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Qualitative assessment of the waters of the coastal aquifer Ghis-Nekor (Central Rif, Northern Morocco) in view of agricultural use

Said Benyoussef[1), 2)], Mourad Arabi[3)] ✉, Hossain El Ouarghi[2)], Mohammad Ghalit[4)], Yassine El Yousfi[2)], Maryam Azirar[1)], Ali Ait Boughrous[1)]

1) University of Moulay Ismaïl, Faculty of Science and Technology Errachidia, Department of Biology, Research team: Biology, Environment and Health, Meknes, Morocco

2) Abdelmalek Essaadi University, National School of Applied Sciences, Laboratory of Applied Sciences, Al Hoceima, Morocco

3) Mohamed First University, Faculty of Sciences, Department of Biology, Laboratory of the Agricultural Production Improvement, Biotechnology, and Environment, P.B. 717, Oujda, Morocco

4) Mohammed Premier University, Faculty of Science, Department of Chemistry, Laboratory of Mineral and Analytical Solid Chemistry, Oujda, Morocco

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Abstract: The rainfall irregularity in the Al-Hoceima area places the Ghis-Nekor coastal aquifer as a primary resource for water supply. However, it is of paramount priority to adopt management and optimization plans that can mitigate the effects of the irrational use of the resource and the deterioration of its quality in the region of our study. In order to study the alteration aspects of this aquifer, 26 wells were sampled and their suitability for irrigation was assessed. The sodium adsorption rate (SAR) values indicate that most groundwater samples fall into the risk classes of high salinity and low sodium (C3-S1) and high salinity and medium sodium (C3-S2). The results also show a medium to high alkalinity risk due to the high concentration of HCO_3^-. The excess of salts is largely due to the intensive exploitation of groundwater and to the phenomenon of salt-water intrusion into the coastal karst aquifer. As a result, the quality of groundwater is not adapted to sustainable agricultural production and soil balance, which requires controlled monitoring to ensure its rational use with a view to the sustainable development of the region.

Keywords: aquifer, Ghis-Nekor, groundwater, irrigation, quality, salinity

INTRODUCTION

Water resources in the Central Rif are insufficient for agricultural activities at the area level. It is therefore essential to use underground resources to meet the needs. Indeed, such intensive irrigation use of groundwater in coastal areas degrades its quality and quantity, which can lead to a negative water balance, resulting in salt-water intrusion [Prasanth *et al.* 2012]. The qualitative aspect of groundwater is a more important axis for the approval of its consumption, use for irrigation and industrial purposes [Nagaraju *et al.* 2014]. For surface water source, this area has two dams: Mohamed Ben Abdelkrim Al Khattabi (MBAK) fed by the Nekor Watershed and the new Aghzar Ghis Dam (under construction), which is established in the Ghis Watershed, thus, it contains a very large network of wells [Chafouq *et al.* 2018]. We note that despite the presence of the MBAK dam, the problem of dam silting prevents the exploitation of its water sources [Arrebei *et al.* 2019]. As a result, the use of groundwater is necessary in many situations. In addition, the climatic context is generally of the semi-arid Mediterranean type, with an alternation of two seasons (dry and wet) [HCP 2017].

In this context of fragility, the objective of this study is to assess the spatial extent of groundwater quality and to examine its suitability for the different specific agricultural uses in the region.

MATERIALS AND METHODS

STUDY AREA

The Ghis-Nekor plain (North of Morocco) is bordered in the North by the Mediterranean Sea, in the West by the commune of Ajdir and the Douars of Ait Youssef or Ali and the MBAK dam in the South, and in the East by the commune of Trougout (Fig. 1).

The plain is an intra-mountainous valley occupied by a heterogeneous alluvial filling made up of sands, gravel and conglomerates of the Plio-Quaternary and the Actual [Mourier 1982]. It is also characterized by a semi-arid climate with alternating two dry and wet seasons [Chafouq *et al.* 2018]. In this area, due to the lack of surface water, the majority of water needs for irrigation are met by the use of groundwater.

METHODS

Samples were collected in 2019 from 26 wells distributed in abundance thanks to agricultural activity in the study area.

Hydrogen potential (pH), electrical conductivity (*EC*) and total dissolved solids (*TDS*) were measured in situ using a portable multi-meter (HANNA, HI 991300). The concentrations of the major chemical elements were determined in the laboratory according to the methods recommended by Jean Rodier [Rodier 2009]. Chlorides (Cl^-), bicarbonates (HCO_3^-), total hardness (*TH*) and calcium ions (Ca^{2+}) were analysed using titrimetric methods. Magnesium (Mg^{2+}) concentrations were calculated from *TH* and calcium levels. The sodium (Na^+) and potassium (K^+) concentrations were determined by flame spectrophotometer, while nitrogen ions (NO_3^-, NO_2^-, and NH_4^+) and sulphates (SO_4^-) were measured using the ultraviolet spectrophotometer (UV 12000). The Geographic Information System (GIS) was used to perform a spatial projection of various parameters analysed, using the inverse-distance-weighted interpolation (IDW) technique. To identify all potential Pearson correlation relationships for all results obtained, a statistical analysis was performed using the software (IBM SPSS Statistics version 25).

The study was complemented by the assessment of the suitability of groundwater quality for irrigation, thus, indices such as residual sodium carbonate index (*RSC*, in meq·dm^{-3}) and the sodium adsorption ratio (*SAR*, in meq·dm^{-3}) were calculated through the following equations:

$$SAR = \frac{\mathrm{Na}^+}{\sqrt{(\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+})/2}} \tag{1}$$

$$Na(\%) = \frac{(\mathrm{Na}^+ + \mathrm{K}^+)\,100}{(\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+} + \mathrm{Na}^+ + \mathrm{K}^+)} \tag{2}$$

$$RSC = (\mathrm{CO_3}^{2-} + \mathrm{HCO_3}^-) - (\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+}) \tag{3}$$

RESULTS AND DISCUSSION

HYDROCHEMISTRY

Results of assessed indicators and physicochemical parameters (pH, *EC*, *TDS*, Ca^{2+}, Mg^{2+}, Na^+; K^+, Cl^-, SO_4^{2-}, HCO_3^-, CO_3^{2-}, *SAR*, *RSC*, and *Na*), are presented in Table 1.

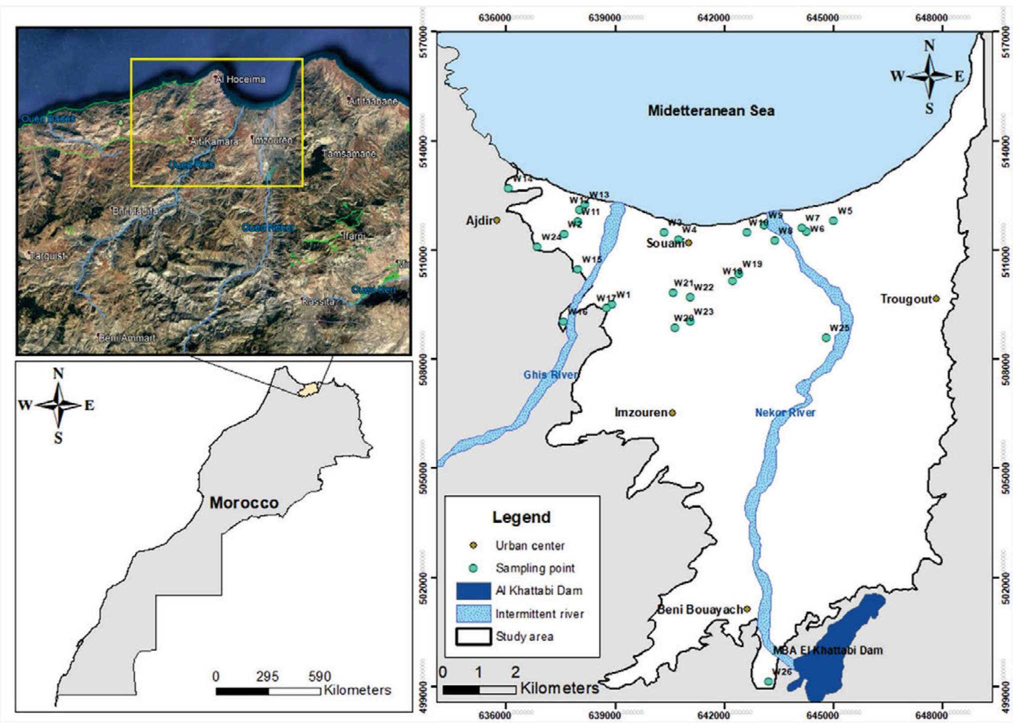

Fig. 1. Geographical situation of the sampled groundwater; source: own elaboration

Table 1. Physicochemical composition and irrigation quality parameters of the groundwater samples from the Ghis-Nekor plain

Sample	pH	*EC* (μS·cm^{-1})	*TDS* (mg·dm^{-3})	Ca^{2-}	Mg^{2-}	Na^{-}	K^{-}	Cl^{-}	SO_4^{2-}	HCO_3^{-}	CO_3^{2-}	*SAR*	*RSC*	*Na*(%)
				meq·dm^{-3}										
w1	6.65	2170	1085	12.80	11.45	17.14	0.20	710	15.46	6.30	0	4.92	−17.96	41.69
w2	7.02	1762	882	12.40	12.20	14.75	0.31	426	15.14	7.50	0	4.20	−17.10	37.97
w3	7.17	4142	1806	16.40	16.59	24.38	0.15	1029.5	25.65	7.50	0	6.00	−25.49	42.64
w4	7.12	3640	2095	13.20	13.03	19.68	0.12	674.5	19.68	6.60	0	5.43	−19.64	43.01
w5	7.79	2039	1021	10.40	10.66	17.16	0.05	532.5	14.79	5.90	0	5.29	−15.17	44.96
w6	6.88	5440	2718	14.00	12.64	21.79	0.15	887.5	14.67	10.40	0	5.97	−16.24	45.16
w7	7.04	2347	1162	10.80	9.87	19.18	0.15	639.0	9.86	9.10	0	5.97	−11.58	48.32
w8	7.16	6472	2043	18.00	19.35	25.95	0.16	1065.0	32.74	7.30	0	6.00	−30.06	41.13
w9	7.56	5594	2803	17.20	15.01	20.34	0.20	852.0	23.10	5.10	0	5.07	−27.11	38.93
w10	7.28	3568	1784	12.40	9.48	14.11	0.14	461.5	12.88	5.60	0	4.27	−16.28	39.45
w11	7.34	2586	1359	9.20	8.29	10.74	0.16	355.0	9.48	5.40	0	3.63	−12.10	38.39
w12	7.57	1632	815	11.20	9.08	12.44	0.18	390.5	10.90	6.70	0	3.91	−13.59	38.35
w13	7.23	3508	1756	11.60	10.66	16.03	0.12	781.0	13.09	6.50	0	4.80	−15.77	42.04
w14	7.80	4389	2200	4.80	7.11	21.81	1.00	852.0	7.98	4.00	0	8.94	−7.91	65.70
w15	7.17	1498	749	12.30	6.71	11.24	0.09	461.5	8.79	3.66	0	3.65	−15.36	37.34
w16	7.40	3212	1610	1.92	10.27	13.05	0.13	532.5	9.19	5.70	0	5.29	−6.49	51.95
w17	7.45	3684	1055	12.40	14.22	15.55	0.22	532.5	13.63	5.90	0	4.26	−20.72	37.20
w18	7.35	3299	1230	11.60	9.48	13.46	0.08	532.5	10.88	5.00	0	4.15	−16.08	39.12
w19	7.18	3467	1734	12.80	9.87	13.75	0.08	568.0	11.28	5.10	0	4.08	−17.58	37.88
w20	6.74	6254	3129	18.00	18.96	22.27	0.17	923.0	24.10	8.90	0	5.18	−28.06	37.78
w21	6.97	5739	2871	16.40	17.77	20.44	0.12	958.5	20.34	6.90	0	4.95	−27.28	37.57
w22	7.11	2983	1490	16.80	16.59	20.64	0.12	958.5	21.45	7.00	0	5.05	−26.39	38.33
w23	8.78	4335	2167	7.60	8.69	18.23	0.16	781.0	12.21	2.30	30	6.39	−13.99	53.02
w24	7.26	6746	3372	8.40	12.24	26.23	0.47	1278.0	10.95	0.90	0	8.16	−19.74	56.40
w25	7.15	2477	1236	17.60	14.61	16.70	0.10	710.0	18.86	5.40	0	4.16	−26.82	34.28
w26	6.96	6264	3134	12.00	12.24	32.38	0.22	1349.0	11.40	10.30	0	9.30	−13.95	57.35
Min	6.65	1498	749	1.92	6.71	10.74	0.05	355.00	7.98	0.90	0	3.63	−30.06	34.28
Max	8.78	6746	3372	18.00	19.35	32.38	1.00	1349.00	32.74	10.40	30.00	9.30	−6.49	65.70
Avg	7.27	3817	1819	12.39	12.20	18.44	0.19	740.04	15.33	6.19	1.15	5.35	−18.40	43.31
SD	0.41	1613.96	785.31	3.97	3.54	5.19	0.18	266.17	6.18	2.16	5.88	1.50	6.39	7.70

Explanations: *EC* = electrical conductivity, *TDS* = total dissolved solids, *SAR* = sodium adsorption ratio, *RSC* = residual sodium carbonate index, avg = average, *SD* = standard deviation.
Source: own study.

The pH values range from 6.65 to 8.78, with an average value of 7.27. This shows that the groundwater in the study area is primarily alkaline. *EC* values range from 1498 to 6746 μS·cm^{-1}. Unsuitable values for irrigation (i.e. *EC* values higher than 3000 μS·cm^{-1}; see Tab. 2) were measured at 65.38% of the sites studied where crop yield is significantly affected [Wilcox 1955].

Water uptake by the plants decreases due to increased mineralization and negatively affects production [Ahamed *et al.* 2013]. Chloride (Cl^{-}) concentrations ranged from 355 to 1349 mg·dm^{-3} (Tab. 1) with an average of 740.04 mg·dm^{-3}.

According to the classification of van der Aa [2003] (Tab. 2), the majority of samples are of high salinity. Indeed, the high salinity of the prospected groundwater can probably be the result of several factors such as the lithology, climate [Bekkouch, Zanagui 2018], the phenomenon of marine intrusion [Chafouq *et al.* 2018; Saaidia *et al.* 2017] due to the proximity of the study area to the coastline, as well as the anthropic activities [Barakat *et al.* 2020]. As for chlorides in groundwater, it can have various origins, such as rock alteration and leaching from sedimentary soils, salt water intrusion, domestic and industrial waste discharges, etc. [Karanth 1987]. Thus, the excessive concentration in chlorides indicates a groundwater contamination [Loizidou, Kapetanios 1993]. However, *TDS* values range from 372 to 749 mg·dm^{-3}.

Table 2. Classification of groundwater based on Cl^-, *TDS*, *EC*, *Na* %, *SAR*, *RSC* in the study area

Parameters	Range	Water class	Total samples	Percentage
Cl^- (mg·dm^{-3}) [van der Aa 2003]	<5	fresh	–	–
	5–30	slightly saline	–	–
	30–150	saline	–	–
	150–300	more saline	–	–
	300–1000	very saline	26	100
TDS (mg·dm^{-3}) [Davis, De Wiest 1966]	<3000	useful for irrigation	23	88.46
	>3000	unfit for irrigation	3	11.53
EC (μS·cm^{-1}) [Wilcox 1955]	<250	excellent	–	–
	250–750	good	–	–
	750–2000	permissible	3	11.53
	2000–3000	doubtful	6	23.07
	>3000	unsuitable	17	65.38
Na(%) [Wilcox 1955]	<20	excellent	–	–
	20–40	good	13	50
	40–60	permissible	12	46.15
	60–80	doubtful	1	3.84
	>80	unsuitable	–	–
SAR (meq·dm^{-3}) [Richards 1954]	<10	excellent	26	100
	10–18	good	–	–
	18–26	doubtful	–	–
	>26	unsuitable	–	–
RSC (meq·dm^{-3}) [Richards 1954]	<1.25	good	26	100
	1.25–2.50	doubtful	–	–
	>2.50	unsuitable	–	–

Explanations: *TDS* = total dissolved solids, *EC* = electrical conductivity, *SAR* = sodium adsorption ratio, *RSC* = residual sodium carbonate index. Source: own study.

Leaching of salts from the soil and infiltration of domestic wastewater into wells have been shown to be responsible for the high concentration of soluble salts in groundwater [Prasanth *et al.* 2012]. Based on the Davis and De Wiest [1966] *TDS* groundwater classification (Tab. 2), 88.46% of groundwater samples are within the maximum allowable limits for irrigation (*TDS* < 3000 mg·dm^{-3}) and 11.53% are unsuitable for irrigation (*TDS* > 3000 mg·dm^{-3}). As a result, these salt concentrations in the sampled well waters highlight a possible impact of domestic wastewater on groundwater salinization in the Ghis-Nekor region.

SUITABILITY FOR USE IN IRRIGATION

- **Percentage of sodium (*Na*%)**

The percentage of Na is a very important factor used in the classification of water for irrigation. Sodium reacts with soil, and its excess can affect soil structure, resulting in reduced permeability and aeration, which decreases crop yield [Raju 1992; Singh *et al.* 2009]. According to the Wilcox classification [Wilcox 1955], the percentage of Na in the water from the wells studied indicates that the water table is "good to permissible" for irrigation, with the exception of a sample w14 (Tab. 1, 2). Thereby, the Wilcox diagram (Fig. 2) showing the percentage of water soluble sodium as a function of the *EC* reveals that most groundwater samples are into the category of "doubtful and not suitable for irrigation" due to the very high mineralization and conductivity [Boujghad *et al.* 2019], with the exception of a few samples in the "good to acceptable" category.

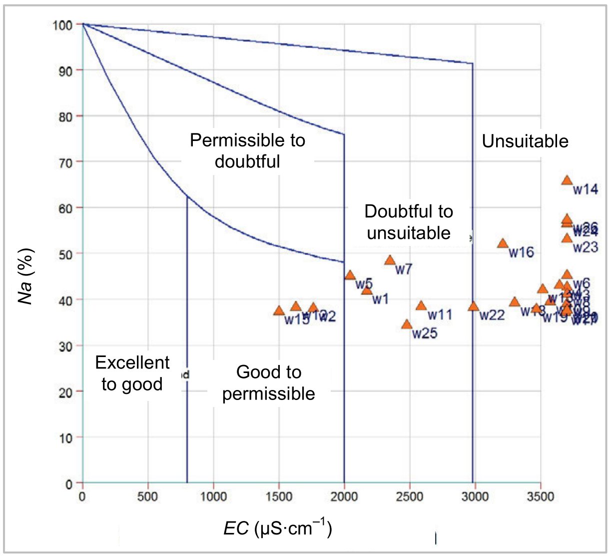

Fig. 2. Suitability of the groundwater studied for irrigation in the Wilcox diagram; source: own study

- **Sodium adsorption report (*SAR*)**

Excess sodium in water can reduce the permeability and ability of the soil to form stable aggregates, resulting in loss of soil structure [Prasanth *et al.* 2012]. According to Richards [1954], the classification of groundwater in the Ghis-Nekor plain coastal aquifer indicates that 100% of the samples are in the "excellent at irrigation" category (Tab. 2), while the Richards diagram in which the *EC* is taken as a salinity risk and the *SAR* as an alkalinity risk shows that, the water samples belong to categories C3-S1, C3-S2, C4-S2 and C4-S3 (Fig. 3). This explains that the samples are medium or strongly alkaline with high salinity.

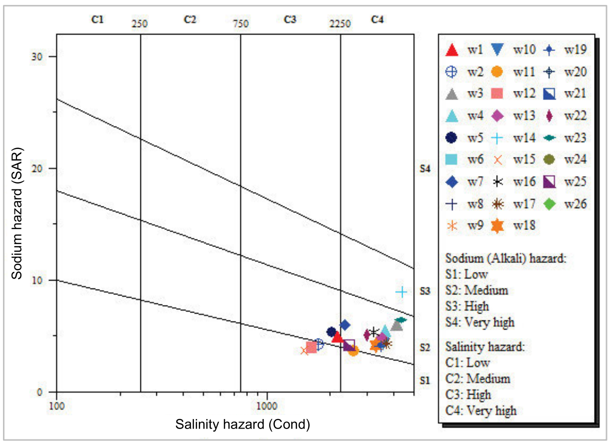

Fig. 3. Ghis-Nekor plain groundwater quality classification for irrigation, based on the Richards method; source: own study

- **Residual sodium carbonate (*RSC*)**

One of the most important criteria for determining the impact of CO_2 and HCO_3^- on irrigation quality is *RSC* [Eaton 1950; Richards 1954]. *RSC* is used as an indication of soil alkalinity risk [Al Numakbakth *et al.* 2019]. The study shows that 100% of water samples are of good quality for agriculture (Tab. 2). Groundwater in the study area has *RSC* values ranging from –30.06 to –6.06 meq·dm^{-3} with an average of –18.40 meq·dm^{-3} (Tab. 1).

CONCLUSIONS

In this study, groundwater resources were assessed by their chemical composition and their suitability for irrigation. Hydrochemical data reveal that the waters sampled near the coastal aquifer of the Ghis-Nekor plain are saline and have high amounts of Cl^-, Na^+, SO_3^{2-}, Ca^{2+} and Mg^{2+} ions. The Wilcox classification, as observed during the year 2019, shows that a high proportion of the samples studied are of a "good to acceptable" nature for irrigation. The Richards diagram linking the *SAR* and the *EC* also showed that most of the samples studied, which are often used for irrigation, present a very high risk of salinity (Class C3 and C4). In addition, the *RSC* indicates a medium to high alkalinity risk due to the high concentration of HCO_3^-.

In summary, the results of this study reveal that the quality of groundwater for irrigation in the study sites requires a reconsideration of spatial irrigation methods in order to control their high salinity while selecting salt-water tolerant crops, to improve the yield of agricultural production. However, the continued use of these waters in the long term could increase salinity and alkalinity problems in the soils.

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