Hydro-Chemical Study with Geospatial Analysis of Groundwater Quality Illizi Region, South-East of Algeria

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ABSTRACT: *For the aim of evaluating the physical and chemical groundwater quality of six layers (the Lower Devonian, Mio Pliocene, Infero Flux, Cambro Ordovician, Albian, and Zaraitine in Illizi, and to identify the sources of its chemical composition and detect the suitability for drinking and irrigation purposes, 44 samples were collected during tow years 2018-2019 to measure pH, T°, Electrical Conductivity (EC) and Total Dissolved Salts (TDS), major elements concentrations were analyzed in the laboratory. The suitability of groundwater for irrigation and other uses was assessed by determining the sodium adsorption ratio (SAR), Soluble-Sodium Percentage (SSP), Permeability Index (PI), Kelly Index (KI), and Total Hardness (TH) of water samples. The spatial distribution of key parameters was assessed using a GIS-based spatial gridding technique. This analysis indicated that the Zaraitine groundwaters used to have the worst chemical quality, while the Infero Flux, Cambro Ordovician and Albian groundwaters have suitable water for drinking. Based on Sodium Absorption Ratio (SAR), Solubility Sodium Percent (SSP), Kelly Index (KI), Permeability Index (PI), Residual Sodium Carbonate content (RSC), and Magnesium Hazard (MH). we find that the Lower Devonian, the Infero Flux, and Cambro Ordovician have suitable water for irrigation, on the other hand, all of Mio-Pliocene, Albian, and Zaraitine consider as unsuitable for agriculture practice. PCA analyses with the comparison between Lower Devonian wells in Illizi town and Lower Devonian wells in Fadnoun town in groundwater quality confirm that the local environmental conditions are a more important factor for groundwater quality than geographical distribution. Geospatial mapping of hydro-chemical parameters shows that the southeast of Illizi and the western part of Djanet are the best sub-areas for agriculture practice.*

KEYWORDS: *Groundwater; GIS; Hydrochemistry; Lower Devonian; Illizi.*

INTRODUCTION

Groundwater is an essential source of clean water in the whole globe [1]. When we speak about arid and semiarid zones, we could say that groundwater is the first water resource available there. One from the master's

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factors holding back economic progression is the accessibility of water resources in the study area because of the poverty of water resources, which makes the groundwater is the only supplier for different uses. The chemical composition of water from the natural environment is very variable. It depends on the geological nature of the soil where it comes from and also on the reactive substances it could have encountered during the flow. Thus, the quantitative and qualitative composition of groundwater in the suspended and dissolved matter, of mineral or organic nature, determines its quality [2]. However, this quality can be altered when external substances come into contact with the aquifer. Such is the case with undesirable or even toxic substances which make groundwater unfit and toxic for various uses, for use as drinking water in particular. The intensive use of natural resources and the increase in human activities have caused serious problems with the quality of groundwater [3]. On the other hand, the increasing tendency of the agricultural Illizi in the last years pushes us to make this study. Illizi is located in the South-East of Algeria which is considered as an arid region. We choose the hydrochemical investigations as a method for the determination of groundwater chemical characteristics; this method makes good links between ratio, statistical, and graphical approaches. Moreover, geochemical associations are also involved [4,5]. A geospatial work was executed by realizing fourteen (14) maps of the spatial distribution of seven (7) parameters in Illizi town and Djanet town.

Many factors such as the bedrock geology, soil properties, climatic conditions, and flow of water through the environment. could influence the groundwater chemistry. The bedrock formation chemistry and erosion which are considered as a physical process, control the hydrogeochemical characteristics of groundwaters by the dissolution of minerals and the enrichment with ions and other elements. [6]. The presence of nitrates in groundwater with high concentrations is considered as a pollution type which the main source of nitrates is the practice of irrigation activities, could be also due to the industry or wastewater, where they influence also on salinization and considered as an anthropogenic impact. [7,8]. In Algeria, Groundwater quality has been investigated by many researchers [9-15]. Multivariate Statistical Tchniques (MST) help in the effective management of large and complex groundwater data. Principal Component Analysis (PCA) widely used statistical technique for the characterization and evaluation of groundwater quality [16,17]. During the past years, irrigational uses in Illizi have been increased and especially in Illizi town and Djanet town. This paper is considered the first scientific work of his kind in the study area, it aimed for : (1) to study groundwater quality of six deferent layers (Lower Devonian, Mio-Pliocene, Infero Flux, Cambro Ordovician, Albian, and Zaraitine) to estimate the suitability of groundwater for drinking and irrigational uses and in the same way to assess the influences of irrigational and industry practices on groundwater quality, and (2) to assess the more important predictor for groundwater quality between whether local conditions and geographical distribution. Assessing groundwater quality could be applied in such a way in other unexplored areas of the county and for better water preservation, management, and human health.

STUDY AREA CHARACTERISTICS

Geographic localization of study area

Illizi is located in the extreme southeast of Algeria (Fig. 1). It covers an area of 284 618 km², and it is bordering with three countries on a border of about1200 km, Tunisia to the north-east, about 25 km, Libya to the east, about 1000 km, and Niger to the south, about 102 km. In the interior of the country, it is limited by Tamanrasset to the west and the county of Ouargla to the north [18]. It is divided into six municipalities:

Bordj Omar Driss, Deb Deb, In Aménas, Illizi, Djanet and Bordj El Houes.

Geological aspect:

According to the national agency of hydrographic network (A.N.R.H), the city of Illizi is built on a plateau land consisting of the Lower Devonian clay-sandstone and Emsian clay-sandstone soils and Quaternary. To the north, about 12 km outcrops the middle to upper undifferentiated Devonian layers, these are overcome much further north by Upper Devonian to Carboniferous layers formed mainly by the Khenig sandstone, upper Famennian at Tournaisien, with average coastlines of 550 to 650 meters may have peaks exceeding 700 meters. This difference in elevation gives rise to a landscape of canyons favoring the runoff of water and the acceleration of flows.

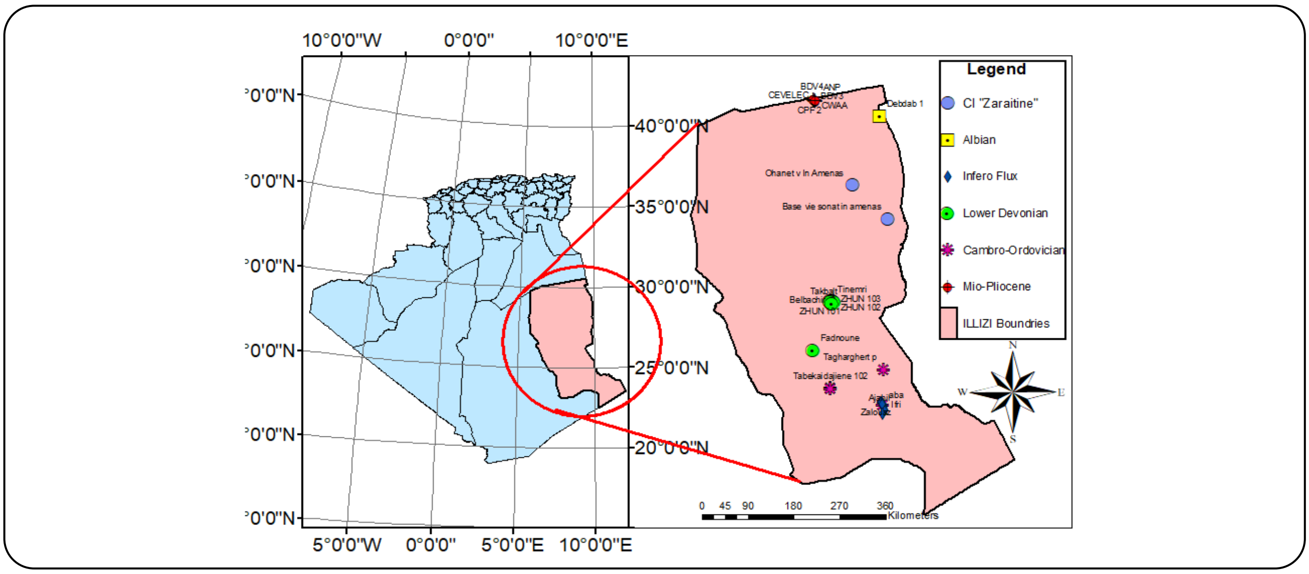

Fig 1: a,b, localization of ILLIZI county, sampling locations.

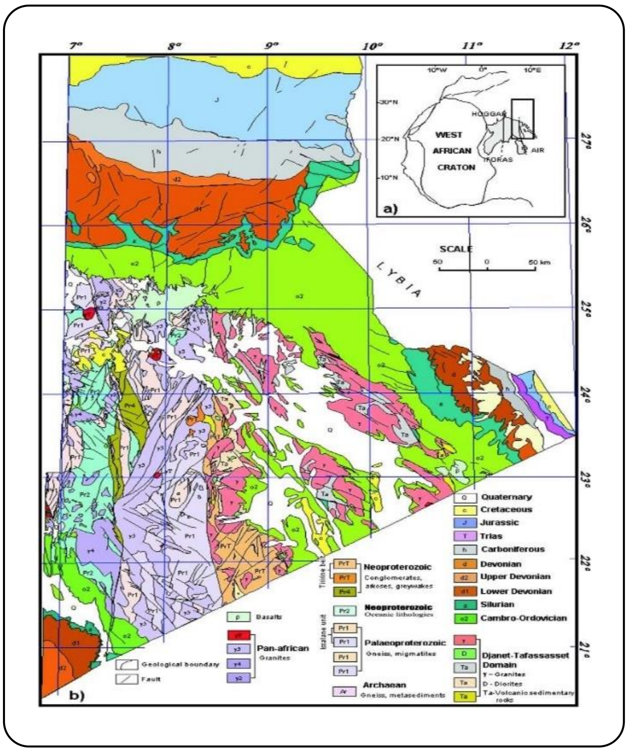

Fig. 2: Geological map of eastern Hoggar(Bertrand and Caby (1981))

A plain landscape extends from the side of Tin-Tourha to the northeast, the area of Halloufa to the east, and south to the side of Gara Souf Mellene passing through Adjnadjane to the Gara Tan Harab. This plain, on a radius of 8 km, is mainly composed of post-Mesozoic formations (Quaternary), with altimetry between 560 and 570 meters. To the south and beyond 8 km are the lower Devonian formations, which are recognized under the name formations of the Oued Samène (Siegenien). Their altitudes exceed 700 meters. These formations constitute a tectonic domain, with frank deformations and major fractures. affected by important faults spread over several tens of kilometers and have a north-south direction, and others less important of east-west direction.

In the strict sense, the geology of the state of Illizi is presented under two large units distinct from the point of view of lithostratigraphy, namely the crystalline basement and the sedimentary cover. Fig. 2 present the different geological layers founded in the eastern part of Algeria.

Hydrogeological aspect

According to the authority of agricultural development in Saharan regions (CDARS), the hydrogeology of Illizi region is characterized by several aquifer formations. The region is characterized by a very extensive surface, from which we can distinguish several aquifer horizons as Cambro-Ordovician: The Cambro-Ordovician sandstone formations of Tassili, besides having a very low porosity, are traversed by a system of cracking and faults. These characteristics facilitate their circulation of water, tassili sandstones have good permeability.

Devonian (Illizi): it is recognized in Illizi and its surroundings, particularly in the north, by exploitation from 250 to 1450m respectively in the regions of Illizi and El Adeb Larach. The static level relative to the ground varies from one region to another: It is a few centimeters to a few meters in the high areas, on the other hand, the water is springing north and east of Illizi.

The Carboniferous: This aquifer is exploited at depths ranging from 800 to 1100 m in the region of In Aménas. Water drained by "lifting" is used only for maintaining the pressure of the oil slicks and irrigation; the static level varies between 200 and 300m.

The aquifer system of the Continental Intercalaire (CI): It occupies the stratigraphic interval between the Triassic and the summit of the Albian. The aquifer levels are mainly contained in the Barremian and Albian, which consist of sandstone and sandy-clayey Lower Cretaceous continental deposits. It drains the sandstone and clay-sandstone formations of the Triassic and Jurassic in the region of Stah and In Aménas (in its regions the CI is called the Zaraitine and Taouratin Series), from Barremian and Albien to Deb Deb and Albien to BOD and RhourdNouss. The aquifer is captured either by medium-depth (400 to 500m), T.F.T, Ohanet, and B.O.D drilling, or relatively deep (800 to 1200m) at RhourdNouss and the north of Deb Deb. The waters of the sheet are gushing at RhourdNouss, Bordj Omar Driss, Tabankort, Maouar, ZemeletMederba, and the north of Deb Deb; they are exploited by pumping at varying depths (from a few meters to 300m) at Tinfouyé, Ohanet, south of Deb Deb and Stah; the power of the useful tank is greater than 250m. Static pressure measurements indicate values that can reach 18 bars (egRhourdNouss, gushing water).

The aquifer system of the Terminal Complex (CT): Due to its depth close to the ground and its ease of capture, the aquifer of the terminal complex (CT) is very much in demand for the supply of drinking water and irrigation. The total number of holes in this sheet is 33, the whole is in use; these holes capture the following horizons:

The Turonian: Is formed by limestones and constitutes a free aquifer, locally cracked. Its depth varies between 200 to 400m, the average thickness is of the order of 80m and rests on an impermeable substratum of Cenenomanian anhydritic and clayey; Its dry residue is high, generally exceeding 6 g/L. The total number of boreholes that captures the Turonian in this area is three (03) of which one (01) is plugged (Fort Saint III) and 02 artesian, flow into the wild with an unknown flow (Fort Saint I and Fort Saint II), causing large swamps to spread across the Algero-Libyan and Algero-Tunisian borders.

The Mio-Pliocene: Composed of an alternation of sands and clays, limiting to the extreme north-west of the Wilaya, the aqueduct is that of the Mio-Pliocene. It is exploited in the area of Rhourd Nouss and El Hamra by drilling 160 to 300m deep. The water is pumped off at varying levels between 80 and 100m.

The Infero-Flux (Oued Illizi): The geophysical study carried out in 1970 by electric sounding refraction allows us to specify the extension of the alluvial filling. The latter is notched in the Middle Devonian formations. relatively large area. The average thickness of the aquifer is 25m, and floods of the wadi are annual. The depth of the boreholes capturing this aquifer is of the order of 40 to 50m while the static level varies between 2 to 10m; the chemical quality of the water is relatively good.

The Infero-Flux (Bordj El Haoues): This sheet is requested by 05puits (generally dispersed in the palm groves) and 02 boreholes, which constitute an important source of water supply for the population of Bordj El Haoues and the agglomeration of Ihrir (tourist site at 80 km from Bordj El Haoues).This sheet consists of alluvial wadis. It is used mainly for irrigation and drinking water supply, the water of this table is of good quality; the dry residue varies between 320 to 860 mg / l.

The Infero-Flux (Alluvial) of Oued Djanet: Before the discovery of the Cambro-Ordovician aquifer, the alluvial aquifer of Wadi Djanet was the main and only water resource of the region. It is a small aquifer covering an area of 17 km²; they are heterogeneous alluviums, ranging from silty sand to pebbles of small size resting on about twenty kilometers. Currently, it is requested by 24 boreholes (including 01 wells) including 09 boreholes and 01 wells are in service (we note that several wells are missing after the last flood); the water of this sheet is of good quality, the dry residue varies between 146 to 340 mg /L.

EXPERIMENTAL SECTION

Sampling and physicochemical analysis

During 2018–2019, a total of forty-four (44) samples of groundwater were collected from six different layers (lower Devonian, Mio-Pliocene, Infero Flux, Cambro Ordovician, Albian, and Zaraitine), to investigate the quality of this water for irrigation use, samples locations and exploited layers shown in (Table 1). The location of each site, the coordinates, and the elevation of the sampling location were taken from Google earth. 1.5 L plastic bottles used to collect the samples. All the bottles had been cleaned with tap water and then distilled water. During field preparation, the bottles had been washed by the sample water itself before sampling. The vials were rinsed thoroughly with the sample water to ensure that the sample is representative of the water source. After collecting the water samples, we give each vial a proper label for identification, then we packed it all in a special box and transported it to the "laboratory of water and environment engineering in the Saharan environment, Ouargla" for analysis. Groundwater quality parameters used in the Examination included potential hydrogen (pH), Electrical Conductivity (EC), temperature (C°), salinity, major cations include sodium (Na^+), potassium (K^+), magnesium (Mg^{2+}) and calcium (Ca^{2+}), major anions include chloride (Cl^-), sulfate ($SO4_2^-$), bicarbonate (HCO_3^-). To do the necessary analysis we relied on flame Atomic Absorption Spectrophotometer (AAS), the material used for measuring the major anions and cations referencing under "Analytik Jena, NovAA 350", while the physical parameters (pH, EC, °C, and salinity) were measured on the field using a multi-parameter referencing under "HANNA HI9829", other calculation formulas were used to analyze the water quality variables. These various water quality parameters were calculated and classified to determine the suitability of irrigation groundwater quality based on the recommendation of *Eaton* (1950)[19], *Ayers* and *Westcot* (1985)[20], and *Todd* and *Mays* (2005)[21].

The precision of chemical analysis is specified by the calculation of ionic balances of each sample, error values below ± 5% are the best analytical estimation and the accepted error level is no more than ± 10% [22-24].

If the error percentage exceeds ± 10%, it means that the existence of some errors in calculation or in sampling. The IB error values of the studied samples had an average value of 3.35 %, a minimum value of 2%, and a maximum value up to 12%, a totally 79% of the founded ionic balances under 5%, 16% under 10% and 5% of samples had an IB value of -12%.

Hydro-geo-chemistry

The hydro-geo-chemical study is based on a number of indices and parameters used to detect the suitability of groundwater quality for drinking and irrigation purposes; all the parameters and calculated indices are shown in Table 2 and Table 3, and the formulas used in the

Table 1: sampling location and samples ID

Well Sample	ID	location	layer
ZHUN 101	D1	ILLIZI	LOWER DEVONIAN
ZHUN 102	D2	ILLIZI	
ZHUN 103	D3	ILLIZI	
zone activ	D4	ILLIZI	
Ain el kours	D5	ILLIZI	
Takbalt	D6	ILLIZI	
Tintourha	D7	ILLIZI	
Sidi bouslah	D8	ILLIZI	
Tinemri	D9	ILLIZI	
Fadnoune	D10	FADNOUN	
Belbachir	D11	ILLIZI	
Puit ABB	M1	EL MERK	MIO PLIOCENE
EMK 8	M2	EL MERK	
CEVELEC	M3	EL MERK	
CWAA	M4	EL MERK	
CPF 2	M5	EL MERK	
BDV3	M6	EL MERK	
BDV4	M7	EL MERK	
ANP	M8	EL MERK	
Aba	I1	DJANET	INRERO FLUX
Zalouaz	I2	DJANET	
Ajahil	I3	DJANET	
Kanfar 3	I7	DJANET	
inabarber 2	I8	DJANET	
Ifri	I4	DJANET	
Kanfar 1	I5	DJANET	
Tagharghert	I9	DJANET	
Kanfar 2	I6	DJANET	
Tagharghert p	C2	DJANET	CAMBRO ORDOVICIAN
inabarber	C1	DJANET	
Tabekai	C3	B EL HAOUAS	
dajiene 102	C4	B EL HAOUAS	
Debdab 1	A1	DEBDAB	ALBIAN
Debdab 2	A2	DEBDAB	
Debdab zhun	A3	DEBDAB	
H10	Z1	IN AMENAS	ZARAITINE
H7	Z2	IN AMENAS	
Station Brut	Z3	IN AMENAS	
H8	Z4	IN AMENAS	
MR104	Z5	IN AMENAS	
Base vie sonat	Z6	IN AMENAS	
ZR602	Z7	IN AMENAS	
Al607	Z8	IN AMENAS	
Ohanet	Z9	IN AMENAS	

the calculation is presented. The Permeability Index (PI), is generally used to take an idea on the interactions between soil and aquifer [25]. Kelly's index, calculated by the concentrations of Na+ against Ca2+ and Mg2+, is measured in samples, and the water is classified according to excess or deficiency of sodium [26,27]. If Kelly's index is below 1, we say that water samples are suitable for irrigation. The Total Hardness (TH) is an indicator of the mineral content in a water sample in the function of Ca2+ and Mg2+ concentrations. Four categories can be found to classify water samples: soft, moderately hard, hard, and very hard [28]. Sodium percentage (%Na) or Soluble Sodium Percentage (SSP) is a very important parameter to detect the Na+ diffusion. Hazard and water hardness are inversely correlated with the sodium values [29]. The sodium hazard of irrigation water can be evaluated using the Sodium Adsorption Ratio (SAR) [30], SAR is the balance between calcium (Ca^{2+}) plus magnesium (Mg^{2+}) ions and sodium (Na^{2+}) ions which gives us an idea about how much soil particles with a negative charge are stick together or flocculated. Flocculation is desirable because it's made water movements and plant roots gown difficult. There are four classes of the possibility of the soil sodicity hazard that is related to SAR values: low if SAR < 10), medium if SAR 10–18, high if SAR, 18–26, and very high if SAR > 26. We have drawn all of Piper, USSL, and Wilcox diagrams according to the finding chemical analyses, after that we determined the type and the different indices of water suitability for irrigation. Furthermore, a description of the spatial distribution of Nitrates (NO_3^-), Electro Conductivity (EC), Total Hardness (TH), potential hydrogen (pH), Sodium Adsorption Ratio (SAR), Kelly Index (KI), and permeability index (PI) is available in seven maps in two sites, Illizi town, and Djanet town. This mapping was done by the software surfer which consists of automated processing, the kriging method chosen to create the grids. Fig. 3 describes the methodology adopted to determine the spatial variation of irrigation water quality suitability parameters.

RESULTS AND DISCUSSION

Hydrochemistry

After obtaining the results of groundwater analyzes of the six layers, it became clear to us that Illizi has basic groundwater in 89% of samples, with a minimum of 6.16 and a maximum of 8.96, in the other hand, 11% of samples showed a pH under 7, we speak here about one sample from the Lower Devonian (Fednoune) and four samples from the Infero Flux (Aba, Khanfar 1, Khanfar 2 and Khanfar 3), in general, 95% of water samples are respecting the guidelines. there is no dominant cation in the samples of Mio-Pliocene, Cambro-Ordovician, and Albian, while the groundwater of the Infero-Flux, Zaraitine, and Lower Devonian showed that there were no dominant cations in 56% and 77% and 45% of samples with the presence of magnesium as a dominant cation in 22% and 33% and calcium by 55 % respectively. The descending order of cations in the studied layers founded as follow: $Ca^{2+} > Na^+ > Mg^{2+} > K^+$ in the Lower Devonian and Cambro Ordovician , $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ in the Mio-Pliocene, Infero-Flux and Albian, $Na^+ > Mg^{2+} > Ca^{2+} > K^+$ in the Zaraitine layer. The Na/Cl ratio average equal to 1.29 (greater than 1), typically suggests that the Na^+ ion source is the dissolution of silicate minerals and is associated with Ca^{2+} and Mg^{2+} ions in the samples [31]. On the other hand, the descending order of anions is as follow: $SO_4^{2-} > Cl^- > HCO_3^- > NO_3^-$ in the Mio-Pliocene, Infero-flux, Albian and Zaraitine, $SO_4^{2-} > HCO_3^- > Cl^- > NO_3^-$ in the Lower Devonian and $HCO_3^- > SO_4^{2-} > Cl^- > NO_3^-$ in the Cambro-Ordovician. The lithology of the study area explains the main source of SO_4^{2-} and HCO_3^-which is the presence of gypsum and sedimentary carbonate rocks (Cambro-Ordovician) in the geological formations respectively [32]. NO_3^- is usually considered a minor anion in unpolluted water, their high concentration is an indication of agricultural excessive use of fertilizer or mineral fertilizers. [7,33]

Hydrogeochemical facies

To find out the groundwater quality as well as the possible pathways for geochemical development, we represent the chemical data of the main ions on a triple piper. Which consists of three well-defined fields: a diamond-shaped central field and two triangular fields (positive ions and anions). By dropping the indicators in the triple fields the general characteristics of the water are represented in the central field. The plotted Piper diagram (Fig. 4) shows that the hydrochemical facies of groundwater in Lower Devonian, Zaraitine, Mio-Pliocene, 50% of Cambro Ordovician wells and 55% of Infero-Flux wells is Cl^-_SO_4^{2-}_Ca^{2+}_Mg^{2+}, the facies of Albian layer is

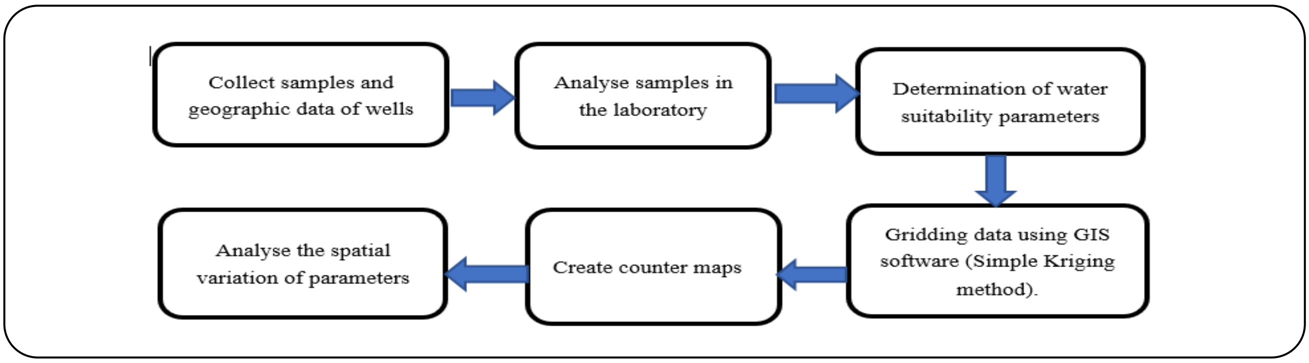

Fig. 3: Methodology adopted to determine the spatial distribution of irrigation water quality suitability parameters.

Cl^-_Na^+_K^+ and the rest 50% of Cambro Ordovician and 30% of Infero Flux is HCO_3^-_Ca^+_Mg^+. Water-type or categories that form the basis for one common classification scheme for natural waters. Lithology, solution kinetics, and flow patterns of the aquifer control hydrochemistry of any facies. [34]

Water quality for drinking water purposes

To determent the suitability of the six layers of groundwater for drinking purposes, we compared the analysis results with the standard guideline values as recommended by the Regulation of Algeria and the World Health Organization (W.H.O.) [35].

pH: The six layers have suitable groundwater in 95% of samples according to the pH analysis results, with a minimum of 6.16 and a maximum of 8.96, two wells (Tagharghart and Khanfar 3) have a pH value under (6.16) and higher (8.96) than the acceptable limit values.

Electroconductivity (EC): the analysis results show that all of the Lower Devonian, Cambro Ordovician, and the Albian layers have an EC value under the guidelines values with a maximum value in the three layers equal to 1442 µS/cm. On the other hand, the three other layers (Mio-Pliocene, Infero Flux, and Zaraitine) have groundwater exceed the acceptable limits with an average equal to 3662 µS/cm.

Total Hardness (TH): with mean values equal to 45.73 , 20.67 , 17, and 26 F° we consider the groundwaters of the Lower Devonian , Infero Flux , Cambro Ordovician, and Albian layer as adequate groundwaters, in the other side we find that the mean values of total hardness in the Mio Pliocene and Zaraitine layer equal to 93.63 and 104.78 F° are exceed the maximal accepted value for Algerian guidelines which is 50 F°.

Ions: the chemical composition of lower Devonian groundwater conforms to Algerian guidelines, except in Tinemri, Sidi Bouslah, TinTourha, and Ain Elkours wells, where we find a high concentration of sulfate (SO_4^{2-}) 405, 425, 482, and 500 mg/L respectively. The presence of gypsum and anhydrite generally is the main reason of those high values.

For the Mio Pliocene layer, we found that magnesium (Mg^{2+}), bicarbonate (HCO_3^-), and Nitrate (NO^{3-}) are presented in water with an acceptable value under the standards, we could add potassium (K^+) as an adequate presence in the chemical composition of groundwaters except in the CPF 2 and BDV 4 wells where the concentrations exceed the value of the standard with 44.98 and 42.47 mg/L respectively. On the other hand, all of the chloride (Cl^-), Calcium (Ca^{2+}), sodium (Na^+) and sulphate (SO_4^{2-}) values have exceeded the maximal accepted value in all wells (except sulphate in CPF 2 well).

The chemical analysis results of Infero Flux, Cambro Ordovician, and Albian groundwaters show that the three layers have suitable water for drinking, except one well (Ajahil) of the Infero Flux where we found a high concentration of calcium and sulphate (236.58mg/l and 746.43 mg/l respectively). We explain this case with the presence of gypsum and the depth of the well (7 meters) which favorit the infiltration of shallow waters and the accumulation of salts.

Zaraitine groundwaters used to have the worst chemical quality between the six layers studied in this paper, all of Mg^{2+}, Na^+, So_4^{2-}, Cl^- and NO_3^- concentration exceed the maximal limit value in all wells except Z3, Z7, Z8 , Z9 for Mg^{2+}, Z3, Z8, Z9 for Na^+, Z8 and Z9 for SO_4^{2-} , Z1, Z2, Z8, Z9 for Cl^- and Z1, Z2, Z3 for NO_3^-. This poor quality is due to two main factors, the first factor is the type of activity in Ain Amenas zone (industry), and the second

Table 2: Descriptive statistics of physicochemical properties of groundwater samples.

	pH	EC (µs/cm)	TDS	TH (F')	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	SO_4^{2-}	HCO_3^{-}	Cl^{-}	NO_3^{2-}
Lower Devonian												
Max	8.40	991.00	1100.00	65.00	140.28	85.06	54.00	22.00	500.00	292.80	133.00	0.70
Min	6.76	353.00	236.00	15.00	30.00	17.40	20.10	0.80	62.50	73.91	20.00	0.00
Avg	8.00	472.00	762.91	45.73	111.67	43.34	43.65	12.12	359.05	138.39	54.64	0.19
range	1.64	638.00	864.00	50.00	110.28	67.66	33.90	21.20	437.50	218.89	113.00	0.70
SD	0.57	181.79	224.52	13.80	31.19	22.20	9.07	6.84	118.20	64.27	32.22	0.20
Mio-Pliocene												
Max	7.90	3120.00	2473.00	123.00	325.25	126.22	313.20	44.98	1127.50	129.50	563.77	46.70
Min	7.60	2225.00	1646.00	76.00	194.39	67.49	214.20	23.81	573.50	87.57	436.12	39.00
Avg	7.71	2444.38	1887.38	93.63	231.14	87.61	242.66	30.26	707.69	108.51	479.56	42.25
range	0.30	895.00	827.00	47.00	130.86	58.73	99.00	21.17	554.00	41.93	127.65	7.70
SD	0.10	279.94	285.24	17.93	45.25	18.64	31.19	8.46	202.31	12.53	40.33	2.30
The Infero-Flux (Alluvial) of Oued Djanet												
Max	8.96	1688.00	1447.00	69.00	236.58	28.80	191.26	7.00	746.43	207.40	241.40	11.00
Min	6.16	210.00	149.00	10.00	10.00	4.80	4.00	1.00	22.00	3.33	0.00	0.00
Avg	7.25	663.67	447.56	20.67	53.94	17.56	59.16	3.78	136.43	87.42	89.17	3.31
range	2.80	1478.00	1298.00	59.00	226.58	24.00	187.26	6.00	724.43	204.07	241.40	11.00
SD	0.82	448.10	385.96	18.34	70.44	10.05	55.10	1.79	233.04	73.41	84.29	4.65
Cambro-Ordovician												
Max	7.52	532.00	508.00	34.00	80.00	33.60	66.00	4.00	188.32	216.55	127.80	5.80
Min	7.00	193.00	183.00	9.00	18.44	8.20	13.00	0.80	6.00	15.81	3.00	0.00
Avg	7.33	351.75	333.00	17.00	42.74	15.40	35.36	2.85	69.32	107.28	59.93	2.58
range	0.52	339.00	325.00	25.00	61.56	25.40	53.00	3.20	182.32	200.74	124.80	5.80
SD	0.24	166.79	156.67	11.63	27.18	12.16	22.55	1.41	81.25	96.08	51.92	3.02
CI Albian												
Max	7.86	1442.00	1001.00	27.00	64.00	29.00	200.00	45.00	260.00	201.00	249.00	7.00
Min	7.49	1321.00	938.00	25.00	60.00	24.00	180.00	3.00	240.00	200.00	195.00	0.00
Avg	7.63	1365.33	962.67	26.00	62.00	26.00	186.67	23.00	250.00	200.33	214.67	2.33
range	0.37	121.00	63.00	2.00	4.00	5.00	20.00	42.00	20.00	1.00	54.00	7.00
SD	0.20	66.67	33.65	1.00	2.00	2.65	11.55	21.07	10.00	0.58	29.84	4.04
CI Zaraitine (Taouratin Series)												
Max	8.20	28570.00	2551.00	147.00	226.40	235.00	394.00	47.50	1330.32	270.00	582.00	164.83
Min	7.24	870.00	597.00	34.00	43.00	57.00	40.00	3.00	185.00	142.00	67.00	1.00
Avg	7.88	7877.78	1886.78	104.78	153.49	161.84	207.67	18.39	776.56	206.74	362.17	44.54
range	0.96	27700.00	1954.00	113.00	183.40	178.00	354.00	44.50	1145.32	128.00	515.00	163.83
SD	0.38	11254.63	692.91	36.90	60.39	62.44	115.63	15.66	377.09	48.10	196.34	62.29

Concentration of ions and TDS in mg/l); TDS-Total Dissolved Salts; min—minimum; max—maximum; avg—average; SD—standard deviation

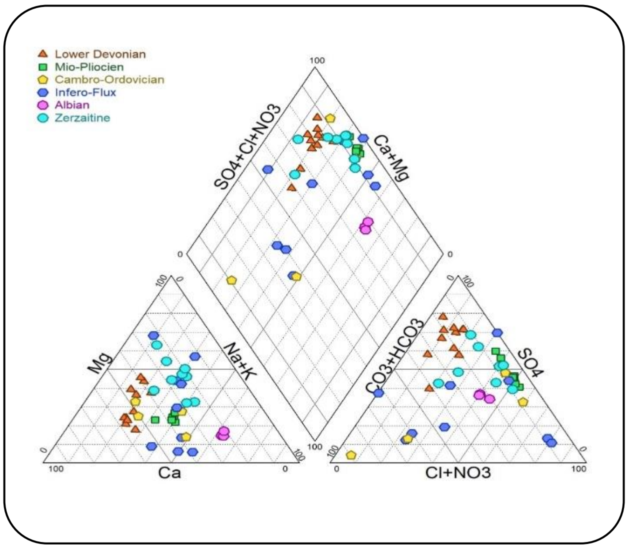

Fig. 4: Piper diagram for ILLIZI town hydrogeochemical facies.

the factor is the depth of wells that started from few meters.

We propose the examination of similar researches in other zones of Algeria and other parameters of safe water cited in the Algerian guidelines that are not studied in this paper.

Suitability of groundwater for irrigation purposes

The quality of groundwater was assessed by comparison with guidelines established for livestock and irrigation. The salinity and sodicity are considered as the principal elements in the judgment of irrigation water [36]. Table 2 summarized the results of analysis and the deferent parameters determined, with a key statistical attribute.

Groundwater intended for irrigation has an impact on both plants and soil, therefore, it is necessary to know their quality. Changes in soil permeability, soil structure, and ventilation may be due to the high salt content in the groundwater. Drainage is a factor in crop growth. As long as there is good drainage, crop growth will be good, and crop growth will be poor if there is poor drainage. To assess the suitability of groundwater use in irrigation, it is necessary to identify the various characteristics of irrigation water, for this aim, the ratio of sodium absorption (SAR), permeability index (PI), Kelly Index (KI), Sodium Solubility Percentage (SSP or N%), Residual Sodium Carbonate (RSC) and Magnesium Hazards (MH) were calculated and interpreted.

Permeability Index (PI): From the important physical properties of soils, we find Porosity and permeability, the permeability is defined as the ability of the soil to transmit water and air. The long-term applications of irrigation water affected soil permeability as it is influenced by the groundwater which contains ions, such as Na^+, Ca^{2+}, Mg^{2+}, and HCO_3^- the content of the soil [37,38].

Doneen (1964)[39] suggests a method of classification of irrigation water based on the Permeability Index (PI). The expression of PI is given by the following formula.

$$PI = \frac{\left(Na^+ + \sqrt{HCO_3^-}\right)100}{Ca^{2+} + Mg^{2+} + Na^+}$$

Where concentrations are given in meq/l.

PI values >75, 25–75, and < 25 which fall in class I (safe), class II (marginally safe), and class III (unsafe), respectively, based on the Doneen method all the groundwater samples from the six studied layers fall in the safe and marginally safe classes.

Kelly Index (KI): describe the presence of Na^+ in the water according to the presence of Ca^{2+} and Mg^{2+} and calculated by the following formula of *Kelly* (1963).

$$KI = \frac{Na^+}{Ca^{2+} + Mg^{2+}}$$

Where all concentration in meq/L.

Values less than 1 reveals the suitability of water for irrigation. In this study, we found that the Albian layer and Ifri well from the Infero Flux layer exceed 1, which indicating groundwater is unsuitable for irrigation.

Based on *Wilcox* (1955) [29,40], we find that Lower Devonian, Infero Flux, and the Cambro Ordovician layers samples are situating in excellent to good and good to the permissible category for irrigation uses according to the water quality diagram (Fig. 5). in the other hand the Albian layer samples are considered as permissible to doubtful. While the Mio-Pliocene and Zaraitine layers fell in the doubtful to unsuitable and unsuitable category except the wells Z8 and Z9 where they situate in good to permissible category.

The sodium percentage (Na %) is calculated using the formula of *Todd* (1995) [41] given below:

$$SSP(Na\%) = \frac{\left(Na^+ + K^+\right)100}{Ca^{2+} + Mg^{2+} + Na^+ + K^+}$$

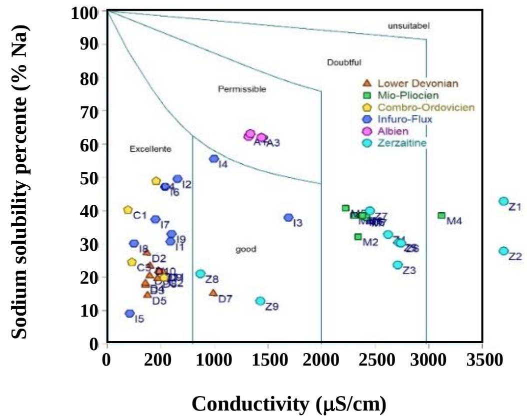

Fig. 5: Wilcox diagram for suitability of water for irrigation.

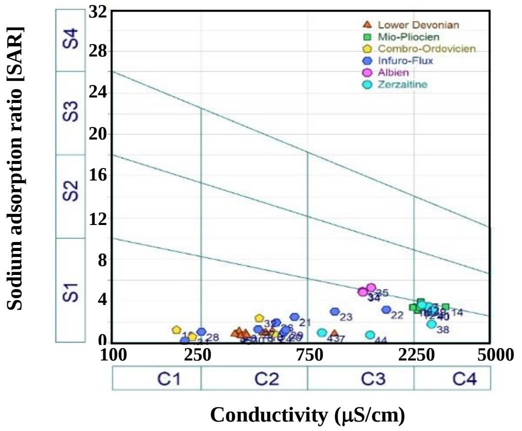

Fig. 6: USSL salinity hazard diagram for classification of water for irrigation.

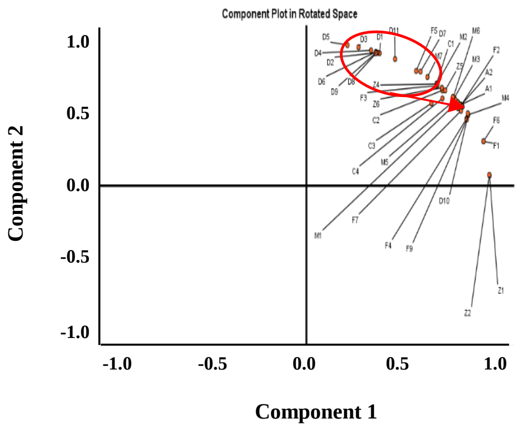

Fig. 7: Projections of the groundwater sources from the six studied layers in respect to the first two factors (PCA).

USSL diagram (Fig. 7) used to plot SAR vs EC values of our samples, where SAR is calculated using the formula given below [42].

$$SAR = Na^{+} \Big/ \sqrt{Ca^{2+} + Mg^{2+} \big/ 2}$$

Where all concentration in meq/L

From USSL diagram we find that samples of the deferent layers fall in C1-S1 (low salinity with low sodium), C2-S1 (medium salinity with low sodium), C3-S1(high salinity with low sodium), C3-S2 (high salinity with medium sodium), and C4-S1(very high salinity with low sodium) category. These groundwater samples show low to very high salinity hazards with low to medium alkali hazards. Based on the USSL diagram, the groundwater samples are satisfactory for irrigation use in all soil types.

Eaton (1950) [19] suggested that Residual Sodium Carbonate (RSC) is defined by the formula:

$$RSC = \left(HCO_3^- + CO_3^-\right) - \left(Ca^{2+} + Mg^{2+}\right)$$

is a good index of the sodicity hazard of irrigation water. The anions HCO_3^- and CO_3^- in the irrigation water tend to precipitate calcium and magnesium ions in the soil resulting in an increase in the proportion of the sodium ions. For this reason, RSC was considered to be indicative of the sodicity hazard of water. Wilcox (1958) concluded that water with more than 2.5 mmol (+)/1 of RSC is not suitable for irrigation. Water containing 1.25 to 2.5 mmol (+)/1 was considered marginal and that with less than 1.25 mmol (+)/1 is probably safe.

All the analyzed samples from the deferent six layers fall in the “probably safe” category.

The presence of magnesium in high concentrations in irrigation water negatively affects the soil quality by converting it to alkaline soils, which leads to a decrease in the yield of agricultural crops [45].

In 1964, *Szabolcs* [46] proposed an indicator called MH to determine whether water samples were suitable for use in irrigation.

$$MH = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} 100$$

The MH ›50 means that water is unsafe for irrigation use, whereas ‹ 50 suggests that water is safe for irrigation uses. As per this index, all the water samples of Mio Pliocene, Cambro Ordovician, and Albian samples fall

Table 3: irrigation water indices.

	SAR	PI	SSP	KI	RSC	MH
Lower Devonian						
max	1.56	61.40	27.14	0.30	-1.63	54.11
min	0.94	23.43	14.51	0.13	-11.3	24.43
mean	1.27	38.55	20.04	0.22	-7.00	38.52
range	0.62	37.98	12.63	0.17	9.69	29.67
SD	0.20	11.16	3.67	0.05	2.60	11.14
Mio-Pliocene						
max	5.54	43.94	40.55	0.61	-13.8	43.5
min	4.39	35.45	31.94	0.44	-23	34.12
mean	4.87	42.02	37.75	0.57	-17.1	38.68
range	1.15	8.50	8.61	0.16	9.16	9.41
SD	0.32	2.79	2.49	0.05	3.48	2.83
The Infero-Flux (Alluvial) of Oued Djanet						
max	4.47	105.12	55.44	1.20	0.24	82.36
min	0.25	37.79	9.07	0.09	-13.8	12.26
mean	2.39	67.11	36.59	0.61	-2.8	44.09
range	4.23	67.33	46.37	1.12	14.02	70.10
SD	1.42	24.66	13.62	0.34	4.28	28.17
Cambro-Ordovician						
max	3.26	117.44	48.80	0.93	0.46	46.46
min	0.79	26.11	19.68	0.23	-6.19	27.42
mean	1.75	74.42	33.28	0.52	-1.72	37.06
range	2.47	91.33	29.12	0.69	6.65	19.04
SD	1.08	44.09	13.54	0.33	3.11	8.43
CI Albian						
Max	7.47	85.23	62.96	1.61	-1.91	44.62
min	6.81	83.91	61.83	1.48	-2.24	39.22
mean	7.07	84.42	62.30	1.54	-2.09	41.09
range	0.66	1.31	1.13	0.12	0.33	5.40
SD	0.35	0.71	0.59	0.06	0.17	3.06
CI Zaraitine (Taouratin Series)						
max	6.95	57.25	42.64	0.71	-3.69	72.44
min	1.04	34.46	12.70	0.14	-25.4	51.07
mean	3.79	42.04	28.91	0.41	-17.9	63.82
range	5.91	22.79	29.94	0.57	21.65	21.37
SD	1.89	8.16	9.23	0.18	7.49	8.18

under the safe category, whereas for Lower Devonian and Infero Flux samples the majority of samples fall under the safe category, only a few samples fall in the unsafe category, on the other hand, all the samples of Zaraitine layer fall under unsafe for agriculture use.

After evaluating the groundwater samples quality of the studied layers, and in order to verify the results obtained, we have compared our finding with a set of analyzes conducted by the "Directorate of Water Resources ILLIZI" in the years 2000 and 2002, through Fig. 8 we find that in the Lower Devonian and Mio Pliocene layers, there is some similarity between the old results and our finding, with a noticeable increase in the sulphate concentration in Lower Devonian wells caused by the presence of gypsum in the geological composition of the region. The Cambro-Ordovician layer and according to the results of the comparison, there was an increase in the concentration of nitrates. The reason for this increase is the agricultural activity known in the Djanet region. Attention is also drawn to the high level of chlorine in groundwater with a slight increase in the amount of sodium due to the continuous dissolution of both elements. Concerning the Albian layer, we noticed a decrease in the concentration of almost all elements. This is due to the nature of the layer (captive layer), which makes the stock of groundwaters in this layer non-renewable.

Principal Component Analysis (PCA)

The variety of studied layers push us to make a comparison between their hydro-chemical characteristics, PCA is considered as one of the useful methods to make a comparison between a large number of variables by explaining the same amount of variance with reducing the number of variables (principal component).

The new variables generated have no relation to each other and they appear in a perpendicular way.

In our study, the results show that the first factor (all analyzed variables) explains 89.68% of the total variability, and the second factor accounts only for 7.90%. Through the ACP we concluded that the wells close to each other located in the same space are collected, and this is evident in the wells of the Devonian layer, where we find that the well D10 (Fadnoun) is located far from the rest wells of the same layer. Also, we notice the separation of the wells of the Infero Flux, this is due to the difference in the depths of the wells, which gives each well different chemical property according to the layers which the water passes through.

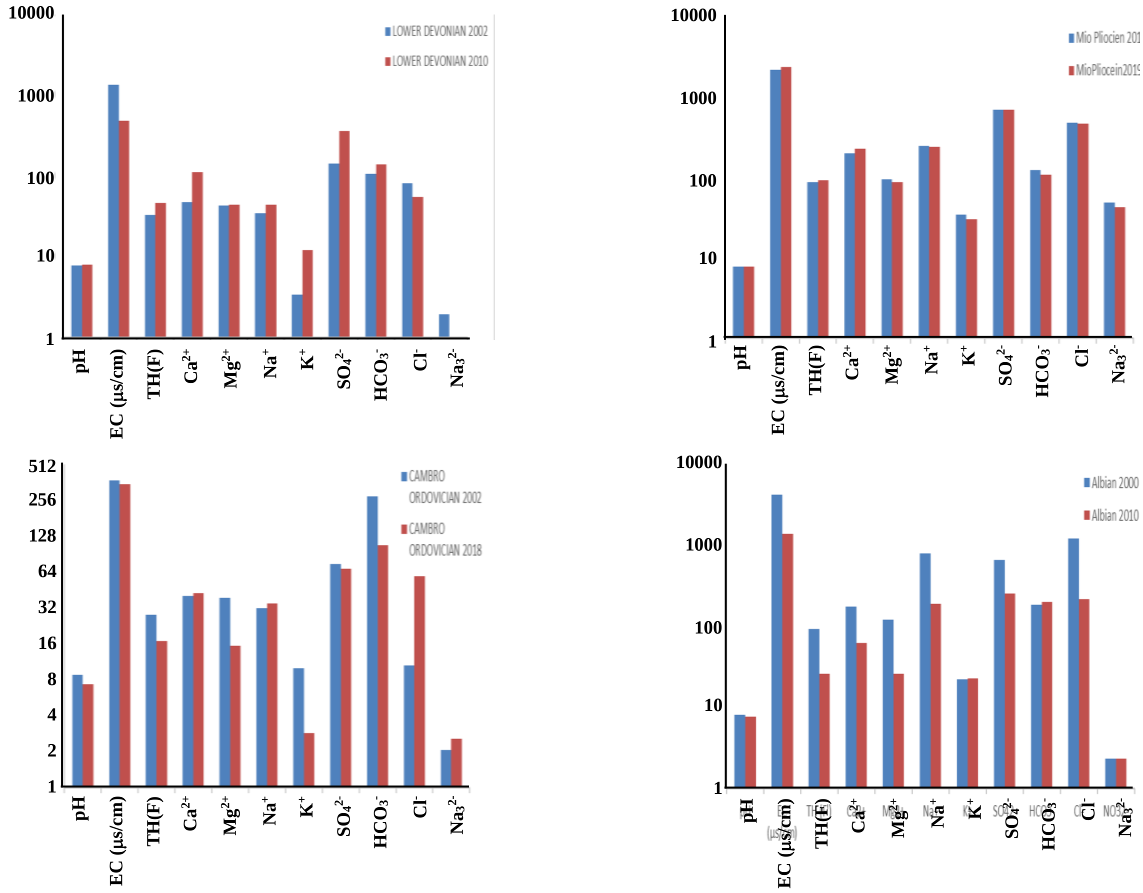

Fig. 8: Statistical comparison between hydrochemical analyzes from different years

From the analysis of the main component, we can say that the hydrochemical quality of groundwater changes in two directions, the first horizontal, here we mean the change in geographical location, and the second vertical (perpendicular) as seen in the Infero Flux wells, where the depths of wells control the main characteristics of groundwater quality.

Geospatial evolution of groundwater quality

Fourteen (14) maps for ILLZI town and Djanet town (Fig.9 a,b) were gridded using GIS software represent seven hydro-chemical parameters (SAR, TH, pH, NO_3^-, KI, EC, and PI) for the aim of creating corresponding geospatial distribution models (Fig. 10) (Fig. 11). This part of our study permits geospatial analysis of groundwater quality and detects suitable sub-areas for irrigation. Illizi town has very hard groundwater (TH > 50 F°) with a maximum value up to 65 F° in the northwest and southeast parts of the area (Fig. 8). From the probable sequences of high hardness values the scaling of contact surfaces, problems in irrigation lines system, pipes, and electrical appliances [36,43]. According to the W.H.O. guidelines [35], the SAR, SSP

(or %Na) and PI values (Table 3) of groundwaters sampled in Illizi town confirm that the D/I aquifer is suitable for irrigation purposes. NO_3^- values in groundwater vary approximately from 0.94 mg/L to 1.56 mg/l. The highest value (1.56 mg/L) was observed in the north-western part of the aquifer within an area named (Tinemri), the waste-water rejection in this zone is considered as the probable reason for the presence of nitrate in groundwater. The highest values of KI (0.56 and 0.77 meq/L) founded in zone ZHUN 102. This problem may appear when irrigation water contains relatively more sodium ions than calcium and magnesium ions (KI). For easy movement of water and air through soil ports, a good structure made by soils aggregates is dispensable, this latter is under the threat of sodium (Na^+) accumulation which may cause

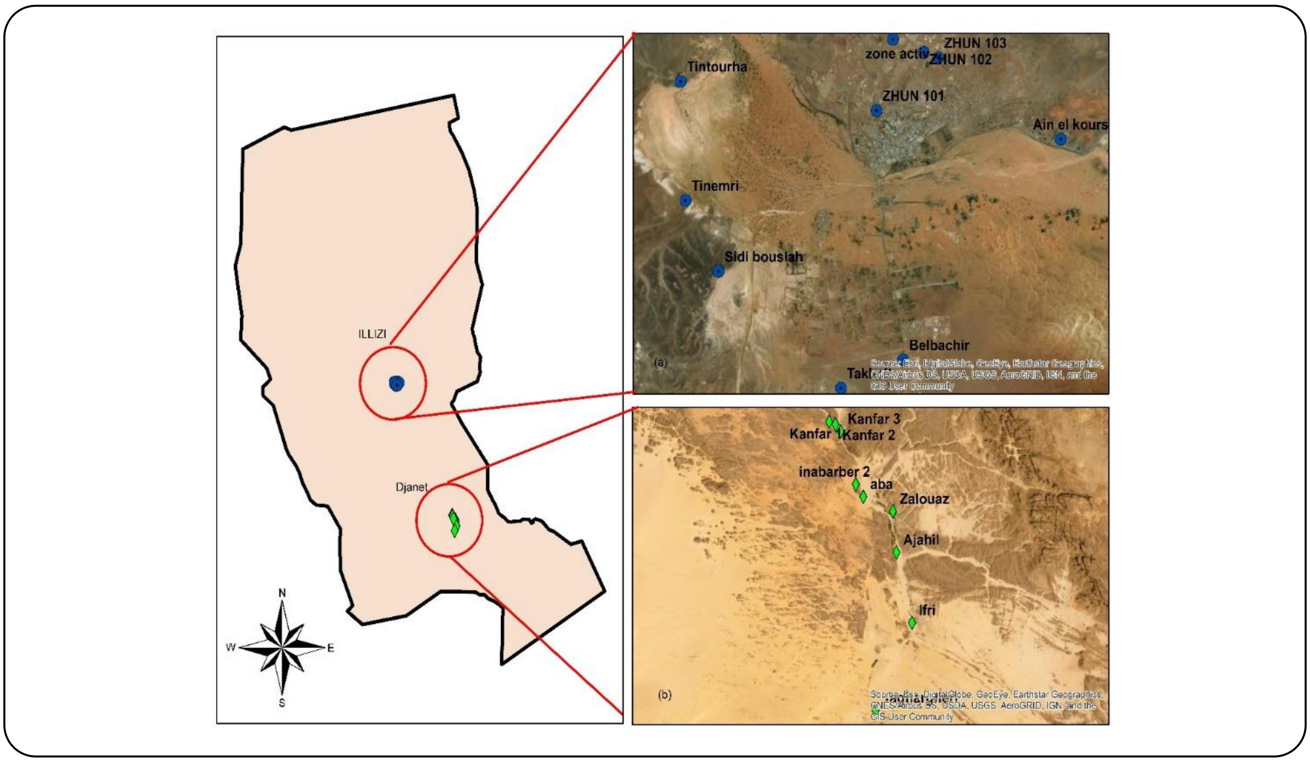

Fig. 9: Entier studied areas ILLIZI town (a), and Djanet town (b).

degradation. The Infero Flux in Djanet town characterized with a remarque variety in total hardness values with a range equal to 59 F°,

The center part of Djanet has the maximal value of total hardness (69 F°), we note also the presence of the maximal value of electroconductivity (1688 us/cm) in the same sub-area. The agriculture practices in the north part of the town cause a presence of nitrates in the groundwater, the geospatial distribution of (NO_3^-) shows the variation of nitrates between (inaberber 2) and (Kanfar 3) wells. We note the maximal values of SAR and KI values in the south-east part of Djanet with values equal to 4.47 meq/l and 1.2 respectively.

Referring to the WHO standards and the spatial distribution of hydro-chemical parameters (Fig. 10) and (Fig. 11), the south-eastern part of Illizi town and the western part of Djanet town are considered as the best sub-areas for agriculture practice using Lower Devonian and Infero Flux groundwaters respectively.

CONCLUSIONS

This study is a common combination between physical and chemical analysis and geospatial distribution of groundwater samples in Illizi county using different software and GIS techniques. The results show that the hydrochemical facies of groundwater the six studied layers in Illizi county is as follow: Cl-_SO42-_Ca2+_Mg2+ for the Lower Devonian (illizi) , Cl^-_$SO4^{2-}$–Ca^{2+}–Mg^{2+} for the Zaraitine (In Amenas), Cl^-_$SO4^{2-}$–Ca^{2+}–Mg^{2+} for the Mio-Pliocene (El Merk), Cl^-_$SO4^{2-}$–Ca^{2+}–Mg^{2+} for 50% of Cambro Ordovician (Djanet), Cl-_$SO4^{2-}$–Ca^{2+}–Mg^{2+} in 55% of Infero-Flux (Djanet) wells, and Cl-_Na+_K+ in the Albian layer (Debdab).

Groundwater resources in the studied layers from different regions are controlled by many factors (physical, chemical) Where do we find her contribution lies in the human activity, bedrock geology and hydrogeological setting, and depth of the layer groundwater.

The suitability of groundwater quality for drinking water purposes is evaluated based on comparison with the standard guideline values as recommended by the Algerian standards and the World Health Organisation (W.H.O.) [35]. The comparison shows that the Concentrations of all the measured parameters are suitable for domestique use with regard to inorganic pollutants, except in Zaraitine layer where we find that all of Ca^{2+}, Mg^{2+}, Na+, Cl- and NO_3^- exceed the maximal acceptable value.

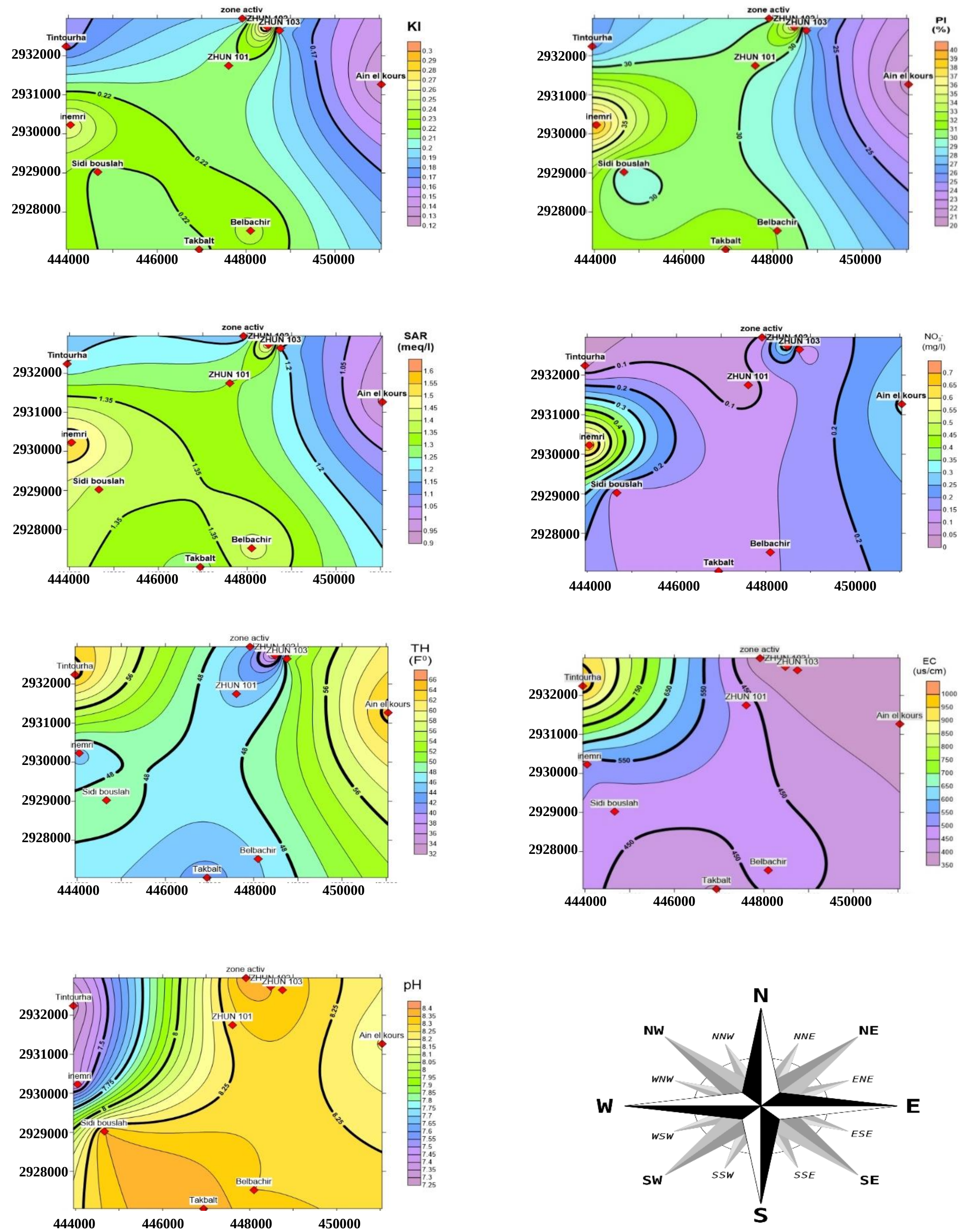

Fig. 10: Geospatial distribution of indices and parameters analyzed in ILLIZI (lower Devonian layer.

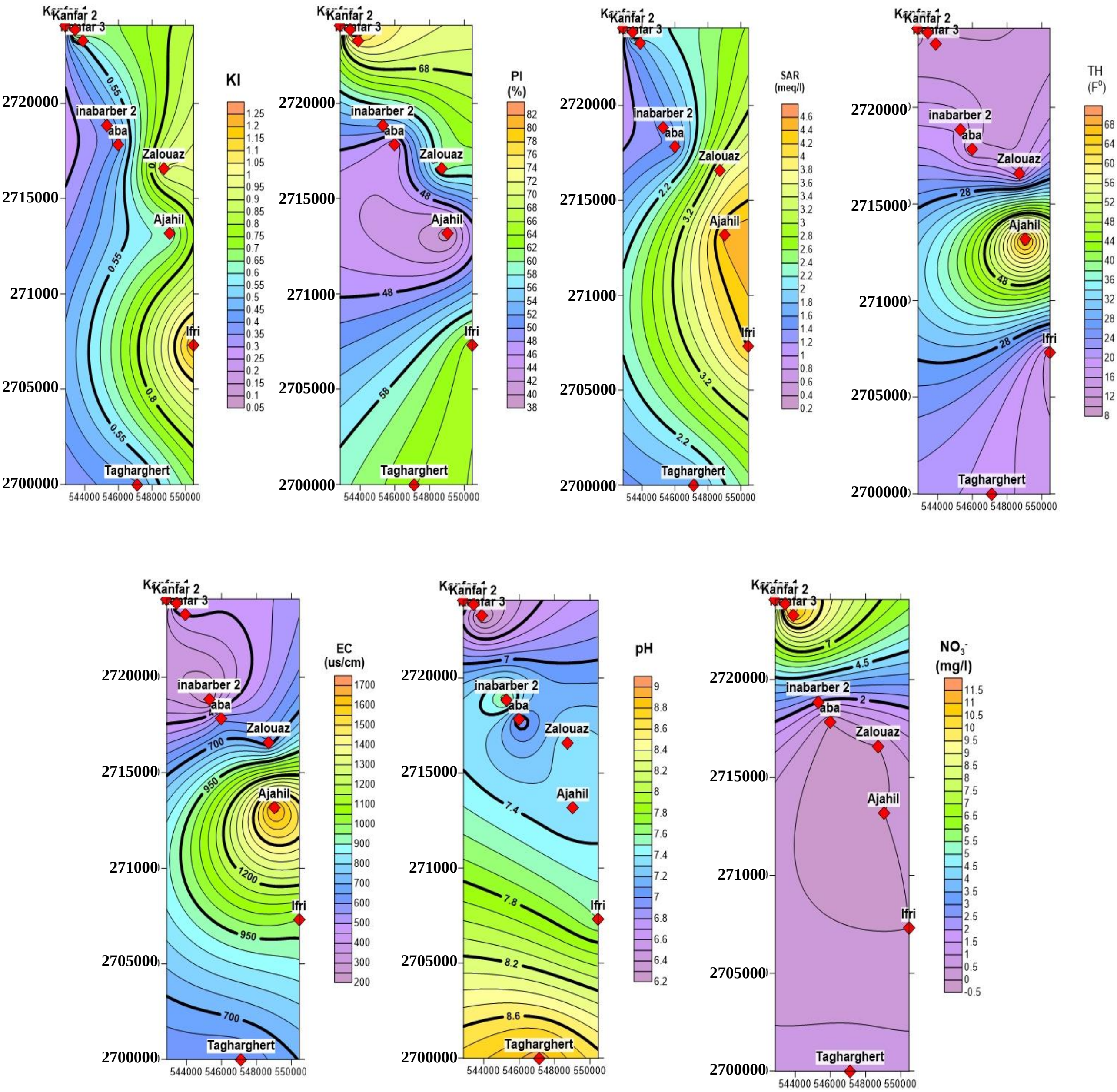

Fig. 11: Geospatial distribution of indices and parameters analyzed in Djanet (Infero Flux layer).

The suitability of groundwater for irrigation is evaluated based on permeability index (PI), Kelly Index (KI), Solubility Sodium Percent (Na%), and Sodium Absorption Ratio (SAR). Based on Solubility Sodium Percent, samples of the Cambro Ordovician classified as the best waters for irrigation, while we find that the lower Devonian and the Infero Flux samples lie in excellent and good categories, in the other hand the waters of Albian layer considered as permissible for irrigation, the Mio-Pliocene, and Zaraitine layers samples fall in doubtful and unsuitable for irrigation. Based on the USSL diagram (SAR), All the groundwater samples are satisfactory for irrigation use in all soil types. Based on Kelly index (KI) we found that all of lower Devonian, Mio-Pliocene, Infero Flux, Cambro Ordovician, and Zaraitine layer samples have suitable waters for irrigation, while Albian groundwaters and "Ifri" well (Infero Flux) considered as unsuitable with a KI value exceed 1. the Doneen diagram shows that all samples from deferent layers are suitable for irrigation in almost types of soil.

Principal Component Analysis (PCA) showed that all analyzed variables have explained 89.68% of the total variability. Another factor (geographical distribution) accounts only for 7.90%. In the case of comparison with lower Devonian wells in ILLIZI town and lower Devonian well in Fadnoun town in groundwater quality, we confirmed that the local environmental conditions are a more important factor for groundwater quality than geographical distribution. The geospatial analyses show that the south-eastern part of Illizi town and the western part in Djanet town are the best sub-areas for agriculture practice using lower Devonian and Infero Flux groundwaters respectively.

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