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Assessment of Water Quality Index for the Groundwater in the Upper Cheliff Plain, Algeria

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ABSTRACT

Assessment of groundwater suitability for drinking and agricultural purposes was carried out in the plain of upper Cheliff. The study area covers an area of 375 km² and lies in a semiarid climate. Groundwater is the major source for domestic and agricultural activity in this area. Groundwater samples were collected from 19 wells during dry and wet periods in 2012, and they were analyzed for major cations and anions and compared with drinking and irrigation specification standards. The concentration of the majority of chemical constituents exceeds the standards of WHO as a result of various sources of pollution. It indicates the dominance of groundwater types: Ca-Mg-Cl, and Ca-Mg-HCO_3. Suitability of groundwater for drinking was evaluated based on the water quality index; it shows more than 60% of samples have very poor quality for dry and wet periods, which means water is severely contaminated and unsuitable for drinking purpose. In terms of the irrigation usage, generally groundwater is suitable for both periods in the major part of the plain. The Mineralization processes in this area is determined by the lithology of the aquifer (exchange water-rock), by anthropogenic factors (discharges of urban sewage, use of fertilizers) and also by evaporation (semi-arid climate).

INTRODUCTION

Groundwater in the arid and semi-arid regions plays an important role as freshwater; it is the major source for different uses such as domestic, agricultural and industrial purposes. So, the groundwater quality needs to be given greater attention in these areas. It is estimated that approximately one third of the world's population uses groundwater for drinking (Nickson et al. 2005). The groundwater quality is influenced by diverse natural and anthropogenic activities such as local climate, geological factors, and agricultural practices. Once the groundwater is contaminated, its quality cannot be restored by stopping the pollutants from the source. The chemical characteristics of groundwater play an important role in assessing the water quality. Geochemical studies of groundwater provide a better understanding of possible changes in quality (Alexakis 2011; Ramesh and Elango 2012). In Algeria and in other parts of the world, numerous studies have been carried out to assess the geochemical characteristics of groundwater (Touhari et al. 2015; Bouderbala et al. 2016).

The groundwater resources in northern Algeria are overexploited up to more than 80%. It is noted that rainfall in northern Algeria has decreased during the last three decades by nearly 20% compared to five decades earlier. About 70% of drinking and irrigation waters in the study area is from groundwater resources. However, this water resource is facing problems, including quality hazard, essentially due to the exposure to pollution from the intensive use of fertilizers in agriculture and uncontrolled urban discharges. It makes the groundwater unfit for human consumption.

The aim of the present study is to assess suitability of groundwater for drinking and irrigation proposes in the upper Cheliff plain based on computed water quality index values. The assessment of groundwater quality has become a necessary and important task for the present and future groundwater quality management.

STUDY AREA

The upper Cheliff plain is located approximately 120 km southwest of the capital Algiers, between 36°10' and 36°20' north latitude and 02°00' and 02°25' east longitude and covers an area of 375 km².

The plain lies between the massif of Zaccar in the north and the Ouarsenis chain in the south.

The study area is characterized by a Mediterranean semi-arid climate, with hot dry summer and cold rainy winter. The annual average temperature for the period of 1980-2014 is 19 °C, and the precipitation average for the same period is about 400 mm. The estimation of the real annual evapotranspiration by Thornthwaite method gives a value of 328 mm, while runoff estimated by Tixeront-Berkaloff method gives a value of 40 mm, however the infiltration is about 32 mm (Boukendil and Aichaoui, 2016).

The hydrographic network of the study area is extremely dense. The most significant wadis are the main Cheliff wadi and its tributaries like Deurdeur, Harreza, Boutane, Erraihane, Telbanet, and Massine wadis. Three dams were built on the periphery of the upper Cheliff plain: Ghrib, Harreza and Derdeur. Those dams and the groundwater of the plain contribute to the irrigation of the agricultural plain with more than 20.000 ha irrigated.

The large part of the plain is used for vegetables and tree crops and the other parts for cereals.

The irrigation is ensured by private drillings and by a pressure networks supplied by dams.

The groundwater of upper Cheliff plain is used for drinking, irrigation and industrial purposes.

GEOLOGICAL FRAMEWORK

The upper Cheliff elongated in an E-W direction within the Tellian Atlas. The stratigraphical succession in the study area from the older to recent formations is as follows (Fig. 1):

- The primary formation is observed in Zaccar and Doui massifs, and comprises of alternate black schist, clays and quartzites;
- The Triassic is characterized by massive gypsum and dolomite formations;
- The Jurassic in Zaccar massif is mainly underlain by sedimentary rocks of limestone, dolomite and other carbonate rocks. The thickness is 1000 m. In the Jurassic, Doui massif is mainly represented by dolomitic limestones;
- The Cretaceous outcrops on the lateral borders of the plain is represented by the following series:
    - A highly thick series of Neocomian schists with a thickness about 1000m;
    - A grey schists alternating with benches quartzite of Albian-Aptian, with a thickness near to 1000m;

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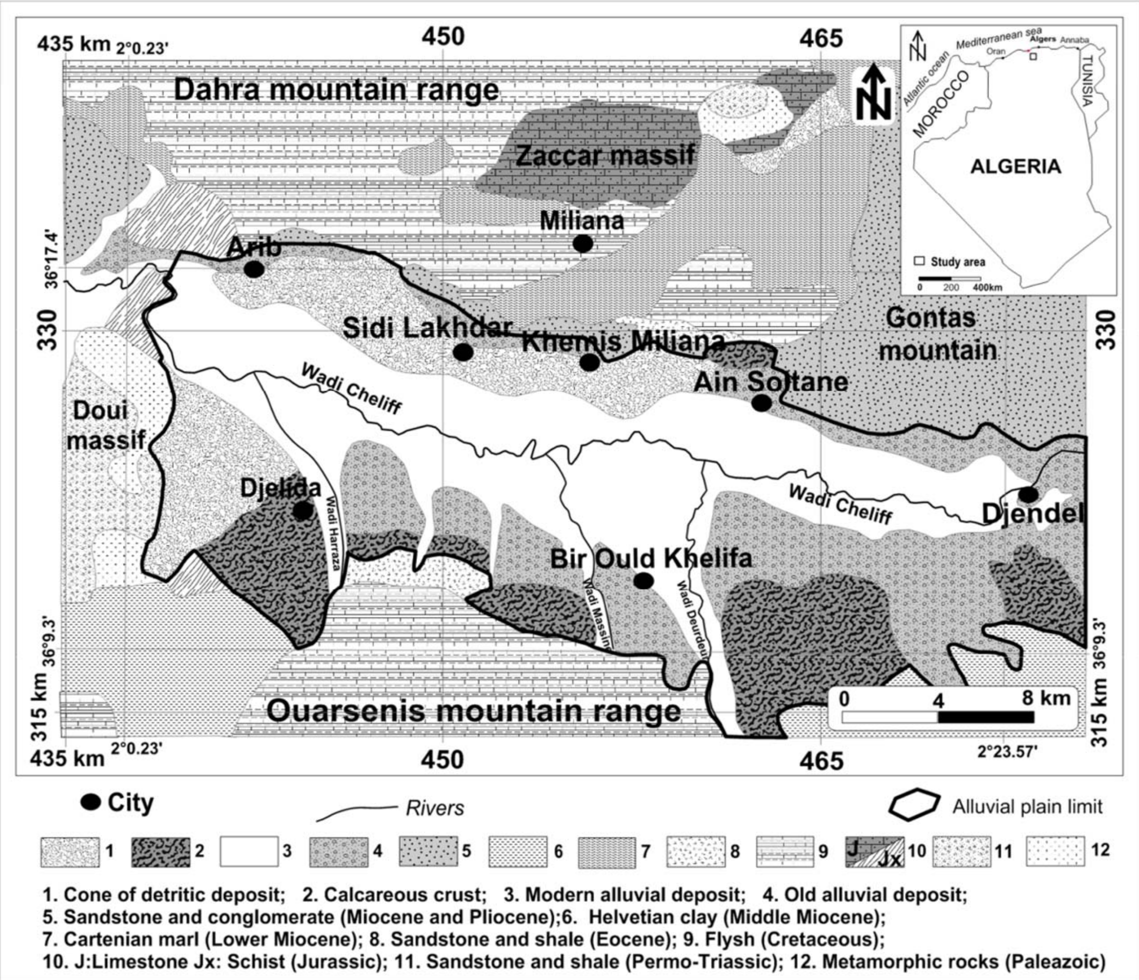

Fig.1. Geological map in the Upper Cheliff plain.

- It is intercalated also by yellowish limestone of the Senonian.
- The Miocene formation is about 300 m thick. The lower Miocene is essentially represented by quartzites, sandstones and schists. It is surmounted by Burdigalian (middle Miocene) with sandstone, conglomerates and marls. The Mio-Pliocene is formed by limestones, sandstone, conglomerates, clays and the sandstones of Gontas, with thickness of about 100m.
- Old alluvial deposits are represented by conglomerates and pebbles.
- Calcareous crust is formed by calcareous tuff which is whitish, compact or powdery. It is especially developed in the southern boundary of the Cheliff plain.
- A cone of detritic deposits (alluvial cone) are developed on the slopes at the boundary of the plain; it is formed of loose material washed down the slopes of mountains by ephemeral streams.
- The recent alluvial deposits are pebbles, gravels, clay and silt covered by an organic soil. There is also an alluvial plain observed just near the beds of Cheliff wadi.

HYDROGEOLOGICAL SETTING

The principal aquifer of the upper Cheliff plain are alluvial deposits, including pebbles, gravels, sands and clay formations; with a thickness between 50 and 150 m. It is a confined aquifer, because it is covered by silt and clay on the surface, with a thickness from 5 to 20 m. The alluvial aquifer is overlain by the Mio-Pliocene formations, as the sandstones occur in the northeast at Gontas and in the southeast in Ain-Lechiekh. In both of these two zones, there are several drilled wells with good groundwater quality.

The Mio-Pliocene formations can reach 200 m of thickness. Thus, the Mio-Plio-Quaternary formations have been considered as a multi-layer aquifer system. The hydraulic continuity between these formations, indicate continuity in some area and a separation by clay lenses in the other part of the area. In this study, only Quaternary alluvial aquifer is considered.

The groundwater of this alluvial aquifer flows from the north and south of the plain toward the centre where the main drainage axis is located which coincides with Cheliff wadi, and the main flow is from east to west.

The depth of water table varies from 5 m in the west zone (near to Djendel) to 30 m in the east zone (near to Arib and Djelida), with an average depth of 10 m in the central part of the plain.

METHODOLOGY

A total of 19 groundwater samples were collected from wells in the study area during October, 2012 (dry period) and April, 2012 (wet period). Sample bottles were cleaned by rinsing them with distilled water. The water samples were collected after pumping for 10 to 15 minutes in order to remove stagnant groundwater. Physical parameters such as pH, total dissolved solid (TDS) and electrical conductivity (EC) were measured in the field by a conductivity meter using the standard procedures. The samples were then analyzed in the laboratory of National Agency of Hydraulic Resources (NAHR). The analyzed parameters included four cations (Mg^{2+}, Ca^{2+}, Na^{+} and K^{+}) and four anions (SO_4^{2-}, Cl^{-}, HCO_3^{-} and NO_3^{-}). The samples were subjected for computation of ionic-balance-error between the total concentrations of cations and anions, for the interpretation of the chemical data. The value of the ionic-balance-error is observed to be within the acceptable limit of ±5%.

The assessment of suitability for drinking and irrigation purpose was evaluated by water quality index (WQI). The calculations of WQI are based on the standards suggested for uses, where ten groundwater quality parameters (pH, EC, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^-, Cl^-, SO_4^{2-}, NO_3^-) are considered. In the first step, weights (*wi*) are assigned to measured parameters based on their relative importance in the overall water quality for drinking purposes and possible health effects (Table 1). The maximum weight of 5 has been assigned to parameters like EC, Mg^{2+}, Na^+, Cl^- , NO_3^- and SO_4^{2-} due to their importance in water quality assessments. A minimum weight of 1 has been given to HCO_3^- since it plays a comparatively less significant role in water quality assessment (Vasanthavigar et al., 2010; Gibrilla et al., 2011; Srinivasamoorthy et al., 2011). However, weights (*wi*) are assigned to measured parameters based on their relative importance in the overall water quality of irrigation purposes and possible soils and plants effects. The maximum weight of 5 has been assigned to parameters like EC, Na^+, Ca^{2+}, Mg^{2+}, Cl^- , and SO_4^{2-} due to their importance in water quality assessments. A medium weight of 3 has been given to pH and K^+, and minimum weight of 2 has been given to NO_3^- and HCO_3^- (Table 1).

In the second step relative weights (*Rwi*) are calculated using the following equation.

$$Rwi = wi/\Sigma_{i=1}^{n} wi$$

Where *Rwi* is the relative weight, *wi* is the weight of each parameter, *n* is the number of parameters.

In the third step, a quality rating scale (*qi*) for each parameter is assigned by dividing its concentration in each water sample by its respective standard according to the guidelines laid down in the WHO (2008) and FAO (Ayers & Westcot, 1985)

$$qi = (Ci/Si)\ x\ 100$$

Where *qi* is the quality rating, *Ci* is the concentration of each chemical parameter in each water sample in mg/L. *Si* is the concentration permissible of water for irrigation, for each chemical parameter in milligrams per liter according to the guidelines.

For computing the WQI, the following equation is used:

$$WQI = \Sigma\ Rwi \times qi$$

Water quality types were determined based on WQI. They are usually classified into five categories (Table 2).

The spatial distribution maps for values of WQI were prepared using inverse distance weighted (IDW) interpolation technique.

Evaluation of Water Quality for Drinking Purpose

The quality of drinking-water is a powerful environmental determinant of health. Assurance of drinking-water safety is a foundation for the prevention and control of waterborne diseases. Drinking-water supplies that cause greatest risks to public health should be identified (Mishra and Jha, 2014). The groundwater index is used for the evaluation of the quality of drinking water. It is defined as a technique of rating that provides the composite influence of individual water quality parameter on the overall quality of water for drinking; it transforms the entire groundwater quality data for each well into a single number called index (Sadat-Noori et al. 2014). The water quality index for drinking purposes (WQID) has been widely used to characterize the usability of water resources for domestic purposes. Water Quality Index is an important parameter for determining groundwater quality and its suitability for drinking purposes (Avvannavar and Shrihari, 2008; Yidana et al. 2010; Varol and Davraz, 2015).

Table 1. The weight (*wi*) and relative weight (*Wi*) of each chemical parameter.

Parameter	Drinking water			Irrigation water		
	WHO (2008)	Weight (*wi*)	Relative weight (*Wi*)	Ayers & Westcot (1985)	Weight (*wi*)	Relative weight (*Wi*)
EC (µS/cm)	1500	5	0,135	2250	5	0,125
pH	8,5	3	0,081	8,5	3	0,075
Cl^- (mg/l)	250	5	0,135	350	5	0,125
SO_4^{2-} (mg/l)	200	5	0,135	250	5	0,125
HCO_3^- (mg/l)	300	1	0,027	400	2	0,050
Na^+ (mg/l)	150	5	0,135	200	5	0,125
Ca^{2+} (mg/l)	100	2	0,054	200	5	0,125
Mg^{2+} (mg/l)	50	5	0,135	100	5	0,125
NO_3^- (mg/l)	50	5	0,135	50	2	0,050
K^+ (mg/l)	12	1	0,027	10	3	0,075

Table 2. The classes proposed for water quality index for drinking (WQID) (Sahu and Sikdar 2008).

Class	Range of WQI for drinking or irrigation purposes	Type of water
1	< 50	Excellent water
2	50,1 – 100	Good water
3	100,1 – 150	Permissible water
4	150,1 – 200	Doubtful
5	> 200,1	Water unsuitable for drinking or irrigation uses

Water Quality for Irrigation Uses

The quality of irrigation water has a profound effect on crop growth and its productivity, and also on the soil properties (porosity and permeability).

Appropriate information is required in relation to its influence on soil texture, on the accumulation of salts, development of soil sodicity and the crop growth condition under different soil environments. Excessive salt can limit crop yield or may even prohibit crop growth. On the other hand, the presence of salt in very small amount may reduce water infiltration, which may have an impact on crop growth and yield.

So an understanding of the quality of water used for irrigation and its potential negative effects on crop growth is essential to avoid drawbacks and optimize yield.

To assess the water quality for irrigation suitability purpose, the analytical results have been evaluated in the study area: Electrical conductivity (EC), sodium percentage (Na %), sodium absorption ratio (SAR), soluble sodium percentage (SSP), residual sodium carbonate (RSC), and permeability index (PI). All the ions are expressed in (meq/l). The water quality index for irrigation (WQII) is also used to evaluate the quality of irrigation water. It is defined as a technique of rating that provides the composite influence of individual water quality parameter on the overall quality of water for drinking; it transforms the entire groundwater quality data for each well into a single number called index (Ramakrishnaiah et al., 2009; Sadat-Noori et al., 2014).

RESULTS AND DISCUSSION

Understanding the groundwater quality is very important, because it is the main factor which decides its suitability for different purposes (domestic, agricultural and industrial). The chemical composition of groundwater is result of the geochemical processes occurring due to the reaction of water and geologic materials (aquifer) through which it flows. It is also influenced by other natural and anthropogenic factors that affect the quality of groundwater.

Water Quality for Drinking Purposes

Statistics of the groundwater quality parameters for the dry period (October 2012) as also wet period (April 2012) are presented in Tables 3 and 4 respectively.

The pH of groundwater samples in the study area ranges from 7.4 to 8.3, and 7.3–8.7 for dry and wet periods respectively. It suggests that all of the samples conform to WHO (2008) standard of 6.5–9.0, it also indicates that the groundwater in this area is slightly alkaline (pH > 7.0).

During the dry period, the average of electrical conductivity (EC) is 3213 µS/cm. While in the wet period there is a slight decrease in the average of EC as 2667 µS/cm. It suggests that more than 85 % of water samples are exceeding the standard recommend value by WHO (2008) i.e., 1500 µS/cm.

Total dissolved solids (TDS) of groundwater are related to the solute load in the water. TDS of the dry period ranges from 700 to 3944 mg/L (average of 2144 mg/L), while in the wet period the concentrations ranges from 878 to 4066 mg/L (average of 2046 mg/L) (Tables 3 and 4). In both the periods, more than 90 % of the samples are above the permissible limit of 1000 mg/L. This suggests that groundwater in the study area is moderately mineralized. It depends on the lithology of the aquifer, climate conditions, and anthropogenic pollution.

- The concentrations of nitrates for the two periods indicate more than 60 % of samples exceeding the standard WHO of drinking water, this is due to the excessive use of fertilizers and pesticides in agricultural activities.
  The arboricultural and vegetable cultures have occupied the most part of the upper Cheliff plain.
- The analysis of sulphate concentrations of groundwater in this plain for the two periods show that more than 55% of wells exceed the standard recommended by WHO (200 mg/l). These high concentrations may be due to the effect of: the use of some fertilizers in agriculture, the evaporation, untreated wastewater, the dissolution of gypsum outcropping in the southern part of the study area. The high levels of sulphates can cause health hazards, particularly gastrointestinal problems.
- The excess of chlorides in groundwater of this area (over 70%) may be related to the dissolution of salt deposits, salt spreading on roads, wastewater, the return flow of water from irrigation. Each of these pollution sources can locally cause groundwater contamination.
- The most common source of calcium and magnesium in groundwater is through the erosion of rocks, such as limestone and dolomite, and minerals, such as calcite and magnesite. Very high levels of calcium and magnesium in drinking water have some negative health effects. High levels of calcium promote vascular degeneration (arteriosclerosis) and osseous degenerative (osteoarthritis). The majority of the wells in this area have high concentrations of Ca^{2+} (more than 85 %) and Mg^{2+} (more than 90%) compared to WHO standard.

The maps of water quality index for drinking (WQID) for the dry and wet periods 2012 (Figs. 2 and 3) show a little variation between them. The values of WQID for dry and wet periods ranged from 67.2 to 365.4 and from 86.23 to 341.21 respectively. Only one sample of groundwater has “good water quality” near to Arib city, five and six samples for wet and dry periods indicate “permissible water quality”, while the majority of samples (more than 60%) have “very poor quality” or “quality unsuitable for drinking purpose” in wet and dry period.

This classification of groundwater in the study area indicates a poor or very poor quality in the major part of the plain. This may be due to effective leaching of ions, effect of direct discharge of urban discharge (infiltration of pollutants present in the surface) and agricultural impact (agricultural fertilizers). Also, it is probably due to the impact of low rate of precipitation and increase of temperature (evaporation).

Water Quality for Irrigation Purposes

The suitability of groundwater for irrigation purpose in the study area was discussed by the following basic criteria: Electrical conductivity (EC), chlorides (Cl), sodium percentage (Na %), sodium absorption ratio (SAR), soluble sodium percentage (SSP), residual sodium bi-carbonate (RSC), and permeability index (PI). They are important parameters for determining the suitability of groundwater for agricultural uses.

Electrical conductivity (EC). The results of the geochemical analysis of groundwater for the period 2012 (Tables 3 and 4) indicate values of EC more than 50 % and 60 % of groundwater samples exceed 3000 µS/cm in wet and dry period respectively. The high value of EC has an impact on crop productivity and on the soil structure, because plants cannot transpire water. The amount of water transpired through a crop is directly related to yield; therefore, irrigation water with high EC reduces yield potential (Wilcox and Durum1967).

Chlorides (Cl^-). The usual toxic major ions in irrigation water are chloride and sodium (Bouderbala 2015). Chlorides are not absorbed or held back by soils, therefore, it moves readily with the soil-water, and is taken up by the crops, moves in the transpiration stream and accumulates in the leaves. If the chloride concentration in the leaves exceeds the tolerance of the crop, injury symptoms develop, such as leaf burn or drying of the leaf tissue, yellowing of leaf and spotting on the leaf. The limits for chloride toxicity for some fruit crops are given by Ayers and Westcot (1985).

In the present study, 60 % of the water samples are unsuitable for irrigation with Cl^- more than 12 meq/L in dry and wet periods (Tables 3 and 4). The high concentration may be related to the dissolution of salt deposits, road salt, fertilizers, sewage, and the flow of seepage

Table 3. Statistical summary of groundwater quality parameters during dry period 2012

	pH	EC (µS/cm)	TDS (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	Na^+ (mg/l)	K^+ (mg/l)	Cl^- (mg/l)	SO_4^{2-} (mg/l)	HCO_3^- (mg/l)	NO_3^- (mg/l)
Min.	7,4	1060	700	79,2	32,2	43,0	0,7	130	54	183	1
Max.	8,3	7000	3944	379,4	306,8	496,8	30	1405	1028	640,5	100
Mean	7,8	3213	2144	212,8	128,6	182,1	4,9	566,9	373,7	326,4	64,6
SD	0,2	1516	962	89,0	67,3	124,3	7,5	325,8	259	105	37,8

Table 4. Statistical summary of groundwater quality parameters during wet period 2012.

	pH	EC (µS/cm)	TDS (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	Na^+ (mg/l)	K^+ (mg/l)	Cl^- (mg/l)	SO_4^{2-} (mg/l)	HCO_3^- (mg/l)	NO_3^- (mg/l)
Min.	7,3	1324	878	88,9	53,3	30	1,0	85	122	244	0
Max.	8,7	6100	4066	355,6	320	395	16,7	1385	750	671	165
Mean	7,8	2972	2046	220,3	143,6	147	4,2	535,7	341,2	361,7	64,7
SD	0,3	1278	898	84,2	67,6	102,9	4,6	355,2	184,6	108	46,2

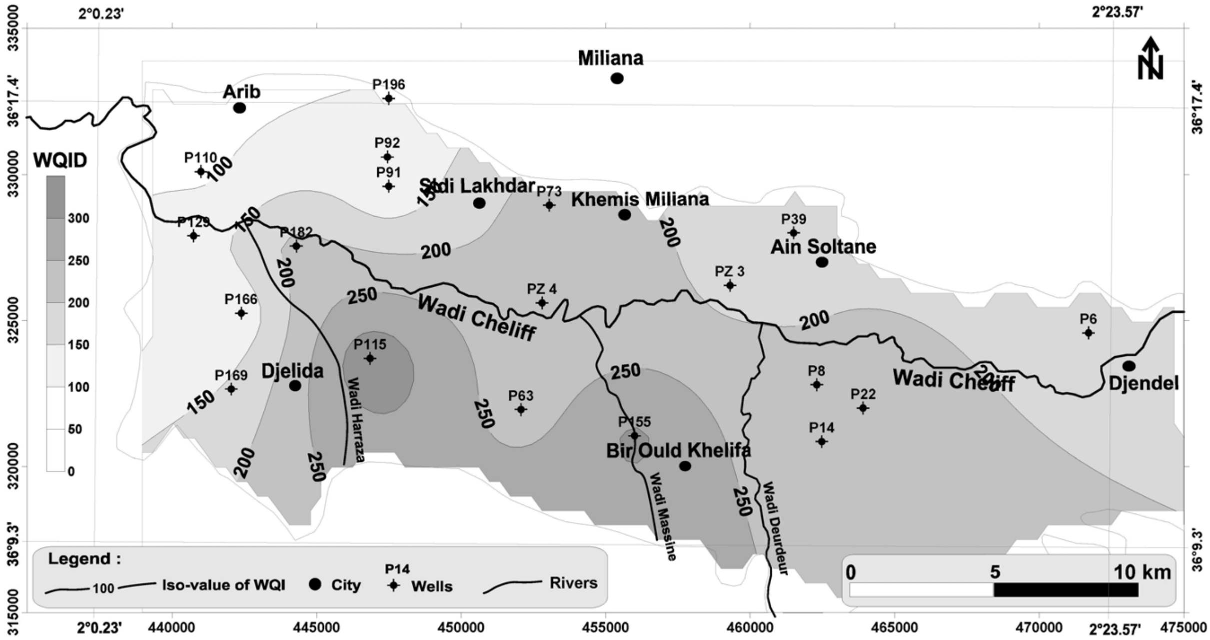

Fig.2. Water quality index for drinking purpose (wet period 2012).

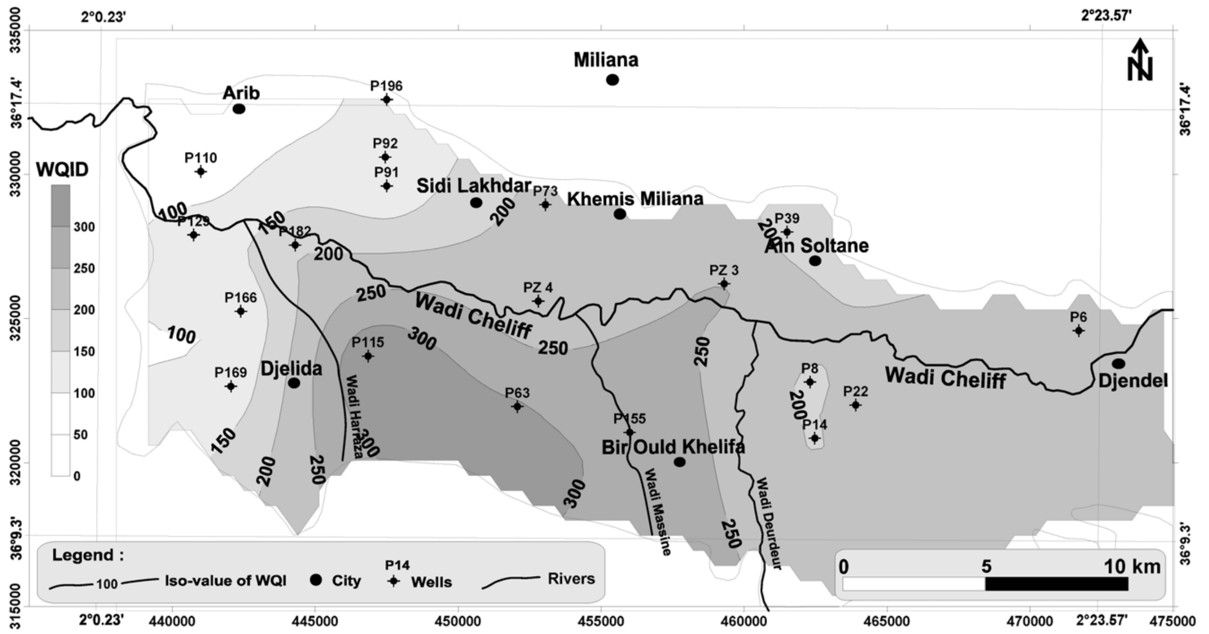

Fig.3. Water quality index for drinking purpose (dry period 2012).

water from irrigation. Each of these pollution sources can produce local groundwater contamination.

Sodium percentage (% Na). The sodium percent (%Na) called also soluble sodium percentage (SSP). It is also widely utilized for evaluating the suitability of water quality for irrigation; it is obtained by the equation:

$$\% Na = \frac{Na + K}{Ca + Mg + Na + K} \times 100$$

Groundwater always contains measurable quantities of dissolved substances, salts. The salts present in the water, besides affecting the growth of the plants directly, also affect the soil structure, and reduce its permeability and aeration, which indirectly affect the plant growth (Joshi et al., 2009). The sodium percentage in the study area varies from 10.8 to 43.8 (Tables 5 and 6). As per the world health organization, the sodium percentage of 60 is the maximum recommended limit for irrigation water. According to Wilcox classification, more than 90 % of samples have an excellent or good quality for irrigation for the two periods.

Sodium Adsorption Ratio (SAR), is calculated by the following equation:

$$SAR = \frac{Na}{\sqrt{(Ca + Mg)/2}}$$

SAR is an important parameter for determining the suitability of groundwater for irrigation because it is a measure of alkali/sodium hazard to crops. A very low SAR (less than 2) indicates no danger from sodium, low SAR (2 to 12) indicates little danger from sodium, medium hazards are indicated between 12 and 22, and high hazards are between 22 to 32 and very high hazards more than that.

Table 5. Statistical summary of criteria of suitability of water quality for irrigation (wet period 2012).

Wells	EC (µS/cm)	Cl (meq/l)	% Na	SAR	SAR_{adj}	PI	RSC	MAR	KR	WQII	Class
P129	2000	7,84	15,56	1,04	2,85	26,89	-11,50	52,94	0,18	97,40	C3S1
P166	1501	3,07	16,58	1,01	2,89	35,30	-4,28	33,06	0,20	75,50	C3S1
P115	6100	39,07	28,07	3,66	10,75	31,38	-39,87	59,70	0,39	197,78	C5S2
P8	3000	17,63	18,48	1,56	4,23	25,00	-20,31	45,15	0,22	134,71	C4S1
P155	5310	36,39	32,29	3,90	11,37	36,59	-28,99	54,24	0,47	187,52	C5S2
P14	2850	19,04	26,11	2,44	6,74	32,42	-19,81	45,15	0,35	134,02	C4S1
P39	3440	19,75	14,75	1,24	3,53	21,78	-21,50	49,69	0,17	126,01	C4S1
P63	3780	20,87	15,48	1,47	4,37	21,33	-27,62	51,69	0,18	129,97	C4S1
P91	1500	3,95	16,29	0,81	2,06	28,26	-8,20	51,86	0,16	68,15	C3S1
P92	1653	6,43	16,67	1,12	2,99	28,21	-11,02	47,28	0,20	82,65	C3S1
P110	1450	4,09	11,16	0,57	1,42	29,45	-5,75	57,51	0,12	54,88	C3S1
P169	3000	11,99	28,92	2,40	6,80	39,44	-10,65	55,94	0,40	98,19	C3S1
P182	3400	15,94	18,20	1,59	4,81	25,67	-20,29	60,02	0,21	134,46	C4S1
P196	1324	2,40	11,61	0,63	1,72	30,27	-5,35	64,00	0,13	67,85	C3S1
PZ 3	2970	12,48	24,51	2,15	6,03	32,42	-16,60	45,69	0,32	113,03	C4S1
PZ 4	3400	17,63	10,77	0,93	2,72	17,58	-24,76	48,59	0,12	116,52	C4S1
P6	2450	15,51	32,07	2,96	8,31	40,36	-13,88	46,36	0,47	120,63	C4S1
P22	4080	22,00	13,14	1,16	3,32	18,86	-26,39	56,84	0,15	125,61	C4S1
P73	3800	17,77	16,98	1,58	4,86	24,12	-23,42	49,69	0,20	131,74	C4S1

Table 6. Statistical summary of criteria of suitability of water quality for irrigation (dry period 2012)

Wells	EC (µS/cm)	Cl (meq/l)	% Na	SAR	SAR_{adj}	PI	RSC	MAR	KR	WQII	Class
P129	2070	8,01	24,12	1,63	4,36	35,32	-9,26	46,91	0,30	97,64	C3S1
P166	1572	6,69	25,03	1,55	3,96	41,05	-5,39	24,30	0,33	67,34	C3S1
P115	7000	39,63	29,24	3,83	11,79	33,12	-37,40	58,19	0,41	208,75	C5S2
P8	3500	16,78	21,33	1,84	5,07	28,39	-18,88	43,55	0,27	119,26	C4S1
P155	5020	26,66	29,95	3,48	10,35	34,61	-28,29	44,27	0,42	176,40	C5S2
P14	3430	22,00	19,42	1,70	5,00	27,48	-18,73	46,49	0,24	124,55	C4S1
P39	3020	20,73	20,41	1,80	4,80	26,37	-21,32	57,20	0,26	120,20	C4S1
P63	5000	23,55	43,80	5,80	15,10	47,29	-24,74	50,44	0,78	175,27	C5S2
P91	1600	4,80	15,68	0,81	1,99	25,01	-10,37	51,93	0,15	72,06	C3S1
P92	1645	8,46	22,92	1,46	3,42	33,72	-9,23	40,38	0,30	68,74	C3S1
P110	1060	3,67	20,66	0,98	2,32	44,40	-2,50	45,41	0,26	44,65	C3S1
P169	2140	10,44	39,53	3,19	8,17	51,03	-6,75	54,86	0,65	70,83	C3S1
P182	3080	12,91	29,36	2,50	7,04	37,80	-13,17	65,31	0,40	128,42	C4S1
P196	1600	4,80	15,59	0,92	2,37	30,53	-7,57	39,70	0,18	74,62	C3S1
PZ 3	4000	18,19	29,65	3,16	8,86	36,41	-20,75	47,84	0,42	148,44	C4S2
PZ 4	4000	20,24	16,27	1,40	3,85	22,53	-22,37	47,31	0,19	120,13	C4S1
P6	3190	22,78	28,30	2,69	7,79	36,09	-16,81	52,60	0,39	133,44	C4S1
P22	4500	20,93	15,37	1,38	3,99	21,72	-24,41	55,25	0,18	122,84	C4S1
P73	4470	20,03	20,47	1,88	5,43	27,07	-21,92	48,78	0,25	130,95	C4S1

SAR can indicate the degree to which irrigation water tends to enter into cation-exchange reactions in soil. Sodium replacing adsorbed calcium and magnesium is a hazard as it causes damage to the soil structure owing to the dispersion of the clay particles and the soil becomes compact and impervious.

The values of SAR of groundwater samples in the study area range from 0.6 to 5.8. The combination of EC and SAR had also been used to determine the suitability of water for irrigation (Tables 5 and 6).

Out of 19 groundwater samples analyzed, 36.8 % fall under C3S1 class, indicating a moderate salinity hazard and low sodium water. Such waters can be used on soils with drainage. Even with adequate drainage, special management for salinity control may be required and plants with good tolerance should be selected. Crops with good salt tolerance should be selected. 52.6 % and 42.1 % of samples in wet and dry periods fall in C4S1 class showing high salinity hazard and low sodium hazard. These waters are not suitable for irrigation unless the soil is highly permeable and drainage must be adequate. Salt tolerant crops must be selected. One sample of dry period falls in C4S2 class showing high salinity hazard and medium sodium hazard. Such waters unsuitable for irrigation on fine textured soils under low leaching conditions, but can be used for irrigation on coarse textured or organic soils having good permeability.

Two samples of wet period (10.5 %) and three samples of dry period (15.8 %) fall in C5S2 class showing very high salinity hazard and medium sodium hazard, indicating unsuitability of water for irrigation.

Adjusted Sodium Adsorption Ratio (SAR_{adj}), is calculated by the following equation:

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}} x[1 + (8.4 + pHc)]$$

$pHc = (pK2 - pKc) + p\ (Ca + Mg) + pAlk$ the three terms are obtained from the table of BRGM (1977) after a previous calculation of sums

$(pK2 - pKc)$ is obtained from the sum of (Ca^{2+}+ Mg^{2+} + Na^{+}) in meq/L

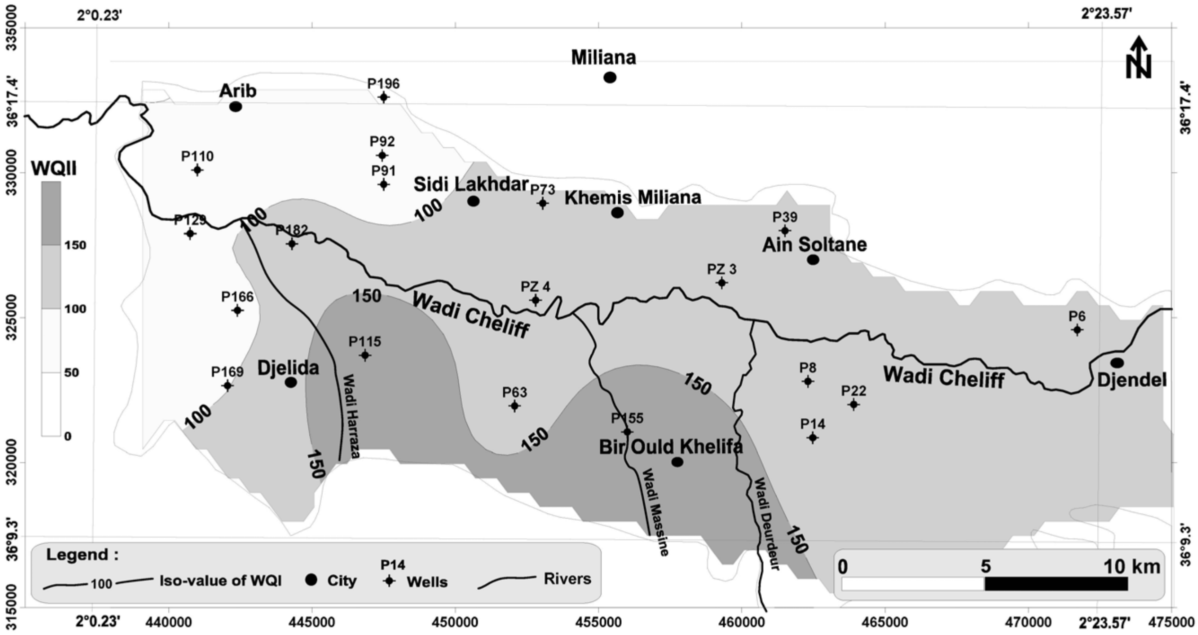

Fig.4. Water quality index of irrigation uses (wet period 2012).

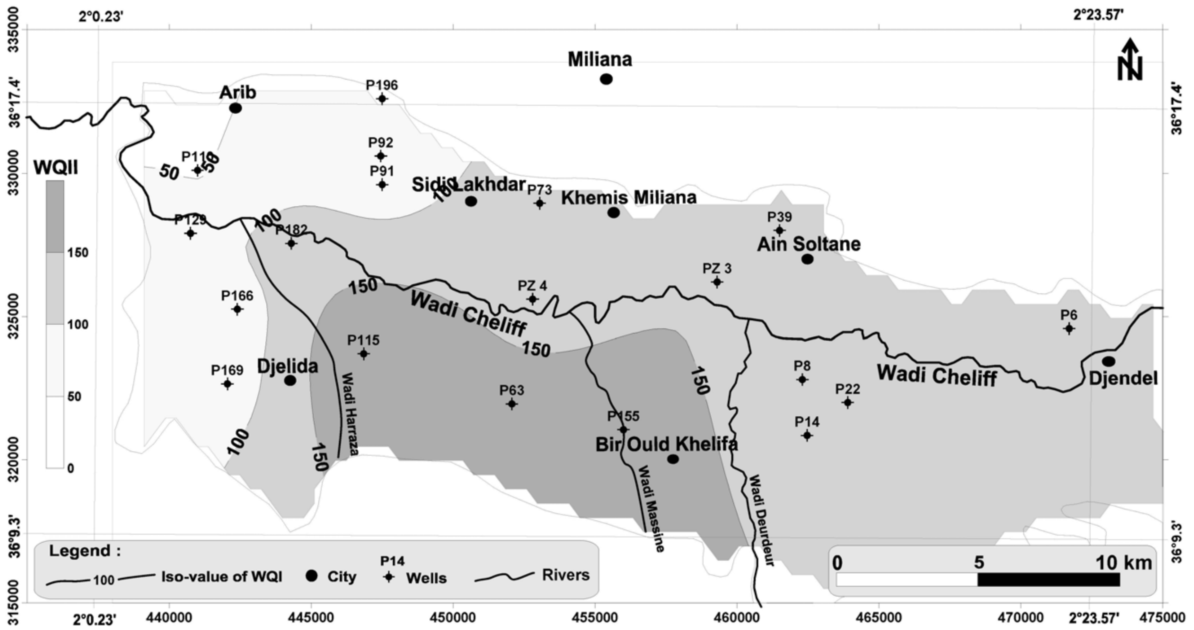

Fig.5. Water quality index of irrigation uses (dry period 2012)

p(*Ca* + *Mg*) is obtained from the sum of ($Ca^{2+} + Mg^{2+}$) in meq/L

pAlk is obtained from the sum of ($CO_3^- + HCO_3^-$) in meq/L

Because large amounts of bicarbonate in irrigation water can increase the sodium hazard in soils, the SAR shoud include an adjustment factor to account for the added effects of precipitation or dissolution of calcium in soils related to carbonate (CO_3^-) and bicarbonate (HCO_3^-) concentrations. As the calcium is precipitated by the high HCO_3^- and CO_3^-, it is easily displaced leaving sodium as the dominant cation. The solution structure can then change, causing further drainage problems (Ayers & Westcot, 1985). In the study area, the adjusted SAR shows two samples of wet period (P115 and P155) and three samples of dry period (P115, P155 and P63) have very high salinity hazard, indicating unsuitability of water for irrigation. It also shows that four samples have significant and high salinity hazard for the two periods. The others samples have low or very low salinity.

Residual Sodium Carbonate (RSC). The residual sodium carbonate (RSC) is calculated as follows:

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

The RSC is a quick test to determine if irrigation water can release free calcium and magnesium in the soil. Richard (1954) has also determined the hazardous effect of carbonate and bicarbonate on water quality in terms of residual sodium carbonate or residual sodium bicarbonate. The high bicarbonate contents in the water are due to the biological activities of plant roots; and from the oxidation of organic matter included in the soils and in the rock, and from various chemical reactions (Handa 1969; Raju, 2007). In the study area, 95% of groundwater samples have RSC values lower than 1.25 meq/l, and they can be used for irrigation without any problem (Table 5 and 6), according to criteria set by Gupta and Gupta (1987). A negative value indicates little risk of sodium accumulation due to offsetting levels of calcium and magnesium (Raju, 2007).

Permeability Index (PI). The permeability index (PI) is calculated according to the equation as:

$$PI = \frac{Na + \sqrt{HCO_3}}{Ca + Mg + Na} x\ 100$$

The soil permeability is affected by long term use of irrigation water. It is influenced by sodium, calcium, magnesium and bicarbonate contents of soil (Raju 2007). Doneen (1964) has evolved a formula, permeability index (PI) to measure the soil permeability for assessing the suitability of water for irrigation purposes. In the study area, the PI values of groundwater samples are lower than 75 (Table 5 and 6). The groundwater quality doesn't create any permeability problem.

Magnesium Adsorption Ratio (MAR). The magnesium adsorption ratio (MAR) is calculated by as follows:

$$MAR = \frac{Mg}{Mg + Ca} x\ 100$$

In ordinary cases, excess magnesium in groundwater can reduce the soil structure, which influences the yield of crops (Nagaraju et al. 2006; Arveti et al. 2011). The magnesium hazard (MAR) of irrigation water is defined by Raghunath (1987). The MAR values in this area exceeding 50 are considered harmful and unsuitable for irrigation use.

The computed values of groundwater samples in this area are between 24.3 and 65.3 (Table 5 and 6). In the present area, more than 45 % of the groundwater samples exceeds the limit (MAR > 50).

Kelly's ratio. The Kelly ratio (KR) is calculated using the following equation:

$$KR = \frac{Na}{Ca + Mg}$$

Kelley et al., (1940) have suggested that the sodium problem in irrigation water could very conveniently be worked out on the basis of the values of Kelley's ratio. A Kelly's ratio of more than one indicates excessive sodium in water. Therefore, water with a Kelly's ratio less than one are suitable for irrigation, while those with a ratio more than one are unsuitable. The Kelley's ratio has been calculated for all the water samples in the study area. The water samples are suitable for irrigation with Kelly's ratio lower than 1 (Table 7).

In the study area, the assessment of groundwater quality for irrigation was carried out to identify its suitability for irrigation purpose through the estimation of Water Quality Index for irrigation

Table 7. Classification of groundwater quality in the study area

Classification pattern	Categories	Ranges	Number of samples	
			(wet period)	(dry period)
Electrical Conductivity (EC) (Wilcox 1955)	Excellent	< 250	—	—
	Good	250 – 750	—	—
	Permissible	750 – 2250	6	7
	Doubtful	2250 – 5000	11	10
	Unsuitable	> 5000	2	2
Chloride (meq/L) (Ayers & Westcot (1985)	Excellent	< 4	3	1
	Good	4 – 7	2	3
	Permissible	7 – 12	2	3
	Doubtful	12 – 20	8	3
	Unsuitable	> 20	4	9
Percent Sodium (% Na) (Wilcox 1955)	Excellent	0 – 20	13	5
	Good	20 – 40	6	13
	Permissible	40 – 60	–	1
	Doubtful	60 – 80	–	–
	Unsuitable	> 80	–	–
Sodium Absorption Ratio (SAR) (Richard 1954)	Very low	< 2	13	12
	Low	2 – 12	6	7
	Medium	12 – 22	–	–
	High	22 – 32	–	–
	Very high	> 32	–	–
Adjusted Sodium Adsorption Ratio (SAR_{adj}) (Ayers & Westcot 1985)	Very low	< 3	7	3
	Low	3 – 6	6	9
	Significant	6 – 8	3	2
	High	8 – 9	1	2
	Severe	> 9	2	3
Permeability Index (PI) (Doneen 1964)	Suitable	< 75	19	19
	Unsuitable	≥ 75	-	-
Residual Sodium Carbonate (RSC) (meq/L)	Permissible	< 1,25	19	19
	Unsuitable	≥ 1,25	-	-
Magnesium adsorption ratio (MAR) Raghunath (1987)	Permissible	0 – 50	9	11
	Unsuitable	> 50	10	8
Kelly's ratio Kelley (1940)	Suitable	< 1	19	19
	Unsuitable	≥ 1	-	-

(WQII). This indice is an important parameter for assessing groundwater quality and its suitability (Avvannavar and Shrihari, 2008).

The advantage of water quality index is based on the relative importance of essential parameters with respect to standards of irrigation purposes. The assessment of groundwater quality index of 19 samples for irrigation (WQII) in dry period 2012 (Tables 6) demonstrates the following classes: one sample in the class 1, 6 samples in the class 2, 9 samples in the class 3, 2 samples in the class 4 and one sample in the class 5. However, for the wet period (Table 5) 7, 10 and 2 samples were classified in the classes 2, 3 and 4 respectively. This estimation of groundwater quality index shows the predominance of good and permissible groundwater quality in the major part of the plain. However, there are few samples with a bad quality of groundwater along Wadi Massine and Harraza, its use in irrigation depend on the salinity tolerance of crops and on the irrigation management (Oliveira & Maia, 1998). Relationships between WQII and the different classical criteria were considered in the assessment of quality of water (EC, Cl, RSC, SAR, % Na, KR, MAR and PI) (Table 8). The relationships observed between the WQII values and EC, Cl, RSC and SAR indicate a good correlation with coefficient more than 0.72, which indicate that WQII can give a satisfactory classification for the irrigation water quality, and its estimation can quantitatively expressed in terms of salt content in the irrigation water, without specifying the types of salts.

Table 8. Correlation coefficient between water quality index of irrigation (WQII) and the parameters used for assessing the water quality of irrigation.

Classification pattern	Relationship with	Correlation coefficient	
		Dry period	Wet period
EC	WQII	**0,95**	**0,94**
Cl	WQII	**0,93**	**0,97**
RSC	WQII	**0,93**	**0,92**
SAR	WQII	**0,72**	**0,80**
SAR_{adj}	WQII	**0,80**	**0,82**
% Na	WQII	0,42	0,57
KR	WQII	0,39	0,57
MAR	WQII	0,38	0,12
PI	WQII	0,12	0,10

Classification of the Groundwater

To classify the groundwater chemical facies and to identify the hydro-chemical processes, a Chadha's diagram (Chadha, 1999) is used. This diagram is a somewhat modified version of the Piper diagram (Piper, 1944) and the expanded Durov diagram (Durov, 1948). In Chadha's diagram, the difference in milliequivalent percentage between alkaline earths ($Ca^{2+} + Mg^{2+}$) and alkali metals ($Na^{+} + K^{+}$), expressed as percentage reacting values, is plotted on the X axis and the difference in milliequivalent percentage between weak acidic anions (CO_3^{2-} + HCO_3^{-}) and strong acidic anions ($Cl^{-} + SO_4^{2-}$) is plotted on the Y axis. As per this diagram in wet period, 89.5 % of the groundwater samples fall in the field of 6. The latter belong to the Ca^{2+}-Mg^{2+}-Cl^{-} type. Such water has a permanent hardness and does not deposit residual sodium carbonate in irrigation use. Two samples (10.5 %) fall in the field of 5 which belongs to the Ca^{2+}-Mg^{2+}-HCO_3^{-} type and such water has temporary hardness. Whereas in dry period, the entire samples have Ca^{2+}-Mg^{2+}-Cl^{-} type hydrochemical facies (Fig. 6).

CONCLUSION

The groundwater quality in the Upper Cheliff plain has been evaluated for drinking and agricultural uses.

The WQID for 19 samples ranges from 67 to 356. Almost ninety five percent of the samples exceeded 100, the upper limit for drinking water. The high values of WQID in this plain have been found to be

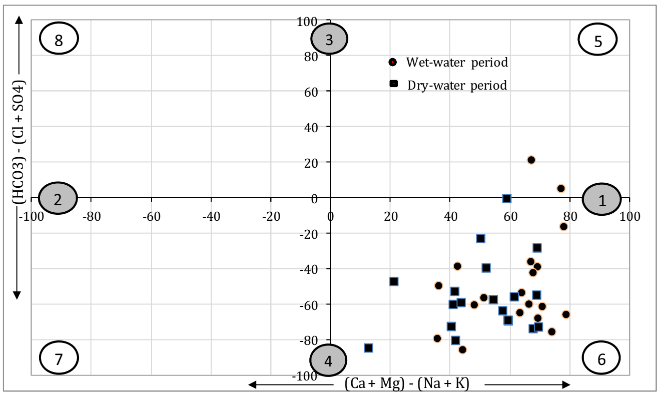

Fig.6. Groundwater quality plotted on Chadha's diagram. *Index:* **1.** Alkaline earth exceeds alkalimetals. **2.** Alkali metals exceed alkaline earth. **3.** Weak acidic anions exceed strong acidic anions. **4.** Strong acidic anions exceed weak acidic anions. **5.** Represent Ca^{2+} -Mg^{2+}-HCO_3^{-} type. **6.** Represents Ca^{2+} -Mg^{2+}-Cl^{-} type. **7.** Represent Na^{+}-Cl^{-} type, Na_2SO4^{2-} type. **8.** Represent Na^{+}- HCO_3^{-} type.

mainly due to the higher values of chlorides, sulphates, nitrates, bicarbonates, calcium, magnesium and sodium. This classification indicates that groundwater in the upper Cheliff plain is characterized by poor and very poor quality. These are due to the direct discharge of urban rejects, agricultural fertilizers and are due also to the low rate of precipitation.

The results, based on EC, Cl, SAR, RSC, %Na, KR, MAR and PI indicate that groundwater quality status varies from good to unsuitable for irrigation purposes. The water quality index of irrigation (WQII) has been computed to better assess suitability of groundwater quality for irrigation. For calculating the WQII ten parameters have been considered such as: pH, EC, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^{-}, Cl^{-}, SO_4^{2-}, and NO_3^{-}. The result shows that only 10 % and 15 % of samples in the wet and dry periods exceed the limit proposed of WQII (equal to 150). The high values of WQII correspond mainly to the higher values of electrical conductivity, calcium, magnesium, sodium, potassium, sulphates and chloride in the groundwater.

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