual framework of the proposed method.

3. Methodology

The proposed approach is summarized in Figure 3. For achieving the desired goal, multitemporal and multiresolution images are used for the characterization of lithological and structural outcrops. Satellite data required for the conducted work include Landsat 8 (OLI) images provided by the United States Geological Survey (USGS) acquired the 13th October 2021 and the 20th October 2021 where four scenes located by paths (199 to 200) and row (39 to 40) are use.

3.1. Overview and Contributions

AHP is the most popular method used for the preparation of groundwater prospect maps. During this work, seven thematic layers are prepared: lithology, drainage density, lineaments density, slope, elevation, topographic wetness index, and land use/ land cover. These maps are elaborated based on the processing, analysis, and interpretation of satellite images (Figure 4). In order to highlight geological features (lithological and structural information) and

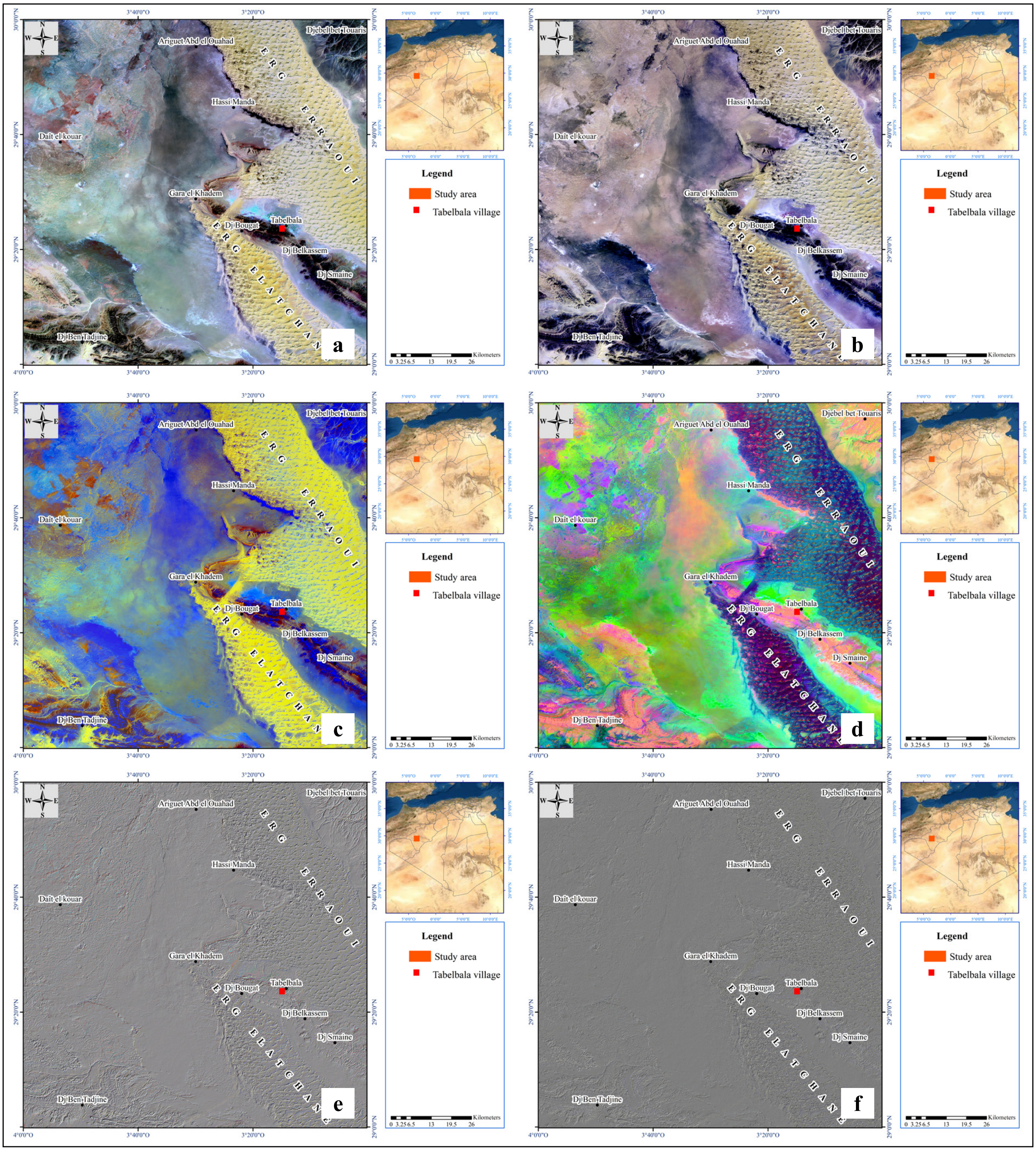

Figure 4- a) Landsat 8 OLI false color composite 7(R)5(G)4(B), b) Sentinel 2 false color composite 8(R)4 (G)3(B), c) Landsat 8 OLI bands ratios 7/3(R), 5/2 (G), 4/7 (B), d) Landsat 8 OLI principal component analysis (P1P2P3), e) Landsat 8 OLI filter 45° and f) Sentinel filter 45°.

update the geological map of the region at 1/200.000 scale, several digital images processing techniques are applied: color composite, enhancements, filtering, principal component analysis, and band ratio. These techniques include Landsat 8 OLI in false color composite (Bands: 754), Sentinel 2 in false color composite (Bands:843), Landsat 8 OLI bands ratios (7/3, 5/2, 4/7) and Landsat8 OLI principal component analysis. The usefulness of such information is considered in many studies as an efficient tool for lithological discrimination, especially in arid zones (Scanvic, 1997; Prost, 1994; Rencz and Ryerson, 1999; Prost, 2013; Nemmour-Zekiri and Oulebsir, 2020). In order to extract and highlight the linear network and structural discontinuities (dykes, faults, lineaments and fractures), directional filters are carried out on Landsat 8 OLI (Bands:754) and Sentinel 2 images (Bands:843) which have suitable spatial and spectral resolutions. In our study area, 414 lineaments are extracted using the semi-automatic extraction tool (Figure 4) in different directions N0°, N45°, N90°, and N135° (Scanvic, 1997; Rencz and Ryerson, 1999; Prost, 2013; Gupta, 2017; Nemmour-Zekiri and Oulebsir, 2020).

To model the complex terrain of Tabelbala, a specific type of raster data (DEM) is used which has an important role in terms of spatial analysis and their integration in the GIS network. The drainage density, slope, elevation, and the Topographic Wetness Index are generated automatically from the Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (30m of spatial resolution).

The land use/land cover map is prepared using the supervised classification of Landsat 8 OLI images.

3.2. The Proposed GIS-Based AHP Method

The AHP method is developed by Saaty (1980) and becomes the widely used method for calculating the weights and rates for the input factors based on their importance to the relative criteria (Kousalya et al., 2012; El abidine and Abdelmansour, 2019). The AHP method is used generally to facilitate decisions, reduce the complexity of different problems, find priorities (Punniyamoorty et al., 2012), planning and distinguish resources. In this work, weight assignment of controlling factors is carried out based on the opinion of experts' judgement, and knowledge, the literature review and field experience (Table 1) in order to increase the precision and reliability of the results. The judgement matrix is established based on pairwise comparison according to a 9-level scale to affect the decision of the parameters (Saaty, 2003) (Table 2).

Several consecutive steps are performed to compute the Consistency Ratio (CR) and evaluate the normalized weights:

1) Pairwise comparison matrix (PCM) conception:

$$P=\begin{pmatrix} P_{11} & P_{12} & \dots & P_{1n} \\ P_{21} & P_{22} & \dots & P_{2n} \\ \dots & \dots & \dots & P_{3n} \\ P_{n1} & P_{n2} & \dots & P_{4n} \end{pmatrix} \qquad (1)$$

Where *Pij* is the n^{th} indicator unit and *Pnn* represents the judgement matrix factor.

2) Normalized weight computation:

$$W_n=GM_n/\sum_{n=1}^{N} GM_n \qquad (2)$$

Where the *W* represents the weight vector and *GMn* is the geometric mean related to the i^{th} row.

3) Judgement's coherence calculation:

$$CR=CI/RCI \qquad (3)$$

Where CR denotes the Consistency Ratio, CI represents the Consistency Index and RCI stands for the Random Consistency Index of Saaty's classification (Saaty, 1990). The RCI value depends on the number of parameters which is estimated to be 1.32 in our case.

4) Consistency Index is computed using the Equation 4:

$$CI=(\lambda_{max}-N)/(N-1) \qquad (4)$$

Where λ signifies the Eigen value of the judgement matrix and it is computed using Equation 5.

5) Eigen value of the X matrix:

$$\lambda=\frac{\sum_{i=1}^{n}(P_iW)_n}{N*W} \qquad (5)$$

The assigned weights as well as the values of the comparison matrix are reported in Tables 1, 2, 3.

The Consistency Ratios (CR) related to the pairwise comparisons were less than 0.1. The values of λ_{max} and the CR values of criterion CI and RI are shown in Table 4.

For groundwater potential mapping, the weighted index overlay is widely used as mentioned in the literature. It is based on human judgements as well as the combination of multiple thematic maps (Boobalan

Table 1- Weights of the controlling factors and their classification.

Factor/class	Subclass	Rating	weight	Normalized rate	Weighting
Lit	Quaternary	5	38.9	0.294	11.441
	Neogene	4		0.235	9.153
	Silurian	3		0.176	6.865
	Ordovician	2		0.118	4.576
	Cambrian	2		0.118	4.576
	Proterozoic	1		0.059	2.288
LD	Very low	1	23.7	0.067	1.580
	Low	2		0.133	3.160
	Moderate	3		0.200	4.740
	High	4		0.267	6.320
	Very high	5		0.333	7.900
LULC	Runoff zone	5	15.4	0.192	2.962
	Sandy deposits	4		0.154	2.369
	Sandy veil	3		0.115	1.777
	ERG	2		0.077	1.185
	Hilly area	1		0.038	0.592
	Valley	5		0.192	2.962
	Settlement	1		0.038	0.592
	Agricultural zone	4		0.154	2.369
	Reg & Hamada zones	1		0.038	0.592
DD	Very low	5	8.7	0.333	2.900
	Low	4		0.267	2.320
	Moderate	3		0.200	1.740
	High	2		0.133	1.160
	Very high	1		0.067	0.580
S	0°-3°	5	5.3	0.333	1.767
	3°-6°	4		0.267	1.413
	6°-12°	3		0.200	1.060
	12°-25°	2		0.133	0.707
	25°-50°	1		0.067	0.353
E	398m-500m	5	4.9	0.333	1.633
	500m-600m	4		0.267	1.307
	600m-700m	3		0.200	0.980
	700m-800m	2		0.133	0.653
	800m-909m	1		0.067	0.327
TWI	03-06	1	3.1	0.067	0.207
	06-10	2		0.133	0.413
	10-14	3		0.200	0.620
	14-18	4		0.267	0.827
	18-22	5		0.333	1.033

Table 2- AHP's comparison matrix.

	Lit	LD	LULC	DD	S	E	TWI
Lit	1.00	2.00	3.00	4.00	6.00	7.00	9.00
LD	0.50	1.00	2.00	3.00	4.00	5.00	7.00
LULC	0.33	0.50	1.00	2.00	3.00	4.00	5.00
DD	0.25	0.33	0.50	1.00	2.00	3.00	4.00
S	0.17	0.25	0.33	0.50	1.00	1.00	2.00
E	0.14	0.20	0.25	0.33	1.00	1.00	2.00
TWI	0.11	0.14	0.20	0.25	0.50	0.50	1.00

Lit: lithology, LD: lineament density, LULC: land use/land cover, DD: drainage density, S: slope, E: elevation, TWI: topographic wetness index.

Table 3- The Normalized AHP matrix.

	Lit	LD	LULC	DD	S	E	TWI	Norm Weight
Lit	0.399	0.451	0.411	0.360	0.342	0.325	0.300	0.370
LD	0.199	0.225	0.274	0.270	0.228	0.232	0.233	0.237
LULC	0.133	0.113	0.137	0.180	0.171	0.186	0.166	0.155
DD	0.099	0.075	0.068	0.090	0.114	0.139	0.133	0.103
S	0.066	0.056	0.045	0.045	0.057	0.046	0.066	0.054
E	0.057	0.045	0.034	0.030	0.057	0.046	0.066	0.048
TWI	0.044	0.032	0.027	0.022	0.028	0.023	0.033	0.030
Sum	**1.000**	**1.000**	**1.000**	**1,000**	**1.000**	**1.000**	**1.000**	**1.000**

CR= 0.02 < 0.1 acceptable, CI= 0.03, λ_{max}= 7.209.

Table 4- Theme quantity (n), highest Eigen value of judgement matrix (λ_{max}), Random Consistency Index (RI), Consistency Ratio (CR) and Consistency Index (CI) of the considered layers.

Themes	N	λ_{max}	CI	RI	CR
Lithology (Lit)	6	6.277	0.109	1.24	0.088
Lineament density (LD)	5	4.73	0.01	1.12	0.01
Land use/land cover (LULC)	9	9.58	0.13	1.45	0.09
Drainage density (DD)	5	5.27	0.06	1.12	0.059
Slope (S)	5	5.25	0.103	1.12	0.092
Elevation (E)	5	5.22	0.10	1.12	0.08
Topographic wetness index (TWI)	5	5.22	0.08	1.12	0.075

and Gurugnanam, 2016). To identify the potential zones for Tabelbala region, a multi-criteria approach was applied after assigning the corresponding rates and weights to all controlling factors. The GWPZ is calculated as shown in the Equation 6 (Das et al., 2019):

$$GWPZ= \sum_{i}^{n} (Litw*Litr)+(LDw*LDr)+(LU\&LCw* LU\&LCr)+(DDw*DDr)+(Sw*Sr)+(Ew*Er)+(TWIw*TWIr) \quad (6)$$

Where *GWPZ*: groundwater potential zones, *r:* rating, *w*: factor weightage *Lit*: lithology, *LD*: lineament density, *LULC*: land use/land cover, *DD*: drainage density, *S*: slope, *E*: elevation and *TWI*: topographic wetness index.

3.3. Lithology

For groundwater studies, lithology is one of the important parameters in determining the permeability of the different formations. The Tabelbala region is part of the marginal (intra-cratonic) depression of the West African platform (Kurek and Preidl, 1987; Ennih and Liégeois, 2001). It is made up of volcano-sedimentary formations of the Proterozoic (lower structural stage), sedimentary deposits (sandstone, sandstone-clay, and sandstone-carbonate) of the Paleozoic (middle structural stage) and Cenozoic deposits of various genesis (Menchikoff, 1930). The lower structural stage is represented by basic and neutral volcanites, tuffs, greywackes, and acidic volcanites. The middle structural stage is formed of Paleozoic rocks (Mekkaoui et al., 2017). The Quaternary formation occupies an important part in the study area and it's made of sand, silt, and alluvial deposits. It has been assigned the highest weight due to its favorable infiltration characteristics. The oldest formation is related to the Proterozoic which is formed of rhyolite, ignimbrite, dacitic porphyry, sandstone, basalt, andesitic basalt, andesitic tuffs, andesitic porphyry tuffs, greywackes, and conglomerate (Figure 5). For this formation, the lowest weight has been assigned due to the low infiltration capability. The Cambrian, the Ordovician sedimentary as well as the Quaternary deposits (alluvium, torrential and aeolian deposits) are the most developed in this region while the Silurian is characterized by a fairly limited extension.

3.4. Lineament Density

Linear structures are straight linear features that appear on the earth's surface as meaningful landscape lines (Hobbs, 1904). Lineaments are indicators of an area of weakness in bedrocks and are defined as curvilinear or linear structures on the surface of the earth. Lineament density is one of the important factors in groundwater delineation as high lineament density indicates high groundwater productivity (Hatefi and Ekhtesasi, 2016). Lineament density is prepared using the following equation (Mandal et al., 2016).

$$\text{Lineament density (LD)} = \sum_{i=1}^{n} Li/S \qquad (7)$$

Where LD stands for the lineament density, Li defines the lineament length, *i* is the lineament number and S signifies the unit area.

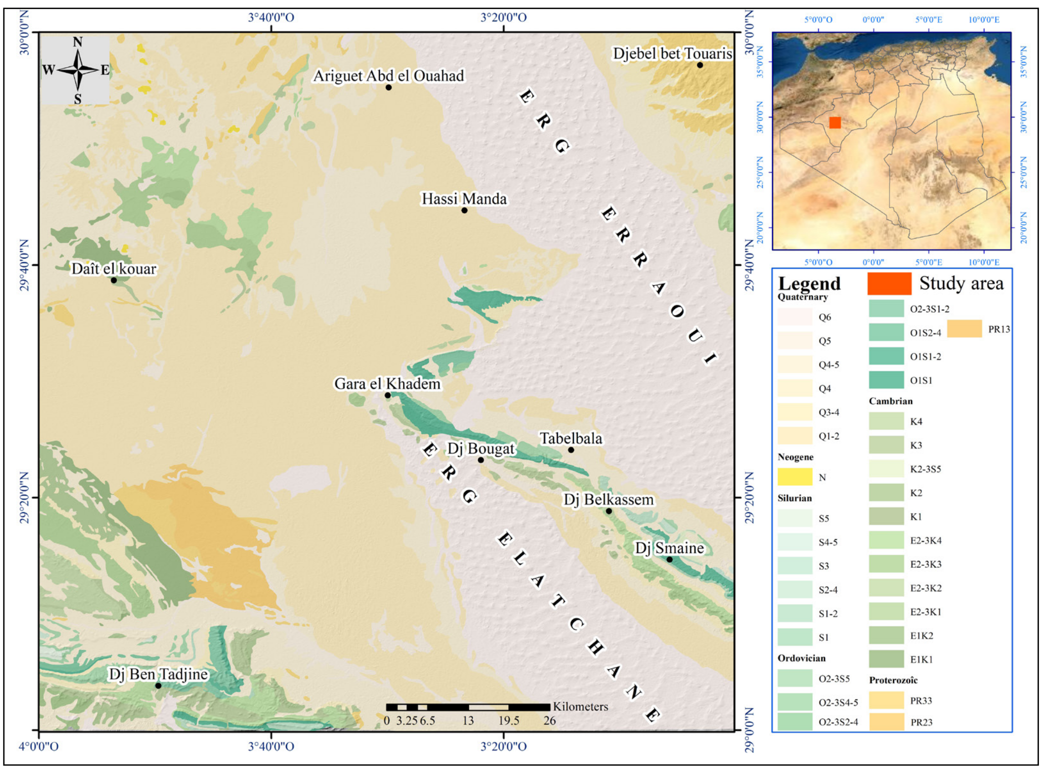

Figure 5- Lithological map of Tabelbala (Rabah et al., 2016).Quaternary: sand, silt, and alluvial deposits; Neogene: sandy-clay, conglomerate, sandstone, and limestone; Silurian: clay-shale, sandstone, and limestone; Ordovician: Quartzite, sandstones, clay-shale, and conglomerate; Cambrian: Quartzite-sandstone, sandstone, copper-sandstone, and intraformational conglomerate; Proterozoic: rhyolite, ignimbrite, dacitic-porphyry, sandstones, basalt, andesitic-basalt, andesitic-tuffs, andesitic-porphyry tuffs, greywackes, and conglomerate.

The lineaments are extracted and mapped from two sources: Geological Survey of Algeria at 1/200000 scale and satellite data. Their length ranges from 0.12 to 24.79 km whereas their directions are interpreted by using rose diagrams. It is found that the majority of lineaments are oriented towards the NE-SW direction followed by the other directions (Figure 7).

In the study area, the lineament density ranges from 0 to 0.00083 km/km^2 and it was arranged into five classes: 0-0.00017, 0.00017-0.00034, 0.00034-0.00051, 0.00051-0.00068, 0.00068-0.00085 with a real percentage of 80.15, 13.62, 4.56, 1.26, 0.38 respectively. The highest lineament density (0.00068-0.00085 km/km^2) has a good groundwater potential while the lowest lineament density (0-0.00017 km/km^2) is characterized by a poor groundwater potential (Figure 6).

The directional statistical analysis of the different lineaments shows two preferential directions. They are generally oriented NE-SW and NW-SE. The histogram of relative frequencies (Figure 7) confirms the same linear classes.

3.5. Drainage Density

The drainage network is prepared and updated using DEM (SRTM) and Landsat 8 OLI images. It is categorized up to the fifth order. Once the network is prepared, the drainage density map can be calculated as it is considered a vital factor for groundwater assessment where it is inversely proportional to the permeability (Shekhar and Pandey, 2015). It is the ratio of total stream length and the total area of the region of interest (Yeh et al., 2016) as shown in the Equation 8:

$$DD=L/S \qquad (8)$$

Where *DD* defines the drainage density, *L* is the length of the stream, and *S* stands for the unit area (Tarboton et al., 1992).

Areas with high groundwater potential are often characterized by a fairly high infiltration rate as well as a sparse and sparsely drained drainage network (Dinesh Kumar et al., 2007). For this reason, we assign the lowest weight value to the highest drainage density and vice versa. As shown in (Figure 8), Tabelbala demonstrates a wide range of density values ranging from 0 to 0.0012 km/km^2.

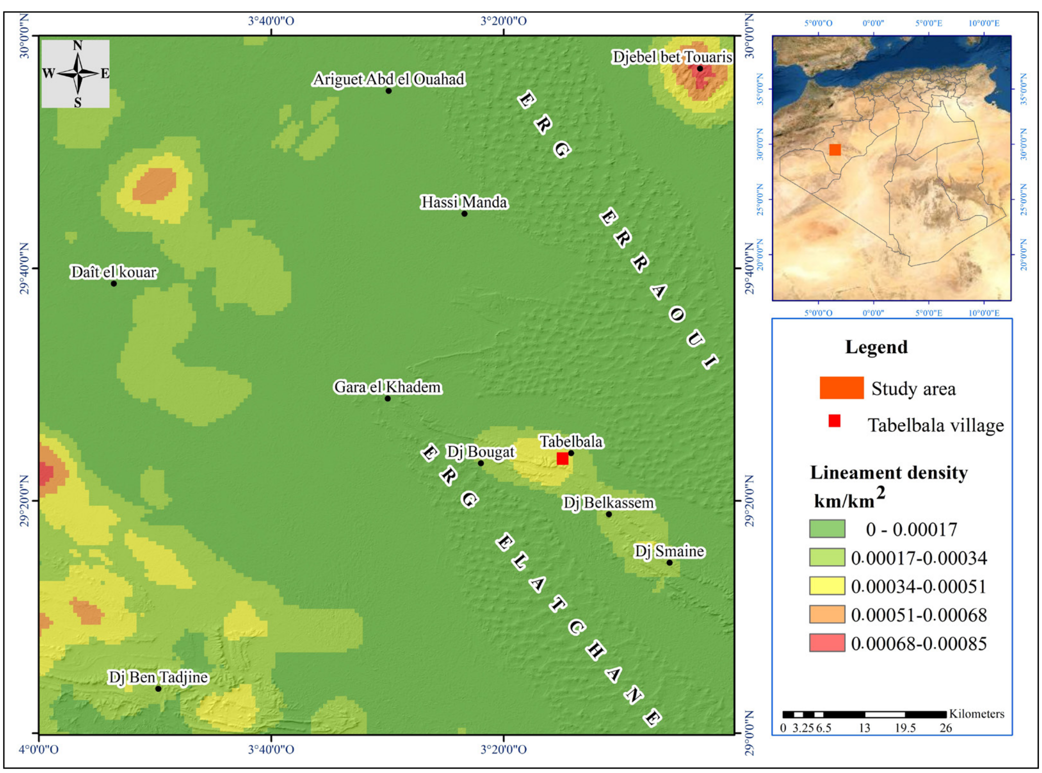

Figure 6- Lineament density.

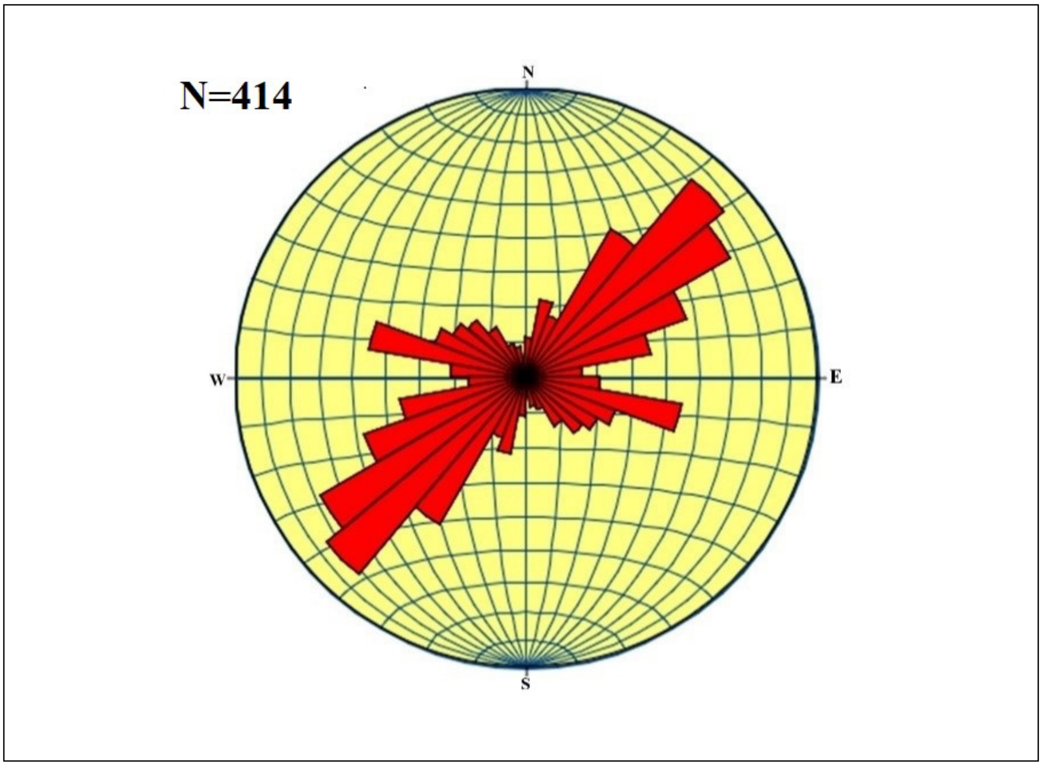

Figure 7- Rose diagram of the lineament orientation.

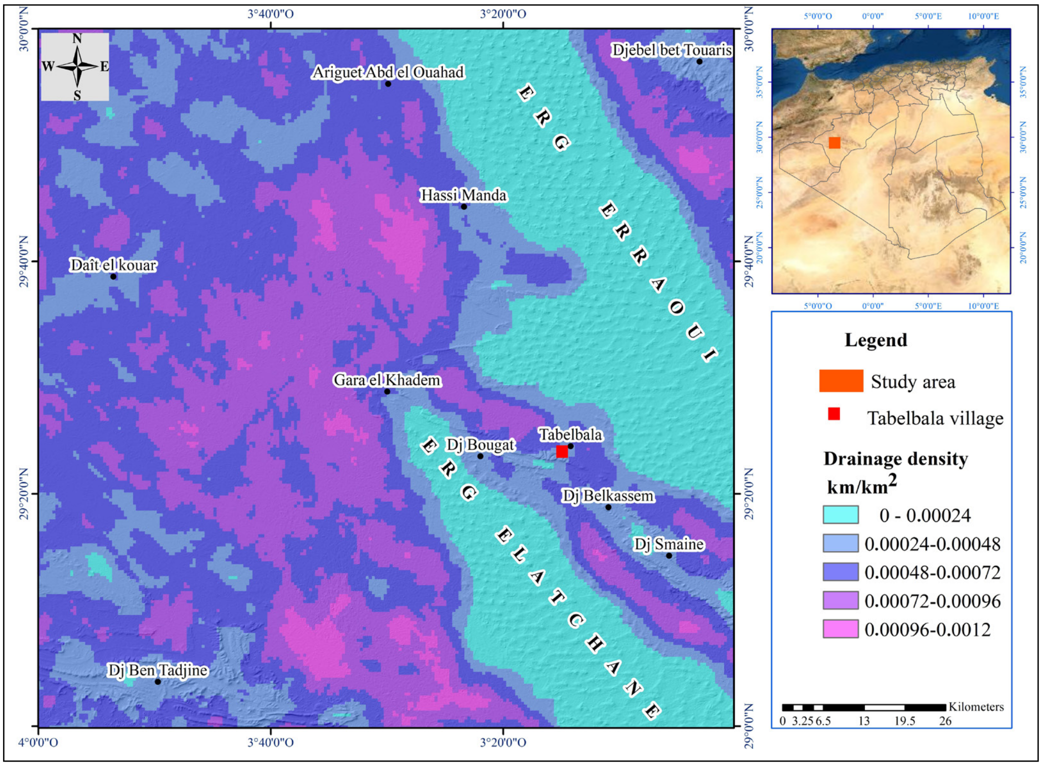

Figure 8- Drainage density of Tabelbala.

3.6. Slope

In groundwater investigation, the slope is a significant factor which has a direct effect on water retention and the infiltration amount (Tanvir Rahman et al., 2012). In Dait el Kouar, Ariguet Abd el Ouahad and Hassi Maanda, the slope is very gentle to nearly flat (0-3°) while it ranges from 6 to 50° on the right side (Djebel bet Touaris, Erg Erraoui, Erg El Alatchane, Gara El Khadem, Djebel Bougat, Djebel Belkassem, Djebel Smaine, and Djebel Ben Tadjine). The hilly, moderate and high elevated areas are characterized generally by a low infiltration rate while the plain areas have high infiltration. (Thapa et al., 2017). The slope map is generated based on the DEM SRTM-30m spatial resolution and it ranges between 0 and 55°. The plain area has high priority while high and moderate elevated points have low priority. Five slope classes are characterized in our study area: 0°-3°, 3°-6°, 6°-12°, 12°-25°, 25°-50° (Figure 9).

3.7. Elevation

For groundwater estimation, elevation is considered one of the most important elements. Generally, the plain zones are characterized by a high rate of infiltration as well as a long retention time in terms of groundwater recharge. On steep slopes, the runoff surface is quite large while the infiltration rate is almost low (Adeyeye et al., 2019). In our region, the elevation value varies from 398 m to 909 m (above mean sea level). The elevation value is subdivided into five classes: 398-500 m (20.20%), 500-600 m (64.34%), 600-700 m (14.52%), 700-800 m (0.84%), 800-909 m (0.07%), respectively (Figure 10).

3.8. Land Use/Land Cover (LULC)

The land use/land cover is one of the most determining factors in hydrogeological prospecting. It has a direct effect on hydrologic parameters, surface runoff zone, infiltration and evapotranspiration (Jasrotia et al., 2016; Thapa et al., 2017; Berhanu and Hatiye, 2020). Land use/land cover of the study area (Figure 11) is composed of runoff zones (35.01%), Oued (0.27%), reg and Hamada zones (27.65%), relief (10.26%), Erg (26.56%), sandy veil (0.002%), sandy deposits (0.13%), agricultural areas (0.106%) and settlements (0.008%). The importance order is given in Table 1. The highest rate is given for a runoff zone and Oued while the lowest rate is assigned to the settlements and relief.

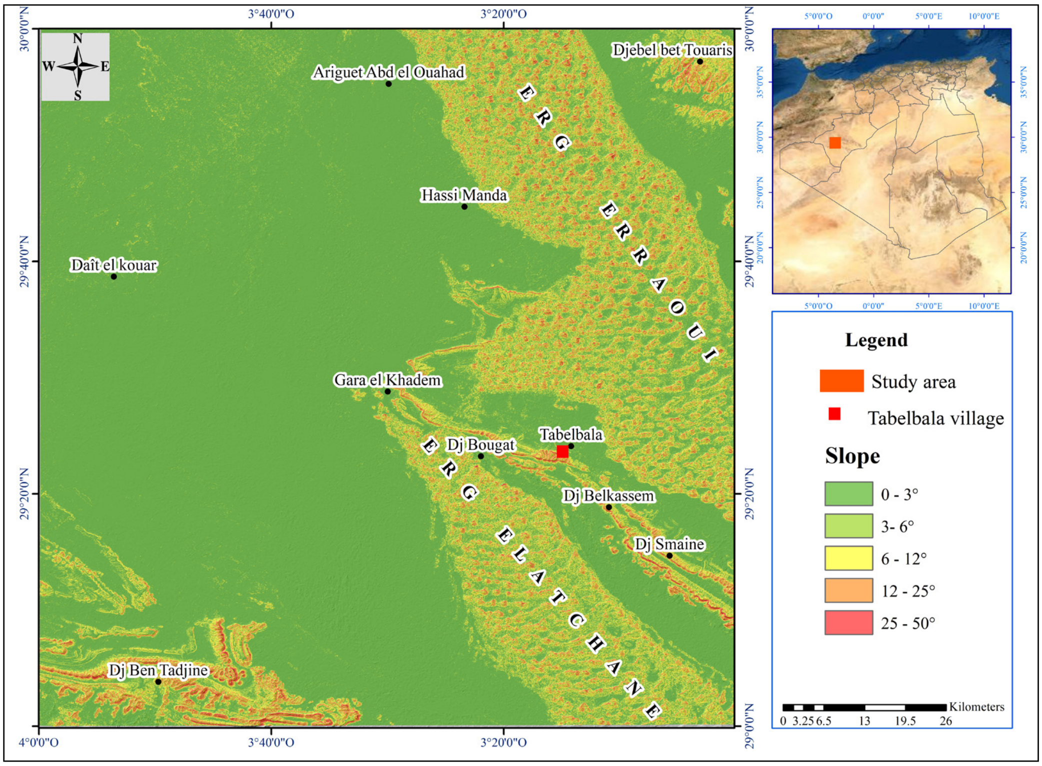

Figure 9- Slope map of the concerned area.

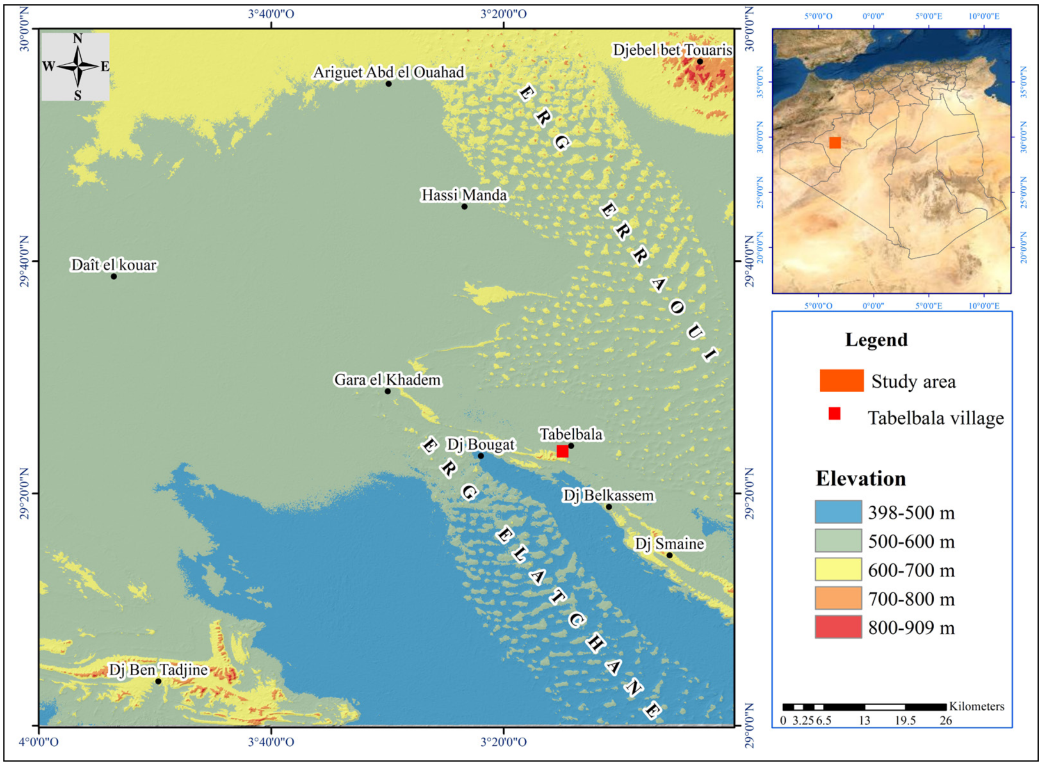

Figure 10- Elevation map of the study area.

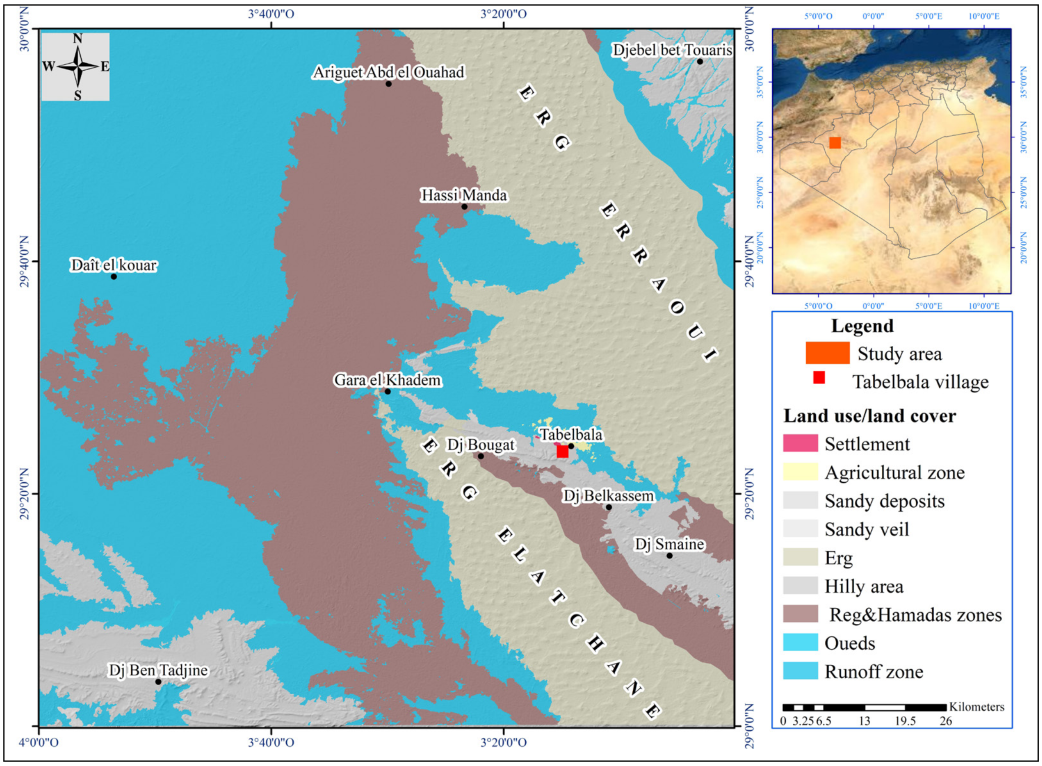

Figure 11- Land use/land cover map of Tabelbala.

3.9. Topographic Wetness Index TWI

Topography is known to have an influence on the different hydrological processes related to permeability, infiltration, runoff and land productivity. The amount of groundwater infiltration of the study area (Kousalya et al., 2012; Nithya et al., 2019) is measured by elaborating the TWI factor and its topographical conditions.

By using the GIS environment, the TWI is prepared and used to trigger the hydrological flow in the watershed (Vadrevu et al., 2006; Bevan and Lake, 2016). TWI can be calculated using the following equation:

$$TWI = \ln \alpha / \beta \qquad (9)$$

where α = slope of the studied area and β = topographic gradient.

The high weight is attributed to the high topographic wetness index value. The TWI value of the study area varies from 3 to 22 (Figure 12), the higher TWI value corresponds to high groundwater potentiality and vice versa. The visual interpretation of the TWI map shows that the high to medium sites favorable to wetlands are situated along the watercourses, Oued, runoff zones, and agricultural zones while the dry areas are located in the Reg and Hamada Zones, Erg, sandy veil, and deposits.

4. Discussion

4.1. Groundwater Prospects Zones

Several studies attempt to analyze Algeria's groundwater resources although these assessments have mostly focused on the country's north region. Based on the available information, this study intends to assess the groundwater resources of the Tabelbala region (Desert area). In the case of the lesser-known aquifers in southwestern Algeria, the used methodology has proven to be effective in a number of data-scarce studies. It is based on the integration of layers that influence potentiality and have been incorporated into a GIS environment. By integrating consistent influencing layers of lineament density, lithology, drainage density, land use/land cover, slope, elevation, and topographic wetness index which were weighed and categorized in a GIS, a multi-criteria analysis was established. The groundwater potential zones map is created by combining (rate*weight)

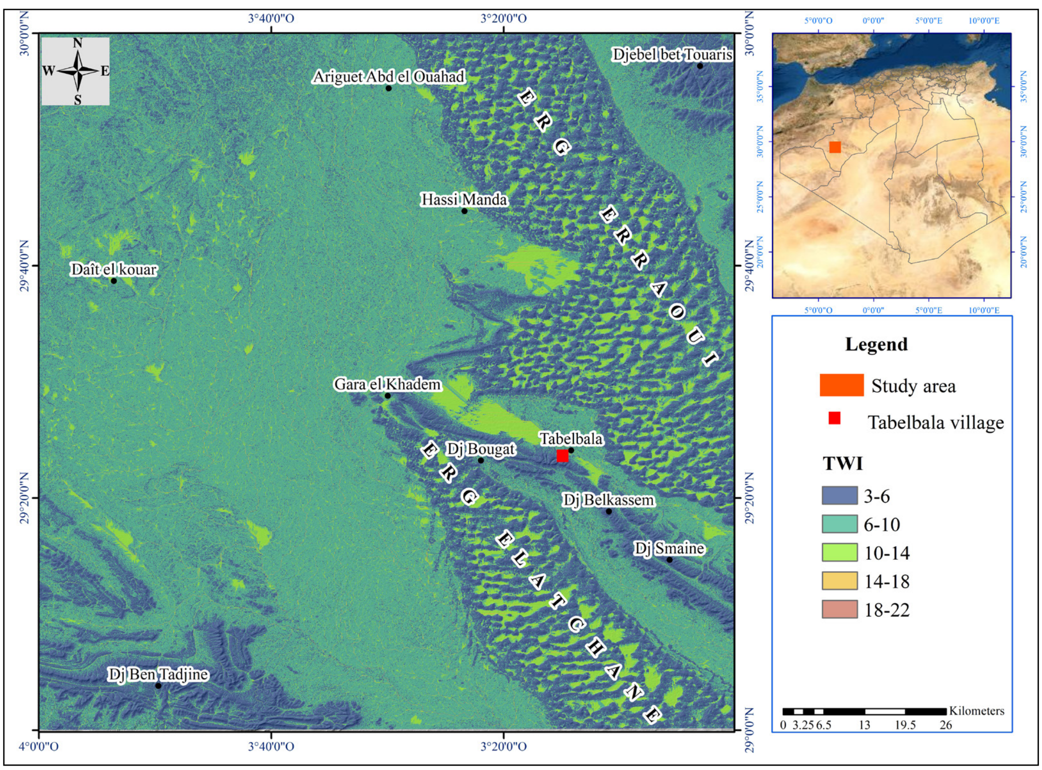

Figure 12- Topographic wetness index map of the study area.

of the layers indicated above with each layer being assigned a weight ranging from 1 to 9 depending on the relevance and value of each factor in groundwater prospects and assessment. The pairwise comparison matrix is created using the techniques outlined in the preceding section. Weights and rates are chosen based on the work of numerous researchers (Kerzabi et al., 2021).

The obtained results provide an assessment of each factor's influence and an estimate of its rate of contributions to the determination of prospective groundwater areas. These results are presented as follows (Figure 13): lithology (38.9%) is the most influential component, followed by lineaments (23.7%), Lu/Lc (15.4%), drainage density (8.7%), slope (5.3%), elevation (4.9%) and TWI (3.1%). It should be highlighted that the CR value (used to aggregate the multiple criteria) is estimated at 0.02 which indicates that our simulation is very consistent (rates and weighs) (Figure 14 and 15).

Figure 16 shows the groundwater potential zones obtained. According to the conducted research, the very high potentiality class accounts for 8.81% of the total area and it is related to a moderate slope, low elevation values, and lithology of sands, conglomerates, and alluvium deposits. It can be found in the South-West of Djebel Ben Touaris, in Tabelbala, in the South-East and North of Dait El Kouar and Djebel Ben Tadjine.

The high potentiality zone (20.53%) is located in the south-west of Erg El Atchane, Erg Er Raoui and Djebel Bet Touaris with an altitude ranging from 500 to 600 meters. It contains a high lineament density and a gentle slope whereas the moderate potentiality zone (58.25%) occupies a good part of the study area and is mainly confined to relatively moderately sloping areas with minor lineaments. It corresponds to the lower part of the upper pediment and relief whose lithological character is composed of an eolian sand at elevations ranging from 398 to 550m and a medium to low TWI rate. The zones of low potentiality (5.94%) are located in the upper part of the pediment (recharge zones) with low lineament density, low elevation, and covered by a Proterozoic formation. The high potentiality near Dait El Kouar, is explained by the high lineament density (main fault). It corresponds to the lower part of the upper pediment and relief whose lithological character is composed of quaternary deposits (sand, silt, and alluvial deposits) at elevations ranging from 398 to 550m.

On the other side, the hilly areas are grouped into runoff areas with a very steep slope and low infiltration. They are characterized by a very low potentiality (6.47%) where groundwater is limited to narrow valleys and belongs to faults and fractures (lineaments). For the well locations, most of them are concentrated on Erg Er Raoui which is known

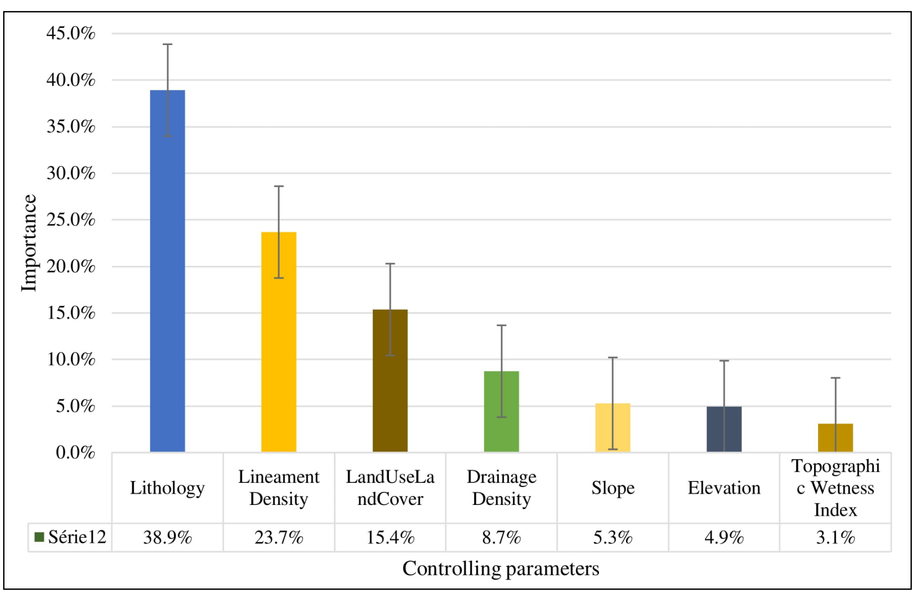

Figure 13- Weights assigned in AHP method (Lit: lithology, LD: lineament density, LULC: land use/land cover, DD: drainage density, S: slope, E: elevation and TWI: topographic wetness index).

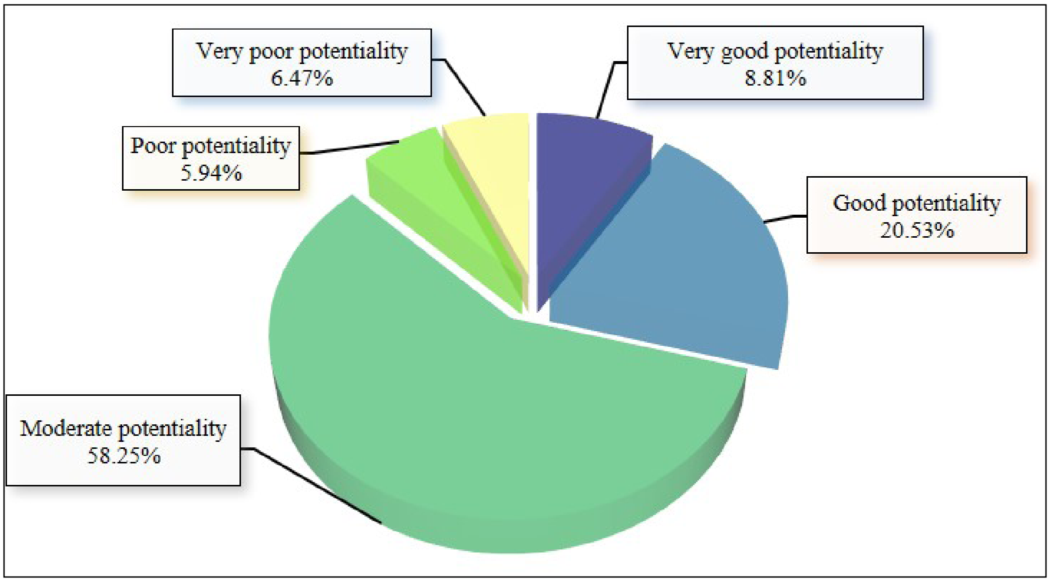

Figure 14- Percentage of different spatial potentiality zones of the study area.

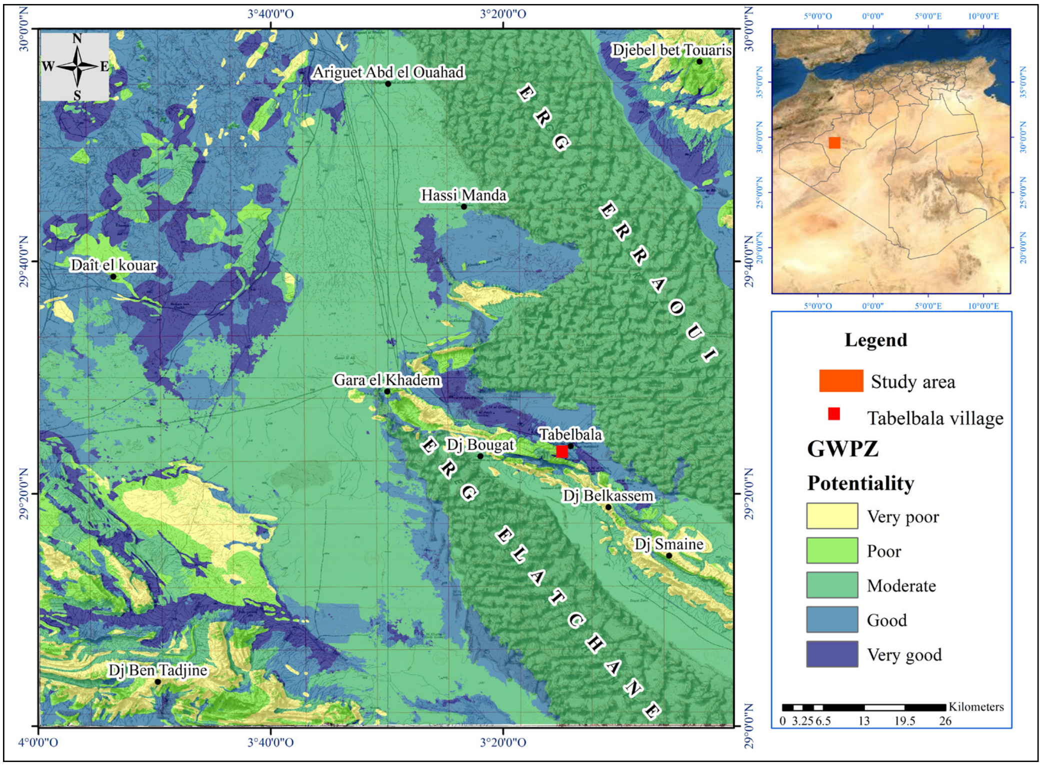

Figure 15- The groundwater potential zones map of the Tabelbala region.

as a drinking-water reservoir. The most famous are Hassi El Hariga, Hasi Aouissia and Hassi El Kheîl (Mekkaoui, 2015).

4.2. Groundwater Validation

The evolution of GIS and RS allowed for substantial advancement, however, filed verification and validation is still required due to the huge margins of error associated with automated algorithms applied to satellite imagery. In this section, we will evaluate the obtained results achieved in this arid zone against a field collected data to provide a global approach accuracy. In order to offer a reliable evaluation, field measurements from well-distributed drilling flows are employed over the whole study region. It is also important to illustrate the accuracy of the different prepared maps. The receiver operating characteristic (ROC) curve analysis and area under curve (AUC) are used to assess the locations of the different wells (222 wells and boreholes got from the National Agency for water resources) with the prepared potential zones map.

The spatial distribution of the wells reveals that 24.32% (54 wells) and 71.62% (159 wells) are in locations with very high and high groundwater potentialities, respectively, while 1.80% (4 wells) and 2.25% (5 wells) are in regions with moderate and low potentialities. The area under curve AUC is 0.89 which indicates good performance (Figure 16). This precision demonstrates that the AHP method is efficient in the study area and it can be used for groundwater delineation in isolated areas.

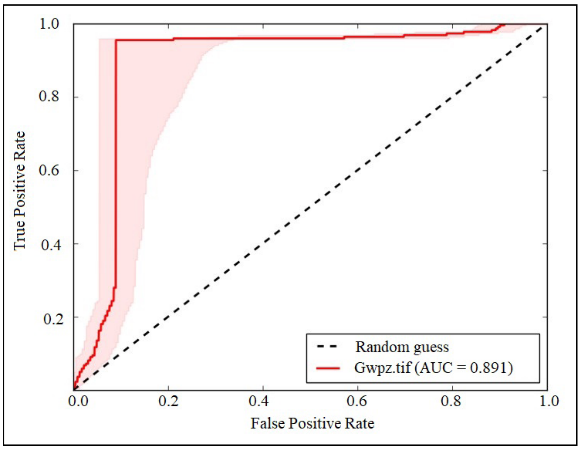

Figure 16- The ROC curve diagram corresponding to the study area.

The research yielded valuable new hydrogeological data that can be used in groundwater fluctuation studies to better understand the behaviour of aquifers in the area. It can also give adequate facilities for better natural resource management, usage, and secure supply, as well as sustainable development.

4.3. Material

During this work, different GIS and image processing software is used. ENVI and ERDAS Imagine are used to process satellite data through color composite, bands ratios, principal component analysis, and filtering. This processing is the key for updating lithological units, extracting lineaments and the preparation of the land use/land cover map. ArcGIS software is used to prepare the drainage density, slope, elevation and TWI maps. Stereonet software is used for the elaboration of the rose diagram which is related to the lineament orientation.

5. Results

Groundwater mapping has become extremely important in the Algerian desert region due to the country's rapid population development, which has increased the requirement for water supplies for the area's population and agricultural operations. The identification and spatial classification of promising areas from a hydrogeological point of view, requires a detailed examination of data from preliminary studies (geomorphological, geological, structural… etc.). In this study, a GIS database was gathered and prepared for the Tabelbala region using seven predictive factors then the AHP approach was applied. The analysis of potentiality was initiated with the combination and integration of controlling factors. The combination that brings together the predictive factors lithology, land use/land cover, lineament density, slope, drainage density, elevation, and topographic wetness index turns out to be the best possible combination for our area. It makes it possible to predict about 80% of water points. This study shows that the approach adopted using GIS can provide promising results in the analysis of field-oriented data. Lithology, land use/land cover, lineament density, slope, drainage density, elevation, and topographic wetness index are prepared to characterize the region. The results show that the groundwater potential map can be divided into five categories: very good potentiality (943.34 km^2), good potentiality (2197.36 km^2), moderate potentiality

(6236.47 km^2), poor potentiality (635.70 km^2), and very bad potentiality (692.88 km^2). More than 29.34% of the study area has extremely good groundwater potential according to the findings. It can be noted that the zone covered by Oued under sedimentary deposits (sandstone, sandstone-clay, and sandstone-carbonate) has a moderate slope, high lineament density, and low drainage density, is defined as a very high groundwater potential zone with a 943.34 km^2 area. We also observe that the area made up of volcano-sedimentary formations of the Paleozoic and Cenozoic deposits of various genesis which has a very low lineament density, high drainage density, very high slope, and is covered by runoff zones, is characterized by a very poor groundwater potential zone (692.88 km^2). The accuracy of the obtained map is validated using the ROC curve analysis and the AUC by taking into account the location of the field collected wells (222 boreholes and wells). Results show that AUC is 0.89 which demonstrates that the proposed method can be used as a high-precision investigation tool for groundwater resources particularly in data-scarce areas. It can also be confirmed that in the absence of field data, remote sensing and GIS techniques are one of the most effective tools for determining groundwater potential zones. This work will provide a digital and an update digital information (digital database) of the different influencing factors which will be used and increase the general knowledge and digital database of the Tabelbala region. Thus, applying this method might be beneficial for saving money and time.

This multi-criteria approach has nevertheless certain limits, particularly in relation to the working scale, due to the coarse resolution of the available data; DEM (30 m), Landsat (30 m), and Sentinel 2 (10 m), indeed the drilling operation management must be supported by ground reconnaissance or other parallel support (electrical sounding). As future work, it is therefore planned to improve the scale of processing, in particular via optical satellite imagery (Alsat2 at 2.5m in pansharpened mode), and also with a digital terrain model of better resolution (based on topographic campaign), while prospecting other emerging approaches including machine learning and microwave remote sensing SAR.

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