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Assessment of the chemical quality of irrigation waters in the plain of Sidi Bel Abbès (northwestern Algeria).

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ABSTRACT/RESUME

Abstract: *The city of Sidi Bel Abbes is home to one of the most fertile plains of Algeria, where agriculture is mostly groundwater based. Unfortunately, the quality of this water resource has been considerably deteriorated by pollution over time. The present article aims to prove that the salinity hazard constitutes the main restrictive factor to the use of ground waters for irrigation in the plain of Sidi Bel Abbès. The chemical results demonstrate that ground waters are unbefitting for irrigation from a salinity point of view; the EC values show that said waters belong in their majority to the doubtful/unusable water class and the PS values reveal that their use for irrigation must be followed, either by an extensive leaching or by drainage of the irrigated soils. The chemical results also emphasize the toxicity of ground waters with respects to chloride. The concentrations in (Cl) exceed 350 mg/l for the majority of samples, making them harmful for most sensitive plants. On the other hand, the values of the ratios: SARadj, ESP, CROSS and PI illustrate that the sodium levels characterizing ground waters in the study area do not constitute a risk to the permeability, infiltration and structural stability of the soils in the plain of Sidi Bel Abbès.*

I. Introduction

Salinity and sodicity problems, whether due to soil composition, topography, type of climate or poor irrigation water are becoming a major concern.

According to Tóth *et al* (2008) [1], around 15% of the total land area of the world has been degraded by salinization. Dajic (2006) [2] on the other hand estimated the total surface of saline and sodic soils respectively around 397 and 434 Mha. In arid and semi-arid regions, around 10% of irrigated lands are degraded by salinity and sodicity (Meireles *et al*, 2010 [3]). In Africa for instance, affected surfaces estimated in 1980 exceeded 154 million hectares, with more than 3 million hectares in Algeria (Kovda, 1980 [4]).

Salinity can affect soil physical and chemical proprieties, notably the pH, the organic matter, the exchangeable sodium percentage (ESP), the cation exchange capacity (CEC) and the osmotic potential of the soil solution (Wang *et al*., 2014 [5]). Salinity can also decrease irrigation fittings performance and longevity, by either plugging drip line emitters and sprinklers or corroding metal equipments. As for sodicity, it can decrease soil infiltration, threaten its structural stability and reduce the availability of micronutrients such as iron, copper, manganese, phosphor, etc., for plants. Most salinity problems in non-polluted environments derive from salts transported by irrigation water.

In the plain of SBA, just like in many regions around the world, irrigated agriculture is depleting and polluting groundwater supplies, causing their overexploitation and deteriorating their chemical quality. The deterioration is aggravated in polluted environments, such as the plain of SBA (Ramdani, 2007 [6]; Bensalem, 2008 [7]; Bellaredj, 2018 [8]), where the salinity, sodicity and toxicity hazards are amplified due to the contamination of groundwater by wastewaters.

Numerous parameters found in the literature are used to define irrigation water quality; most, pertaining to salinity and sodicity, in addition to the concentrations (toxicity) of certain ions, especially chloride and boron.

The main objectives of this study are: 1) demonstrate that the salinity and chlorinity hazards of the polluted groundwater in the study area represent the major restrictive factor regarding their utilization for irrigation and 2) prove that the sodium levels of said groundwater do not pose a threat to the stability of the soils in the plain of SBA.

II. Materials and methods

II.1. Description of the study area

The plain of Sidi Bel Abbès (SBA) is an agricultural region by excellence. The agriculture is mostly groundwater based, due to the low and irregular precipitations characterizing the area. Most irrigation waters are pumped from the unconfined Plio-quaternary aquifer (PQA), which represents the major groundwater reservoir in the region. The aquifer is subjected to serious risks of deterioration due to pollution (domestic and industrial wastewaters, fertilizers and pesticides).

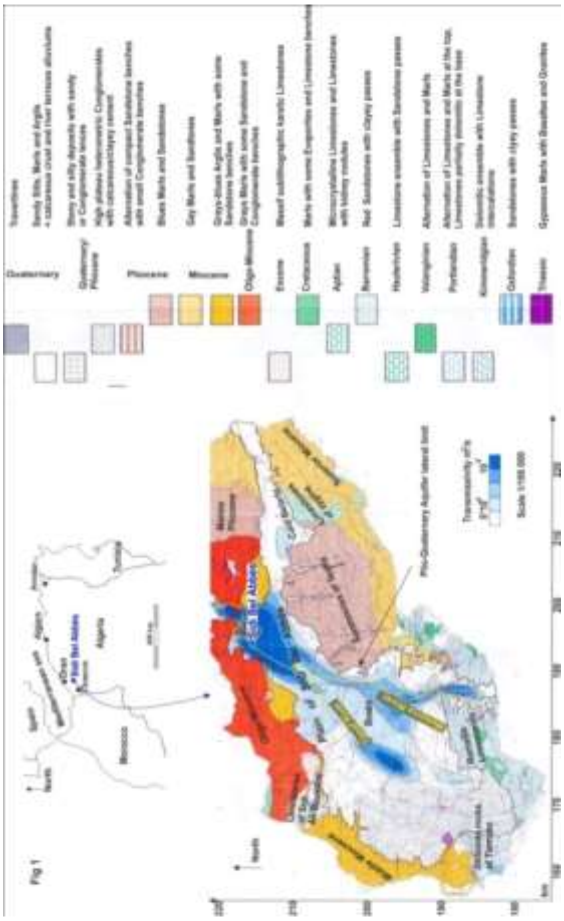

Figure 1*. General localization and hydrogeologic map of the study area (MH, 1974 [9]).*

II.2. Sampling locations

Samples utilized in this study are relative to the campaign undertaken by the “Agence Nationale des Ressources Hydriques d’Oran” [National agency of hydric resources of Oran] (ANRH), which concerned over 70 sites (Fig.2). All the samples were analyzed at the aforementioned agency’s laboratory. 50 samples whose percent charge balance error was inferior to 5% were utilized to assess the suitability of the PQA waters for irrigation.

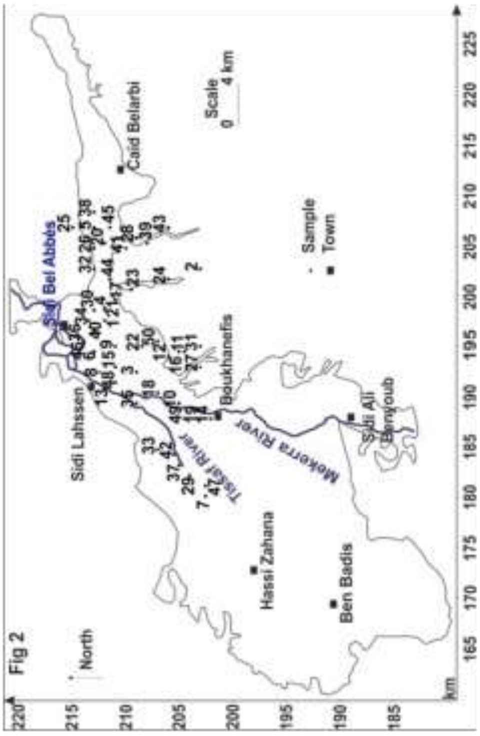

Figure 2. *Sampling sites.*

II.3. Methods*

Water salinity is either expressed in total dissolved solid (TDS in mg/l or ppm) or based on the electrical conductivity (EC) (also known as specific conductance) of the considered water (expressed in dS/m, or mmhos/cm). Both parameters (EC &TDS) are used to evaluate the osmotic effect of salts on crops growth. However, the EC is more practical, because it is easily measured in the field. Another parameter used to assess the salinity hazard is the potential salinity (PS) introduced by Doneen (1964) [10] and given by the formula:

$$PS = Cl - \frac{1}{2} SO_4 \qquad (1)$$

Due to the absence of data, the toxicity of the PQA waters was only tested with respect to the chlorides (Cl).

The sodicity hazard, which represents a very important factor when assessing irrigation water quality was evaluated for the PQA waters based on the following parameters:

- the Adjusted Sodium Adsorption Ratio (SARadj) :

$$SARadj = \frac{Na}{\sqrt{\frac{1}{2}(Ca_x + Mg)}} \qquad (2)$$

Ca_x : the calcium concentration expected to remain in soil-water (few millimeters near soil surface) after equilibrating with the $CaCO_3$ solid phase present in the soil (Ca_x is obtained using the HCO_3/Ca ratio and either Suarez (1981) [11] or Ayers and Westcot (1976) [12] tables.),

- the Sodium Percentage (Na%) (Wilcox, 1995 [13]; Todd, 2005 [14]):

$$Na\% = \frac{(Na \times 100)}{\sum cations} \qquad (3)$$

- the Residual Sodium Bicarbonate (RSBC)(Gupta, 1983 [15]): $RSBC = HCO_3 - Ca$ (4)

Another concern associated with poor irrigation water is the potential negative effect it can have on the structure of the soil. In most studies dealing with irrigation water quality, the Exchangeable Sodium Percentage (ESP, [16]) is considered an indicator of soil structural stability

$$ESP = \frac{100 \times ESR}{1 + ESR} \qquad (5)$$

With ESR : Exchangeable Sodium Ratio
($ESR = 0.01475\,SAR - 0.0126$)
The ESP however, does not include the effect of the exchangeable potassium on soil stability. To alleviate this problem, Rengasamy and Marchuk (2011) [17] proposed the Cation ratio of soil structural stability (CROSS), which does not consider the dispersive power of (Na, K) and the flocculating power of (Mg, Ca) to be identical. The CROSS ratio is defined by the formula:

$$CROSS = \frac{Na + 0.56K}{\sqrt{\frac{1}{2}(Ca + 0.6Mg)}} \qquad (6)$$

***Chemical elements in all equations are expressed in milli-equivalents/liter (meq/l)**

III. Results and discussion

III.1. Salinity

In the plain of SBA, the salinity of the PQA waters is mainly the result of pollution (Bellaredj, 2018 [8]). The latter considerably deteriorates the chemical quality (by augmenting their total salinity) of the PQA waters, especially North and East of the plain of SBA. Indeed, almost half of the samples (23) are either saline or extremely saline with TDS ranging from 3 to 5 g/l. Due to their contamination by sewages, most of the PQA samples are inappropriate for irrigation from a salinity point of view, as is clearly illustrated on Table 1.

Table 1. *Adaptation of the PQA waters for irrigation based on EC values.*

Classification	**EC(µS/cm)**	**N°of samples**
U.S.S.L,1954 [18]		
Excellent	100–250	-
Good	250–750	-
Doubtful	750–2250	11
Unusable	> 2250	39
Vasanthanvigar *et al.*,2010 [19]		
Excellent	< 250	-
Good	250–750	-
Permissible	750–2000	6
Doubtful	2000–3000	16
FAO (Mass, 1990 [20])		
Fresh	<700	-
Slightly saline	700– 3000	23
Moderately saline	3000– 6000	22
Saline	6000–14000	5
Highly saline	>14 000	-
Extremely saline	14 000– 42 000	-
brine	>42 000	-

The information in Table 2 shows that any usage of the PQA waters for irrigation must be followed by either an extensive leaching or drainage of the irrigated soils. In fact, and based on Doneen's classification (Doneen, 1962 [21]), which combines water quality, only 7 samples out 50 (belonging to the Class 2) can be used as irrigation waters (Table 3).

both the EC and PS parameters to assess irrigation

Table 2. *Recommendation use for irrigation waters (Bauder et al., 2010 [22]).*

Use limitation	**EC (µS/cm)**	**N° of samples**
None	≤ 750	-
little	750–1500	3
Moderate (extensive leaching required)	1500–3000	20
Severe (drainage necessary and culture of sensitive plants to be avoided)	≥ 3000	27

Table 3. *Classification of irrigation waters Doneen,1962 [21]).*

	Effect on soil			
	Minimal leaching and slow percolation	Moderate leaching and slow percolation in depth	Maximal leaching and rapid percolation in depth	**Class / Water quality**
PS*	3	5	7	1 / excellent to good
EC*	500	800	1200	
PS	3 – 5	5 – 10	7 – 15	2 / good to bad
EC	500–800	800–1700	1200–2500	
PS	> 5	> 10	> 15	3 / bad to unusable
EC	> 800	> 1700	> 2500	

From the above it appears clearly that the salinity risk is very high in the study area. The highest EC and PS values are located near Caïd Belarbi and especially around SBA's chef-lieu (Fig 1); the most populated/industrialized region in the study area and through which most of the polluted Mekkera River waters transit (Bensalem, 2008 [7]). The high salinity hazard in Caïd Belarbi and SBA's chef-lieu is also due to the small section, thickness and closeness to the surface of the aquifer in this region, which makes it more vulnerable to evapotranspiration, especially during drought periods.

III.2. Toxicity

In the study area, most of the PQA waters have Cl concentrations > 350 mg/l. According to Mass (1990) [20], exceeding this limit will cause severe problems for many crops. Only samples 11, 19 and 49 have Cl concentrations < 350 mg/l and can be used for sensitive cultures such as Onion, Carrot, Lettuce, etc. (Tanji, 1990 [23]). 12 samples with Cl concentrations oscillating between 525 and 875 mg/l can be used for more tolerant crops such as Corn, Potato, Cucumber, Tomato, etc. (Tanji, 1990 [23]).

The majority of samples with Cl concentrations < 875 mg/l are localized along the Rivers Mekerra and Tissaf, i.e., zones with low to medium salinity

(Bellaredj, 2018 [8]). In the plain of SBA, the high levels of salinity and Cl concentrations (most samples have Cl concentrations ranging from 1 to 2.5 g/l) of the PQA waters are the direct result of pollution by domestic and industrial wastewaters. All the PQA samples have a ratio ($\frac{Na}{Na + Cl} < 0.5$), which indicates according to Hounslow (1995) [24], the presence of an external source of chloride.

All the PQA samples have also a Revelle Indexe > 1 (meq/l) and a mean concentration of nitrates >10 mg/l (Fig. 3) which confirm their contamination by anthropogenic sources (Revelle, 1946 [25]; Blum *et al.*, 2002 [26]).

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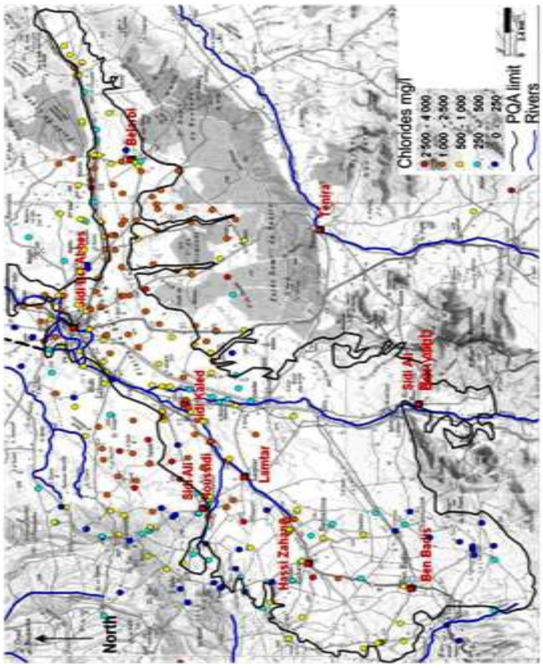

Figure 3. *Spatial variation of Chlorides in the study area (1970-2006)*

III.3. Sodicity

In the study area, the results show that the sodium hazard of the PQA waters is low and does not constitute a restrictive factor to their use as irrigation waters; all the PQA samples present low to medium SARadj values and belong either to the excellent or good water class (Table 4).

Fig 4a reveals that most samples belong to the classes 4 and 5. According to Mohan and al., 2000 [27], these types of waters should only be used for high salt tolerance cultures and with restrains, especially for low drainage soils.

From Fig 4b (projection of about 15 samples out of the diagram (Na vs EC)) and Table 4, it is clear that in comparison to the sodium levels, the salinity of the PQA waters represents the major hazard in the study area.

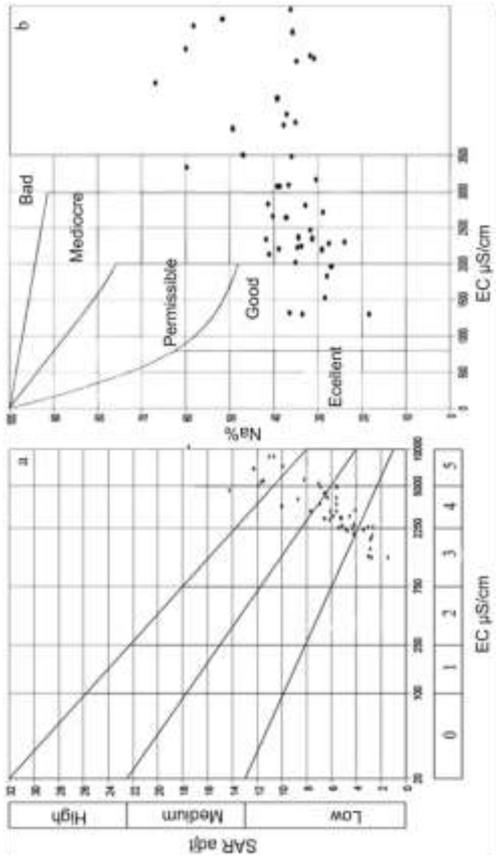

Figure 4. *SARadj vs CE (U.S.S.L, 1954 [18]) and b) Diagram Na% VS CE (Wilcox, 1995 [13]).*

Table 4. *Sodicity parameters of the PQA waters.*

	Range	Quality	N° of samples
SARadj	< 10	Excellent	41
	10 – 18	Good	9
	19 – 26	Mediocre	-
	> 26	Bad	-
NA %	0–20	Excellent	1
	20–40	Good	33
	40–60	Admissible	13
	60–80	Mediocre	3

	80–100	Bad	-
ESP	< 6	Non sodic	18
	06–10	Moderately sodic	32
	10 – 15	Sodic	-
	15 - 25	Strongly sodic	
	> 25	Very sodic	-

III.4. Effects of salinity and sodicity on soils

According to Michael (1978) [28], when the ratios Mg/Ca and Na/Ca are inferior respectively to 4 and 3 (meq/l), soil dispersion and infiltration problems are unlikely to occur due to the presence of sufficient Ca to counter the dispersing effect of Na. In the study area, only samples 5, 26, 32 and 38 have Mg/Ca and/or Na/Ca ratios exceeding those limits, indicating that the PQA waters are unlikely to cause soil dispersion and infiltration problems in the plain of SBA. A conclusion also confirmed by the information depicted on Table 5 and Fig 5.

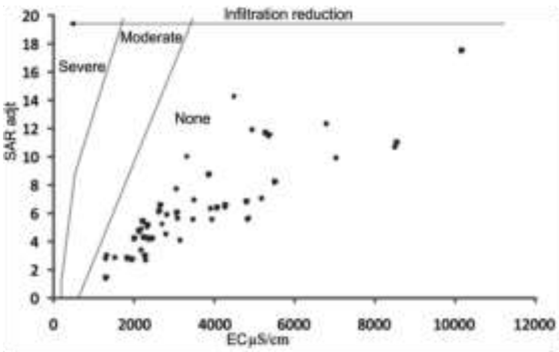

Figure 5. *Effects of on soil infiltration (Rhoades, 1977 [29]; Oster et al., 1979 [30]).*

In the study area, the Mg concentrations are relatively elevated. Indeed, half of the samples have a Mg% > 40 %.

$$Mg\ \% = \frac{Mg \times 100}{Mg + Ca} \qquad (7)$$ (Ragunath 1987 [31]),

In light of that we calculated the CROSS ratio. The latter compared to the SAR and ESP permits a better appreciation of the effects of monovalent cations Na and K on soil dispersion and divalent cations Ca and Mg on flocculation (Emerson and Bakker, 1973 [32]; Chen *et al.*, 1983 [33]; Rengasamy *et al.*, 1986 [34]; Rengasamy, 2002 [35];Rengasamy and Marchuk, 2011[17]). The values of the CROSS ratio for all samples in the study area (mean for all samples = 4 meq/l) were found to be well below the threshold for good irrigation water.

Table 5. Effects of the EC and SAR on soil infiltration (Ayers and Westcot, 1976 [12]; Oster *et al.*, 1979 [30]).

	EC (dS/m)	≤ 0,7	0,7 – 3	3 – 6	6 – 14	> 14
Reduction of infiltration based on SAR values	none	< 1	< 10	< 25	< 35	no effect
	slight	15	10 à 15	> 25	> 35	no effect
	medium	5 à11	11 à 23	no effect	no effect	no effect
	Severe	> 11	> 23	no effect	no effect	no effect
	SAR	0–3	3–6	6–12	12–20	20–40
Infiltration problems based on EC variations (dS/cm)	improbable	> 0,7	> 1,2	> 1,9	> 2,9	> 5
	Probable	< 0,2	< 0,4	< 0,5	< 1	< 3

Another major negative effect associated with poor irrigation water is soil permeability reduction. According to Doneen (1964) [10] and Ragunath (1987) [31], the predisposition of any water for irrigation can be assessed based on a permeability index (PI) given in (meq/l) as follow:

$$PI = \frac{Na + \sqrt{HCO_3}}{\sum cations} \qquad (8)$$

Waters are classified as Class 1 and Class 2, representing waters, which are good for irrigation (50–75% or more of maximum permeability), whereas Class 3, waters that are considered

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unsuitable for irrigation (with 25% of maximum permeability). All the PQA samples belong to the Class 1(Fig 6), i.e., waters that are not susceptible to induce soil permeability problems.

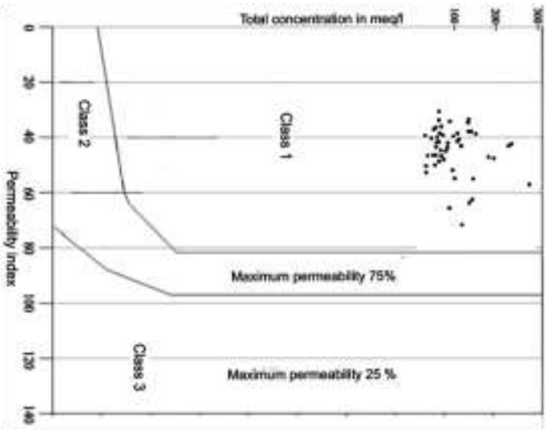

Figure 6. *PQA waters class based on the PI.*

IV. Conclusion

The hydrochemical study of the PQA waters reveals a significant salinity hazard regarding their use in irrigation. In fact, more than half of the samples analyzed show EC values exceeding 3000 (µS/cm). The chemical results show that the usage of most samples in irrigation must be followed either by extensive leaching or by
drainage of the farming lands. The salinity hazard of the PQA waters is mainly attributed to their contamination by domestic and industrial wastewaters. The latter being not only a consequence of the deficiency of sanitization networks and plants in the area, but also the result of the non-application of the legislations regarding the protection of the environment.
The contamination by sewages of the PQA waters is also confirmed by their high concentrations in chloride. As a result, the majority of samples are inappropriate for most sensitive plants.
The chemical analysis of the PQA waters demonstrates that their use in irrigation presents a low sodium and magnesium hazard as shown by the SARadj, NA%, and MAR values. In addition, the low values of the PI, ESP and CROSS-ratio confirmed that the PQA waters do not pose a threat to the quality of the soils in the plain of SBA.

V. References

1. Tóth, G.; Montanarella, L.; Rusco, E. Updated Map of Salt Affected Soils in the European Union.Threats to Soil Quality in Europe. *Official Publications of the European Communities. Luxembourg,* (2008) 61–74.
2. Dajic, Z. Salt Stress. In : Madhava Rao KV, Raghavendra AS, Janardhan Reddy K, Physiology and Molecular Biology of Stress Tolerance. *Dordrecht,* (2006) 41–99.
3. Meireles, A.C.M.; Maia de Andrade, E.; Guerreiro Chaves, L.C.; Frischkorn, H.; Crisostomo, L.A. A new proposal of the classification of irrigation water. *Revista Ciencia Agronomica*, 41(03) (2010)349-357.
4. Kovda, V.A. Problem of combating salinization of irrigated soils. *Centre for International Projects, Moscow*, (1980).
5. Wang, L.; Sun, X.; Li, S.; Zhang, T.; Zhang, W.; Zhai, P. Application of organic amendments to a coastal saline soil in North China: Effects on soil physical and chemical properties and tree growth. *PLoS ONE*, 2014, 9(2): e89185.
6. Ramdani, N. Contribution à l'étude des boues urbaines de la station d'épuration des eaux usées résiduaires; effets sur la fertilité d'un sol sableux. *Dissertation, Magister, University of Oran*, 2007.
7. Bensalem, M.B. Contribution à l'étude de l'efficacité de l'épuration des eaux usées dans la ville de Sidi Bel Abbès. *Dissertation, Magister, University of Djillali Liabes*, 2008.
8. Bellaredj, A. El M.; Hamidi, M. The hydrochemical characterization of the underground waters of the plain of Sidi Bel Abbès (northwestern Algeria). *Algerian J. Env. Sc. Technology*, 4(1)(2018)671–682.
9. (MH) Ministère de l'hydraulique et de la mise en valeur des terres et de l'environnement. Carte hydrogéologique de la plaine de Sidi Bel Abbes au 1/100 000. Notice explicative + carte. Oran, Algeria, 1978.
10. Doneen, L.D. Notes on water quality in agriculture. In Water Science and Engineering. Dept. of Water, Science and Engineering, *Univ. of California, Davis*, 1964, Paper 4001.
11. Suarez, D.L. Relation between pHs and Sodium Adsorption Ration (SAR) and alternate method of estimating SAR of soil or drainage waters. *Soil Science Society of America Journal*, 45(1981) 469-475.
12. Ayers, R.S.; Westcot, D.W. Water quality for agriculture. *FAO irrigation and drainage paper*, 1979, 29 (rev 1).
13. Wilcox, L.V. Classification and use of irrigation waters. *US Department of Agriculture, Washington DC*, 1995.
14. Todd, D.K.; Mays, L.W. Groundwater hydrology. *John Wiley & Sons, Inc. NJ, USA*, 2005.
15. Gupta, S.K. Variations of water table in Yamuna drainage basin of Haryana-implications and management strategies. *Paper presented at the Seminar on Strategies for Irrigation Water Management, Patna*, 1983.
16. Bower, C.A. Cation exchange equilibrium in soils affected by sodium salts. *Soil Science*, 88(1959) 32-35.
17. Rengasamy, P.; Marchuk, A. Cation ratio of soil structural stability (CROSS). *Soil Research*, 49(2011)280-285.
18. U.S.S.L. Diagnosis and Improvement of Saline and Alkaline Soils. Washington, DC, 1954.

19. Vasanthavigar, M.; Srinivasamoorthy, K.; Rajiv Gantha, R.; Vijayaraghavan, K.; Sarma, V.S. Characterization and quality assessment of groundwater with special emphasis on irrigation utility: Thirumanimuttar sub-basin, Tamil Nadu, India. *Arabian Journal of Geosciences*, 5(2010)245-258
20. Mass. Crop salt tolerance. Agricultural Assessment and Management Manual. In: K.K. Tanji (ed) Agricultural Salinity Assessment and Management, *ASCE, New York*, (1990) 262-304.
21. Doneen, L.D. The influence of crop and soil on percolating water. *In Proceedings of the Biennial Conference on Ground Water Recharge*, (1962)156–163.
22. Bauder, T.A.; Waskom, R.M.; Davis, J.G. Irrigation Water Quality Criteria. *Colorado State University Extension, Colorado, USA*, 2010.
23. Tanji, K.K. Agricultural Salinity Assessment and Management. *ASCE, New York*, 1990.
24. Hounslow, A.W. Water quality data: Analysis and interpretation. *CRC Press*, *Lewis Publishers, Boca Raton*, 1995.
25. Revelle, R. Criteria for recognition of seawater. *Transactions of the American Geophysical Union*, 22(1946) 541-593.
26. Blum, A.; Chery, L.; Barbier, J.; Baudry, D.; Petelet-Giraud, E. Contribution à la caractérisation des états de référence géochimique des eaux souterraines. Outils et méthodologie. *Rapport BRGM/RP-51549-FR*, 2002, 5 volumes.
27. Mohan, R.; Singh, A.K.; Tripathi, J.K. Hydrochemistry and quality assessment of ground water in Naini Industrial area, Allahabad district, Uttar Pradesh. *Journal of the Geological Society of India*, 55(2000) 77–89.
28. Michael, A.M. Irrigation theory and practices. *Vikas Publishing, New Delhi*, 1978.
29. Rhoades, J.D. Potential for using saline agricultural drainage waters for irrigation. *Proceedings from Water Management for Irrigation and Drainage. American Society of Civil Engineers, Reno, Nevada*, USA, 1977.
30. Oster, J.D.; Schroer, W. Infiltration as influenced by irrigation water quality. *Soil Science Society of America Journal*, 43(1979) 444-447.
31. Ragunath, H.M. Groundwater. Wiley *Eastern Ltd, New Delhi*, 1987.
32. Emerson, W.W.; Bakker, A.C. The comparative effects of exchangeable calcium, magnesium, and sodium on some physical properties of red-brown earth subsoils. The spontaneous dispersion of aggregates in water. *Australian Journal of Soil Research*, 11(1973) 151-157.
33. Chen, Y.; Banin, A.; Borochovitch, A. Effect of potassium on soil structure in relation to hydraulic conductivity. *Geoderma* 30, (1983) 135-147.
34. Rengasamy, P.; Greene, R.S.B.; Ford, G.W. Influence of magnesium on aggregate stability in sodic redbrown earths. *Australian Journal of Soil Research*, 24(1986) 229-237.
35. Rengasamy, P. Clay dispersion. In : McKenzie B.M. *et al* (ed), Soil physical measurement and interpretation for land evaluation. *CSIRO Publishing, Collingwood*, (2002) 200-210.

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