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# Delineation of Potential Groundwater Area in Semi-arid and Arid Region: A Case Study of Wadi Mekerra North West Algeria Using Remote Sensing, GIS and Analytic Hierarchy Process

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**Abstract**

Groundwater is a vital natural resource and has an important role in the economy. It is the main source of water for irrigation and food industry. In general, groundwater is a reliable water source for agriculture and can be used flexibly during dry periods. Moreover, the use of geographic information systems (GIS) has shown great effectiveness in the study of groundwater since they present a very essential and rapid result. It allows the establishment of thematic maps that are useful for future developments and to control the quality of groundwater.

For this reason, the present study aims to delimit the potential of Wadi Mekerra groundwater basin, located in the North-Western part of Algeria, characterized by an arid and semi-arid climate. This aquifer, which extends over more than 2800 km2, sis unconfined, drained through Wadi Mekerra, and exploited by a fairly impressive number of wells and deep wells, almost the majority of which are used to irrigate agricultural land. In the current study, an analytical hierarchical process technique (AHP) was integrated with a geographic information system.

A total of eight thematic layers were established and assessed for groundwater potential zone delineation, including geomorphology, geology, land use/cover, lineament density, drainage density, rainfall, soil and slope. All thematic maps' weights for each class are determined by the AHP approach based on each class's attributes and water potential capacity. Data from springs, wells, and deep wells and their chemical analyses were carefully used for validation. The map of the groundwater potential zone was, then, divided into five categories: very good, good, moderate, low, and very low.

The study shows a very low and low groundwater potential zone that covers around 50.55% of the study area. The percentages of areas with very good and good groundwater potential are 4.15 and 11 percent, respectively. The moderate groundwater potential zone covers 59 % of the basin.



**Keywords:** *Groundwater potential zones (GWPZ), Analytic hierarchy process (AHP), Wadi Mekerra North West Algeria, Remote-sensing (RS), Geographic information system (GIS), Water Resources.*

## 1. Introduction

Water is an essential element for life and is present in the atmosphere in the form of clouds, vapour, or rain. It is also reserved in the underground layers, which contain enormous quantities. Seasonal climatic extremes and irregular rainfall variations are characteristics of arid and semi-arid zones. Compared to drought, which can occur in both arid and humid climates, it is a structural climatic event.

Groundwater is the most essential component of the hydrological cycle (Chiedozie and Tosan, 2022). It can be vulnerable to many sources of contamination and land cover change resulting from human activities (Rehman et al., 2019). An aquifer's function is to store groundwater and control how much water is held and released. The ability of the aquifer to recover and convey water is determined by hydrodynamic parameters (Mallick et al., 2015). They are crucial in understanding the aquifer and the amounts of water that are produced by a well. These traditional methods, used to identify, delineate, and map the groundwater potential zones, are expensive. Furthermore, groundwater aquifers may be evaluated and managed rapidly and effectively by combining the use of remote sensing, GIS, and satellite data (Adiat et al., 2012; Verma and Singh, 2013; Alqahtani and Qaddah, 2019).

Some researchers have reported on a variety of techniques for groundwater monitoring and management, such as identifying potential zones (Thakur et al., 2018; Pande et al., 2020; Bhattacharya et al., 2021). As an illustration, several studies have used probabilistic models such as the frequency ratio (Razandi et al., 2015), multi-criteria decision analysis (Rahmati et al., 2015), and logistic regression (Pourtaghi and Pourghasemi, 2014).

The groundwater potential zones were identified in the present study using Analytical Hierarchy Process (AHP) and GIS approaches (Machiwal et al., 2011). The Analytical

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Hierarchy Process (AHP) is an approach for organizing and evaluating complicated decisions. Thomas L. Saaty developed the AHP in 1980 (Saaty, 1980). By quantifying its criteria and alternative choices and integrating these components into the overall purpose, the AHP offers a coherent framework for a critical decision, particularly in domains related to groundwater (Saaty, 2001).

Groundwater is influenced by many factors, such as water quality, the available amount of water, management costs, environmental aspects, etc. The Analytic Hierarchy Process (AHP) is a decision-making methodology commonly used in the field of groundwater management. This approach offers the possibility of structuring and comparing various criteria and options, thus contributing to the formulation of informed decisions. Several studies have demonstrated the effectiveness of this method in this specific context. A research has used the AHP to assess the vulnerability of groundwater to pollution, taking into account various hydrogeological parameters (Gangadharan and Vinoth, 2016). In another study, this method is used in the selection of drilling sites based on criteria such as recharge, water quality, and accessibility (Gdoura et al., 2016; Li et al., 2023). Additionally, for the mapping of groundwater quality, the AHP can be applied by considering various chemical and physical parameters, as illustrated by a study on the struggling Asan River in India (Mishra et al., 2022). Furthermore, this method is employed as a bottom-up strategy to track changes in soil characteristics (Tobore et al., 2023).

This study makes it possible to adjust priorities and approaches according to new information and new challenges since groundwater conditions can change over time due to factors, such as climate change or human activity. The proposed methodology also makes it possible to integrate scientific data and research results into the groundwater management process, thus ensuring that decisions are based on solid data.

This study is significant as it proves the possibility to managing water resources optimally and dynamically and collecting reliable preliminary information on the state of the hydrogeological environment. In addition, the data the study provides can be so efficient in any potential decision-making to solve the difficult problem of groundwater quality.

The main objective of the study is to delimit, identify, and map the area of groundwater potential of the Wadi Mekerra basin located in the North-West of Algeria. This study area is subject to an arid and semi-arid climate characterized by very irregular rainfall. For this reason, this study is an example of the application of the principles of sustainable development to the water resources sector, and decisions are made methodically and can be explained and justified.

## 2. Study Area

The Oued-Mekerra sub-basin study area is located in the western part of the Macta basin, in northwestern Algeria. Geographically, the study site is located between latitude 34°19′20” to 35°21′34” N and longitude 0°56′39” to 0°25′22” W with an aerial extent of 2120 Km$^2$ and the main Wadi length is about 106 km. The main stream of the Mekerra sub-basin is of the fifth order and has a dendritic drainage pattern. Figure 1 shows that the study area is generally expected to have a higher elevation in the north and northwest areas and a lower elevation in the south with a minimum and maximum elevation of 295 m and 1484 m from the mean level of the sea (datum), respectively, and the standard deviation is of 280.94m. The climate of the study area is arid to semi-arid, characterized by cold, wet winters and hot, dry summers with the average annual rainfall in the region being between 310 and 450 mm over five months (December to April) (Otmane et al., 2019). The average temperatures of the maxima and minima are respectively 39°C and -2°C with an annual average of 19.52°C. The relative humidity is high all year round (more than 50%) and becomes maximum during the winter months when it oscillates between 68% and 80% when the temperatures are minimum. In addition, the geology of the study area is characterized by the formation of limestone and alluvial deposits, which occupy more than 79% of the surface of this sub-basin and play a role in increasing the permeability of the rocks (Hallouche, 2017).

## 3. Materials and Methods

### *3.1 Data used and preparation of thematic layers:*

Topographic elevation (DEM), slope, and drainage density maps are developed from ASTER DEM images that have been downloaded from (www.search.earthdata.nasa.gov/search). These topographical maps were georeferenced using the WGS 84 datum, UTM zone 30 N projections in ArcGIS 10.4.1. The geomorphological and geological maps were downloaded respectively, from the Global Landform classification (Meybeck et al., 2001; Iwahashi and Pike, 2007) and the Surface geology of Africa, in order to prepare the thematic layers ( Table1).

**Table 1.** Data sources used for thematic layers preparation.

| Thematic layers | Data type | Scale/resolution | Data sources |
|---|---|---|---|
| Administrative boundary shapefile | Polygon | 1:15 000 000 | DIVA-GIS (https://www.diva-gis.org/) |
| Slope | Raster (ASTER) | 30m | NASA website (www.search.earthdata.nasa.gov/search) |
| Drainage density | | | |
| Lineament density | | | |
| Geology | Polygon | 1:750 000 | Surficial geology of Africa(https://catalog.data.gov/) |
| Geomorphology | Raster (ASTER) | 30m | Global Landform classification (https://esdac.jrc.ec.europa.eu) |
| Soil | Polygon | 1: 5 000 000 | FAO-UNESCO Soil Map of the World(https://data.apps.fao.org/) |
| Rainfall | CSV | Hight resolution | Global weather data (https://globalweather.tamu.edu/) 1979-2014 |
| Land use/land cover | Polygon | 10m | global land use/land cover (LULC) (Esri Inc.) ( https://www.arcgis.com/) |

Soil data for the study area were downloaded from Digital Soil Map of the World in ESRI shape file format. In addition, shaded relief maps of eight different azimuth angles are respectively 0°, 45°,50°, 60°,90°, 100°, 200°, and 315°. They were developed from ASTER DEM and processed in ArcGIS to extract the Mekerra Wadi sub-basin lineaments (Das and Pardeshi, 2018). Therefore, the line density tool was used to prepare a lineament density map of the study area. The land use/land cover map of the study area was extracted after downloading the layer which displays an overall land use/land cover (LULC) map. This map is derived from the ESA Sentinel-2 imagery at 10 m resolution. It is a composite of LULC predictions for 10 classes throughout the year to generate a representative snapshot of 2020. Daily rainfall data for the study area were uploaded to (globalweather.tamu.edu) over the 36 years from 1979 to 2014 (Ahl, Woods, et al. 2008). These data were used to generate the rainfall map using the inverse distance weighting (IDW) method of interpolation.

Geospatial techniques have been applied in this paper to delineate potential groundwater areas of the Mekerra Wadi sub-basin. Eight thematic maps, such as geomorphology, rainfall, lineament density, lithology, slop, soil, LULC, and drainage density were prepared (Rajaveni et al., 2017). The flowchart in Figure 2 shows the processes for delineating groundwater potential zones in our study area.

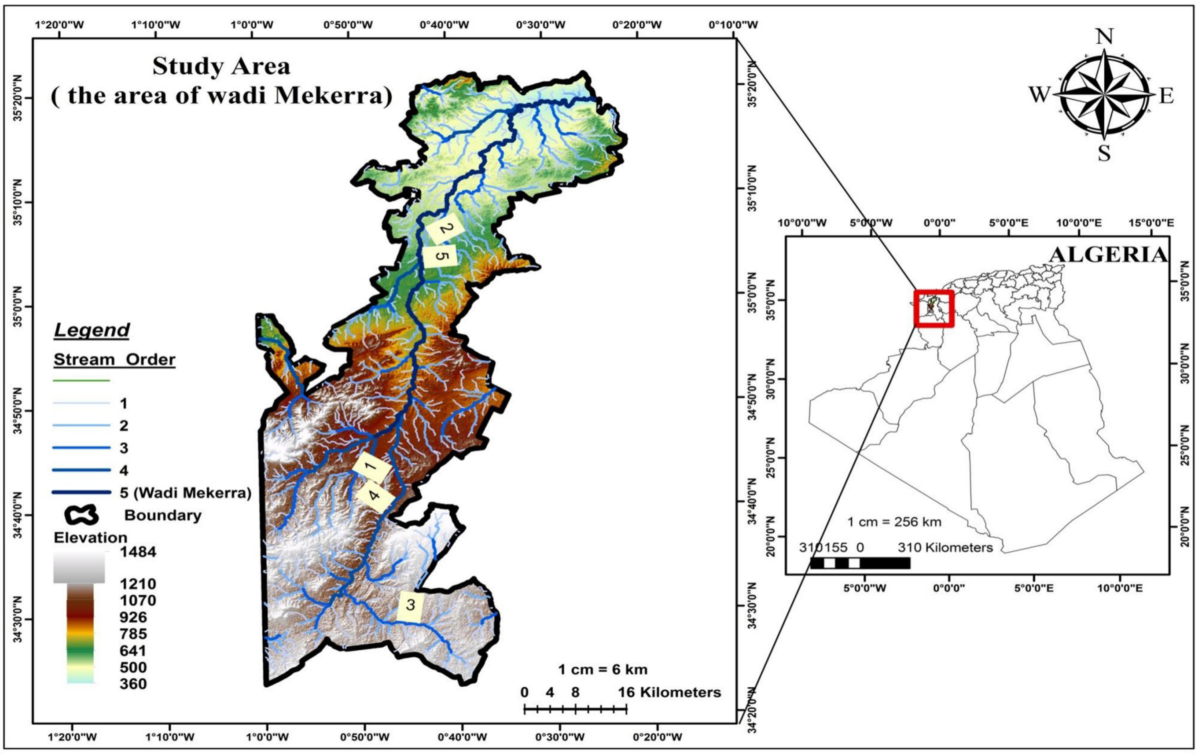


**Figure 1.** Location of Wadi Mekerra and Study area.

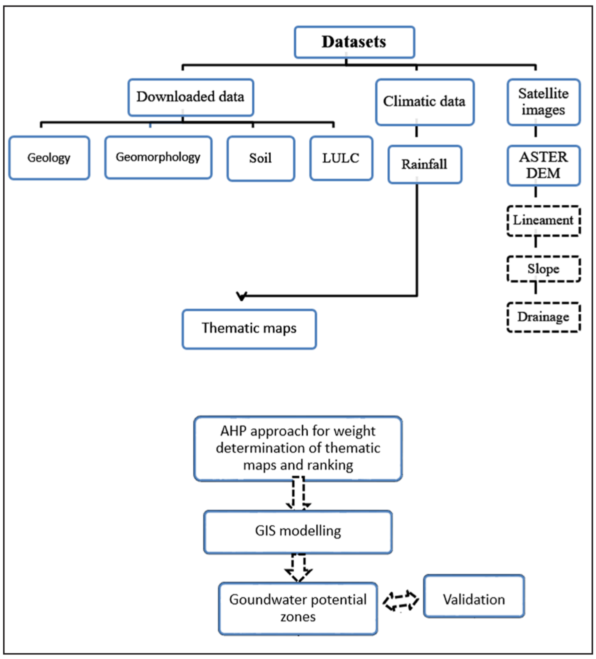


**Figure 2.** Flowchart of the methodology applied in the study area.

*3.2 Geomorphology*

Geomorphology addresses the landform and landform evolution of an area and is one of the main factors generally utilized for the depiction of groundwater potential zones. It offers data about the distribution of diverse landform features. Processes, like understanding issues of deforestation, soil properties, and seasonal precipitation, can better assess frequencies of flooding events and their potential danger of freezing and thawing (Rajaveni et al., 2017; Thapa et al., 2017). (Figure 3).

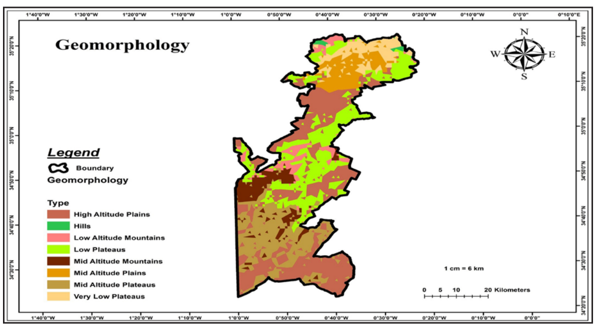


**Figure 3.** Geomorphology map of the study area.

### 3.3 Rainfall

Rain is the primary source of water in the hydrological cycle and the most important element, influencing groundwater in a region (Shekhar and Pandey, 2015). The intensity and duration of precipitation are crucial for infiltration and the amount of runoff (Abuzied et al., 2016). For the present study, precipitation data from 1979 to 2014 are used, with yearly precipitation, varying between 486 and 695 mm. The precipitation map was constructed using the IDW interpolation approach (Figure 4).

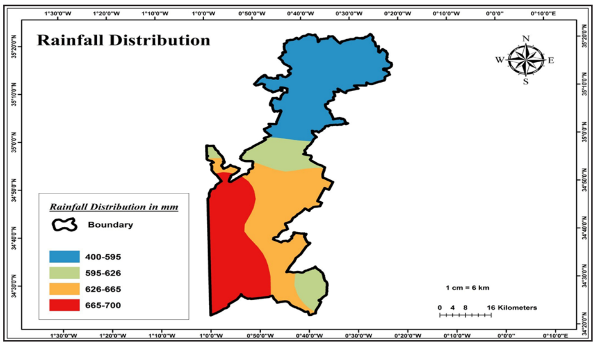


**Figure 4.** Rainfall distribution map of the study area.

### 3.4 Lineament density

Lineaments are linear geological or geomorphological elements such as faults, fractures, watercourse, roads, etc. (Pradhan and Youssef, 2010). Linear geologic features are expected to be primarily the fractured zone with good porosity and permeability (Devi et al., 2001). The Lineament density was determined according to the following formula (Edet et al., 1998):

$$Ld=\sum_{i=0}^{i=n} Li/A \ (\mathrm{Km^{-1}}) \qquad (1)$$

Where ΣLi is the total length of all lineaments (km), and A is the area of the grid (km$^2$).

### 3.5 Lithology

Lithology describes the geochemical, mineralogical, and physical properties of rocks. It plays a fundamental role in the processes that control, on the surface, the flow of materials to soils, ecosystems, rivers, and oceans. It impacts both the porosity and the permeability of aquifer rocks and plays an important role in the apparition and movement of groundwater (Acharya et al., 2012).

### 3.6 Slope

Overall, a steep slope promotes runoff at the expense of infiltration (Gupta et al., 2018), while flat areas have high infiltration and can accumulate more groundwater (Rahman et al., 2012). The slope is important for many applications, particularly in geomorphology, natural resource management, and spatial planning. The slope map can be useful for identifying areas with low, moderate, or high slopes.

### 3.7 Soil

Soil governs the natural cycle of water, air, and organic and mineral substances. It filters and purifies water and stores and transforms substances. It represents an essential link in the permanent flows of energy and matter in the Earth's ecosystem, thus influencing the control of runoff and infiltration rates and then groundwater recharge (Fagbohun, 2018).

### 3.8 Land use/Land cover

The thematic map of land use in an area to be studied is a factor to be taken into account when prospecting groundwater. It is also a good indicator to quantify recharge, runoff, soil erosion (Al-Sababhah and Al maqablah, 2022) and infiltration (Ibrahim-Bathis and Ahmed, 2016; Bera et al., 2020). LULC map represents the spatial distribution of the different categories of land in the study area.

### 3.9 Drainage density

Drainage density is indicative of the infiltration and permeability of a drainage basin and plays a tremendous role in groundwater availability and contamination (Bera et al., 2019). It is also important in geomorphology, hydrology, and water resource management. To calculate the drainage density, The following formula is used:

Drainage density = (Total length of drainage) / (Total area of the study area) (2)

### 3.10 Analytic hierarchy process weightage analysis

This study determines thematic map weights, using the Analytical Hierarchy Process (AHP). The AHP was developed by Tomas L. Saaty in (1980), and, as a multicriteria, decision-making analysis arranges the factors in a hierarchic structure. The structure is composed of an overall goal of criteria, sub-criteria, and alternatives (Satty, 1990). The advantage of AHP in multi-criteria decision-making is that it takes into account the intuitive knowledge of the decision-maker in the analytical decision (Saaty, 2000). The AHP is structured in two parts: the problem structure and the weighting of the different parts of the problem structure. The decision maker must first analyse the decision into hierarchical sub-problems that are easier to understand (Saaty,1987) . Second, decision-makers need to assess the different elements systematically, comparing them to each other in pairs. This comparison is made using Saaty's basic comparison scale, ranging from 1 to 9, (see Table 2 in the appendix, Saaty, 1987). This scale of importance defines the value 1 as factors having "equal importance", and 9 defines the "extreme importance" of a factor compared to another factor. The analytical hierarchy process in GIS has been widely studied (Malczewski, 2006). The topics examined are agriculture ( Beigbabayi and Azadi,2011), environment (Ying et al., 2007), particularly in the field of groundwater, exploration, and management (Gangadharan and Vinoth,2016; Arulbalaji et al., 2019; Al-Djazouli et al., 2021). Accordingly, the criteria are analysed using the AHP matrix (Table 2, Table 3). We give the parameter geomorphology the highest weight, whereas precipitation, and lineament density were given moderate weight, and land use/land cover, lithology, soil, slope, and drainage density, were given low weight (Table 4). In addition, Table 2 shows the rank and weights assigned to the thematic layers.

**Table 2.** Saaty's 1–9 scale of relative importance.

| Intensity of importance | Definition |
|---|---|
| 1 | Equal importance |
| 2 | Weak |
| 3 | Moderate importance |
| 4 | Moderate plus |
| 5 | Strong importance |
| 6 | Strong plus |
| 7 | Very strong or demonstrated importance |
| 8 | Very , very strong |
| 9 | Extreme importantce |

*LuLc : Land use/Land cover.*

**Table 3.** Pair-wise comparison matrix (eight layers) developed for AHP based groundwater potential zoning.

| Factors | Geomorphology | Rainfall | Lineament Density | Lithology | Slope | Soil | LuLc | Drainage Density | Weight |
|---|---|---|---|---|---|---|---|---|---|
| **Geomorphology** | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0.37 |
| **Rainfall** | 8/2 | 7/2 | 6/2 | 5/2 | 4/2 | 3/2 | 2/2 | 1/2 | 0.18 |
| **Lineament Density** | 8/3 | 7/3 | 6/3 | 5/3 | 4/3 | 3/3 | 2/3 | 1/3 | 0.12 |
| **Lithology** | 8/4 | 7/4 | 6/4 | 5/4 | 4/4 | 3/4 | 2/4 | 1/4 | 0.09 |
| **Slope** | 8/5 | 7/5 | 6/5 | 5/5 | 4/5 | 3/5 | 2/5 | 1/5 | 0.07 |
| **Soil** | 8/6 | 7/6 | 6/6 | 5/6 | 4/6 | 3/6 | 2/6 | 1/6 | 0.06 |
| **LuLc** | 8/7 | 7/7 | 6/7 | 5/7 | 4/7 | 3/7 | 2/7 | 1/7 | 0.05 |
| **Drainage Density** | 8/8 | 7/8 | 6/8 | 5/8 | 4/8 | 3/8 | 2/8 | 1/8 | 0.046 |

**Table 4.** Categorization of factors influencing of Groundwater Potential Zoning.

| Parameter | Classes | weight | Influence (%) | Rank | Area (sq km) |
|---|---|---|---|---|---|
| **Geomorphology** | High Altitude Plains | 0.37 | 37 | 4 | 1277.903826 |
| | Hills | | | 3 | 16.049945 |
| | Low Altitude Mountains | | | 4 | 148.644935 |
| | Low Plateaus | | | 5 | 654.784206 |
| | Mid Altitude Mountains | | | 5 | 246.023682 |
| | Mid Altitude Plains | | | 3 | 204.127049 |
| | Mid Altitude Plateaus | | | 6 | 652.713914 |
| | Very Low Plateaus | | | 5 | 187.193251 |
| **Rainfall** | 1(486-595) | 0.18 | 18 | 1 | 954.542709 |
| | 2(595-626) | | | 1 | 348.481986 |
| | 3(626-665) | | | 2 | 785.447755 |
| | 4(465-694) | | | 3 | 732.698764 |
| **Lineament Density** | Very High( 1.12-1.40) | 0.12 | 12 | 5 | 129.650732 |
| | High (0.84-1.12) | | | 4 | 369.002481 |
| | Medium(0.56-0.84) | | | 3 | 608.18116 |
| | Low(0.28-0.56) | | | 2 | 847.286627 |
| | Very Low(0.08-0.28) | | | 1 | 887.438973 |
| **Lithology** | Jurassic | 0.09 | 9 | 4 | 660.193015 |
| | Cretaceous | | | 4 | 269.970883 |
| | Lower Cretaceous | | | 4 | 623.878811 |
| | Quaternary | | | 2 | 10.334615 |
| | Pleistocene | | | 2 | 247.792056 |
| | Tertiary | | | 3 | 1023.882024 |
| **Slope(degree)** | 0-3.6 | 0.07 | 7 | 5 | 1317.924085 |
| | 3.6-7.4 | | | 4 | 918.882549 |
| | 7.4-12.7 | | | 3 | 412.453821 |
| | 12.7-20.1 | | | 2 | 102.929178 |
| | 20.1-48.4 | | | 1 | 69.514624 |
| **Soil** | Chromic cambisols | 0.06 | 6 | 4 | 1808.159408 |
| | Calcic Cambisols | | | 3 | 967.607736 |
| | Xerosols | | | 2 | 57.409059 |
| **LuLc** | Annual Broadleaf Vegetation | 0.05 | 5 | 5 | 665.237595 |
| | Broadleaf Crops | | | 5 | 0.586084 |
| | Barren Land | | | 1 | 93.091426 |
| | Built | | | 1 | 79.337862 |
| | Closed Shrublands | | | 4 | 1819.016725 |
| | Shrubs | | | 5 | 162.057048 |
| | Water | | | 5 | 2.562314 |
| **Drainage Density** | Very High (4.05-5.05) | 0.046 | 4.6 | 1 | 157.200871 |
| | High(3.04-4.04) | | | 2 | 298.854688 |
| | Medium(2.03-3.03) | | | 3 | 475.094541 |
| | Low(1.02-2.02) | | | 4 | 565.915158 |
| | Very Low (0.05-1.01) | | | 5 | 617.676699 |

The groundwater potential map was created by summing the weight values of eight thematic maps: geomorphology, lithology, slopes, soils, land use/land cover, precipitation, lineament density, and drainage density map. The overall weights of various polygons inside the included layer had been derived from the subsequent equation to acquire groundwater potential index (Rao and Briz-Kishore, 1991; Kumar et al., 2016):

$$GWPI = ((GM_W)(GM_{Wi})+(RF_W)(RF_{Wi})+(LD_W)(LD_{Wi})+(LG_W)(LG_{Wi})+(SP_W)(SP_{Wi})+(SL_W)(SL_{Wi})+(LCW)(LC_{Wi})+(DD_W)(DD_{Wi})) \quad (3)$$

GWPI= groundwater potential index, GM = geomorphology, RF=Rainfall, LD=LineamentDensity, LG=Lithology, SP=Slope, SL=Soil, LC= land use/land cover, DD=Drainage Density, and the subscripts "w" and "wi" talk to the normalized weight of a topic and the normalized weight of individual features of a topic, respectively.

Specific diagrams have been developed to represent the results of hydrochemical analyses and to derive particular information from them using the DIAGRAM software, developed by Roland SIMLER from the University of Avignon. The use of these diagrams (Chadha, Piper's, Riverside) proves to be valuable because it makes it simple and direct to interpret rich analyses that are difficult to interpret. The Piper diagram uses the major elements to represent the different groundwater facies. The Riverside diagram is mainly used to assess the risk of soil salinization. For this, he uses the electrical conductivity (EC) or the total dissolved charge, both relating to the salinity of the water and the sodium absorption index (SAR) which is a measure of the risk of sodization of the soil due to irrigation. Finally, geochemical classification and hydrochemical processes of surface and groundwater samples are illustrated in a Chadha diagram.

## 4. Results and Discussion

The study area presents diverse geomorphological features, including High and Mid-Altitude Plains, Low and Mid-Altitude Mountains, Low and Very Low Plateaus, Mid-Altitude Plateaus, and Hills (Figure 3). The High Altitude Plains are expansive, with varying elevations from 830m in the middle to 1120m in the south and 523m in the north. They feature Calcimagnesic clayey loam soils with textures, ranging from coarse to fine, and have relatively moderate groundwater permeability.

In contrast, the Mid-Altitude Plains in the north are relatively uniform, with altitudes ranging from 447m to 554m, slightly undulating and are often affected by rainwater runoff and soil erosion. The Hills occupy an altitude between 253m and 500m and have limited groundwater potential. The Low and Mid-Altitude mountains are predominantly forested and unsuitable for agriculture due to steep slopes, interrupted wadis, and severe erosion. The Low and Mid-Altitude Plateaus are relatively flat (Meybeck et al., 2001), mainly covered by forests and plantations, with calcimagnesic, Limono-clay soils. Additionally, Very low Plateaus at elevations of 400m to 550m are characterized by coarse, stony materials in major wadi beds and glacis formations connected to mountains and hills, occasionally intersected by faint gullies.

Rainfall has been categorized into five groups every year: (486-595mm), (595-626mm), (626-665mm), and (665-694 mm) (Figure 4). High weights are ascribed to heavy precipitation and vice versa. In the study region, we discovered that very low and low lineament densities, along with medium lineament density, occupy a major part, whereas high and very high lineament densities are represented by minor parts (Figure5). The lineaments density was divided into five categories: Very Low (0.08-0.28 km/km$^2$), Low (0.28-0.56 km/km$^2$), Medium (0.56-0.84 km/km$^2$), High (0.84-1.12 km/km$^2$), and Very High (1.12-1.40 km/km$^2$) (Figure 5).

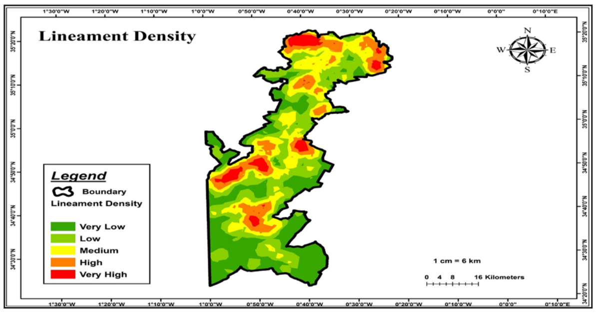


**Figure 5.** Lineament density map of the study area.

The geological map of the study area reveals a diverse range of lithologies spanning different geological periods, including Jurassic, Cretaceous, Lower Cretaceous, Quaternary, Pleistocene, and Tertiary formations (Figure 6). The predominant Tertiary strata, particularly in the northern part of the basin, comprise marine Pliocene deposits consisting of robust conglomerate banks, layers of coarse sandstone intercalated with greyish silt, and occasionally lacustrine limestone. The Pleistocene layer essentially encompasses the entire Quaternary period. In additionally, we encounter the Tensiftian, Soltanian, and Moulouyen climatic cycles (Choubert and Faure-Muret,1956), representing the late Pleistocene and manifesting in various forms: gravelly and stony crusted formations along the Mekerra Wadi, silts embedded with calcareous granules further from the Wadi, and the presence of calcareous crusts. The coloration of the silt ranges from pale red to brownish-red, depending on whether the area has been cultivated or not.

The degree of slope of the study area varies between 0° and 50°. The study area was divided into five slope classes (Figure 7), namely, gentle (0–3.6°), low (3.6–7.4°), relatively high (7.4– 12.7°), high (12.7–20.1°) and steep (20.1-48.4°). Most of the area of the basin falls into a gently sloping category with a coverage of 1317.92 km$^2$. The class with the high slope value receives the lowest rank due to relatively highest runoff and low infiltration. Figure 8 shows the soil map, which is dominated by Chromic Cambisols (1808.16 km$^2$), Calcic Cambisols (967.60 km$^2$), and Xerosols (57.40 km$^2$). The calcimorphic soils are carbonated in the majority of the horizons, which is due to the calcareous rocks and the semi-arid climate. The soil is classified into two types: The poorly developed soils of alluvial contribution and calcimagnesic soils (Mahfoud et al., 2020). Land use and cover in the study area are classified into seven categories: Annual Broadleaf Vegetation, Broadleaf Crops, Barren Land, Built-up Areas, Closed Shrublands, Shrubs, and Water (as shown in Figure 9). The high weights are assigned to waterlogged areas, agricultural land, and forests due to their favorable groundwater percolation capabilities, whereas low weights are allocated to built-up areas and arid lands, as they have limited potential for groundwater recharge. Figure 10 shows the drainage density of Wadi Mekerra is classified into five classes, such as very low (<1.01km/km$^2$), Low (1.02-2.02km/km$^2$), Medium (2.03-3.03km/km$^2$), High (3.04-4.04km/km$^2$) and Very High (4.05-5.05 km/km$^2$), occupying an area of 617.67 km$^2$, 565.91 km$^2$, 475.09 km$^2$, 298.85 km$^2$, and 157.20 km$^2$, respectively. We assign high weight values to areas with high drainage density.

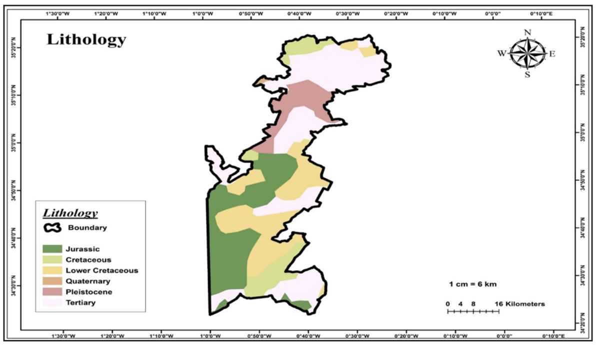

**Figure 6.** Lithology map of the study area

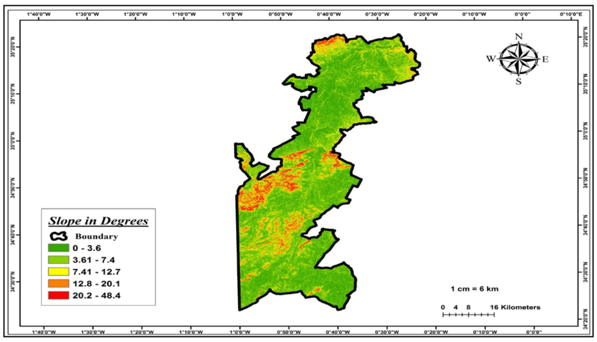

**Figure 7.** Slope map of the study area.

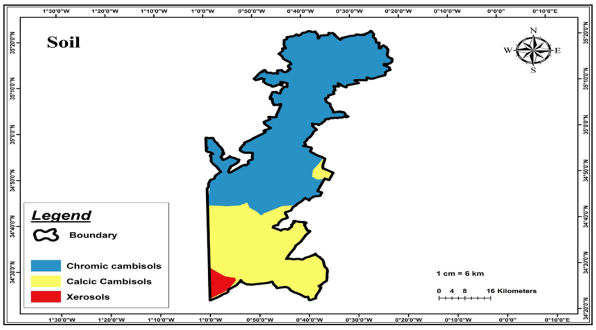

**Figure 8.** Soil map of the study area.

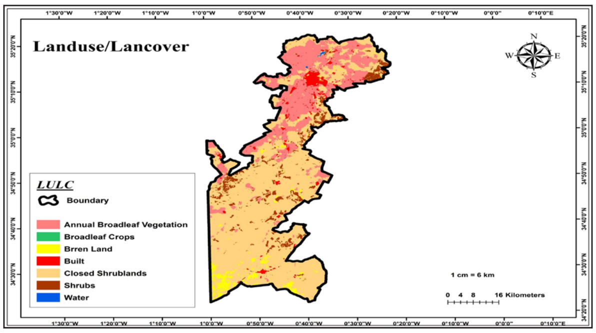

**Figure 9.** Land use/land cover map of the study area.

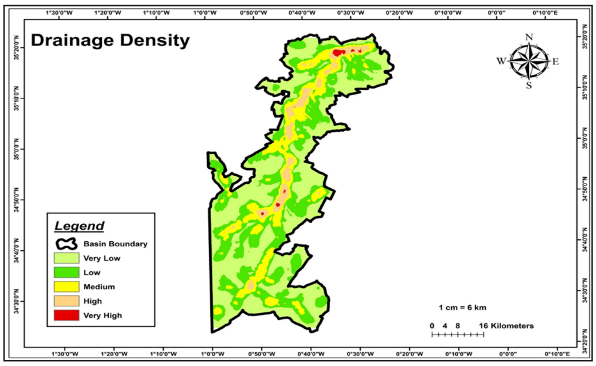

**Figure 10.** Drainage density map of the study area.

Figure 11 shows the groundwater potential map, which has been divided into five classes with groundwater potentials of very good, good, moderate, low, and very low, and the aerial distribution of these categories is 69.51km$^2$, 102.92 km$^2$, 412.45 km$^2$, 918.88 km$^2$, and 1317.92 km$^2$. Except for a small area in the northwest, the north and center of the study area are considered very low to low water potential, while areas, considered potentially moderate, good to very good, occupy large areas in the south-western region of the Mekerra Wadi, which explains— by a good permeability— a good density of lineaments, and a density of drainage.

Piper's diagram (Figure12a) shows that the majority of the waters of the Plio-Quaternary aquifer in the northern area is sulphated chloride and magnesium calcium. The diagram of Chadha (1999) (Figure13a) ( Figure13b), shows that the majority of the samples represents water of the Cl-Ca-Mg type in the northern and southern study area. These water types have a permanent hardness and do not deposit residual sodium carbonate when they are used for irrigation (Chadha 1999). Figure14a shows, according to the Riverside diagram, that the groundwater in the northern area of the study area belongs to 3 classes: C4S1, C4S2, and C3S1 and the conditions of usage are in Table.6. The Piper diagram of the southern of study area shows that the groundwater is chloride-sulfated (Figure12b). The 17 examined wells of southern area all include water that is C3S1-class, which includes water suiTable for crop irrigation according to SAR value (Figure14b).

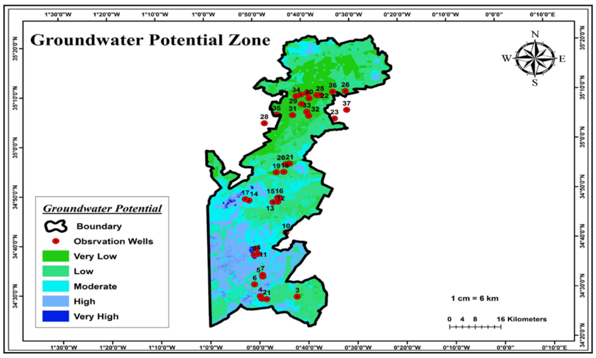

**Figure 11.** Groundwater potential zones of the study area.

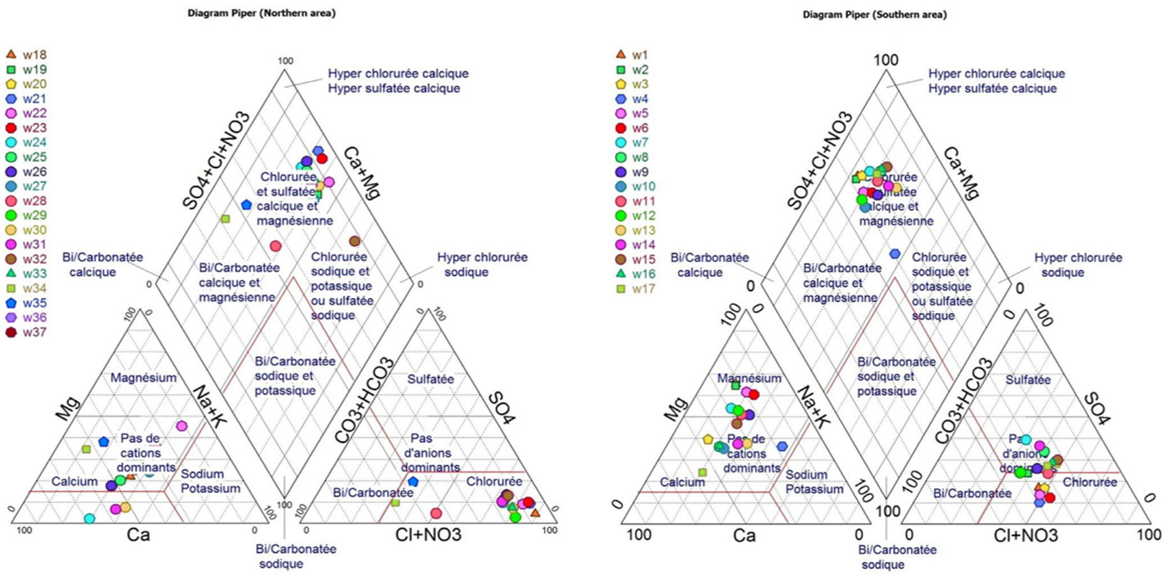


**Figure 12. (a)** diagram Piper in the northern of the study area ; **(b)** diagram Piper in the southern of the study area.

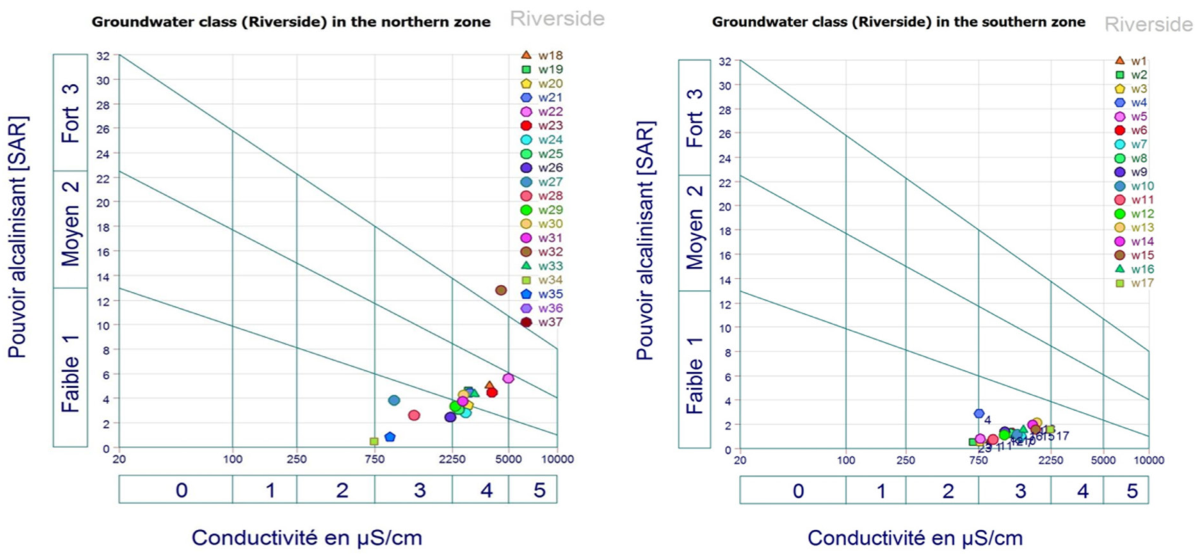


**Figure 13. (a)** diagram Chadha groundwater in the northern of the study area ; **(b)** diagram Chadha groundwater in the southern of the study area.

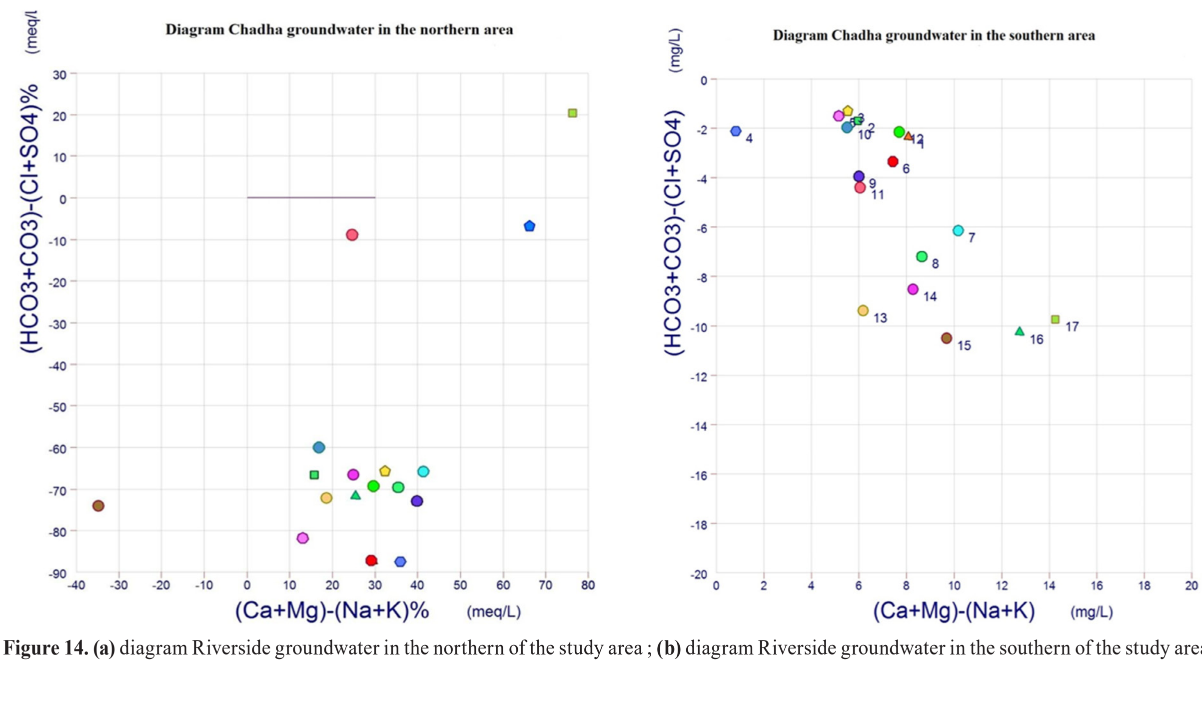


**Figure 14. (a)** diagram Riverside groundwater in the northern of the study area ; **(b)** diagram Riverside groundwater in the southern of the study area.

**Table 5.** Location and physico-chemical characteristics of the observation well-2018

| n° | Name | Department | X1 | Y1 | TDS | pH | $Ca^{2+}$ | $Mg^{2+}$ | $Na^{+}$ | $K^{+}$ | $Cl^{-}$ | $SO_4^{-2}$ | $NO_3^{-}$ | $HCO_3^{-}$ | EC | Depth (m) | GWL (mbgl) | Yield |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Puits Sidi Naïmi | Radjm Demouch | 701456.673 | 3817337.63 | 2732 | 7.61 | 47 | 87.48 | 32.2 | 2.35 | 150.66 | 82.13 | 24.8 | 220.86 | 886 | 100 | 2.3 | (63-100) |
| 2 | Dar EL Beida | Ras El Ma | 699894.686 | 3817497.93 | 2213 | 7.27 | 36 | 63.67 | 24.15 | 1.56 | 103.87 | 98.94 | 27.9 | 200.11 | 685 | 150 | 2.72 | (15-80) |
| 3 | Forage Faraat Zit | Ras El Ma | 710988.395 | 3818298.39 | 2238 | 7.44 | 72 | 38.03 | 25.07 | 3.91 | 95.01 | 62.92 | 71.3 | 164.13 | 763 | 150 | 2.6 | (15-80) |
| 4 | Forage Z'nina | Ras El Ma | 699425.961 | 3818502.77 | 3211 | 7.12 | 38 | 47.26 | 112.93 | 2.35 | 198.87 | 57.64 | 22.94 | 286.14 | 756 | 80 | 2.1 | (15-80) |
| 5 | Sidi Hamlili 3 | Ras El Ma | 700 209.496 | 3825770.07 | 3030 | 7.31 | 32 | 63.18 | 35.42 | 3.91 | 130.1 | 60.52 | 47.12 | 209.87 | 770 | 180 | 2.92 | (15-80) |
| 6 | Sidi Hamlili 2 | Ras El Ma | 697652.342 | 3822848.53 | 3563 | 6.91 | 46 | 100.9 | 70.15 | 5.08 | 220.14 | 75.41 | 42.16 | 270.27 | 1237 | 160 | 3.83 | (15-80) |
| 7 | Forage Titten Yahia | Ras El Ma | 700152.082 | 3826399.260 | 2122 | 7.19 | 90 | 101.1 | 57.73 | 4.69 | 166.97 | 309.79 | 17.98 | 305.05 | 1432 | 155 | 3.3 | (15-80) |
| 8 | F OS1 | Oued Sbaa | 698723.079 | 3834223.73 | 1985 | 7.25 | 129 | 65.97 | 71.07 | 5.08 | 210.93 | 252.16 | 19.22 | 244.04 | 1200 | 125 | 5.5 | (15-100) |
| 9 | F OS2 | Oued Sbaa | 697543.712 | 3833832.16 | 1678 | 7.66 | 58 | 76.91 | 70.84 | 5.47 | 168.03 | 148.41 | 13.02 | 236.72 | 1120 | 200 | 6.8 | (30-100) |
| 10 | Hçaiba | CW39A-Hçaiba | 707451.229 | 3842250.74 | 1725 | 7.53 | 86 | 44.47 | 53.59 | 4.3 | 137.9 | 131.12 | 11.16 | 283.7 | 1348 | 150 | 7.2 | (20-80) |
| 11 | F OS | Oued Sbaa | 697988.213 | 3836237.225 | 1352 | 7.29 | 58 | 68.65 | 36.8 | 35.19 | 180.8 | 138.33 | 37.82 | 219.03 | 933 | 50 | 9.28 | (15-80) |
| 12 | Serradj Zouaoui | Mouley Slissen | 703391.735 | 3853538.7 | 1687 | 7.13 | 70 | 83.84 | 59.8 | 3.13 | 159.53 | 168.11 | 45.26 | 357.52 | 1102 | 150 | 6.3 | (15-80) |
| 13 | Serradj Zouaoui2 RN95 | Mouley Slissen | 704883.823 | 3853725.28 | 1898 | 7.12 | 104 | 76.55 | 119.6 | 4.69 | 300.62 | 254.56 | 26.04 | 267.22 | 1813 | 160 | 10.53 | (27-100) |
| 14 | Tamatiouna 1 | Mouley Slissen | 695888.890 | 3854206.44 | 1532 | 7.3 | 131 | 85.66 | 119.14 | 5.08 | 228.3 | 365.03 | 83.7 | 336.78 | 1715 | 138 | 9.86 | (27-100) |
| 15 | Serradj Zouaoui3 RN95 | Mouley Slissen | 704896.972 | 3855229.05 | 1678 | 7.01 | 109 | 102.1 | 93.38 | 2.74 | 319.05 | 288.18 | 37.2 | 274.55 | 1794 | 132 | 6.34 | (27-100) |
| 16 | Mouley Slissen 1 | Mouley Slissen | 705293.516 | 3855302.1 | 1783 | 7.2 | 188 | 98.05 | 106.03 | 3.91 | 333.94 | 304.99 | 45.88 | 336.17 | 1480 | 200 | 7.3 | (27-100) |
| 17 | Tamatiouna 2 | Mouley Slissen | 694758.691 | 3854692.06 | 1810 | 7.09 | 269 | 70.96 | 112.93 | 3.91 | 354.15 | 320.84 | 68.82 | 422.19 | 2240 | 80 | 8.2 | (43-100) |
| 18 | Ighti 2 | Bordj Jaafar | 706744.215 | 3864855.3 | 2352 | 6.88 | 120 | 63.06 | 74.75 | 1.17 | 159.88 | 146.01 | 29.14 | 347.15 | 1228 | | 11.8 | 60> |
| 19 | Sidi Ali Benyoub | Sidi Ali Benyoub | 704447.395 | 3864722.23 | 1113 | 7 | 104 | 56.5 | 38.87 | 1.56 | 123.01 | 71.56 | 19.22 | 334.94 | 867 | 150 | 9.88 | 60> |
| 20 | Source Ain Mekareg | Bordj Jaafar | 707388.778 | 3867738.49 | 1418 | 6.91 | 98 | 38.27 | 24.15 | 1.17 | 99.97 | 46.59 | 24.18 | 350.2 | 739 | | 5.2 | 130 |
| 21 | Source Skhouna | CW48-Sidi Ali Benyoub | 708567.898 | 3867967.14 | 1389 | 7.03 | 109 | 55.65 | 45.54 | 2.35 | 158.11 | 124.88 | 6.82 | 376.43 | 924 | | 5.76 | 101 |
| 22 | P-Belawladi | Amarnas | 717106.743 | 3893515.59 | 2356 | 7.32 | 580 | 180 | 541 | 11 | 2061 | 145 | 67 | 252 | 4796 | 60 | 3.7 | (3-10) |
| 23 | Cité El HORIA | Sidi Bel Abbes | 722622.081 | 3884815.940 | 4423 | 7.12 | 240 | 111 | 345 | 13 | 965 | 168 | 32 | 376 | 2812 | 80 | 6.2 | (3-10) |
| 24 | Sidi Khaled | Sidi Khaled | 712287.038 | 3890229.29 | 2123 | 7.05 | 295 | 115 | 275 | 16 | 815 | 190 | 195 | 340 | 2801 | 82 | 4.56 | (3-10) |
| 25 | Cité El HORIA1 CW4 | Sidi Bel Abbes | 718105.491 | 3893573.57 | 3125 | 6.9 | 530 | 225 | 481 | 10 | 1905 | 300 | 196 | 246 | 4866 | 65 | 3.2 | (3-10) |
| 26 | Douar Gouassem | Tilmouni | 726037.702 | 3895036.25 | 4120 | 7.18 | 109 | 270 | 481 | 13 | 1909 | 290 | 45 | 367 | 4960 | 55 | 5.9 | (3-10) |
| 27 | RN 95 Route de Boukhanefis | Sidi Bel Abbes | 714052.543 | 3894340.44 | 3185 | 7.02 | 420 | 160 | 425 | 9 | 1578 | 265 | 85 | 210 | 3940 | 73 | 7.3 | (2-18) |
| 28 | RN7 Route Lamtar | Lamtar | 700679.739 | 3883041.79 | 1695 | 7.13 | 455 | 9 | 220 | 7 | 870 | 160 | 90 | 350 | 2701 | 100 | 4.5 | (5-15) |
| 29 | Sidi Lahcen | Sidi Lahcen | 712084.092 | 3893725.05 | 1152 | 6.92 | 305 | 78 | 232 | 8 | 839 | 178 | 26 | 299 | 2456 | 75 | 6.15 | (2-18) |
| 30 | P-Belawladi | Amarnas | 714667.883 | 3892371.82 | 1782 | 7.09 | 270 | 55 | 171 | 12 | 721 | 191 | 96 | 233 | 2186 | 80 | 4.9 | (2-18) |
| 31 | RN 95 Route de Boukhanefis1 | Boukhanefis | 709522.803 | 3886060.29 | 1854 | 7 | 175 | 75 | 240 | 6 | 550 | 264 | 71 | 320 | 2126 | 92 | 3.7 | (3-17) |
| 32 | RN13 Sidi Khaled | Sidi Khaled | 714545.29 | 3885850.67 | 1685 | 6.93 | 85 | 71 | 135 | 9 | 270 | 35 | 19 | 426 | 1312 | 88 | 4.1 | (3-17) |
| 33 | RN13 Sidi Khaled1 | Sidi Khaled | 713959.005 | 3887319.87 | 1532 | 7.01 | 221 | 105 | 240 | 10 | 916 | 43 | 54 | 295 | 2355 | 90 | 7.75 | (3-17) |
| 34 | Sidi Lahcen1 | Sidi Lahcen | 710615.018 | 3893138.66 | 1798 | 6.94 | 350 | 30 | 310 | 7 | 957 | 120 | 54 | 292 | 2650 | 75 | 9.2 | (3-17) |
| 35 | Habara | Sidi Khaled | 704500.44 | 3886269.83 | 1865 | 7.11 | 355 | 25 | 270 | 5 | 880 | 171 | 50 | 347 | 2628 | 70 | 6.3 | (3-17) |
| 36 | R7 Route Telmouni | Telmouni | 722042.559 | 3894804.34 | 3462 | 6.97 | 119 | 165 | 920 | 13 | 1520 | 360 | 45 | 457 | 4498 | 60 | 7.6 | (3-17) |
| 37 | P-Belarbi | Belarbi | 726443.379 | 3888044.19 | 3328 | 7 | 320 | 141 | 370 | 12 | 1109 | 142 | 25 | 344 | 3078 | 109 | 5.5 | (3-17) |

**Table 6.** Classification of waters according to SAR (Richards (USSL), 1954).

| Degree | Quality | Classe | Condition of use |
|---|---|---|---|
| 1 | Excellent | C1S1 | Waters that can be used safely for irrigation for most crops, on most soils. |
| 2 | Good | C2S1<br>C1S2 | Generally, water that can be used without control, especially for irrigation of plants moderately tolerant to salts on the ground. |
| 3 | AccepTable | C3S1<br>C2S3<br>C3S2 | Generally, water suiTable for irrigation of salt-tolerant crops on well-drained soil. However, the evolution of salinity must be controlled. |
| 4 | Poor | C4S1<br>C4S2<br>C3S3 | Highly mineralized water that may be suiTable for the irrigation of certain species that are well tolerant to salts on the ground and well drained. |
| 5 | Very poor | C3S4<br>C4S3<br>C4S4 | Water not generally suiTable for irrigation but can be used under certain conditions: very permeable soil, well leached, plants tolerant to salts. |

## 5. Validation

By comparing the areas of groundwater potential, delineated in this study, to data from deep wells and springs, the validity of the groundwater potential map was achieved. It is done by overlaying only the point data of the two springs, 36 deep wells with the map generated, using the weighted index overlay analysis. Moreover, within the framework of the good integrated management of water resources, the validity was also achieved by the hydrochemical classification of groundwater in the study area. For this purpose, several methods have been defined by various authors to classify and know the different chemical facies of the waters of the Plio-Quaternary aquifer. The wells (well $n^0$:16-37) and 02 springs (source $n^0$: 18-19) located in the northern of study area, are located in areas with very low and low groundwater potential and have a water production capacity comprised between 2 and 18 liters per minute (LPM). However, the other wells in the study area are located in areas with moderate, high and very high groundwater potential and have a water production capacity of about 20-80 LPM, 80-100 LPM, respectively. Six wells, including four wells (No. 10, 23, 28, and 37) (seefigure) located outside our study area and two other wells (No. 1, 14) are not perfectly suited for various reasons (Table.5).

## 6. Conclusion

The Mekerra Wadi area is located in the department of Sidi Bel Abbes in the Northwestern region of Algeria and is situated in a region with a very diverse geomorphology (plateaus, mountains, plains, hills, etc). Moreover, the wadis of the semi-arid and arid regions of North Africa are the best known intermittent and ephemeral watercourses. Thus, these watercourses are important sources of groundwater supply (Fovet et al., 2021). In addition, the Wadi Mekerra is known by its ephemeral main stream.

The present study aims to delineate potential groundwater areas, using a combination of AHP, remote sensing and GIS techniques. The groundwater potential zones were defined in this study using a total of eight thematic layers, including geomorphology, Rainfall, Lineament Density, Lithology, Slope, Soil, LuLc, and Drainage Density.

The results, obtained according to the final map, the study area could be grouped into five classes, such as very high, high, moderate, low, and very low. Areas, with very high and high water potential, are mainly found in the lower parts of the study area. A large portion of the very low groundwater potential areas are located in the northern part of the area, and the low potential areas are scattered over the entire surface. The northern portion of the basin has the majority of the very low groundwater potential areas, and the low potential areas are dispersed over the entire region. The results show that 59% is covered by an area with moderate water potential. Areas with very low and low groundwater potential occupy 50.55% of the total area. In addition, areas with very high and very low water potential occupy 4.15 and 11%, respectively. Using flow data and results of chemical analyses of wells, deep wells, and springs in the study area, the delineated map of potential groundwater zones was validated.

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For this purpose, the map of the zones groundwater potential of this study provides decision makers with an overview of integrated groundwater management for urban and agricultural uses to avoid environmental, economic and social risks. Since most of the study area is covered with agricultural land and agriculture remains one of the main sources of groundwater pollution due to the use of pesticides and livestock effluents, this study will improve irrigation facilities and preserve the quality of water in the area. It can be used as a communication and stakeholder engagement tool. By involving different actors in the process of prioritizing criteria and decision-making, it is possible to reach a consensus and a better acceptance of the decisions taken.

**Conflict of Interests**

The authors declare no conflict of interest

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