Revue des Sciences de l'Eau
Journal of Water Science

Evaluation of the quality of groundwater used for irrigation in the Mina plain, Algeria
Évaluation de la qualité des eaux souterraines utilisées pour l'irrigation dans la plaine de la Mina, Algérie

Mohamed Gorine, Mohammed Benkhelifa, Farid Gacem and Djamal Bellague

Volume 32, Number 3, 2019

Received 6 November 2018, accepted 22 July 2019

URI: https://id.erudit.org/iderudit/1067306ar
DOI: https://doi.org/10.7202/1067306ar

See table of contents

Publisher(s)

Université du Québec - INRS-Eau, Terre et Environnement (INRS-ETE)

ISSN

1718-8598 (digital)

Explore this journal

Cite this article

Gorine, M., Benkhelifa, M., Gacem, F. & Bellague, D. (2019). Evaluation of the quality of groundwater used for irrigation in the Mina plain, Algeria. *Revue des Sciences de l'Eau / Journal of Water Science*, *32*(3), 223–234. https://doi.org/10.7202/1067306ar

Article abstract

The development of agriculture in the Mina plain is hampered by the drought that has occurred in recent years. As a result, water scarcity has favoured an intensive use of groundwater of poor quality. This behaviour is one of the forerunners of soil degradation. Knowing the quality of the irrigation water used becomes imperative. In this context, water samples from 178 wells in the Mina plain were subjected to a physico-chemical analysis, mainly electrical conductivity (EC), sodium adsorption ratio (SAR), and irrigation water quality index (IWQI), were used to identify water quality classes as well as residual alkalinity (RSC) to determine salinization pathways. The thematic maps established by the two methods (EC and SAR, IWQI) showed that 73.44% of the total area could be used for irrigation and that 87.55% of the total area may be used for irrigation in soils with high permeability where additional water should be applied to prevent salt accumulation. The residual alkalinity revealed two types of salinization: one neutral and one alkaline, representing respectively 149 and 29 wells. The electrical conductivity varied between 2.24 and 16.50 $dS \cdot m^{-1}$, divided into two classes of salinity (C4, 44.03% and C5, 55.97%). SAR values fluctuated between a low of 4.28 and a high of 94.73, with S2 dominance accounting for 49.57% of the total area. IWQI's assessment of groundwater quality revealed that 87.55% of the Mina study area is severely restricted, which is dominant in the southeastern and southwestern parts of the area. The remaining area, 12.44% or less, is in the high restriction category. This simple index uses the most important parameters that evaluate the quality of irrigation water for management.

RSE

EVALUATION OF THE QUALITY OF GROUNDWATER USED FOR IRRIGATION IN THE MINA PLAIN, ALGERIA

Évaluation de la qualité des eaux souterraines utilisées pour l'irrigation dans la plaine de la Mina, Algérie

Mohamed GORINE[1*], Mohammed BENKHELIFA[1], Farid GACEM[2], Djamal BELLAGUE[3]

[1]University of Abdelhamid Ibn Badis, PO Box 17, Bordji Amar 27000 Mostaganem, Algeria
[2]National Soil Institute, Irrigation and Drainage, Pasteur St, PO Box 148, Algiers, Algeria
[3]National Institute of Agronomic Research of Algeria, 2, les frères Ouadek St, PO Box 200, Hassan Badi, El Harrach 16200 Algiers, Algeria

Received 6 November 2018, accepted 22 July 2019

ABSTRACT

The development of agriculture in the Mina plain is hampered by the drought that has occurred in recent years. As a result, water scarcity has favoured an intensive use of groundwater of poor quality. This behaviour is one of the forerunners of soil degradation. Knowing the quality of the irrigation water used becomes imperative. In this context, water samples from 178 wells in the Mina plain were subjected to a physico-chemical analysis, mainly electrical conductivity (EC), sodium adsorption ratio (SAR), and irrigation water quality index (IWQI), were used to identify water quality classes as well as residual alkalinity (RSC) to determine salinization pathways. The thematic maps established by the two methods (EC and SAR, IWQI) showed that 73.44% of the total area could be used for irrigation and that 87.55% of the total area may be used for irrigation in soils with high permeability where additional water should be applied to prevent salt accumulation. The residual alkalinity revealed two types of salinization: one neutral and one alkaline, representing respectively 149 and 29 wells. The electrical conductivity varied between 2.24 and 16.50 dS·m^{-1}, divided into two classes of salinity (C4, 44.03% and C5, 55.97%). SAR values fluctuated between a low of 4.28 and a high of 94.73, with S2 dominance accounting for 49.57% of the total area. IWQI's assessment of groundwater quality revealed that 87.55% of the Mina study area is severely restricted, which is dominant in the southeastern and southwestern parts of the area. The remaining area, 12.44% or less, is in the high restriction category. This simple index uses the most important parameters that evaluate the quality of irrigation water for management.

Key words*: *salinity, sodicity, water quality index, residual alkalinity, Mina plain.

RÉSUMÉ

Le développement de l'agriculture dans la plaine de la Mina est entravé par la sécheresse qui s'est installée ces dernières années. En conséquence, la pénurie d'eau a favorisé l'utilisation intensive des eaux souterraines dont la qualité

*Corresponding author:
Phone: (+213)662941346
Email: gorine2006@yahoo.fr

est méconnue. Ce comportement est l'un des précurseurs de la dégradation des sols. La connaissance de la qualité de l'eau d'irrigation utilisée devient primordiale. Dans ce contexte, des échantillons d'eau de 178 puits de la plaine de la Mina ont fait l'objet d'une analyse physicochimique, principalement la conductivité électrique (EC), le ratio d'adsorption de sodium (SAR) et l'indice de la qualité de l'eau d'irrigation (IQWI) ont été utilisés pour identifier les classes de la qualité des eaux ainsi que l'alcalinité résiduelle (RSC) pour déterminer les voies de salinisation. Les cartes thématiques établies par les deux méthodes (EC et SAR, IQWI) ont montré que 73,44 % de la superficie totale était utilisable pour l'irrigation et que 87,55 % de la superficie totale de la zone d'étude peut être utilisée pour l'irrigation de sols à perméabilité élevée où de l'eau devrait être ajoutée pour éviter l'accumulation des sels. L'alcalinité résiduelle a révélé deux types de salinisation, une par voie neutre et une autre par voie alcaline, représentant respectivement 83,71 % et 16,29 % des puits. La conductivité électrique oscillait entre 2,24 et 16,50 dS·m^{-1}, répartie en deux classes de salinité (C4, 44,03 % et C5, 55,97 %). Les valeurs du SAR fluctuaient entre un minimum de 4,28 et un maximum de 94,73 avec une dominance de la classe S2 représentant 49,57 % de la superficie totale. L'évaluation de la qualité des eaux souterraines par l'IQWI a révélé que 87,55 % de la zone d'étude de la Mina a une restriction sévère, ce qui est dominant dans les parties sud-est et sud-ouest de la zone. Le reste de la zone, 12,44 % et moins, relève de la catégorie de haute restriction. Cet indice simple utilise les plus importants paramètres qui évaluent la qualité de l'eau d'irrigation pour la gestion.

Mots-clés* : *salinité, sodicité, indice de la qualité de l'eau, alcalinité résiduelle, plaine de la Mina.

1. INTRODUCTION

The irrigated perimeter of Mina extends over 9 592 ha and is located in the north-west of Algeria, about 300 km from Algiers. Agricultural activity is based on the intensive production of cereals and arboriculture. Initially, since 1998, irrigation water (average electrical conductivity : EC = 1.70 dS·m^{-1}) came from the Sidi M'Hamed Benaouda dam (SMB), but over time farmers used groundwater more and more (average EC = 5.47 dS·m^{-1}) following the drought that has affected the region since 2003.

The poor quality of groundwater compared to that of the SMB dam has led to a process of physical soil degradation (LAHLOU *et al.*, 2002) and a decrease in crop yields by an average of nearly 50% (BENZELLAT, 2012).

The drop in yields in both market gardening (up to 70%) and arboriculture (up to 40%) severely affected the socio-economic situation of the area and the issue of irrigation water quality attracted the attention of farmers and several observers (GACEM, 2014; LAMSAL *et al.*, 1999; PASCAL and BARBAERI, 1995). The challenge is to understand how irrigation water quality affects crop production. For this purpose, it is necessary to establish a diagnosis of groundwater quality. The objective of this article is to provide an in-depth physico-chemical diagnosis of groundwater irrigation quality using two methods, Riverside and Index of irrigation water quality.

2. MATERIALS AND METHODS

2.1 Study area

The Mina plain is located in the north-west of Algeria, at a distance of about 250 km from the capital and 50 km from the sea as the crow flies. It lies between the longitudes 0°17'31" and 0°41'40" E, and the latitudes 35°41'27" and 35°49'07'' N (Figure 1).

The irrigated plain of the Mina consists of four irrigated areas: Yellel, Mina, Matmar and Oued Djemaa. The plain is characterized by a continental climate with average rainfall of 253 mm·a^{-1} and evapotranspiration of 1 639 mm·a^{-1} (GORINE, 2010).

According to GHOUL and PETER (1974), these soils can be classified into five types: 1) undeveloped soils, 2) halomorphic soils affected by a salt-forming process dating back to the Triassic and Miocene periods, 3) hydromorphic soils affected by physical degradation and no drainage, 4) calcimagnesic soils characterized by high levels of silt, calcium and magnesium and 5) vertisols which contain swelling clay in large proportions. The study area is located in the part of the site that contains calcimagnesic soils and vertisols. The clay content varies between 18% and 49% in the 0-50 cm surface horizon and between 14% and 41% in the lower 50-80 cm horizon. These soils are occupied by cereals, fruit trees, olive trees and market gardening with 46%, 33%, 8% and 4% of the total surface area of the plot respectively (GACEM, 2014).

2.2 Water resources

The Mina plain is crossed in the center by the Mina Wadi and its tributary the Malah Wadi with a very bad quality water, and to the west by the Yellel Wadi. The only source for irrigation of the plain is the water from the Sidi Mhamed Ben Aouda

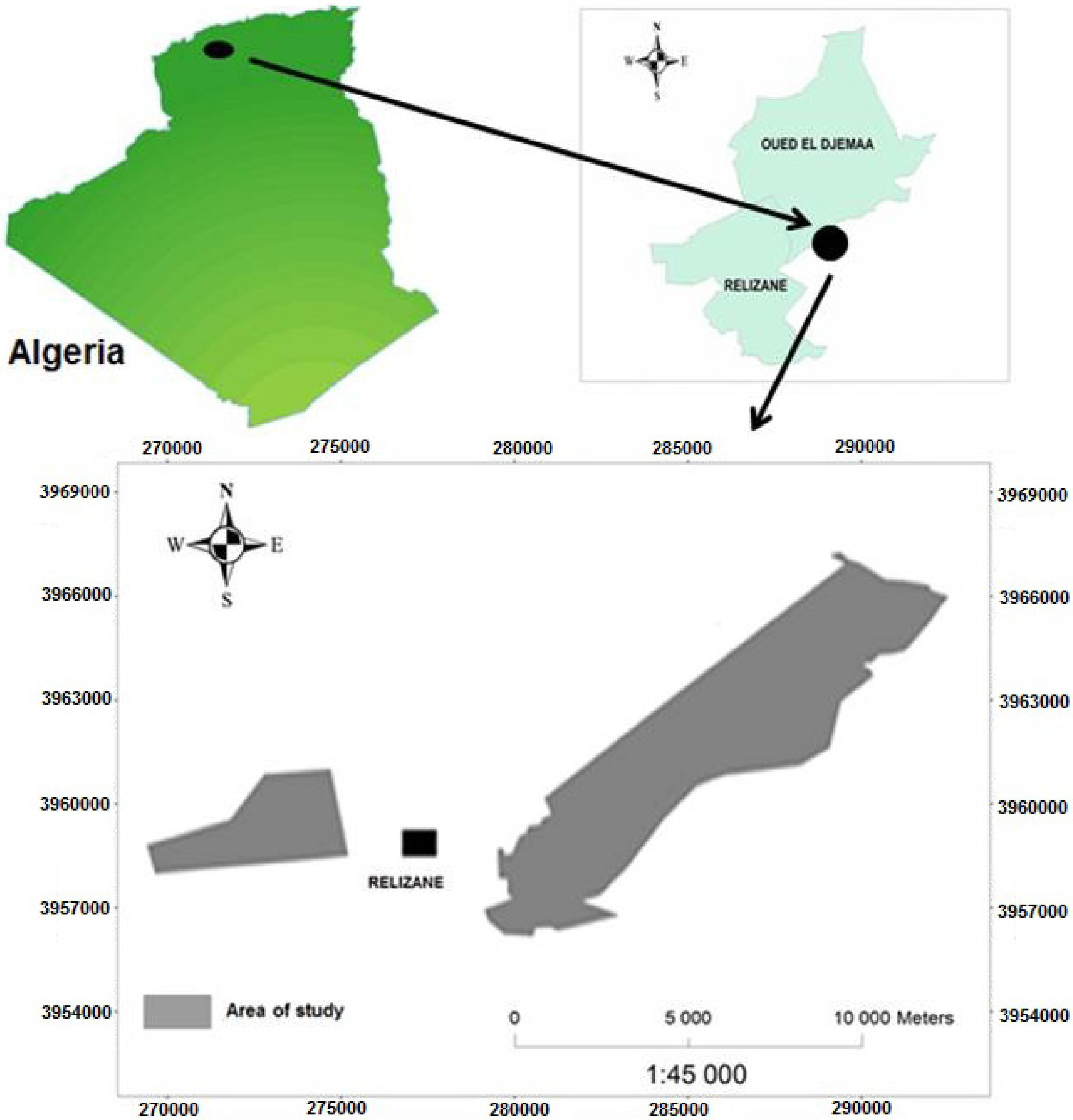

Figure 1. Geographical location of the study area.
Localisation géographique du site d'étude.

dam, capacity of 225 million cubic metres, for the supply of drinking water and irrigation. Two main aquifers constitute the groundwater resources, namely the Quaternary aquifer and the Astian sandstone aquifer (ABH CZ, 2004).

2.3 Sampling and analyses

The well network, consisting of 178 location-based wells distributed over the entire prospected field, is chosen for the sampling operation in order to acquire representative data on the spatial variability of the area groundwater quality. (Figure 2).

Well water sampling is carried out during the spring-summer irrigation period, from May to September 2008. The water was systematically collected during pumping in 1-L bottles and stored in a refrigerator.

The different analyses on the waters, namely the pH, the electrical conductivity and the ionic balance are carried out at the laboratory of the National Institute of Soils, Irrigation and Drainage (INSID, Matmar).

The chloride, bicarbonate and carbonate ions are made by titration. Sulphate ions are analyzed by the gravimetric method. Sodium, potassium, calcium and magnesium ions are analyzed by the atomic absorption method.

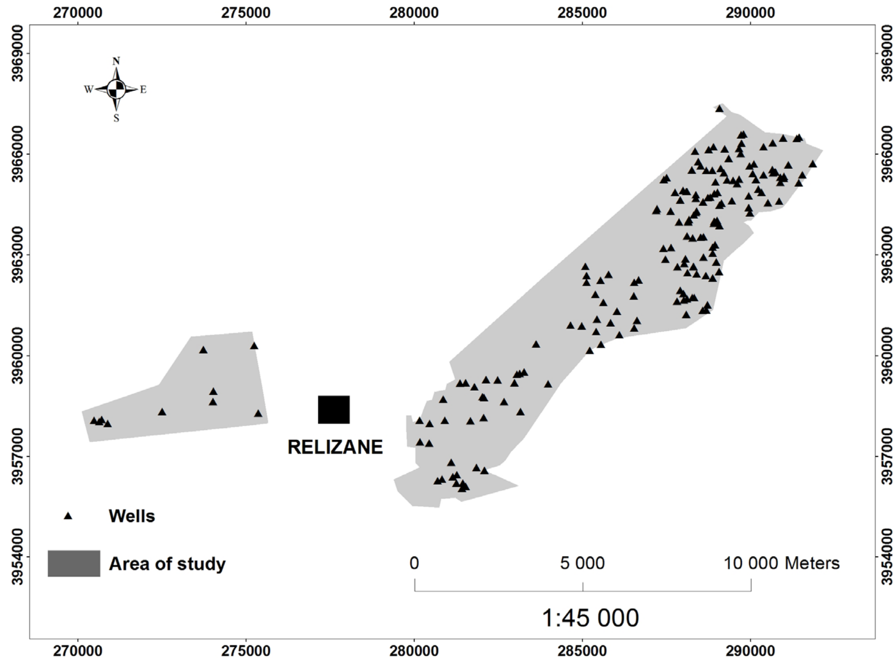

Figure 2. Well network in the Mina plain.
Réseau des puits dans la plaine de Mina.

2.4 Assessment of water quality

2.4.1 Riverside method

To assess the quality of groundwater for agricultural use, the Riverside diagram (RICHARDS, 1954) is used to assess the risk of salinization and soil sodization. For this, the sodium adsorption ratio (SAR) parameter is estimated by the following formula:

$$SAR = \sqrt{\frac{Na^{+}}{\left(\frac{Ca^{2+} + Mg^{2+}}{2}\right)}} \qquad (1)$$

In addition, the residual sodium carbonate (RSC) parameter also contributes to this assessment. It is estimated after EATON (1950), RICHARDS (1954) and MARLET and JOB (2006) by the formula:

$$RSC\ (meq \cdot L^{-1}) = \text{Carbonated alkalinity} - (Ca^{2+} + Mg^{2+}) \qquad (2)$$

If RSC is positive, it is the alkaline route relative to the precipitation of calcite/sepiolite, otherwise (RSC < 0) it is the neutral saline way. In this case, two cases may occur depending on the signs of the residual alkalinity applied to the precipitation of calcite, sepiolite and gypsum (MARLET and JOB, 2006):

- The residual alkalinity becomes positive as a result of the addition of sulphates which will allow the precipitation of gypsum; it is the sulphate-dominated neutral saline pathway;
- The residual alkalinity becomes negative even by the addition of sulphates, we speak then of the chloride-dominated neutral saline way.

2.4.2 Irrigation water quality index (IWQI)

Although the water quality index is usually oriented to describe urban water supply, it has been widely used by decision makers in environmental planning (KHALAF and HASSAN, 2013; HAUSSAIN *et al.*, 2014).

It is a simple index that uses the most important parameters that evaluate the quality of irrigation water (YOGENDRA and PUTTAIAH, 2008). HORTON (1965) is the first designer of the water quality degradation indices. Afterwards, several studies were conducted for the measurement of the water quality index. Indeed, ROKBANI *et al.* (2011), JEROME and PIUS (2010), SIMSEK and GUNDUZ (2007) used the irrigation water quality index (IWQI) as a tool for groundwater quality management.

The IWQI model was developed by MEIRELES *et al.* (2010) in two stages. As a first step, the relevant parameters for the quality of the irrigation water are identified. In a second step, the definition of the quality values (q_i) and the aggregation weight (w_i) are established. Values of q_i were estimated according to the value of each parameter (Table 1), according to the irrigation water quality parameters proposed by the University of California Consultants Committee (UCCC) and according to the criteria established by AYERS and WESTCOT (1999).

Table 1. Limit values for quality (q_i) measurements (AYERS and WESTCOT, 1999).
Tableau 1. Valeurs limites pour la mesure de la qualité (q_i) (AYERS et WESTCOT, 1999).

q_i	EC[a] (dS·m^{-1})	SAR[b] (meq·L^{-1})$^{0.5}$	Na^+ (meq·L^{-1})	Cl^- (meq·L^{-1})	HCO_3^- (meq·L^{-1})
85-100	0.20 ≤ EC < 0.50	SAR < 3	2 ≤ Na < 3	Cl < 4	1.00 ≤ HCO_3^- < 1.5
60-85	0.75 ≤ EC < 1.50	3 ≤ SAR < 6	3 ≤ Na < 6	4 ≤ Cl < 7	1.50 ≤ HCO_3^- < 4.0
35-60	1.50 ≤ EC < 3.00	6 ≤ SAR < 12	6 ≤ Na < 9	7 ≤ Cl < 10	4.50 ≤ HCO_3^- < 8.0
0-35	EC < 0.20 or EC ≥ 3	SAR ≥ 12	Na < 2 or Na ≥ 9	Cl ≥ 10	HCO_3^- < 1.00 or HCO_3^- ≥ 8,50

[a] Electrical conductivity
[b] Sodium adsorption ratio

Thus the values of q_i are determined by the following formula:

$$q_i = q_{imax} - \left\{ \frac{\left[\left(x_{ij} - x_{inf} \right) q_{iamp} \right]}{x_{amp}} \right\} \quad (3)$$

where q_{imax} : the maximum value of the q_i for the class; x_{ij} : the parameter observed value; x_{inf}: the lower limit of the parameter class; q_{iamp} : the amplitude of the class of the q_i and x_{amp} : the amplitude of the class of the parameter.

The values of q_i are represented by nondimensional values. The higher is the value, the better is the quality of the water.

In order to evaluate xamp of the last class of each parameter, the upper limit was considered the highest value determined in the physico-chemical analysis of the water samples. Each weight parameter (w_i) used in the IWQI was obtained by MEIRELES *et al.* (2010) (Table 2).

The irrigation water quality index is the sum of each water quality value (q_i) multiplied by its corresponding weight and is determined by the formula:

$$\text{IWQI} = \sum_{i=1}^{n} q_i w_i \quad (4)$$

The IWQI, ranging from 0 to 100, is subdivided into classes based on the risk of the salinity problem, the reduction of water infiltration in the soil and the toxicity to the plants (Table 3).

Table 2. Weight of irrigation water quality index (IWQI) parameters.
Tableau 2. Poids des paramètres de l'indice de la qualité de l'eau d'irrigation.

Parameter	Weight (w_i)
Electrical conductivity (EC)	0.211
Na^+	0.204
HCO_3^-	0.202
Cl^-	0.194
Sodium adsorption ratio (SAR)	0.189
Total	1.000

3. RESULTS AND DISCUSSION

3.1 Descriptive statistics

Physico-chemical analyses of groundwater reveal very large amplitudes between the minimum and maximum values (Table 4).

The highest electrical conductivities are close to 16.50 dS·m^{-1}, which reflects excessive salinity, due to lithology and high evapotranspiration during the summer period that concentrates the soil solution (CHEVERRY and ROBERT, 1998). Generally, groundwater quality with an average electrical conductivity of 5.47 dS·m^{-1} is considered poor for irrigation. In addition, only nine analyzed wells have an EC ≤ 3 dS·m^{-1} which is the maximum allowable value for most crops (AYERS and WESCOT, 1985). The areas for each class (C4 and C5) are around 50% and have respective values of 44.03% and 55.97% (Figure 3).

As for the SAR parameter, there are four classes (Figure 4). Soils assigned to class S1 are located in the north-east and south-west of the study area. On the other hand, class S4 is gathered into a single area located in the eastern part of the prospected area (Figure 5).

Table 3. Class characteristics of irrigation water quality index (IWQI).
Tableau 3. Caractéristiques des classes de l'indice de la qualité de l'eau d'irrigation.

IWQI	Water use restriction	Soil recommendation	Plant recommendation
85-100	No restriction (NR)	May be used for the majority of the soils with low probability of causing salinity and sodicity problems, being recommended leaching within irrigation practices, except for in soils with extremely low permeability.	No toxicity risk for most plants.
70-85	Low restriction (LR)	Recommended for use in irrigated soils with light texture or moderate permeability, being recommended salt leaching. Soil sodicity in heavy texture soils may occur, being recommended to avoid its use in soils with high clay.	Avoid salt sensitive plants.
55-70	Moderate restriction (MR)	May be used in soils with moderate to high permeability values, being suggested moderate leaching of salts.	Plants with moderate tolerance to salts may be grown.
40-55	High restriction (HR)	May be used in soils with high permeability without compact layers. High frequency irrigation schedule should be adopted for water with electrical conductivity (EC) above 2 000 $\mu S \cdot cm^{-1}$ and sodium adsorption ratio (SAR) above 7.0.	Should be used for irrigation of plants with moderate to high tolerance to salts with special salinity control practices, except water with low Na, Cl and HCO_3 values.
0-40	Severe restriction (SR)	Should be avoided its use for irrigation under normal conditions. In special cases, may be used occasionally. Water with low salt levels and high SAR require gypsum application. In high saline content water soils must have high permeability, and excess water should be applied to avoid salt accumulation.	Only plants with high salt tolerance, except for waters with extremely low values of Na, Cl and HCO_3.

Table 4. Physico-chemical characteristics of groundwater in the Mina plain.
Tableau 4. Caractéristiques physicochimiques des eaux souterraines de la plaine de la Mina.

Parameter	Minimum	Maximum	Mean	SD
pH	6.77	8.79	7.53	0.34
Electrical conductivity (EC) ($dS \cdot m^{-1}$)	2.24	16.50	5.47	2.19
Ca^{++} ($meq \cdot L^{-1}$)	0.05	47.33	6.27	7.06
Mg^{++} ($meq \cdot L^{-1}$)	0.04	65.38	12.14	12.54
Na^{+} ($meq \cdot L^{-1}$)	8.87	100.00	42.43	21.62
K^{+} ($meq \cdot L^{-1}$)	0.01	7.83	0.44	0.81
HCO_3^{-} ($meq \cdot L^{-1}$)	0.04	14.60	2.60	2.88
Cl^{-} ($meq \cdot L^{-1}$)	10.00	192.95	43.33	24.93
SO_4^{2-} ($meq \cdot L^{-1}$)	0.77	42.55	12.65	7.13
Sodium adsorption ratio (SAR)	4.28	94.73	19.60	13.15

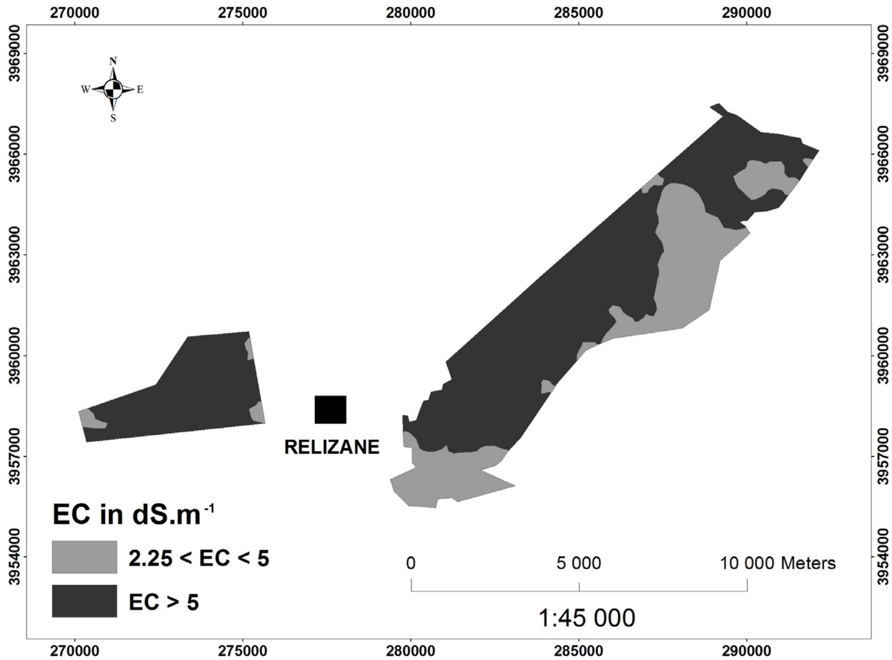

Figure 3. **Spatial distribution of groundwater salinity classes (EC: electrical conductivity).**
Distribution spatiale des classes de salinité de l'eau souterraine (EC : conductivité électrique).

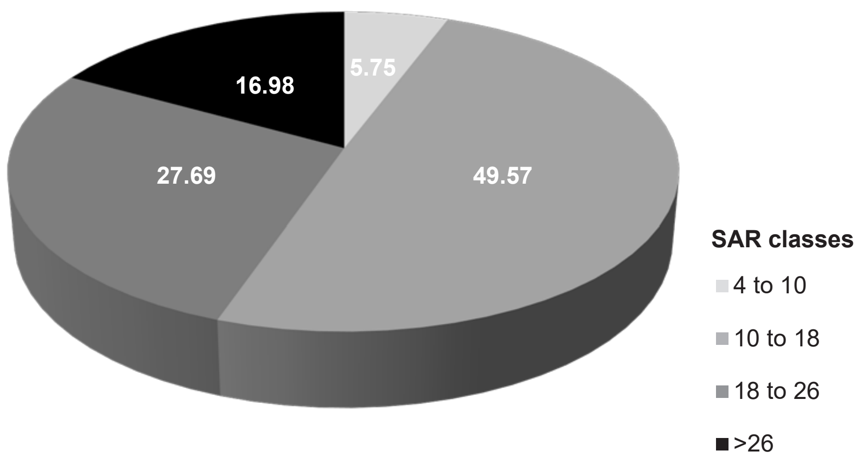

Figure 4. **Percentage of soil area for each sodium adsorption ratio (SAR) class.**
Pourcentage des surfaces de sol pour chaque classe de SAR (ratio d'adsorption de sodium).

3.2 Irrigation water quality

3.2.1 Riverside method

The physico-chemical analys of groundwater reveal a salinity unusable for irrigation. According to RICHARDS (1954) classification, modified by DURAND (1983), there are two classes of salinity (C4 and C5) and three classes of sodization (S2, S3 and S4). The Riverside diagram shows a strong dominance of the C4S4 and C5S4 classes with an overall percentage of 88.77%, which is not recommended for irrigation. It is noted that 1.12% of the water is of poor quality (C4S2) and can only be used for well-drained soils and resistant plants with leaching doses. Class C4S3, representing 10.11% of the waters, is of very poor quality and therefore to be used only for exceptional circumstances. That is, only 20 wells are available for irrigation (Figure 6).

3.2.2 Residual alkalinity of water

Without the use of the residual alkalinity indicator, the SAR alone does not show any risk of sodicity for the use, for irrigation, of poor quality groundwater (BOUZADA, 2013),

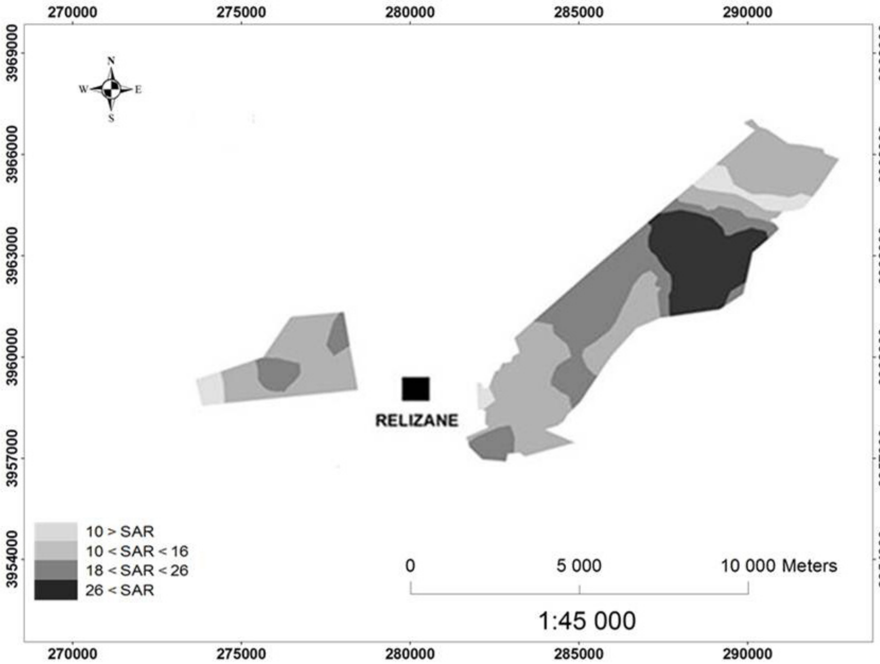

Figure 5. **Spatial distribution of groundwater sodium adsorption ratio (SAR) classes.**
Distribution spatiale des classes de SAR (ratio d'adsorption de sodium) de l'eau souterraine.

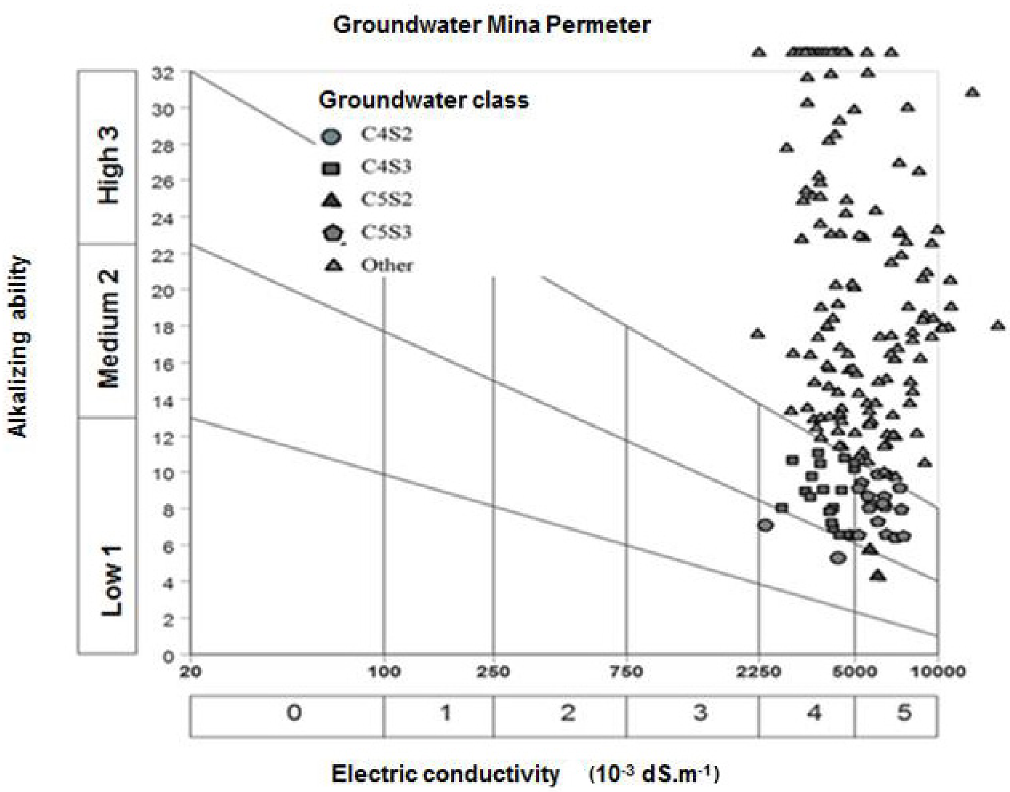

Figure 6. **Riverside diagram of groundwater.**
Diagramme de Riverside des eaux souterraines.

knowing that SAR frequently minimizes the risk of sodization and alkalinization of water in the presence of a chlorinated chemical facies (GOUAIDIA *et al.*, 2012). For this reason, residual alkalinity (RSC) has been chosen as another approach for assessing the quality of these waters. According to the water analyses, there are three residual alkalinity pathways:

- RSC > 0, alkaline salinization (RSC1) (1)
- RSC < 0, neutral salinization (RSC2) :
  - RSC > 0 with sulfated dominance (RSC2.1) (2)
  - RSC < 0 predominantly chlorinated (RSC2.2) (3)

In our case, neutral salinization accounts for 83.71% of all water points (Table 5).

The concentration of bicarbonate ions (HCO_3^-) in water samples is between 0.04 and 14.60 meq·L^{-1} (Table 4). The lower threshold for irrigation water quality standards is 1.50 meq·L^{-1} (AYERS and WESTCOT, 1985). Indeed, an important part of samples records values above the accepted threshold. Under these conditions, the effect of bicarbonates combined with that of salinity favours the infiltration capacity of soils, particularly in the presence of high clay contents (JASSIM and GOFF, 2006).

Chloride concentrations range from 10.00 to 192.95 meq·L^{-1}. All samples recorded values above the irrigation water quality threshold of 4.00 meq·L^{-1} (KHALAF and HASSAN, 2013). Under these conditions, chlorides are likely to cause specific toxicity on the crops produced.

The sodium (Na+) ion concentration of the water samples ranges from 8.87 to 100.00 meq·L^{-1} (Table 4). Indeed, 62% of the water samples collected recorded sodium concentration values higher than the threshold allowed (40.00 meq·L^{-1}) by irrigation water quality standards (US Laboratory of Riverside). Under these conditions, the risk of physical degradation of soils by sodization must be taken into account.

3.2.3 IWQI method

The result of using the IWQI index, for all well waters in the study area, revealed two main classes: a severe restriction class (SR) and a high restriction class (HR) representing a respective percentage of 64.04% and 36.52%. The index revealed that the Mina plain waters can be used in irrigation with high to severe restrictions.

The method downgraded 39 wells belonging to classes C4S4 and C5S4 to the HR class. Thus, the number of wells available for irrigation (20), classified by the Riverside method, has almost doubled (39).

3.3 Capacity map of irrigation water by the method of intersection between the EC map and the SAR map

The groundwater quality class analysis results show that class (4) C5S (C5S2, C5S3 and C5S4) is the most dominant with a percentage of 73.44% of the total area of 5 678.07 ha. According to the thematic map of water suitability, the C5S class is uniformly distributed in the study area (Figure 7). In addition, the C4S3 (2) and C4S4 (3) are present with percentages of 10.02% and 15.39% (Figure 8), and they are located in the northern and the southern parts of the plain. Class (1) C4S2, limited only to the center, has the lowest percentage (1.15%).

The thematic map established has the advantage of spatially visualizing the ability of groundwater used for irrigation over a large area. It can serve, firstly for the good quantitative and qualitative irrigation management, and, secondly, it is a means of raising users' awareness of what has become of the land irrigated by these types of water.

3.4 Irrigation water suitability map by the IWQI method

Figure 9 shows the spatial distribution of IWQI in the study area and ranges from severe restriction (SR) to high restriction (HR) (Table 3). The field of use of water quality (severe restriction) can be found over a large area of the south-east and east-west of the study area. Severe restriction areas account for 87.55% (approximately 4 971.7 ha). The remaining 12.44% (706.37 ha) is classified as high restriction quality. In addition, the IWQI decreased slightly in the south-east and south-west due to increased electrical conductivity, SAR, sodium and chloride ions. According to the recommendation in table 3, these types of water should be used only with high permeability soil and excessive water application with some constraints on the types of plants for the specified soil tolerance.

4. CONCLUSIONS

At the end of this work, after having carried out a diagnosis of the quality of underground irrigation water in the Mina plain, the conclusions are as follows.

Water salinity is very high compared to the threshold allowed by AYERS and WESTCOT, (1985), EC ≤ 3 dS·m^{-1} for most crops. Indeed, the salinity values obtained show increases ranging from 44.03% to 55.97% compared to the threshold value. These waters, which are commonly used, are likely to affect crop growth and yield.

Table 5. Plain water types.
Tableau 5. Types d'eaux de la plaine.

Type of water	Designation	Manpower (%)	SAR[a]
RSC1	Carbonated RSC[b] = Alcalinity - (Ca + Mg) > 0	16.29	37.52
RSC2		83.71	
RSC2.1	Carbonated RSC = Alcalinity - (Ca + Mg) + SO_4 > 0	41.61	19.33
RSC2.2	Carbonated RSC = Alcalinity - (Ca + Mg) + SO_4 < 0	58.39	13.82

[a] Sodium adsorption ratio
[b] Residual sodium carbonate

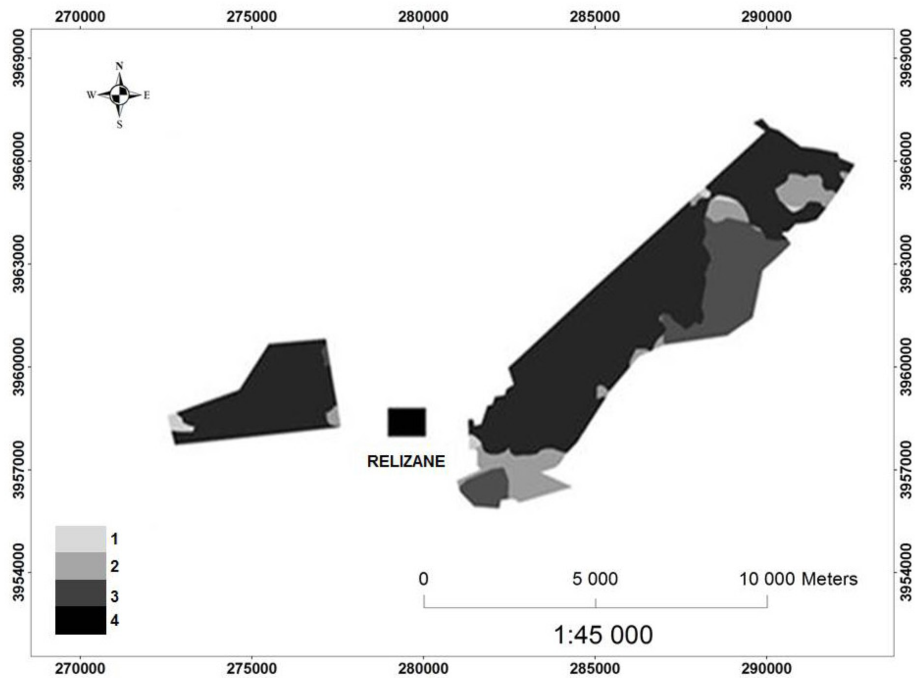

Figure 7. Thematic map of groundwater suitability of the study area.
Carte thématique de l'aptitude des eaux souterraines de la zone d'étude.

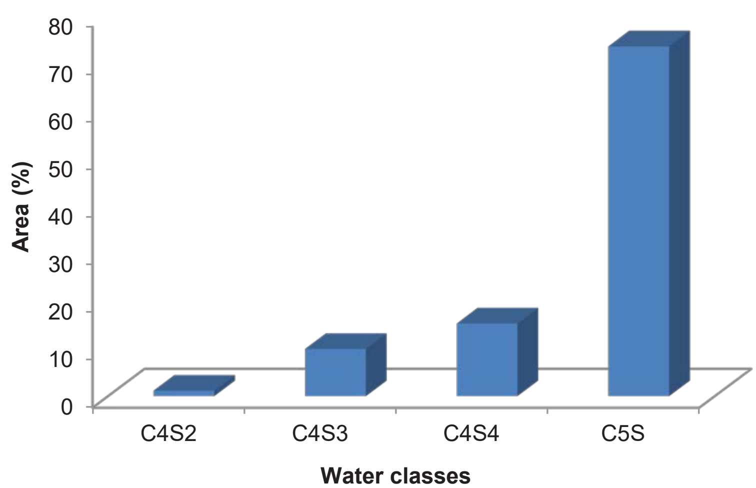

Figure 8. Groundwater ability classes.
Classes d'aptitude des eaux souterraines.

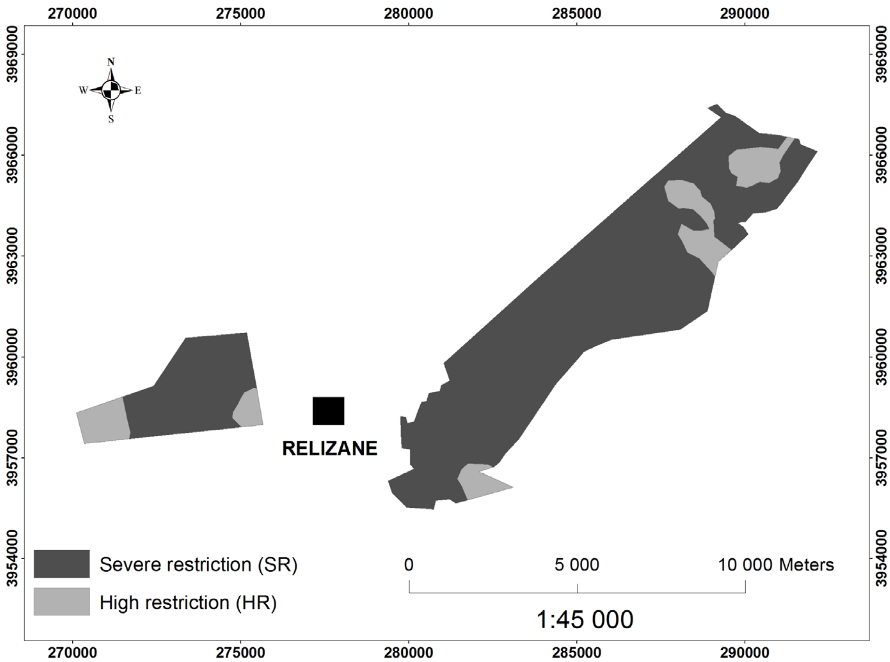

Figure 9. Map of the irrigation water quality index (IWQI) of groundwater in the study area.
Carte de l'indice de la qualité de l'eau d'irrigation des eaux souterraines de la zone d'étude.

Depending on the sodization classes, for the values of SAR ranging 10-18, the risk of sodization is moderate and corresponds to 49.5% of the samples studied. Nevertheless, 16.3% of the samples analyzed shows positive residual alkalinity at low risk. The spatial distribution of the EC and SAR, illustrated by the thematic map established by the intersection method, shows that nearly 73.44% of withdrawals concern water of usable quality but with caution.

According to the map established by the irrigation water quality index (IQWI), 87.55% of the withdrawals concern water that can be used for irrigation but in soils with sufficient permeability and by recommending the addition of additional doses of salt leaching at depth. In this case, a functional drainage network is essential, especially as the clay proportions are relatively high.

The determining parameters for irrigation management in the Mina area are the clay content, which controls the water infiltration capacity of the soil and its occupation. The mapping of these two parameters combined with the thematic maps produced as part of this study could provide a valuable database for optimising irrigation and drainage management in order to limit the risks of soil degradation and yield decline. The evolution of saturated hydraulic conductivity in the study site would be very interesting for the control of soil salinity and sodicity at thresholds favourable to crop production.

REFERENCES

AGENCE DU BASSIN HYDROGRAPHIQUE CHELIFF-ZAHREZ (ABH CZ) (2004). Atlas 3.1 : Exposé, avec cartes et chiffres, un ensemble de données sur la sous-région 2 : Wilaya de Mostaganem, Mascara, Tiaret et Saida. http://www.abh-cz.com.dz/publication.html (consulted 12 October 2018).

AYERS R.S and D.W WESTCOOT (1985). *Water quality for agriculture*. FAO Irrigation and drainage paper, N° 29, Rev. 1, Rome, Italy, 186 p.

AYERS R.S. and D.W. WESTCOT (1999). *The water quality in agriculture*. 2nd Campina Grande: UFPB, FAO Irrigation and drainage paper, N° 29, Rome, Italy, 218 p.

BENZELLAT B. (2012). *Contribution à l'amélioration des rendements des plantes cultivés en sols salés.* Master's thesis, Univ. Abou Bakr Belkaïd, Algeria, 170 p.

BOUZADA N.R. (2013). *Caractérisation géochimique des eaux souterraines utilisées dans l'irrigation dans les plaines du Chéliff.* Master's thesis, Univ. Hassiba Ben Bouali, Algeria, 91 p.

CHEVERRY C. and M.R. ROBERT (1998). La dégradation des sols irrigués et de la ressource en eau. Une menace pour l'avenir de l'agriculture et pour l'environnement des pays au sud de la méditerranée. *Étude et Gestion des Sols*, 5, 217-226.

DURAND J.H. (1983). *Les sols irrigables : étude pédologique.* Presses universitaires de France, Agence de coopération culturelle et technique, Paris, France, 338 p.

EATON F.M. (1950). Significance of carbonates in irrigation waters. *Soil Sci*., 69, 123-134.

GACEM F. (2014). *Étude spatiale et temporelle de la salinité dans les sols de la plaine de Mina, Relizane*. Master's thesis, Univ. Abdelhamid Ibn Badis, Algeria, 77 p.

GHOUL A. and G. PETER (1974). *Étude agro-pédologique du périmètre de la Mina.* Rapport de Secrétariat d'État à l'hydraulique, Sous-direction des études de milieu et de la recherche hydraulique, Alger, Algeria, 17 p.

GORINE M. (2010). *Analyse de la salinité et détermination de la sensibilité à la dégradation des terres agricoles : cas du périmètre irrigué de la Mina, Relizane*. Master's thesis, École nationale de formation supérieure en agronomie, Algeria, 65 p.

GOUAIDIA L., O. GUEFAFIA, B. BOUDOUKHA, M. UGLY HEMILA and C. MARTIN (2012). Évaluation de la salinité des eaux souterraines utilisées en irrigation et risques de dégradation des sols : exemple de la plaine de Meskiana (Nord-Est Algérien). *Physio-Géo*, 6,141-160.

HAUSSAIN H.M., M.J.S AL-HAIDAREY, N. AL-ANSARI and S. KNUTSSON (2014). Evaluation and mapping groundwater suitability for irrigation using Gis in Najaf Governorate, Iraq. *J. Environ. Hydrol*., 22, 1-16.

HORTON R.K. (1965). An index number system for rating water quality. *J. Water Pollut. Control. Fed.*, 37, 300-306.

JASSIM S.Z. and J.C. GOFF (2006). *Geology of Iraq*. First edition, Doline, Prague, Czech Republic, 341 p.

JEROME C. and A. PIUS (2010). Evaluation of water quality index and its impact on the quality of life in an industrial area in Bangalore, South India. *Am. J. Sci. Ind. Res.*, 1, 595-603.

KHALAF R.M. and W.H. HASSAN (2013). Evaluation of irrigation water quality index (IWQI) for Al-Dammam confined aquifer in the west and southwest of Karbala City, Iraq. *Int. J. Civ. Eng.*, 2, 21-34.

LAHLOU M., M. BADRAOUI, B. SOUDI, A. GOUMARI and D. TESSIER (2002). Modélisation de l'impact de l'irrigation sur le devenir salin et sodique des sols. Vers une maitrise des impacts environnementaux de l'irrigation. *Workshop PCSI*, 28-29 May 2002, Montpellier, France, Proceedings, 20 p.

LAMSAL K., G.N. PAUDYAL and M. SAEED (1999). Model for assessing impact of salinity on soil water availability and crop yield. *Agr. Water Manage.*, 41, 57-70.

MARLET S. and O.J. JOB (2006). Processus et gestion de la salinité des sols. In: *Traité d'irrigation*. 2nd edition, TIERCELIN J.R. and A. VIDAL (eds), Tec & Doc. Lavoisier, Paris, France, pp. 797-822.

MEIRELES A.C.M., E.M. DE ANDRADE, L.C.C. CHAVES, H. FRISCHKORN and L.A. CRISOSTOMO (2010). A new proposal of the classification of irrigation water. *Rev. Ciênc. Agron.*, 41, 349-357.

PASCAL S.D. and G. BARBIERI (1995). Effects of soil salinity from long-term irrigation with saline-sodic water on yield and quality of winter vegetable crops. *Sci. Hort*., 64, 145-157.

RICHARDS L.A. (1954). Diagnosis and improvement of saline and alkali soils. United States Salinity Laboratory, US Department of Agriculture, Agriculture Handbook N° 60, Washington (DC), USA, 166 p.

ROKBANI M.K., N.R. GUEDDARI and R. BOUHLILA (2011). Use of geographical information system and water quality index to assess groundwater quality in El Khairat deep aquifer Enfidha, Tunisian Sahel. Iran. *J. Energy Environ*., 22, 133-144.

SIMSEK C. and O. GUNDUZ (2007). IWQ Index: A GIS-integrated technique to assess irrigation water quality. *Environ. Monit. Assess.*, 128, 277-300.

YOGENDRA K. and E.T. PUTTAIAH (2008). Determination of water quality index and suitability of an urban waterbody in Shimoga Town, Karnataka. *Proceedings of Taal2007: The 12th World Lake Conference*, pp. 342-346.