Scientific Research Publishing

International Journal of Geosciences, 2021, 12, 253-279
https://www.scirp.org/journal/ijg
ISSN Online: 2156-8367
ISSN Print: 2156-8359

Using GIS and Geostatistical Techniques for Mapping Piezometry and Groundwater Quality of the Albian Aquifer of the M'zab Region, Algerian Sahara

Mansour Achour[1], Moulay Idriss Hassani[1], Hadjira Benhedid[2], Abla Hadj Brahim[2]

[1]Laboratoire Géoresources, Environnement & Risques Naturels (Géoren), University of Oran 2 MB, Oran, Algeria
[2]Laboratoire de protection des écosystèmes dans les zones arides et semi-arides, University of Ouargla, Ouargla, Algeria
Email: achour_m343@hotmail.com

How to cite this paper: Achour, M., Hassani, M.I., Benhedid, H. and Brahim, A.H. (2021) Using GIS and Geostatistical Techniques for Mapping Piezometry and Groundwater Quality of the Albian Aquifer of the M'zab Region, Algerian Sahara. *International Journal of Geosciences*, **12**, 253-279.
https://doi.org/10.4236/ijg.2021.123015

Received: January 9, 2021
Accepted: March 22, 2021
Published: March 25, 2021

Abstract

The M'zab region is subject to an arid Saharan climate where surface and sub-surface waters are of little importance. The Albian Aquifer, commonly called Continental Intercalary (CI), main component of North Western Sahara Aquifer System (NWSAS/SASS), constitutes the most extensive aquifer formation of the region. In our study area, the CI is identified, as a regional subset, as the Albian Aquifer of M'zab Region (AAMR). Its groundwater resources are considered the only source available to meet the growing needs of drinking water supply, agriculture and industry. This aquifer is heavily exploited by a very large number of wells (more than 750). Its supply is very low, so it is a very low renewable layer. This requires periodic monitoring and control of its piezometric level and its physico- chemical quality. The objective of our study is to know the current state of this aquifer, while studying the variation of its piezometry for the period 2010-2018, and also the chemical quality of its groundwater by analyzing more than 90 samples over the entire study area. The application of geostatistics by kriging and the steps of analysis, modelling and calculation of semivariogram have enabled us to draw up maps of the various hydrogeological and hydrochemical parameters. As a result, twelve thematic maps were gridded using Geostatistical tools of ArcGIS software. The water-level-change map showed a significant drop in the groundwater level over the entire M'zab region and especially around the major cities (Ghardaïa, Berriane, Metlili and Zelfana) with more than 8 meters. Chemical analyses of the Albian groundwater in the study area show the dominance of evaporite facies (Cl^-- SO_4^{2-} -Na^+-Ca^{2+}) with low concentrations than the Algerian Standards for Drinking (ASD). All the water quality indices

(WQI) that have been mapped reveal that the groundwater samples were suitable for drinking and irrigation with a high quality of water located in the south of the study area.

Keywords

M'zab, Albian, NWSAS, AAMR, Groundwater, Geostatistical

1. Introduction

In the Algerian Sahara known for its arid climate, groundwater is the main source of water used mainly for domestic and irrigation practices in the area [1]. In recent decades, there has been a significant increase in water demand due to local population growth and agricultural development. Under these conditions, aquifers are in a situation of over-exploitation with pumped volumes far exceeding natural recharge rates [2]. The aquifer of the Continental Intercalary (CI), identified as a regional subset under the name Albian Aquifer of M'zab Region (AAMR), consists of sand, sandstone and sandy clay [1]. Its waters are the main water resources used in the region. It is exploited by more than 750 water wells with a volume of 531.76 Hm^3 [3]. As the water in this aquifer is not very renewable [1], the impact of its heavy exploitation is the disappearance of artesianism in some areas and a considerable drawdown in the pumping areas [4]. One of the effects is the localized deterioration of the chemical quality of the groundwater.

This requires periodic monitoring and control of the piezometric level and water quality of the aquifer. Within the framework of this work, eleven thematic maps were produced and processed using the geostatistical interpolation technique. The maps obtained can be used to evaluate the data on water level and quality. These maps contribute to the creation of decision support tools with the aim of prioritizing and better targeting of usable areas. All of this is part of the general framework of rational and sustainable management of this resource.

2. Study Area Description

2.1. General Settings

The M'zab region located in the south of Algeria (**Figure 1(a)**, **Figure 1(b)**), which lies between 1˚50' and 5˚10' East longitude and between 28˚50' and 33˚10' North latitude, covering an area of 861.05 km^2, and an estimated population of 309,740 inhabitants [5] spread over 13 municipalities, representing a population density of 3.60 inhabitants/km^2. The average value of recorded rainfall in the study region is about 80.6 mm/year [6]. The period from September to January is the wettest of all year. The low height of the rain is recorded in summer. Disturbing systems resulting in rainfall over the region are linked, generally, the movement of polar fronts, Mediterranean and southern trade winds. Rainfall

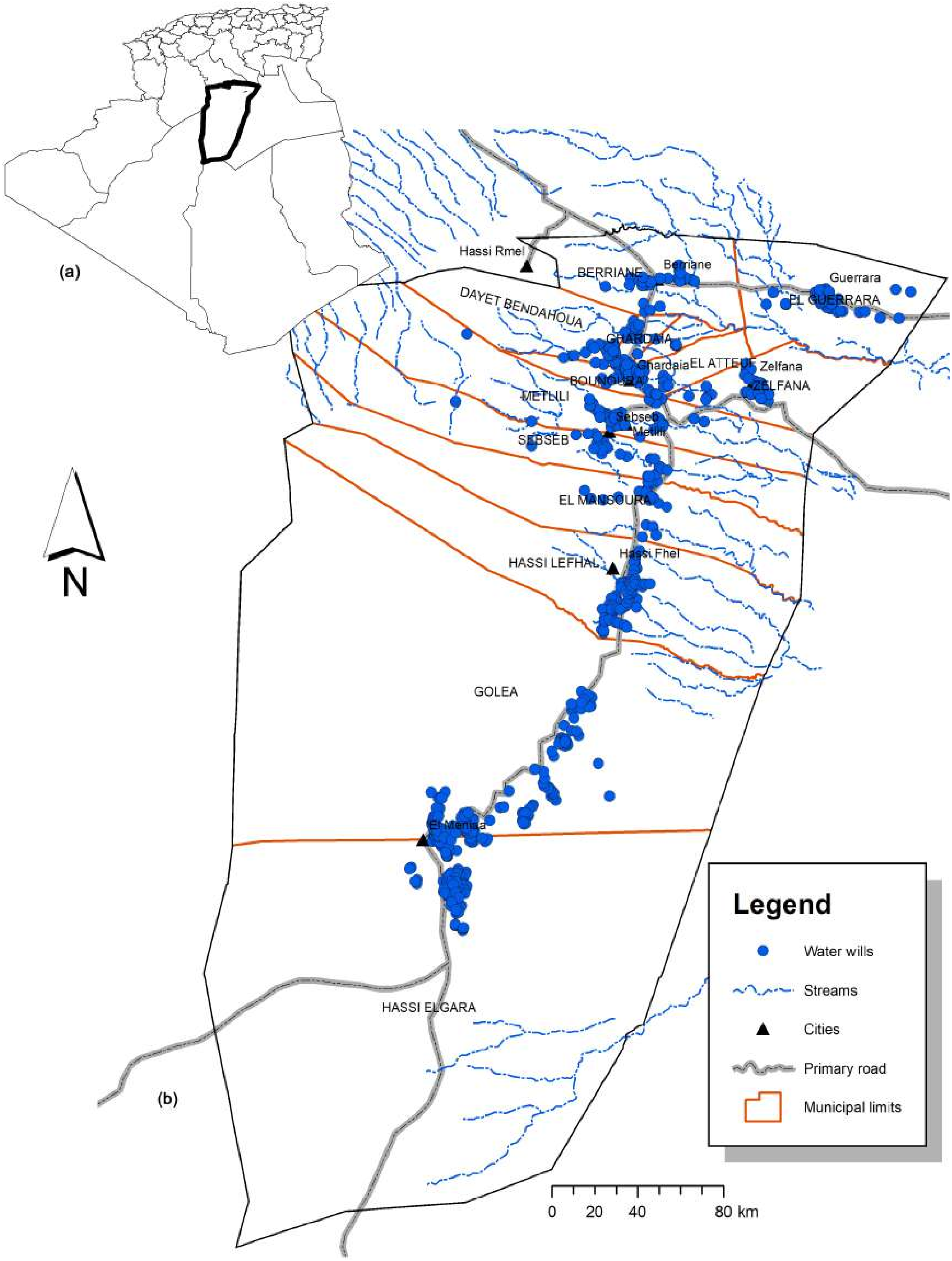


Figure 1. (a) Location map, (b) Water wells points in the study area.

generated may be important thundershowers [7]. The annual average temperature is 22.3˚C. The highest temperature ranges are encountered in oscillating summer between 13˚C to 15˚C. This is one of the climate characteristics of the continental area of the Northern Sahara.

Geologically, the M'zab region is a part of the large area of Saharan platform [8] [9]. The study area presents a series of outcropping geological formations ranging from upper cretaceous to Mio-Pliocene continental [9]. Quaternary alluvial cover corresponds to deposit most of the valleys of the wadis traversing the backbone of M'zab (**Figure 2**).

2.2. Hydrogeology

Groundwater is the main resource of the region. They are contained in two types of aquifers; the surface groundwater of Infero-flux, located in the alluvium of the valleys of the wadis of the region. Their recharge is strongly related to the rainfall. The depth of the water level varies between 10 and 30 m. These aquifers are collected by hundreds of traditional wells, and are mainly used to irrigate palm groves in the valleys [10]. The chemical quality is good for drinking at upstream. bad and unsuitable for drinking at downstream, due to their contamination by wastewater [11] [12]. The second type of aquifer in the study area is the captive deep groundwater of the Albian Aquifer of M'zab Region (AAMR) [2] (**Figure 1(b)**). Depending on the altitude of the area and the variation in the thickness of the formations after the Albian level, the AAMR is gushing and admits pressures at the head of the water well in the north-east and southeast zones and is exploited by pumping at depths ranging from 0.5 m to 140 m in the central and western area [3]. The impact of the high exploitation of the AAMR is generally reflected in the disappearance of artesianism in some areas and a considerable drawdown in pumping areas [13] [14]. At the hydrogeological scale this can lead to more sensitive interference with the surrounding layers and the risk of degradation of chemical quality through differential loading and the lithological nature of the surrounding rock [1].

3. Data and Methodology

3.1. Groundwater Level

Groundwater level is measured be using water level meter. Water levels measured in wells are conveniently studied by means of maps and graphs [15]. Most frequently used are water-level contour maps and water-level-change maps. Mathematically the piezometric level is the result of subtraction of the water level from ground elevation [16] (**Figure 3**). Current research is based on the last described water levels data of 25 water wells collected from measurement campaign carried out in 2010 and in 2018. The ground elevation was obtained from the Digital Elevation Model (DEM) available from the Shuttle Radar Topography Mission (SRTM) data [17] (**Figure 3**).

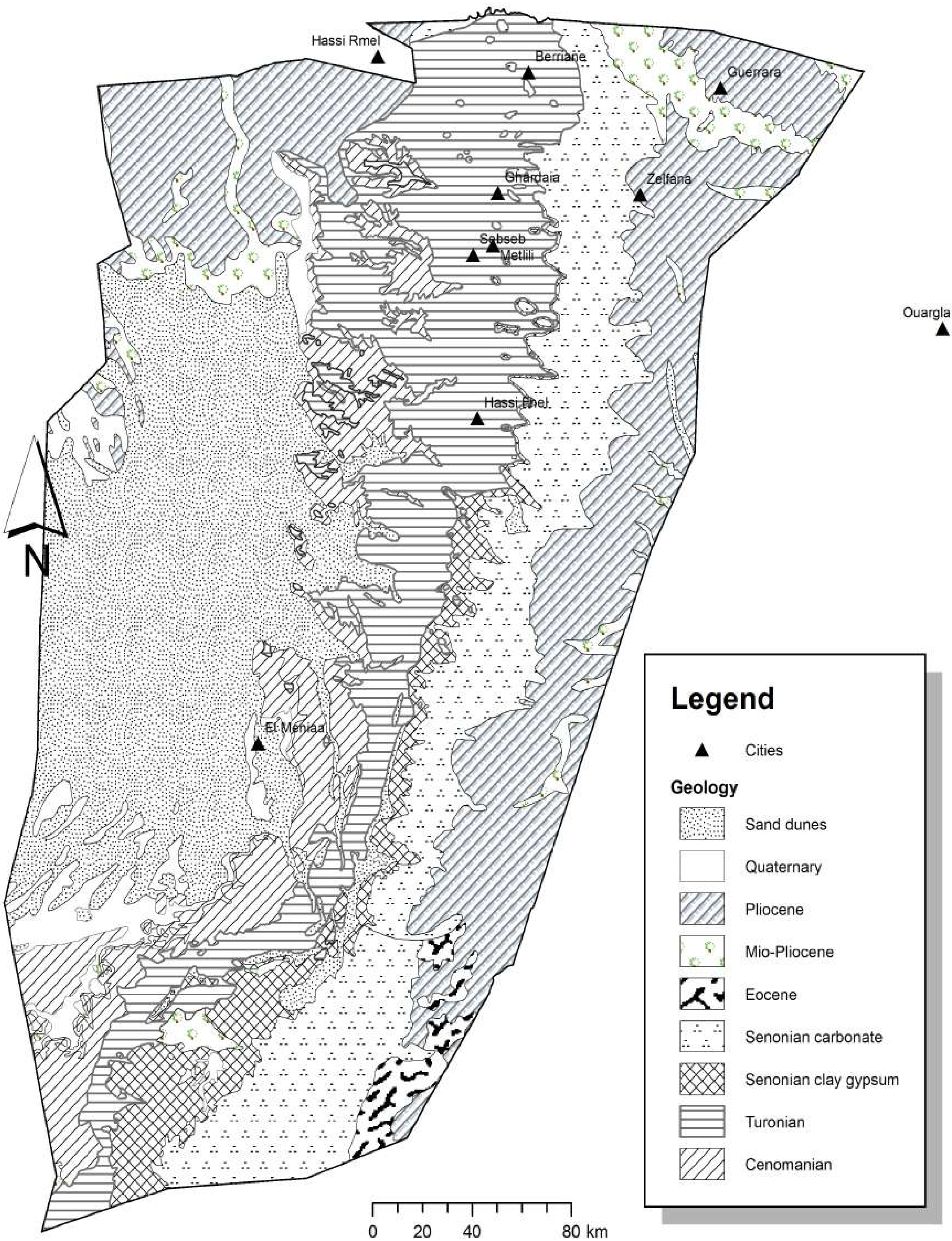


Figure 2. Geological map of the study area (Busson G., 1967).

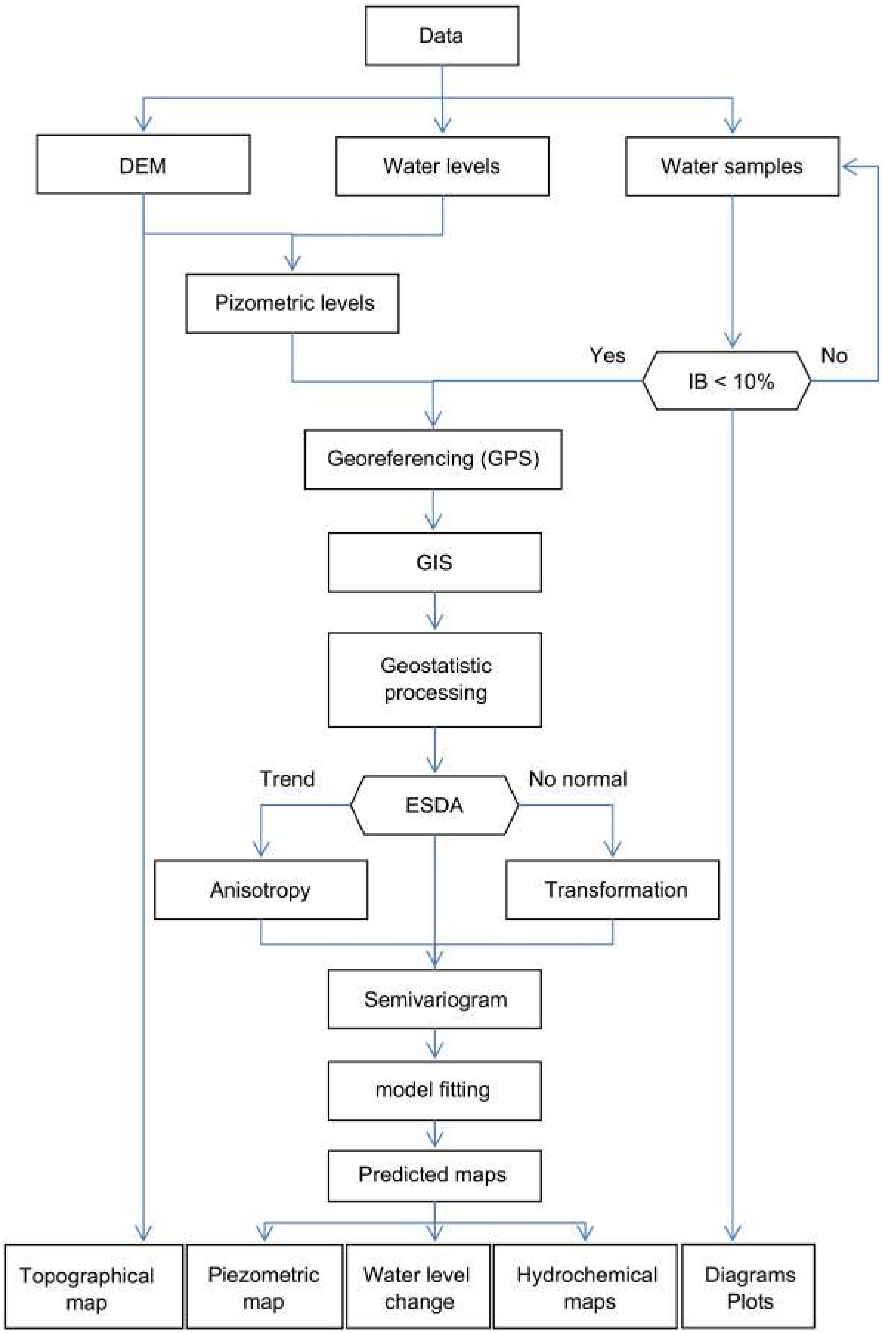


Figure 3. Flow chart showing the methodology adopted for the generation of DataBase.

3.2. Sampling and Analysis

One hundred and sixty-three water samples were collected from available water supply wells that abstract water from the AAMR during March to May 2017. Throughout sampling, the basic field methods and precautions were taken. Each sample was carefully sealed, labeled, and taken to the laboratory for chemical analysis. Samples were analyzed for various water quality parameters as per standard procedures. Chemical analysis of cation elements (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) were performed by spectrometric analysis using an atomic absorption spectrometer. Anion concentrations were estimated using standard analytical methods [18] [19].

The experimental values were compared with standard values recommended by Algerian Standards for Drinking (ASD) and World Health Organization (WHO) purposes. Furthermore, ionic balances (IB) were undertaken on the chemical analyses for quality control purposes and the cation and anion ratio was computed for each. Error values below ± 5% are the best analytical estimation and the accepted error level is no more than ± 10% [20]. The validity of the measured samples data using the IB procedure, where 93 of 163 samples were accepted, the IB error values of the studied samples vary between −9% and 9%. The statistical analyses such as mean, standard deviation (SD), coefficient of variation (CV), Kurtosis, skewness, correlation and regression of obtained data were carried out using Statgraphics Centurion software (**Table 1**).

3.3. Hydrogeochemistry

There are various combinations of the major ions that express collectively the water quality indicators, which can be calculated for each well (groundwater quality sampling points) and then according to given guidelines one can make quality classifications [20] [21]. In our study area eight water quality parameters was integrated in the DataBase: potential of hydrogen (pH). Total Hardness (TH), Total Dissolved Solids (TDS), Chloride (Cl^-), Permeability Index (PI), Kelly's Index (KI), Sodium Adsorption Ratio (SAR), and Mineral Saturation Index (SI) is used to calculate the degree of saturation or unsaturation of the solution [18].

Table 1. Summary Statistics of hydrochemical elements and parameters of AAMR (March-May 2017 data).

Parameters	Ca^{2+}	Mg^{2+}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{2-}	TH	TDS	pH
	meq/l								mg/l	
Samples	93	93	93	93	93	93	93	93	93	93
Mean	115.9	50.5	186.8	11.70	168.97	263.07	413.1	491.7	1221.4	7.62
SD	42.93	22.6	92.35	4.17	39.01	140.4	189.6	194.3	451.94	0.20
CV (%)	37.0	44.8	49.4	35.66	23.1	53.4	45.90	39.5	37.0	2.60
Min	27.25	6.80	33.63	5.00	27.6	27.56	58.02	56	320	7.04
Max	189.1	98.1	433.3	22.00	268.4	513.3	784.9	820	1941	8.23
Range	161.92	91.3	399.7	17.00	240.8	485.7	726.9	764.0	1621.0	1.19
Skewness	−2.753	−1.61	1.44	1.084	−0.146	−1.301	−1.378	−3.081	−3.173	−0.467
Kurtosis	−0.890	−0.73	0.06	−1.402	2.453	−1.945	−1.346	−0.795	−1.007	1.102
ASD	200	150	200	20.00	300	500	400	500	1500	6.5 - 9
WHO	200	150	200	12.00	240	250	400	500	1000	6.5 - 8.5

3.4. Graphical Representations

Graphical representations of different ions have been drawing for the analysis of water samples, such Piper, Wilcox and USSL diagrams. They have been interpreted to determine the different indices of water suitability for irrigation and the water type of our study area. We used the software "Diagram" (Laboratory of Hydrogeology of Avignon) to calculate the various chemical indices and graphs.

3.5. Techniques for Spatial Data Analysis

The objective of the special analysis is to produce thematic maps for the different parameterized analyses and measurements of the water samples and water levels of the Albian Aquifer of M'zab region (AAMR). To accomplish this task, we have been using the technique of geostatistical interpolation [22].

All the data have been explored using the Exploratory Spatial Data Analysis tool (ESDA) [23] [24]. They are plotted in the normal QQ plot for all data has been examined by the QQ graph to check if there is a data that does not follow a normal distribution. It will be transformed to be approximately close to the normal distributed by log or Box-Cox transformation [25]. Then we have been proceeding to study the trends and anisotropy that could influence the distribution of the data. Most of the parameters show very significant trends (PI, TDS, Cl^-, TH, SAR, and water level). The components of each semivariogram (Nugget, Range, Partial sill and Lags) have been calibrated to obtain best fitted semivariogram model (**Table 2**). All these techniques have been applied by the Geostatistical Analyst tool available under ArcGIS software [26].

Table 2. Fitting models and parameters of the semivariogram.

Parameters		SAR	PI	TH	Cl^-	TDS
ESDA	Transformation	log	none	log	Box-Cox	Box-Cox
	Trend	none	Yes	Yes	Yes	Yes
Semivariogram	Lags	12	12	12	12	12
	Nugget	0.44083	0.26848	0.12373	0.052953	19.1395
	Range	1.101075	0.292631	1.4847	0.530405	1.039169
Anisotropy	Direction	94.4	128.8	91.4	8.4375	93.2
	Partial sill	0.69237	0.65522	0.370931	0.56461	0.16485
Model	Model	Stable	Spherical	Spherical	Spherical	Gaussian
	MS	0.009729	−0.032876	−0.09188	−0.0886	0.012176
	RMS	3.181685	0.0894326	108.2275	106.36	169.3705
	RMSS	0.9613797	1.269159	1.640024	0.8083	1.104818

ESDA: Exploratory Spatial Data Analysis; MS: Mean Standardized; RMS: Root Mean Square; RMSS: Root Mean Square Standardized.

4. Results and Discussion

4.1. Mapping Piezometry

The piezometric maps that have been obtained (2010 and 2018) (**Figure 4**, **Figure 5**) confirm very clearly the general flow directions of the continental intercalary aquifer which is already known in the entire northern Sahara basin North-Est and North-Southwest. Locally the piezometry of the AAMR shows depressions located in urban centers and agricultural areas in our study area. These depressions are caused by excessive pumping of the groundwater to meet the growing need for drinking water and irrigation. The piezometric map of 2018 shows the same appearance as the piezometric map of 2010. The water-level-change map (2010-2018) (**Figure 6**) shows the existence of a drawdown over the entire sector with an average of 6.5 m. the highest drawdowns were located around the large northern cities (Ghardaïa, Berriane, Metlili, Zelfana) with more than 8 m of drop (9.5 m around Ghardaïa). The concentration of a large number of functional water wells is the main cause.

4.2. Groundwater Chemistry Properties

Concentrations of major ions and related physicochemical parameters and attributes determined in this study area are summarized in **Table 1** together with key statistical attributes of the results. The pH of water plays an important role in various types of geochemical equilibrium [15]. In fact, along with alkalinity it affects the solubility and availability of nutrients and other chemical characteristics of irrigation water [27]. The groundwater of the investigated area is low to mildly alkaline in nature [18]. The pH of analyzed water samples ranges between 7.04 and 8.23 with an average of 7.62 and a SD of 0.20. Groundwater salinity represented by the parameter TDS, mainly indicates the various kinds of minerals present in the water [28]. The TDS ranges between 1941.0 to 320.0 mg/l with an average value of 1221.40 mg/l and a standard deviation (SD) around 451.9. It indicates the amount of dissolved salts in water which generally comes from natural sources by sediments leaching. It's worth noting that measured mean values of TDS in the AAMR exceed the WHO standards values for drinking water [29]. But they are below the limits set by the ASD. TH values range from 105.9 to 819 ppm with an average of 496.9 ppm and a SD of 188.77. These values indicate that groundwater of AAMR is between moderately hard and very hard. The hardness of water is due to the high concentrations of the alkaline earth elements, calcium and magnesium which are essential plant nutrients [30]. Moderate levels of hardness in groundwater (75 - 150 ppm) are considered ideal for plant growth.

Table 2 shows that among the determined elements and parameters, about 23% of the samples analyzed (28 of 93 samples) have concentrations below the ASD and WHO permissible standards. They are generally located in the South of the study area. The maxi-mum values of these parameters exceed generally the ASD and WHO standards values. They represent about 65% of the samples (65 of

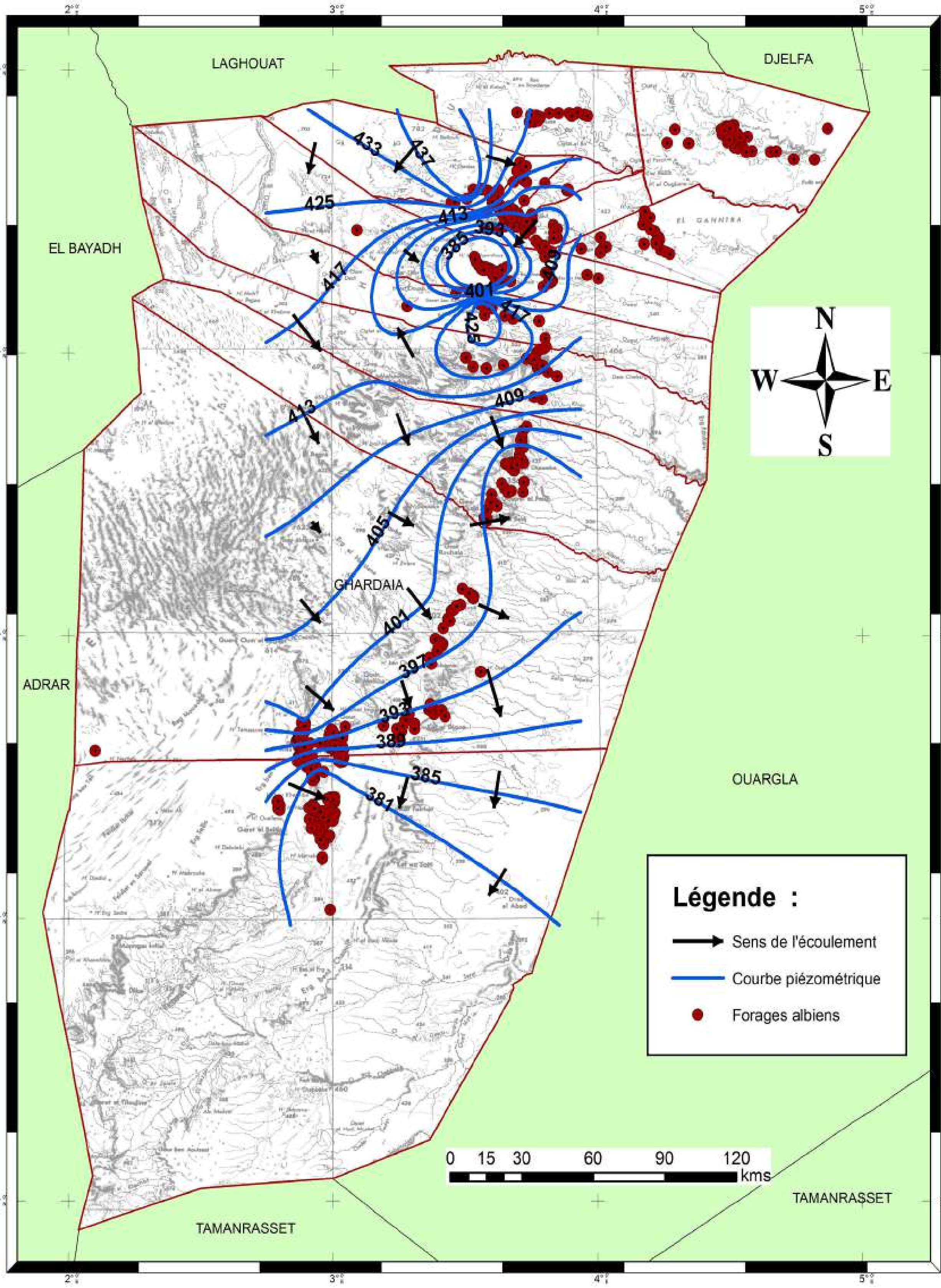


Figure 4. Piezometric surface of the Albian Aquifer of M'zab region (AAMR), year 2018.

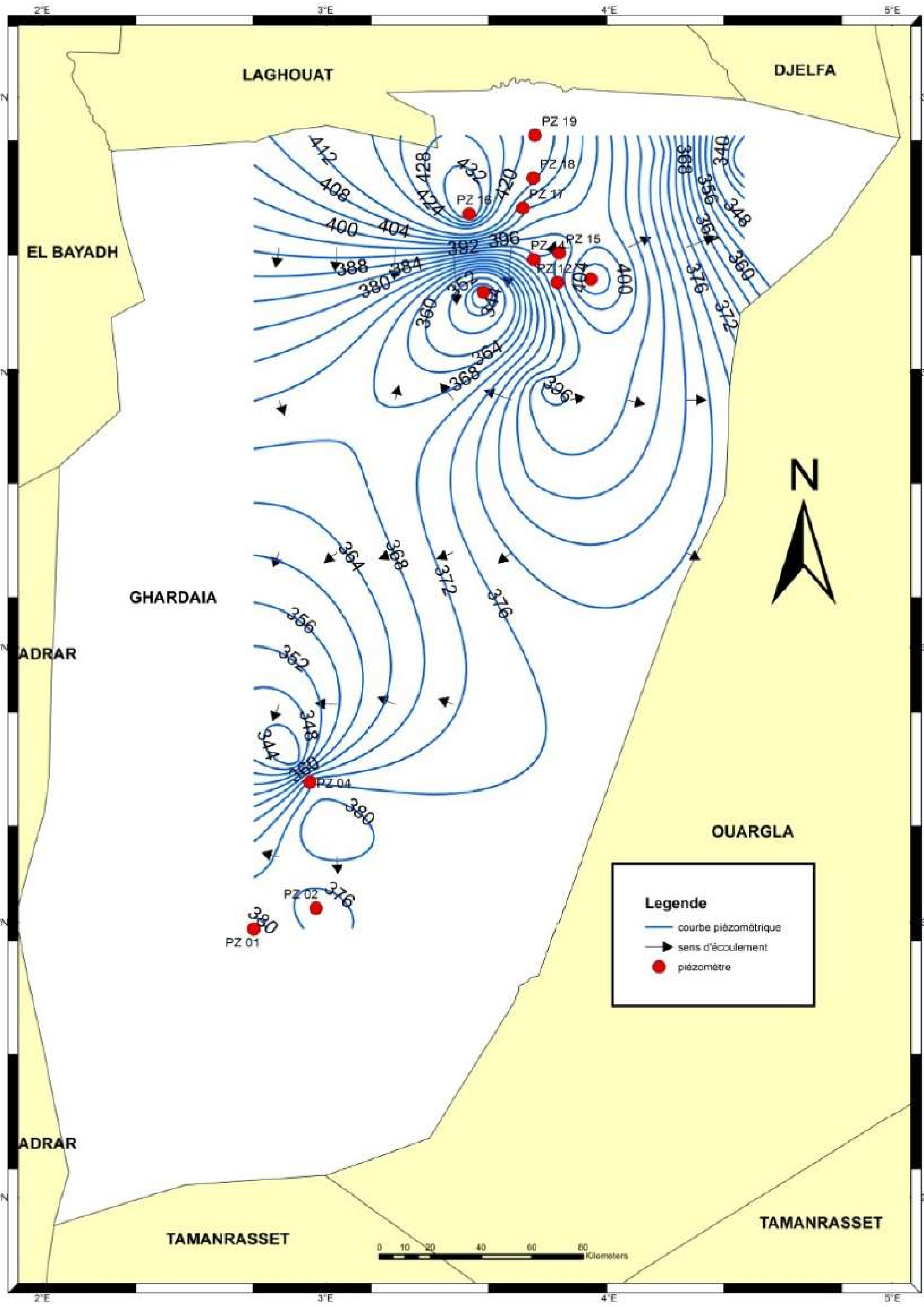


Figure 5. Piezometric surface of the Albian Aquifer of M'zab region (AAMR), year 2010.

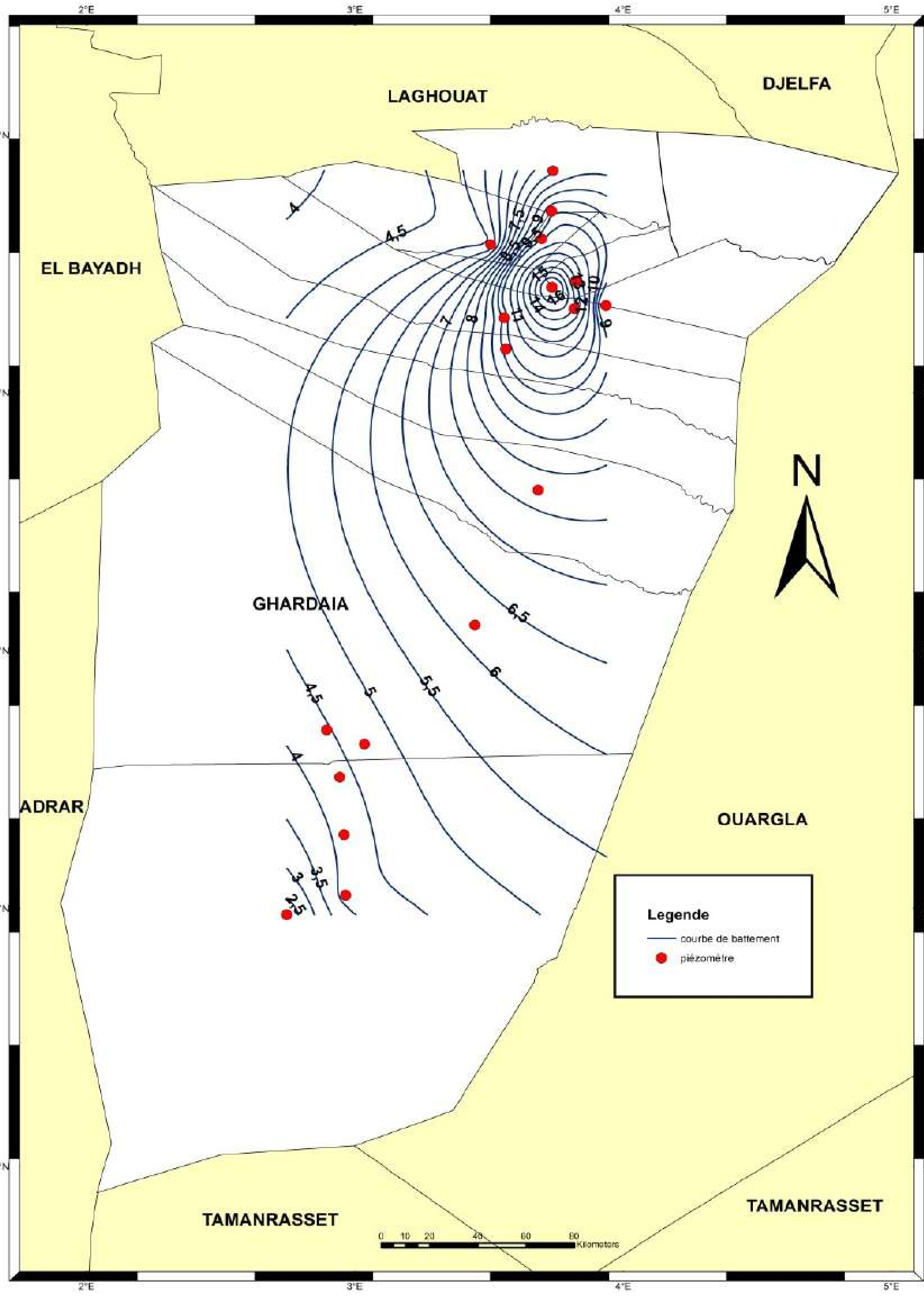


Figure 6. Piezometric surface of the Albian Aquifer of M'zab region (AAMR), years 2010-2018.

93 samples). Samples with maximum concentration values are located in the Northern and North - Eastern part of the study area (Cl^- = 513.3. Na^+ = 433.3. SO_4^{2-} = 784.9. TH = 819.4. TDS = 1941) mg/l. Additionally, sodium displacement from the absorbed complex of rocks and soil by Ca^{2+} and Mg^{2+} could also contribute to water enrichment with Na^+ [20]. Generally, large concentrations of Cl^- and Na^+ increase the corrosiveness of water and give water a salty taste [17]. The R-Squared statistic (R2) indicates that the model as fitted explains 61.4712% of the variability in Na^+ (**Figure 7**).

The correlation coefficient equals 0.79, indicating a moderately strong relationship between the variables (**Table 3**). We suggest that the Na^+ and Cl^- ions may have the same origin, possibly related to the dissolution of halite in the AAMR aquifer.

The TDS represents the total concentration of dissolved substances in water. It's significantly correlated with the most of cations and anions (**Table 3**). The potassium content is an important parameter for water quality assessment.

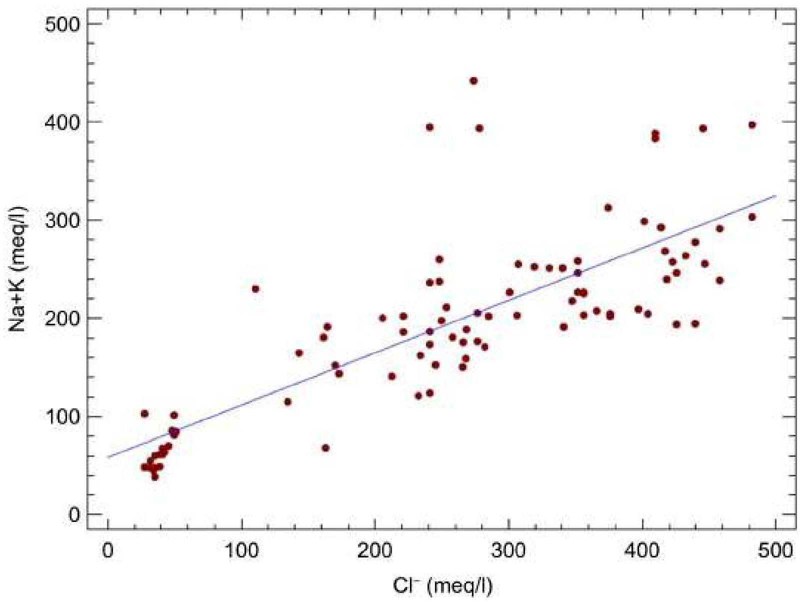


Figure 7. Scatter plots of Na+K versus Cl^-.

Table 3. Pearson's correlation matrix of AAMR waters.

	Ca^{2+}	Mg^{2+}	Na+K	HCO_3^-	Cl^-	SO_4^{2-}
Mg^{2+}	**0.7772**					
Na+K	**0.6875**	0.5626				
HCO_3^-	0.4358	0.355	0.3355			
Cl^-	**0.8349**	**0.6946**	**0.7969**	0.4164		
SO_4^{2-}	**0.7808**	**0.778**	**0.7102**	0.1822	**0.6185**	
TDS	**0.9043**	**0.8177**	**0.879**	0.4218	**0.8892**	**0.8915**

K^+ concentrations in the AAMR vary from 5 to 22 mg/l with an average of 11.70 mg/l and SD of 4.17. The low level of K^+ in natural waters is a consequence of its tendency to be fixed by clay minerals and to participate in the formation of secondary minerals [20]. In general, concentrations of the major ions increase to the Northeast of the study area. Permeability Index (PI) can be used as an indicator of water's suitability for irrigation [15]. The ground-water samples of AAMR show only eleven samples were not suitable for irrigation; they have a PI value below 60% whereas the rest of the samples were good. Calculated Kelley's Index (KI) reveals that most of the groundwater samples (90% of samples) belong to the permissible category for irrigational use.

4.3. Water Quality Graphical

The chemistry of the studied of AAMR seems to have a chemical composition dominated by the ions Na^+, Cl^-, SO_4^{2-} and HCO_3^-. Based on the ionic composition of analyzed water samples, a Piper diagram was plotted to classify water types [31]. This diagram makes groundwater facies variations understanding easier and related hydrochemical processes in the aquifer (**Figure 8**). The plotted diagram shows the water samples located in North and Northeast have a mixed type (no cation - anion exceed 50%) of the major samples and a few are Sodium-Chloride type.

The samples located in the South of de study area have a mixed type. SAR is another important parameter for determining the desirability of irrigation water [20] [32]. It combined with Electrical Conductivity (EC) classification in one graph designed by US Salinity Laboratory Staff [33].

The groundwater samples collected from this area are very good to good for irrigation (**Figure 9**) with a medium salinity hazard (C2-S1) in the South, and good to permissible for the major with low at medium Sodium hazard and a high salinity hazard (C3-S1, C3-S2) in the Northeast of the study area.

4.4. Water Quality Geospatial Evolution

In this study, eight hydrochemical maps were gridded using ArcGIS software tools. The geospatial distribution of the TH in the AAMR shows a very hard water in the most of the area (>300 mg/l) except in the South where the water in soft to moderately hard (150 mg/l < TH < 56 mg/l) (**Figure 10**). The Chlorides map shows low concentration in the South and a hay values located in the Northeast and Northwest of the area (**Figure 11**). The SAR and TDS maps (**Figure 12**, **Figure 13**) show the same allure of concentrations: low in South and height in the North. This situation is explained by the slope of the aquifer layer which increases further to the east (towards the center of the sedimentary basin). The AAMR aquifer becomes deeper in the east and the lithology has been enriched by the clays. The Index Saturation (IS) samples present negative values against 6% positive (located in the North). It means that the aquiferous formation generates high concentrations in Na^+ to the detriment of the Ca^{2+} and Mg^{2+} (**Figure 14**, **Figure 15**).

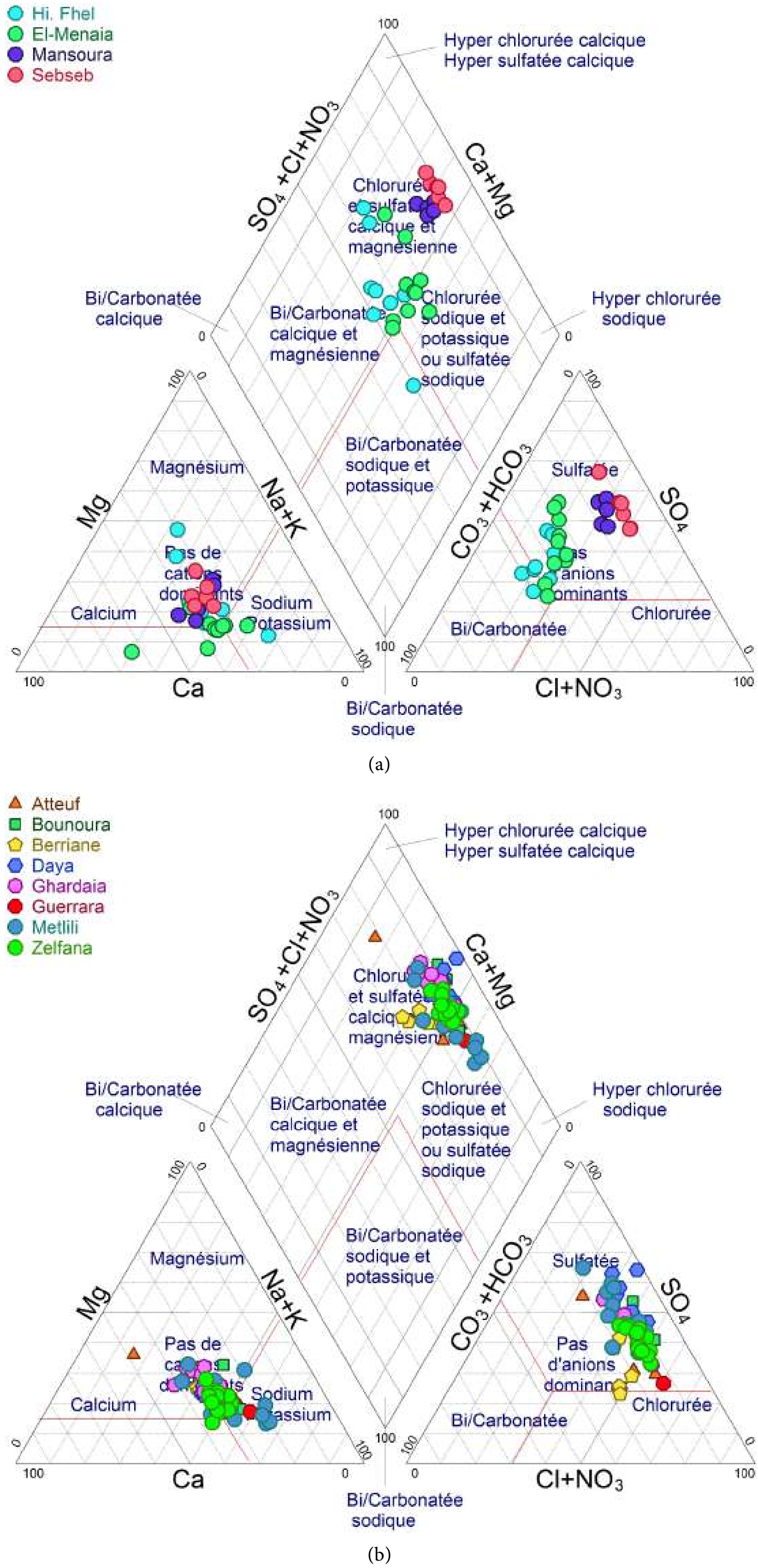
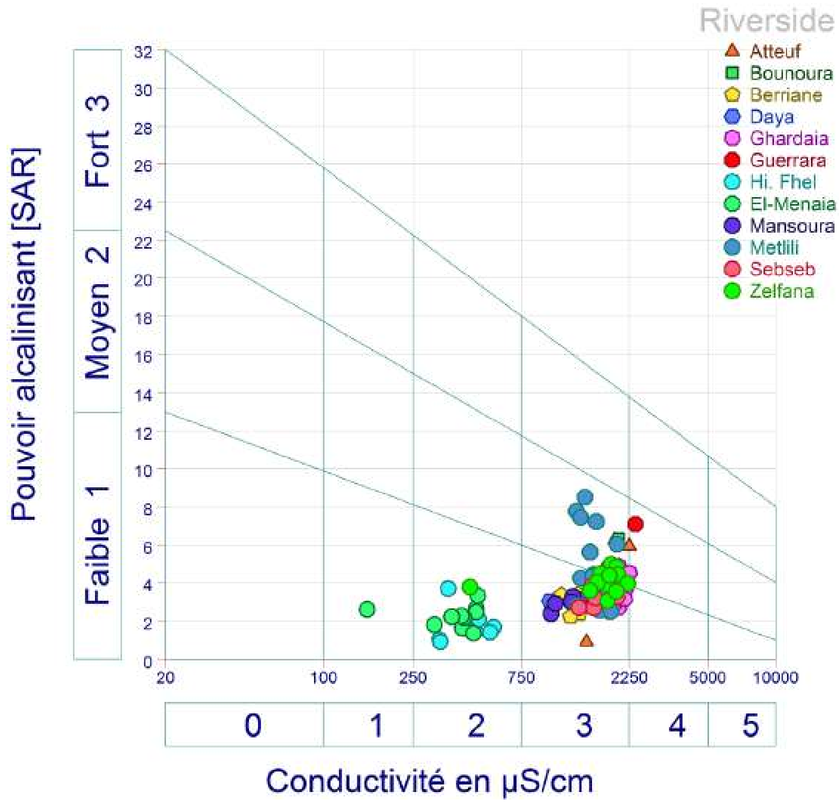
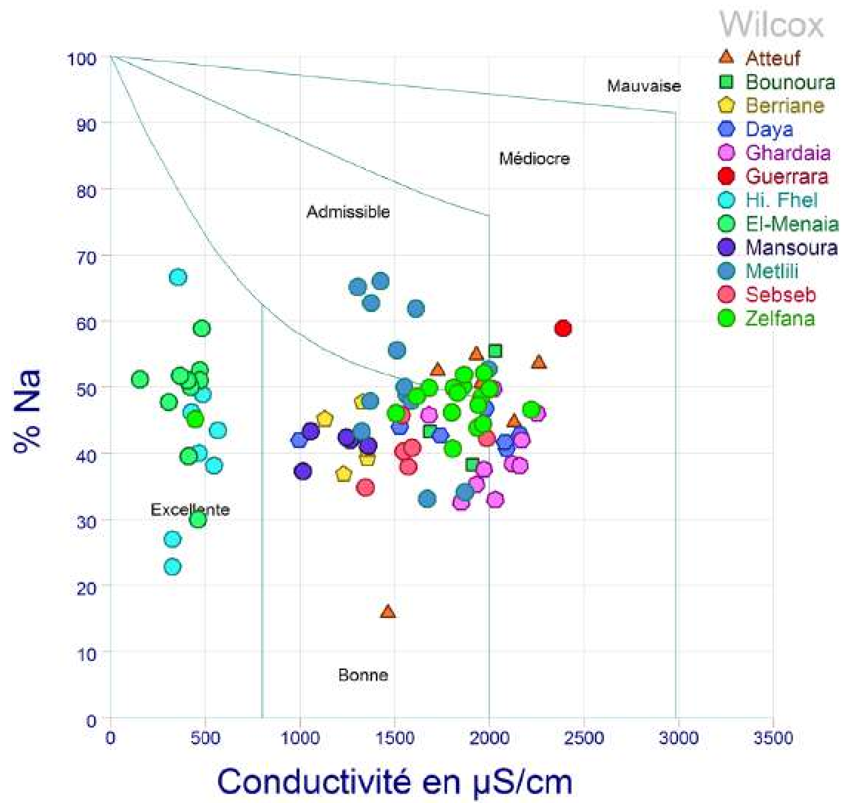


Figure 8. Piper-tri-linear diagram depicting hydrochemical facies of the AAMR.



(a)



(b)

Figure 9. Wilcox-USSL diagrams depicting irrigation water of the AAMR.

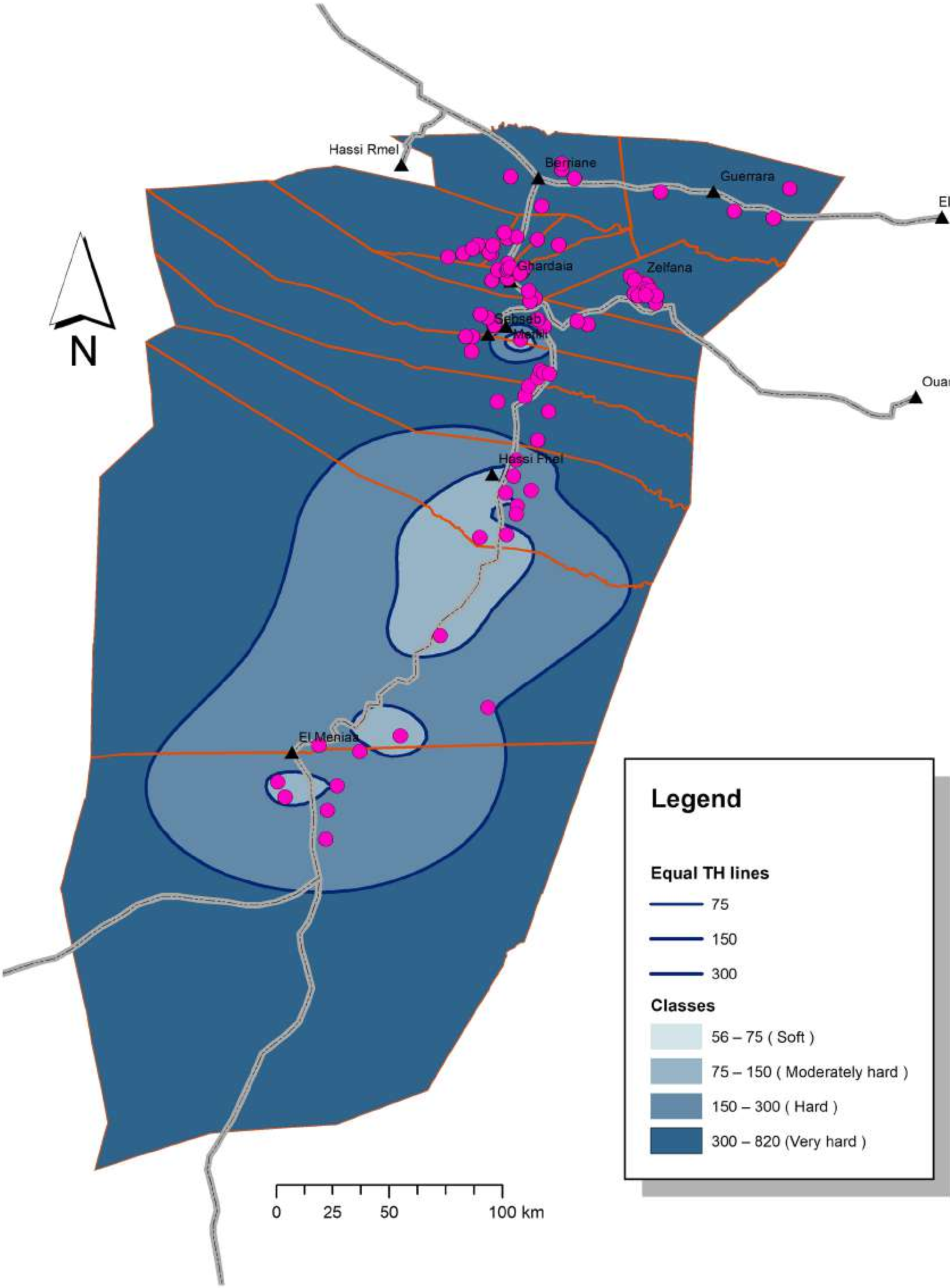


Figure 10. Spatial distribution of the Total Hardness (TH).

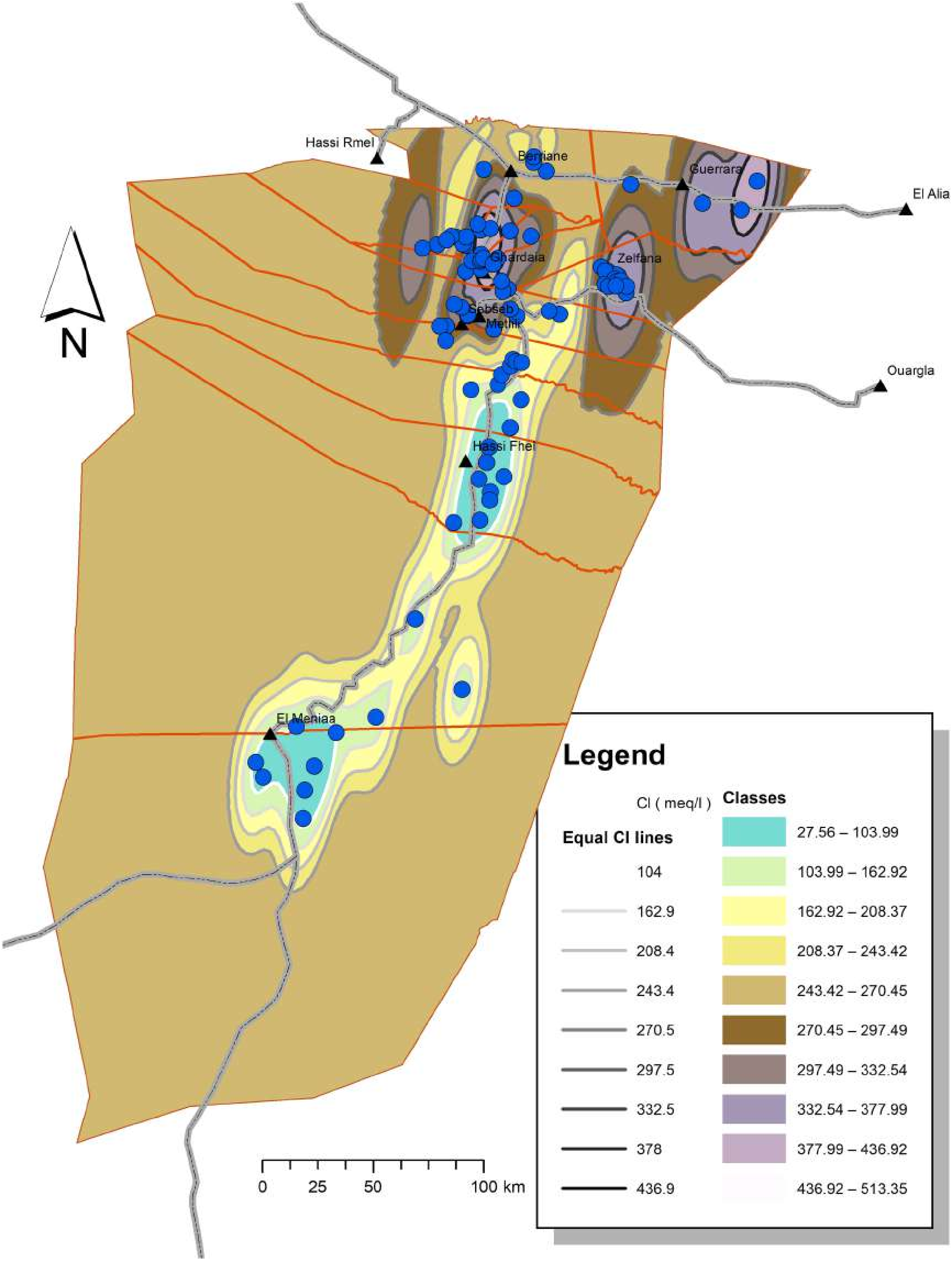


Figure 11. Spatial distribution of the Chlorides (Cl^-).

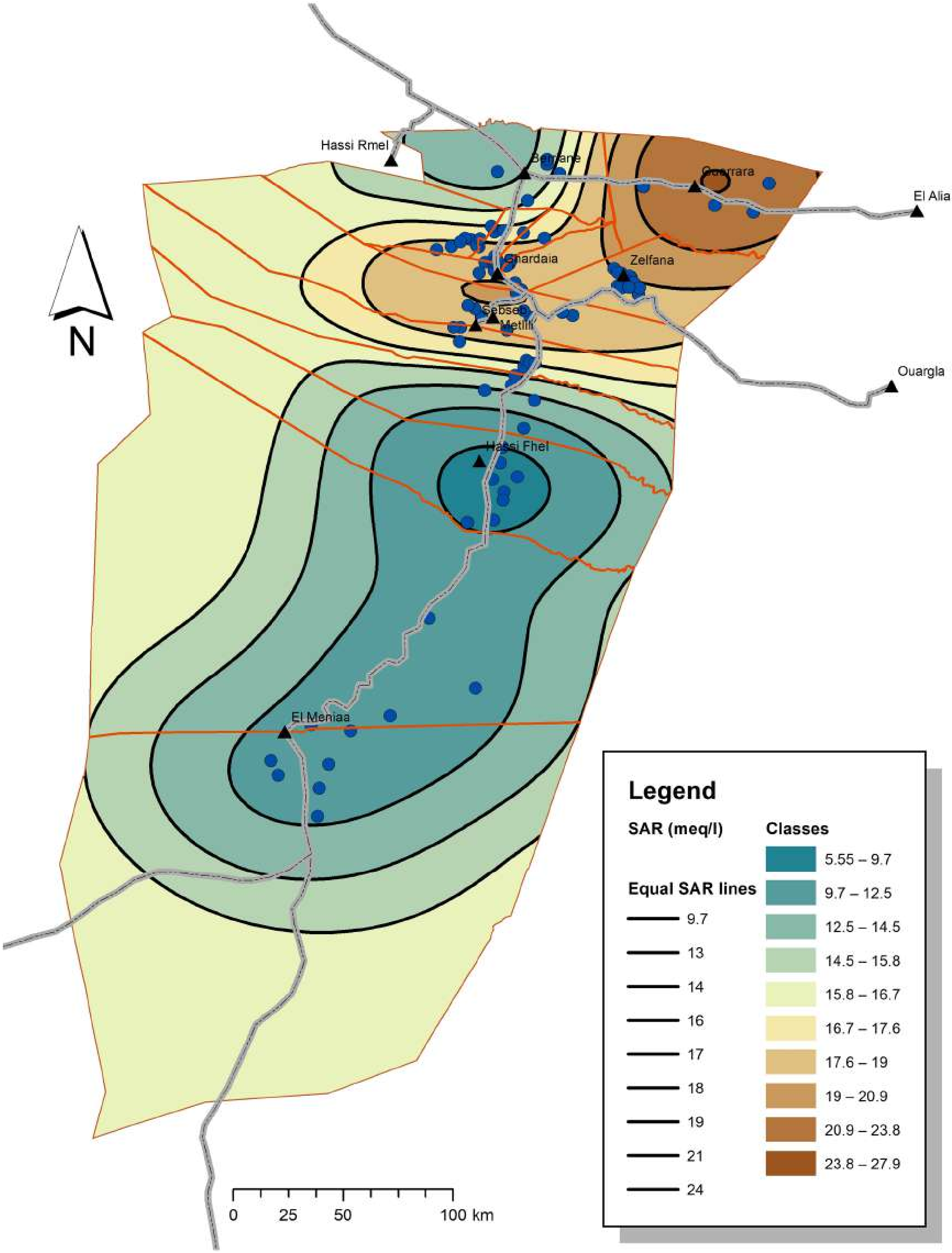


Figure 12. Spatial distribution of the Sodium Adsorption Ratio (SAR).

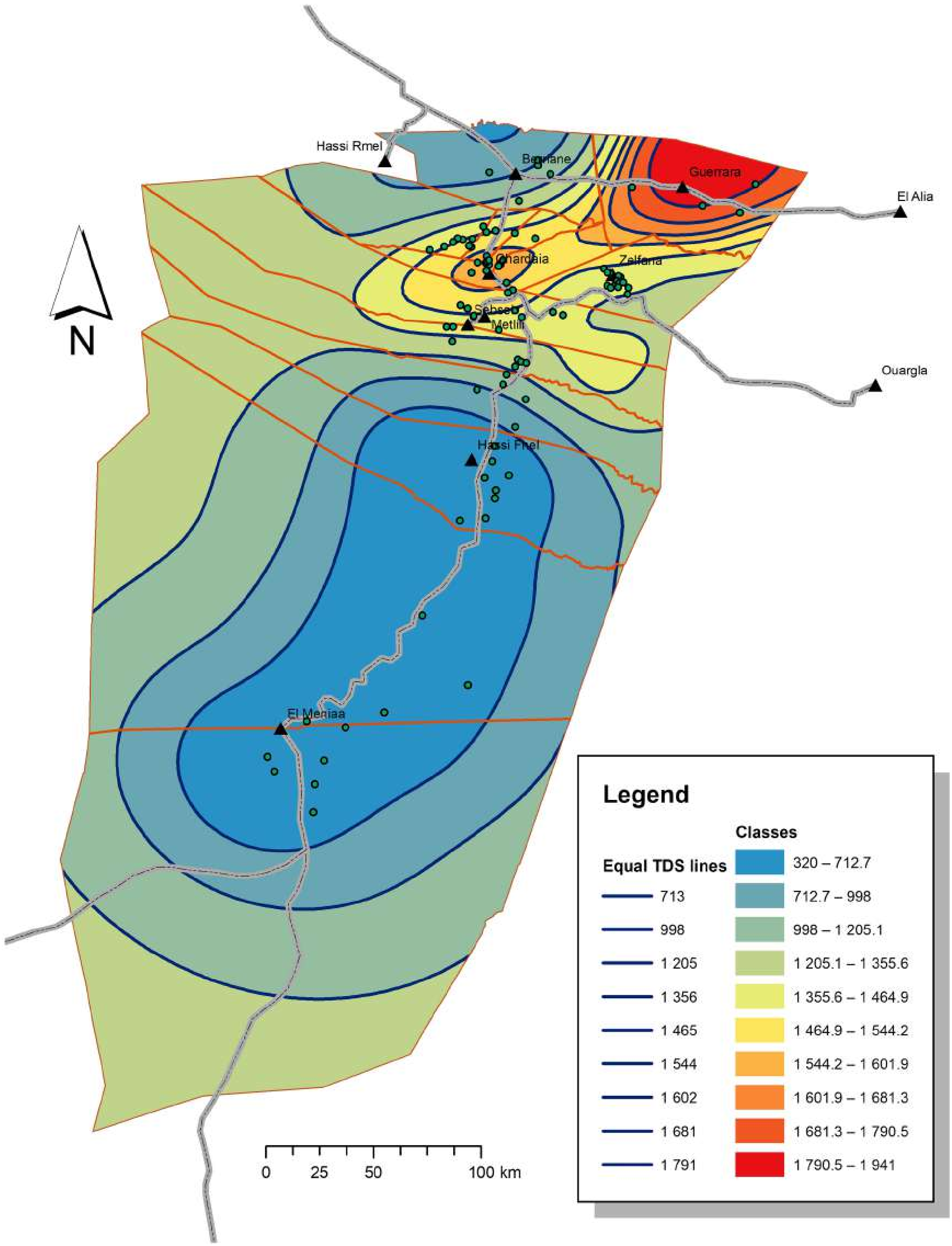


Figure 13. Spatial distribution of the Total Dissolved Solids (TDS).

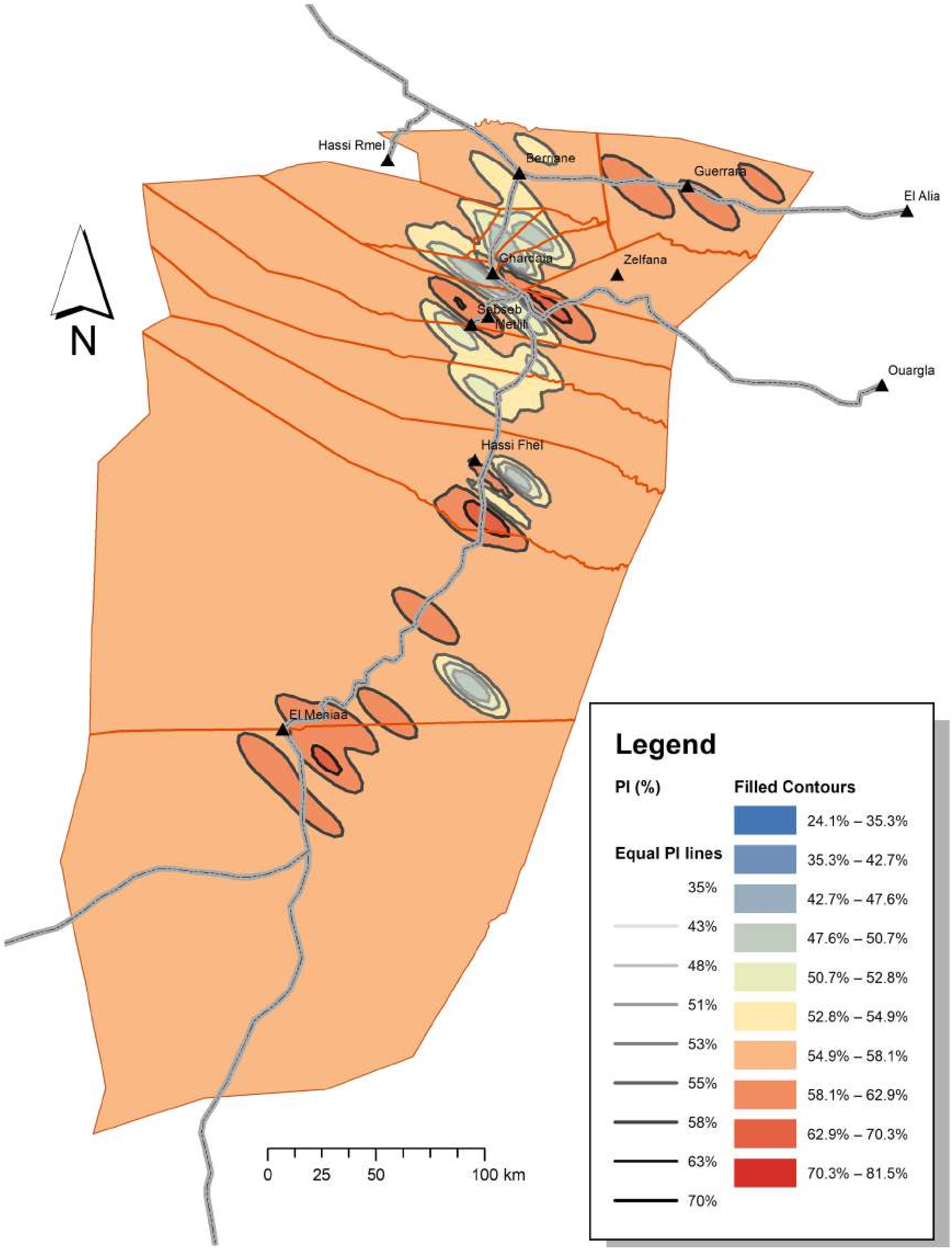


Figure 14. Spatial distribution of the Permeability index (PI).

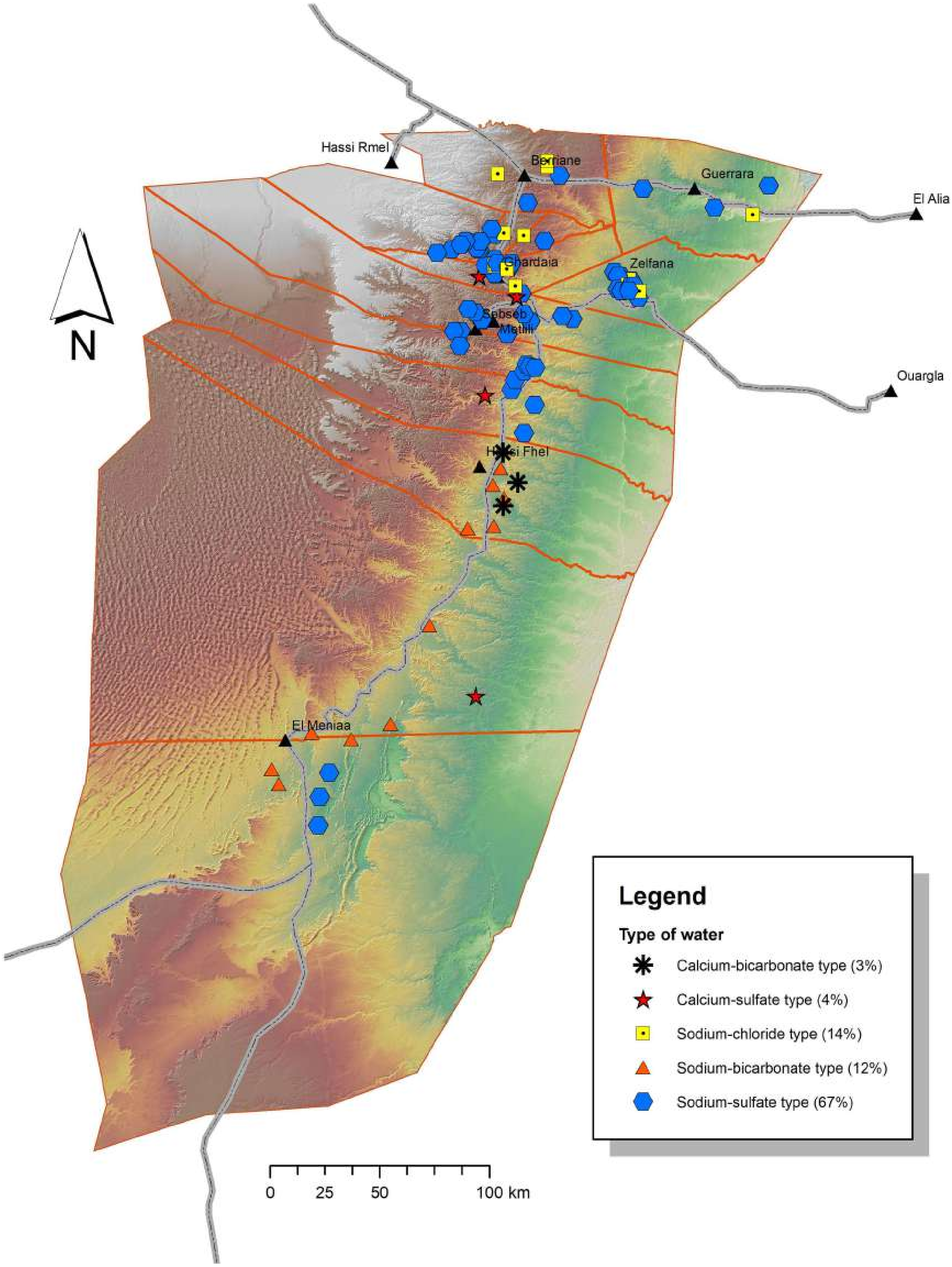


Figure 15. Spatial distribution of the Type of water.

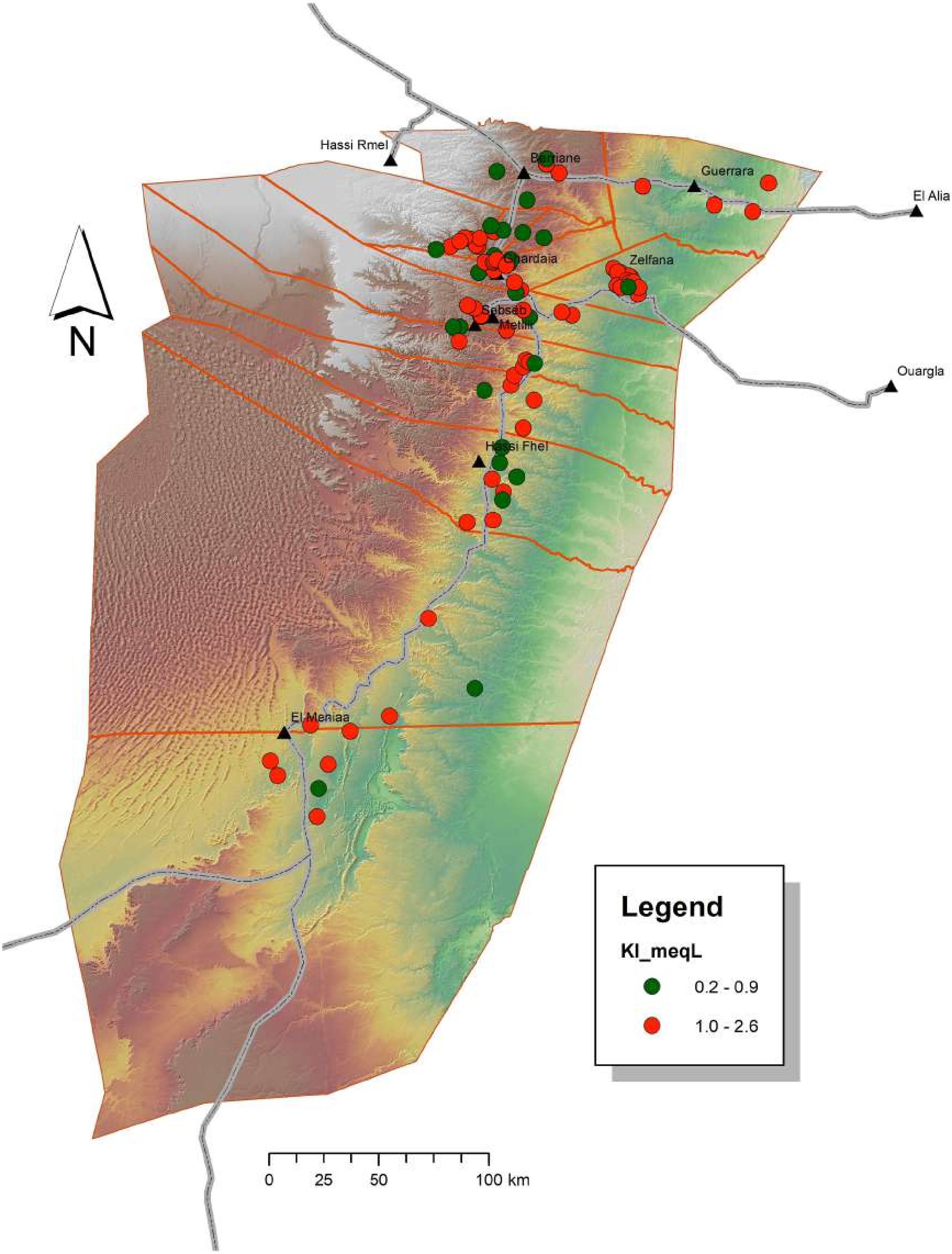


Figure 16. Spatial distribution of (a) Kelly's Index (KI).

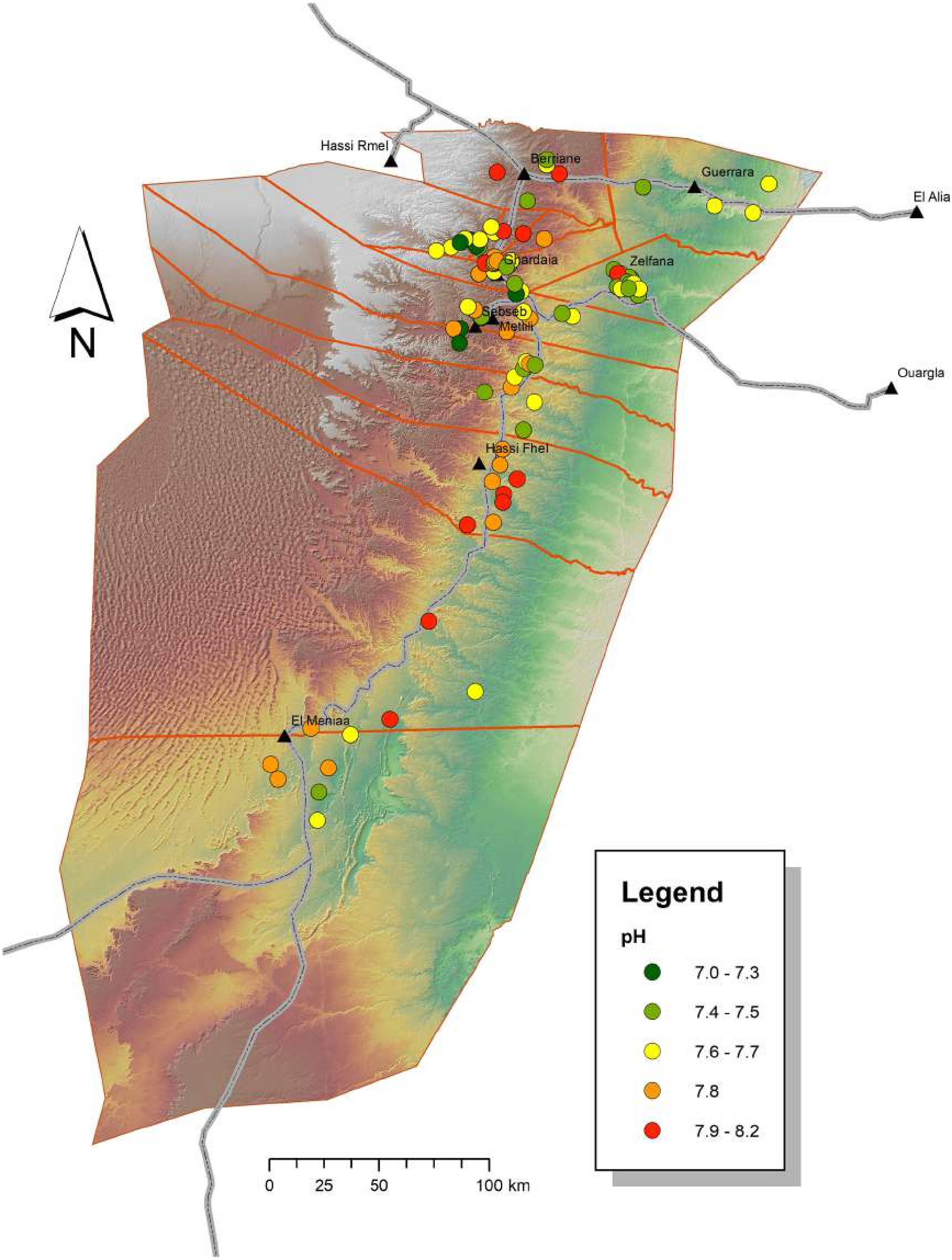


Figure 17. Spatial distribution of the potential of Hydrogen (pH).

A high concentration of TDS and SAR was also observed at Northeast, which is attributed to a natural phenomenon. These values are classified within the tolerated limits of the suitability of water for irrigation purpose. In the south of the study area, the concentration of TDS and SAR are low. Agricultural practices do not seem to be affected by water quality in this area (**Figure 16**, **Figure 17**).

5. Conclusions

In this paper, an attempt was made to study the piezometric evolution and water quality of the main groundwater in the M'zab region by combining GIS and geostatistics. Applied on a set of original data, the geostatistical technique has played an important role in progress and is considered an effective tool for developing various thematic maps showing the spatial distribution of various hydrodynamic and hydrochemical parameters of the aquifer. After validation, these maps were prepared and analyzed. The overall results show that groundwater quality for drinking water or irrigation is declining from South to North and North-East of the study area. This is mainly due to the direction of flow on the one hand. And on the other hand, the frozen effect of the aquifer lithology influences by the clay fraction from the Southwest to the Northeast and also by the increase in its depth in the same direction.

According to standard norms, all quality indices reveal the water of the Albian groundwater in our study area is suitable for consumption, whether for drinking or irrigation. In the South, all practices agricultures are not affected by the water quality of the AAMR. With a clear vision of geographical groundwater quality areas, decision-makers can better plan the exploitation and preservation of these groundwater resources in this arid zone.

Acknowledgements

The authors would like to thank the technical staff of Agence Nationale des Ressources Hydrauliques (ANRH) for their help in using GIS and the laboratory of water analysis of the Algérienne Des Eaux (ADE) of Ghardaia for sharing the data.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Système Aquifère du Sahara Septentrional (2003) OSS. Système Aquifère du Sahara Septentrional. Hydrogéologie. S.R. Interne. Vol. 2, Système Aquifère du Sahara Septentrional, Tunis, 275.

[2] Ould Baba Sy, M. (2005) Recharge et paléorecharge du Système Aquifère du Sahara Septentrional. Doctorat. Département de Géologie. Université de Tunis El Manar, Tunis, 271.

[3] ANRH (2011) Inventaire des forages et enquête sur les débits extraits de la nappe albienne dans la Wilaya de Ghardaïa. Agence Nationale des Ressources Hydrauliques, DRS. Ouargla, Algérie.

[4] ANRH (2010) Note de synthèse sur les premières mesures piézométriques en utilisant les nouveaux piézomètres captant la nappe du CI dans la wilaya de Ghardaïa. Agence Nationale des Ressources Hydrauliques, DRS, Ouargla, Algérie.

[5] DPAT (2016) Monographie de la wilaya de Ghardaia. DPAT. Wilaya de Ghardaia.

[6] Achour, M. (2014) Vulnérabilité et protection des eaux souterraines en zone aride: Cas de la vallée du M'zab (Ghardaia-Algérie). Magister. Département des Sciences de la Terre, Université d'Oran, Es Senia, 155.

[7] Dubief, J. (1953) Essai sur l'hydrologie superficielle au Sahara. Institut de Météorologie et de Physique du Globe de l'Algérie Service des Etudes Scientifiques: Alger, Algérie, 451.

[8] Busson, G. (1972) Principes. Méthodes et résultats d'une étude stratigraphique du Mésozoïque saharien. Mémoires du Muséum National d'Histoire Naturelle-Série C. 26, Paris, 441 p.

[9] Fabre, J. (2005) Introduction à la géologie du Sahara algérien et des régions voisines: La couverture phanérozoïque. Vol. 1, SNED, Alger, 422 p.

[10] Hadj Brahim, A. (2016) Contribution à l'étude piézométrique de la nappe albienne dans la région du M'zab. Master académique. Département des sciences de la terre, Université Kasdi Merbah Ouargla, Ouargla, 50.

[11] Achour, M. (2003) Etude hydrogéologique de la nappe phréatique de la vallée de Metlili. A. ANRH. Secteur de Ghardaïa. Secteur de Ghardaïa. National Agency for Hydraulic Resources, Algérie.

[12] Benhedid, H. (2015) Etude de l'impact des eaux usées sur la variabilité de la pollution des aquifères superficiels à Oued M'Zab. Magister. Département des Sciences et Environnement, Université Kasdi Merbah Ouargla, Ouargla, 149.

[13] Petersen, J., Deschamps, P., Hamelin, B., Fourré, E., Gonçalvès, J., Zouari, K., et al. (2018) Groundwater Flowpaths and Residence Times Inferred by ^{14}C. ^{36}Cl and ^{4}He Isotopes in the Continental Intercalaire Aquifer (North-Western Africa). *Journal of Hydrology*, **560**, 11-23. https://doi.org/10.1016/j.jhydrol.2018.03.003

[14] Agoun, A. (2015) Quantifying the Modern Recharge of the "Fossil" Geothermal Sahara Aquifers by the Gravity Recovery and Climate Experiment (GRACE) Satellite Data in World Geothermal Congress. University of Victoria Melbourne, Melbourne, 7.

[15] Keith Todd, D. and Mays, L.W. (2005) Groundwater Hydrology. 3rd Edition, John Wiley & Sons, Hoboken, 656 p.

[16] Şen, Z. (2014) Practical and Applied Hydrogeology. Elsevier Science, Amsterdam, 424p.

[17] Krishna, B.S., Chavda, S.N. and Prakash, I. (2015) Evaluation of Groundwater Conditions of Mahesana, Gujarat, India Using Geoinformatics Technology. *International Journal for Scientific Research & Development*, **3**, 1-5.

[18] Merkel, B.J. and Planer-Friedrich, B. (2005) Groundwater Geochemistry. Springer, Berlin, Heidelberg, New York.

[19] Rodier, J. and Legube, B. (2009) L'analyse de l'eau. Dunod.

[20] Hounslow, A. (1995) Water Quality Data: Analysis and Interpretation. CRC Press, New York, 516.

[21] Bethke, C.M. (2008) Geochemical and Biogeochemical Reaction Modeling. Cambridge

University Press, Cambridge.

[22] Gaetan, C. and Guyon, X. (2008) Modélisation et statistique spatiales. Springer, Berlin, Heidelberg.

[23] Johnston, K., Hoef, M.V., Krivoruchko, K. and Lucas, N. (2001) Using Arc GIS Geostatistical Analyst. Vol. 380, Esri Redlands, New York, 380 p.

[24] Njeban, H. (2018) Comparison and Evaluation of GIS-Based Spatial Interpolation Methods for Estimation Groundwater Level in AL-Salman District—Southwest Iraq. *Journal of Geographic Information System*, **10**, 362-380. https://doi.org/10.4236/jgis.2018.104019

[25] Joseph, L. and Bhaumik, B.J.M.G. (1997) Improved Estimation of the Box-Cox Transform Parameter and Its Application to Hydrogeochemical Data. *Mathematical Geosciences Journal*, **29**, 963-976. https://doi.org/10.1023/A:1022353401858

[26] Hengl, T. (2009) A Practical Guide to Geostatistical Mapping. Vol. 52, University of Amsterdam, Amsterdam.

[27] Ramkumar, T., Venkatramanan, S., Anithamary, I. and Ibrahim, S.M.S. (2013) Evaluation of Hydrogeochemical Parameters and Quality Assessment of the Groundwater in Kottur Blocks. Tiruvarur District. Tamilnadu, India. *Arabian Journal of Geosciences*, **6**, 101-108. https://doi.org/10.1007/s12517-011-0327-2

[28] Belfar, D., Fehdi, C., Baali, F. and Salameh, E. (2017) Results of a Hydrogeological and Hydrogeological Study of a Semi-Arid Karst Aquifer in Tezbent Plateau, Tebessa Region, Northeast of Algeria. *Applied Water Science Journal*, **7**, 1099-1105. https://doi.org/10.1007/s13201-015-0357-0

[29] World Health Organization (2012) Guidelines for Drinking-Water Quality. Vol. 1, World Health Organization, Geneva.

[30] Hamad, A., Baali, F., Hadji, R., Zerrouki, H., Besser, H., Mokadem, N., *et al.* (2018) Hydrogeochemical Characterization of Water Mineralization in Tebessa-Kasserine Karst System (Tuniso-Algerian Transboundry Basin). *Euro-Mediterranean Journal for Environmental Integration*, **3**, Article No. 7. https://doi.org/10.1007/s41207-017-0045-6

[31] Piper, A.M. (1944) A Graphic Procedure in the Geochemical Interpretation of Water-Analyses. *Eos*, *Transactions American Geophysical Union*, **25**, 914-928. https://doi.org/10.1029/TR025i006p00914

[32] Wilcox, L. (1955) Classification and Use of Irrigation Waters. U.S. Department of Agriculture, Washington DC.

[33] Richards, I.A. (1954) Diagnostic and Improvement of Saline and Alkali Soils. Edit. US Department of Agriculture, Agricultural Handbook No. 60, Washington DC, 160 p.