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Quality assessment of groundwater in the region of Laayoune-Dakhla (southern Sahara Morocco) for drinking and irrigation purposes

K. Mizeb[a], M. Doubi[a]*, M. Ghalit[b], M. El Kanti[c], T. HACHI[e], E.H. Abba[d], H. Erramli[a]

(a)Laboratory of organic chemistry, inorganic, electrochemistry, and environment, Faculty of Science, University Ibn Tofail, B.P 133, 1400, Kenitra, Morocco
(b)Solid Mineral Chemistry, Applied Chemistry and Environment Laboratory, Faculty of Sciences, Mohammed First University, Oujda, Morocco
(c) Hydraulic Basin Agency of Sakia El Hamra and Oued Eddahab
(d) Higher School of Technology khenifra
(e) Laboratory of Agro- physiology, Biotechnology, Environment, and Quality, Department of Biology, Ibn Tofail University, Faculty of Science, Kenitra, Morocco

* Correspondent:
doubi_mostafa@yahoo.fr
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Abstract

The study aimed to understand the quality of groundwater in the Laayoune-Dakhla region, in southern Sahara Morocco. Groundwater samples from 30 wells were collected and analyzed for their physical and chemical properties were collected and carefully studied for their physical and chemical properties (T, pH, EC, NO_3^-, Cl^-, HCO_3^-, SO_4^{2-}, Ca^{2+}, Mg^{2+}, K^+ and Na^+). Based on the data analyzed, we classified the water and calculated some parameters such as sodium adsorption (SAR), the sodium percentage (%Na), the residual sodium carbonate (RSC) and the Magnesium adsorption (%Mg) for each water sample in order to know the suitability for drinking and irrigation. The results showed high levels of salts for most of the water samples studied, where the EC values ranged from 1290 to 6895 µS/cm. According to the water classification based on TDS, 80% of the samples showed very high mineralization. 96.66% of the samples studied were very hard and unfit for human consumption. Also, estimated parameters such as Na% and SAR were within appropriate levels for irrigation, while EC and Cl^- values for most samples were within limits inappropriate for irrigation. According to the Piper diagram 86.66% of the waters are characterized by a sodium chloride facies and 13.33% sulphated calcium. Principal component analysis (PCA) shows that the mineralization of the waters of Laâyoune-Dakhla is of natural origin.

Keywords: *Groundwater quality, classification, agricultural, PCA, Laayoune-Dakhla*

1. Introduction

In developing countries with arid climates, the role of groundwater is all the more important as it is often the only source of drinking water supply and is therefore vital for the development of these countries. Groundwater is one of earth's most vital renewable and widely distributed resources as well as an important source of water supply throughout the world [1]. Over the past decades, the demand for irrigation water has increased worldwide. Globally, around 43% of groundwater is used for agricultural irrigation and this will increase by a further 14% by 2030 [2]. To meet the ever-increasing water needs with the demographic explosion of Moroccan cities, agricultural and industrial extension, the excessive withdrawal of groundwater has resulted in the depletion and deterioration of underground aquifers [2, 3, 4, 5]. The choice of this aquifer is based on the facts that it is the only aquifer in the area intensively exploited and is the most important by its extension across the basin of Laayoune-Dakhla (about 90.000 km^2) and productivity (up to 70 l/s/well). The basin of the Laayoun-Dakhla is now, more than ever, faces multiple constraints:

- Overexploitation of groundwater (the global flow equipped for drinking water is 245 l/s)
- Increasing urbanization (82% of the total population of the study area);
- Emergence of new water needs and (agriculture, breeding, sea fishing and mines…);
- Continued degradation of the surface waters quality.

The degradation of groundwater can cause danger to human health. For this reason, it is necessary to examine and control the quality of groundwater, prevention and reduction of pollution and to provide means of protection and determine treatment processes if this is necessary to produce water acceptable for consumption Human. In addition, the use of uncontrolled water for irrigation is a significant environmental problem due to its direct impact on plant growth and crop yields and therefore on human and animal health. The key goal of the current study is to provide an overview on the physico-chemical quality of groundwater in Sahara Morocco. Thanks to a sampling sufficiently representative of the nature of the water in the region, both water intended for drinking water supply and irrigation water.

2. Study Area

The sedimentary basin of Laayoune-Dakhla (17°E - 11°E. 20°40'N - 28°48'N), situated in southern Morocco, covers an area about 326.810 km^2. It is presented in tabular plains which stretch from north to south along the Atlantic Ocean with a width up to 400 km and altitudes ranged between 0 to 400 m. The basin is bordered in the west by the Atlantic Ocean and southeast by the fault of Zemmour which separate the older African massif, such as Antitlas chain, the Mauritani chain and the Tindouf Basin. It contains significant groundwater resources circulating in a complex aquifer consisting of shallow and deep aquifers (Fig. 1). In this basin three aquifers are known:

- Plio-Quaternary formations containing alluvial aquifers, such as the water layer of Laayoune and the Foum El Oued aquifer;
- The Paleogene aquifer consists of marly sands; it's generally encountered at depths ranging between 150 and 300 m;
- The Lower Cretaceous aquifer containing waters in sandstones, marly limestone and shows a great variability in lithology. It is the largest one in the Sahara basin by its extension and its lithology that allowed a considerable supply of groundwater.

3. Geology

The Tarfaya–Aaiun (Laayoune) Basin in Morocco is the northern continuation of the Dakhla–Laayoune–Tarfaya Basin and stretches from Tarfaya to Ifni along the Moroccan sahara [6]. The regional geology especially in the Tarfaya basin has been discussed by several authors [7, 8, 9, 10, 11]. After a phase of emersion in the late Jurassic, in the North part of the basin, during the Neocomian a thick sequence of continental to marine deltaic (formation of Tan Tan) is

deposited in the basin. The Tarfaya Basin is composed of Precambrian and Palezoic folded rocks which are discordantly covered by Mesozoic sediments whose thickness locally exceeds 12 km [12]. The thickness of the Barremian formation, characterized by a sandy lagoon facies, varies widely from 550 m to 1345 m [11].

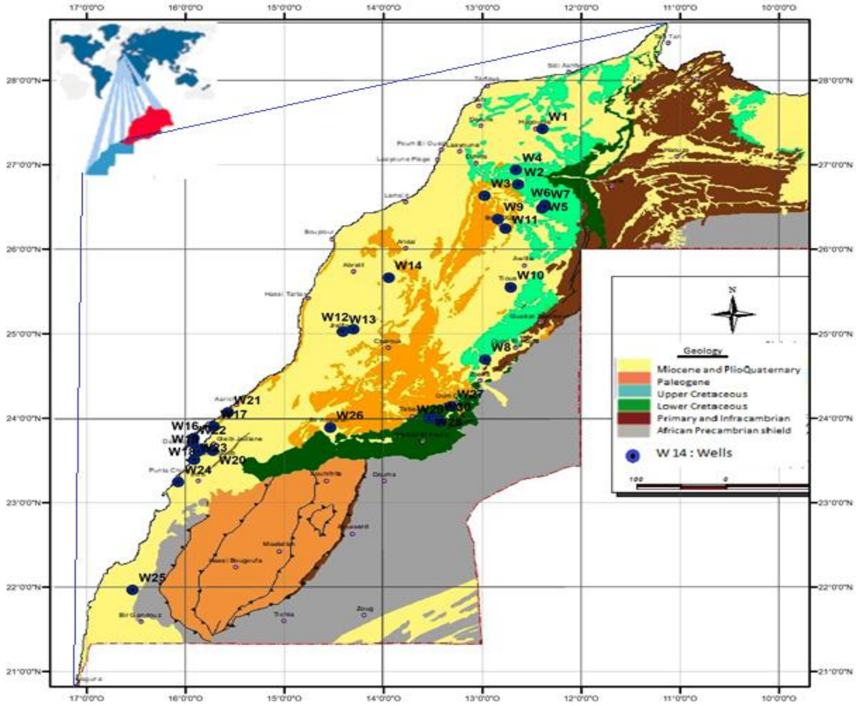

Figure 1. Geographical situation of Laayoune-Dakhla Morocco showing the roof of the Lower Cretaceous formations and structure Basin [14].

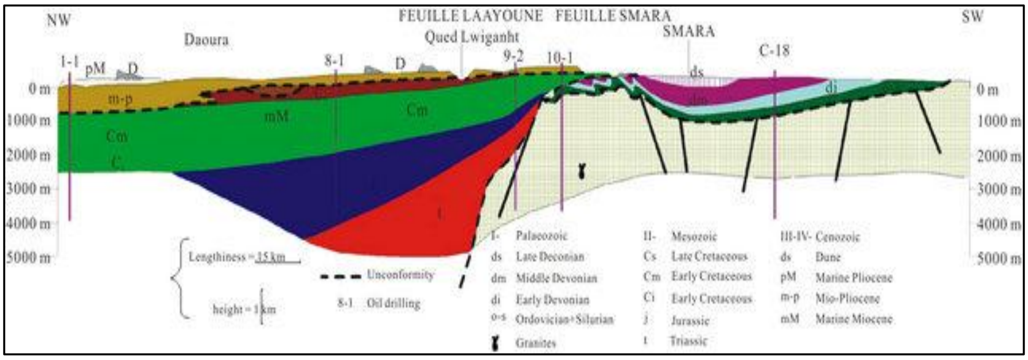

Figure 2. Schematic geological cross sections according to geophysics and drilling in the Laayoune-Dakhla Plain [11].

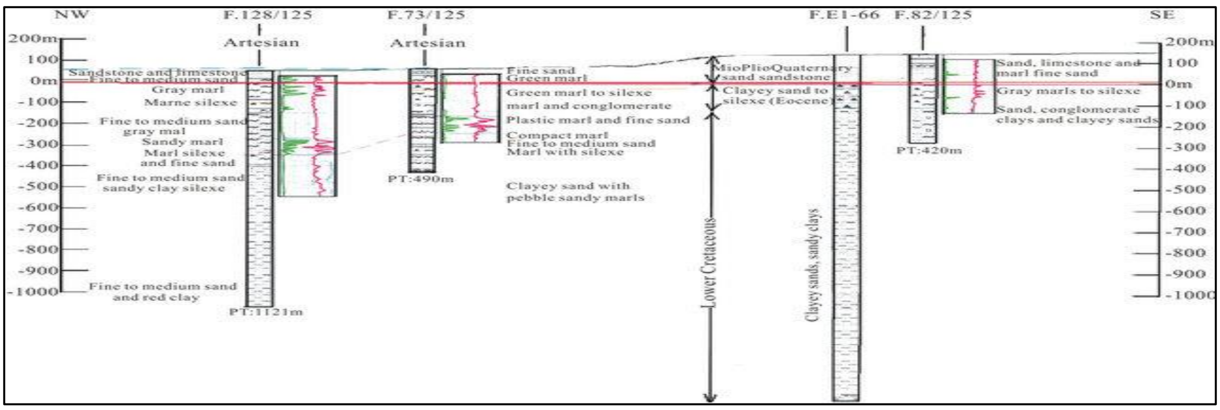

Figure 3. Logs of deep oil and hydrogeologic boreholes showing the stratigraphy of thesubsurface of Laayoune-Dakhla plain [11].

A representative NW-SE cross section linking Gueltat Zemmour (SE) to Laâyoune (NW) (Fig. 2) shows an embedding of regular sedimentary interfaces from East to West. The formation of Lower Cretaceous is beveled towards Gueltat Zemmour in easterly, approaching Infra-Cambrian and Primary outcrops. The substratum consisting of primary quartzite [11]. On these primary formations, were deposited a Lower Cretaceous series which are represented by sands interbedded with clay [11]. The roof of this sand is reached at 625 m deep at the oil drilling. The roof of white sand and red clay rises roughly and is located only at 117 m of depth [11]. This rise in the roof of 1) the Lower Cretaceous; 2) the Triassic formations; and 3) the Jurassic formations, is due to a normal fault or a large flexure found in the north region of Sidi Khattari and even further north between oil drilling [7, 11]. In the west and in the coastal zone, the Lower Cretaceous becomes deep and clayey [11]. The depth of the sands roof reach from 625 m in oil drilling to 850 m in deep drilling of Boucraâ, more than 1800 m in Boujdour region [11]. In this region, the series of Oligocene (formed of chalky clay-micrite, and dolomitic sandstone clay) and of Middle and Late Miocene (formed of red sandstone and plastic clays interbedded with sands) that have developed [11]. In the south part of the basin, indicates a regular embedding sedimentary series from SE to NW reflecting Monocline structure (Fig. 3) [11]. A thick series of clastic Lower Cretaceous, represented by sands interbedded with clay, based unconformably on a Precambrian metamorphic substratum [11]. The Upper Albian to Lower Cenomanian sequence consists of claystone, marl, siltstone and dolomitic limestone [13]. The Upper Cenomanian–Turonian and Coniacian strata contain deeper-water shale and limestone, followed by shallower-water oyster shell beds present in the Santonian. An erosional unconformity truncates all the Palaeocene, Upper Cretaceous and part of the Lower Cretaceous [6]. This erosion probably took place in Santonian to Paleocene times. Thin Eocene and Oligocene units are overlain by a thicker Miocene sequence which reaches up to approximately 1 km in thickness [6].

4. Materials and methods

Groundwater samples were collected from 30 wells (shallow and deep) in 2019. All samples were collected and stored in polyethylene bottles at 4 ° C. The analytical techniques adopted are those published by Rodier and Legube [15]. Physicochemical parameters such as temperature, pH and electrical conductivity were measured in situ. Concentrations of sodium, potassium, calcium and magnesium were analyzed by atomic absorption spectrophotometer (iCE-3000 AAS. Thermo Scientific). Bicarbonates (HCO_3^-) and chlorides (Cl^-) by assay using hydrochloric acid and silver nitrate (0.1 N). Nitrates (NO_3^-) and sulfates (SO_4^{2-}) were determined by the colorimetric assay method using a UV-VIS spectrophotometer (CE-7500. Cecil). Principal component analysis was performed using XLSTAT software (v 2017.1) to illustrate and summarize the variability in the data set in terms of inter-correlation among all the variables. Moreover, Piper and Wilcox's diagram were prepared through Aqua-Chem (version 2014), to interpret hydrogeochemical facies and to classify irrigation suitability of groundwater, respectively.

5. Results and discussion

The results of the physico-chemical analyze of the groundwater of Laâyoune-Dakhla are shown in Table 1.

5.1. Water classification

Water classification according to electrical conductivity (EC)

The electrical conductivity of groundwater in the Laayoune-Dakhla region varied from 1290 to 6895 µS / cm. EC is influenced by geochemical processes and anthropogenic activities [16]. According to EC-based water classification Table 2, the majority of groundwater samples were lightly mineralized (60%) and only 16.66% and 10% of the

samples were moderately to highly mineralized water. The high EC observed for water samples from the study area is likely due to marine intrusion and dissolution of evaporators.

Table 1. ***Results of the different parameters***

	T °C	pH	EC (µs/cm)	TDS mg/L	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	Ca^{2+}	Mg^{2+}	Na^+	K^+
W1	36	7.48	4700	3210	201.37	1303.14	1190.79	0	422.44	129.28	913.85	30.11
W2	34.6	7.55	2880	2540	225.77	1175.00	1510.70	0	402.00	124.42	765.65	24.24
W3	54.5	7.32	6390	4740	152.55	684.19	1908.43	0	724.65	69.98	487.18	17.20
W4	40	7.33	3620	2470	189.16	959.63	744.24	0	349.50	61.24	618.44	20.72
W5	30	6.88	3030	2070	360.02	787.70	371.31	0	301.43	100.12	465.78	18.77
W6	30	7.00	2795	2120	360.02	816.41	381.40	0	333.47	40.34	448.76	19.94
W7	30	7.00	2584	1960	317.30	744.80	353.06	0	209.76	87.84	459.80	17.99
W8	29	6.90	6895	5230	353.92	2164.07	699.39	9.30	423.44	188.69	1310.43	17.20
W9	27	7.40	6750	5900	976.30	1074.14	2200.48	2.48	942.48	269.73	665.78	72.34
W10	29	6.93	1700	1400	475.96	400.94	165.55	0	134.07	59.29	307.84	10.17
W11	40	7.34	5600	4820	353.92	2327.29	239.21	6.82	322.24	128.18	1460.32	51.22
W12	22.1	7.22	4070	2780	139.74	709.71	1418.95	0	619.09	122.47	396.81	52.00
W13	49	7.45	3550	2420	128.14	808.97	600.44	0.62	221.24	39.85	637.97	13.69
W14	44	7.34	5010	4110	268.49	888.02	2378.69	0	733.56	48.60	691.46	19.16
W15	36	7.34	2630	1790	207.47	744.80	254.11	0	227.65	35.72	489.89	17.60
W16	33.5	7.75	2740	1870	164.75	798.33	249.30	0	157.11	30.25	574.75	19.16
W17	38.4	7.55	2307	1750	201.37	758.98	198.38	0	134.27	25.03	580.73	13.69
W18	28.3	7.21	2200	1500	256.28	572.87	266.11	0	224.45	47.63	359.79	8.99
W19	32	7.35	2210	1910	274.59	544.16	260.35	0	218.04	44.35	339.79	12.90
W20	36	7.42	2690	1830	183.06	629.59	717.29	0	343.08	52.49	439.80	18.11
W21	35	7.73	2175	1650	176.96	687.38	95.11	0	105.21	36.94	370.83	17.20
W22	35.5	7.29	2920	1990	170.86	758.98	220.00	0	150.30	37.91	505.67	12.90
W23	36.5	7.74	2780	1900	164.75	716.09	227.21	0.62	87.37	14.58	486.70	12.90
W24	32	7.75	5590	4820	109.84	1059.60	397.29	3.72	237.27	40.82	735.47	19.94
W25	36	7.14	2690	1840	231.88	687.38	199.35	14.88	142.48	36.94	465.55	9.78
W26	26	7.37	3320	2270	231.88	798.33	275.72	56.43	181.02	46.66	569.00	5.87
W27	24	7.38	2170	1480	183.06	487.08	180.13	54.57	129.08	30.13	296.80	5.08
W28	27.9	7.33	1610	1030	262.39	329.33	179.17	27.28	104.45	23.33	220.93	5.08
W29	26	7.44	1290	850	231.88	200.65	147.95	24.80	90.94	18.47	134.03	3.91
W30	26	7.33	1350	920	231.88	229.01	176.29	26.66	82.76	49.57	123.92	5.08

Table 2. Classification of groundwater samples according to EC [17].

EC (µS/cm)	Mineralization	Number of samples	Percentage of samples
< 1000	Very weakly mineralized water	0	0
1000 – 2000	Weakly mineralized water	4	13.33 %
2000 – 4000	Lightly mineralized water	18	60 %
4000 – 6000	Moderately mineralized water	5	16.66 %
6000 – 10000	Highly mineralized water	3	10 %
> 10000	Excessively mineralized water	0	0

Table 3. ***Classification of groundwater samples according to TDS*** [19, 20]

TDS (mg/L)	Mineralization	Number of samples	Percentage of samples
< 50	Very low	0	0
50 – 500	Low	0	0
500 – 1000	Moderate	2	6.66 %
1000 – 1500	High	4	13.33 %
> 1500	Very high	24	80 %

Water classification according to TDS

The TDS in water can vary widely depending on the solubility of the minerals in the water [18]. According to the TDS-based water classification scheme, only 6.66% of the samples exhibited moderate mineralization, while the rest

exhibited high mineralization 13.33% or very high 80% (Table 3). The majority of the water samples which showed strong mineralization were located on the coastal zone (close to the sea). this strong mineralization is probably due to evaporative deposits and marine intrusion.

Water classification according to the total hardness

The hardness evaluated on the basis of the Ca^{2+} and Mg^{2+} content, expressed in mg/L $CaCO_3$. The hardness in the study area ranged from 278 to 3461.4 mg/L $CaCO_3$ (Fig. 4).

Table 4. ***Classification of groundwater samples based on total hardness*** [21, 22]

Total hardness (mg/L $CaCO_3$)	Hardness class	Number of samples	Percentage of samples
0–75	Soft	0	0
75–150	Moderately hard	0	0
150–300	Hard	1	3.33 %
>300	Very hard	29	96.66 %

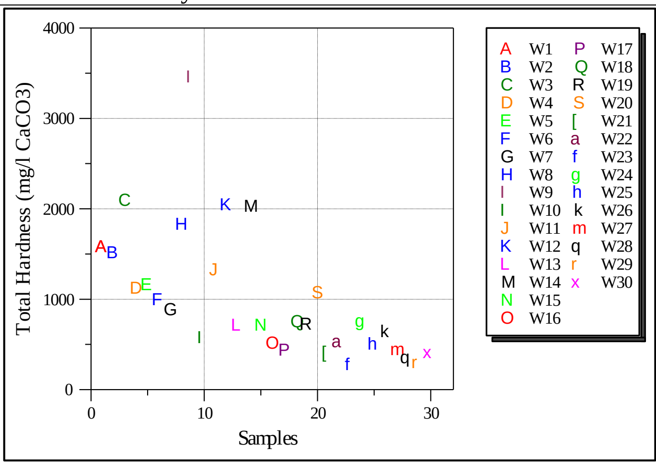

Figure 4. Concentrations of total hardness in water samples

According to Table 4 of water classification based on hardness, almost all of the samples studied were very hard (Table 4), which means that they are unfit for human consumption.

Piper diagram

The chemical nature of the groundwater studied is illustrated in the Piper diagrams (Fig. 5) the representation, focused on 30 water samples taken at the different sampling points during the monitoring of the physico-chemical quality of the waters of the Laayoune-Dakhla region. In the Piper diagram, we observe that: 86.66% of the water samples analyzed have dominant sodium chloride, while the remaining 13.33% of the samples show a dominance of calcium sulphate.

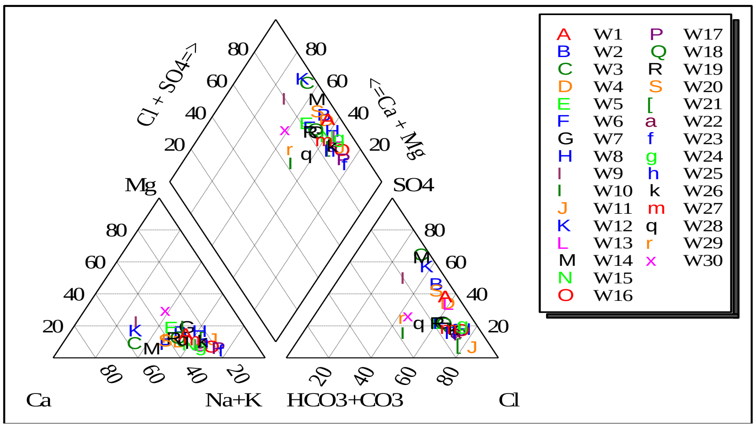

Figure 5. Piper diagrams representing all water categories of studied area

The facies of these water samples are sodium chlorides, probably due to the deposits of evaporites, with a slight tendency towards the sulphated calcium facies, these facies are probably due to the dissolution of the gypsum lens located in the marly formations of the Miocene or schist formations in the south of the Laâyoune-Dakhla region. The quality of groundwater is influenced by many factors such as chemistry, geology of reservoir rocks [23] and anthropogenic factors [24].

Table 5. ***Classification of groundwater in the study area for agricultural use*** [26]

Parameter	**Interval**	**Category**	**%**
Electrical conductivity (µS/cm)	< 250	Excellent	0
	250 – 750	Good	0
	750 – 2250	Permissible	26.66
	2250 – 5000	Doubtful	53.33
	> 5000	Unsuitable	20
[Cl^-] (meq/L)	< 4	Excellent	0
	4 – 7	Good	6.66
	7 – 12	Permissible	6.66
	12 – 20	Doubtful	23.33
	> 20	Unsuitable	63.33
% Na (%)	0 – 20	Excellent	0
	20 – 40	Good	10
	40 – 60	Permissible	50
	60 – 80	Doubtful	40
	> 80	Unsuitable	0
Sodium adsorption ratio (meq/L)	< 2	Very low	0
	2 – 12	Low	86.66
	12 – 22	Significant	13.33
	22 – 32	High	0
	> 32	Very high	0
Residual sodium carbonate (meq/L)	< 1.25	Permissible	100
	> 1.25	Unsuitable	0
Magnesium adsorption ratio (%)	0 – 50	Permissible	100
	> 50	Unsuitable	0

5.2. Suitability of the groundwater for agricultural use

The suitability of the groundwater in the study area for irrigation was assessed based on the following criteria: electrical conductivity (EC), chlorides (Cl^-), percentage of sodium (% Na), sodium adsorption ratio (SAR), residual sodium carbonate (RSC), magnesium adsorption ratio (MAR) and the Wilcox diagram [25], see Table 7. These parameters are the most useful indicators for determining the suitability of groundwater for agricultural use.

Electrical conductivity (EC)

High EC values directly affect crop productivity and soil structure. The electrical conductivities of the samples ranged from 1290 to 6895 µS/cm. 63.33% of the samples exceeded the Moroccan standard for EC (2700 µS/cm).

Chloride (Cl^-)

The most common ions in irrigation water that can damage crops are chloride and sodium [27]. In this study, chloride concentrations ranged from 6.66 to 65.64 meq/L. With, 63.33% of the samples were unsuitable for use as irrigation water.

Percentage of Sodium (%Na)

Na^+ is an important cation which deteriorates beyond the soil structure and reduces crop yield. When the concentration of Na^+ is high in the irrigation water, Na^+ tends to be absorbed by the clay particles and will be replaced by the ions of Mg^{2+} and Ca^{2+}. This process of exchange of Na^+ in water by Ca^{2+} and Mg^{2+} in the soil reduces permeability. Therefore, the sodium percentage is considered an important index for the evaluation of water intended for irrigation [28]. The % Na is calculated according to the formula below:

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

The results recorded in Table 5 summarize the information on the quality of groundwater for irrigation from the evolution of the sodium percentage according to [29].

The values of % Na calculated from the groundwater results are between 10 and 50% of the samples are of good and permissible quality (water suitable for irrigation), on the other hand 40% of the samples are of doubtful quality for irrigation. The projection of the results on the Wilcox diagram (Fig. 6) shows that the majority of the water is of poor quality except for the wells W29, W30 and W28, W10 are of good and admissible quality. Salty waters and high conductivities are poor quality waters for irrigation, the use of these waters can pose a high risk of soil salinization.

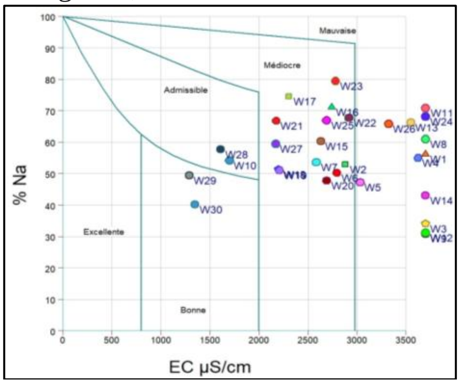

Figure 6. Wilcox diagram showing the suitability of groundwater for irrigation

Sodium adsorption ratio (SAR)

The sodium adsorption ratio (SAR) is an important parameter in determining the suitability of groundwater for irrigation purposes because it measures the danger of alkali-sodium to crops. Sodium enters the aquifer through rain and through the dissolution of rocks. Due to its effects on soils and plants, it is considered among the main factors governing irrigation water. This ratio is determined using the following formula:

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

The waters of the different sites studied showed that the sodium absorption parameter (SAR) varied between 2.66 (W30) and 17.40 meq/l (W11) (Table 5) (Fig. 7). Taking into account the evolution of the electrical conductivity compared to the SAR (Riverside Classification) (Fig. 8), we can deduce that the samples belong to the following classes: C4S3 the most dominant with 53.33% (Very bad quality only used for exceptional circumstances), whereas 23.33% of the collected water belongs to the classes C4S2 (Water of very poor quality), C3S2 (Water of poor-to-poor quality) and C3S1 (Medium to poor quality used with caution, requires drainage with leaching) with the respective percentages of 16.66 % and 6.66%.

Residual sodium carbonate (RSC)

Residual sodium carbonate (RSC) is a valuable parameter that has a significant effect on the use of irrigation water, which determines the dangerous effect of HCO_3 and CO_3 on the quality of irrigation water, the RSC index of water samples at the study site is estimated by the equation (Eaton. 1950):

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

Where, all ionic concentrations are expressed in meq/L. Lloyd and Heathcote [30] classified irrigation water based on the RSC as good (< 1.25) and no recommended (> 1.5). According to RSC values, all groundwater samples are suitable for irrigation (Table 5).

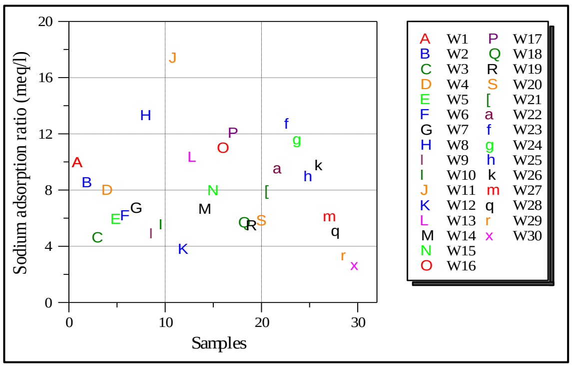

Figure 7. Sodium adsorption ratio diagram of groundwater

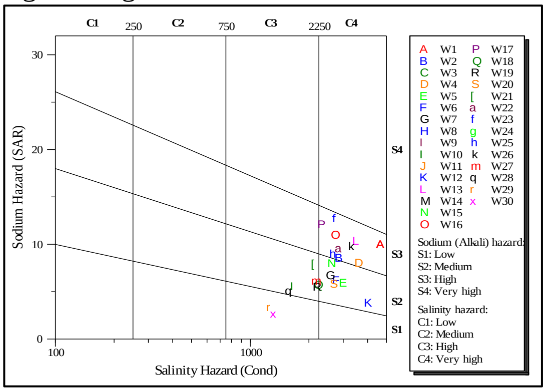

Figure 8. Riverside diagram showing the suitability of groundwater for irrigation

Magnesium adsorption ratio (%)

The values in magnesium adsorption ratio calculated from the groundwater of the study area are between 9.8 and 49.7%, these results show that all the samples have values in % Mg < 50%, which makes the groundwater suitable for use irrigation (Table 5).

5.3. Principal Component Analysis (PCA)

PCA is a method that allows the number of variables (parameters measured in water samples) to be reduced [31]. This approach has been used to extract related variables and infer the processes that control water chemistry [32]. Several studies were used PCA in the groundwater studies [33, 34]. For this study, the principal component analysis was carried out for 30 samples and 10 variables (EC, TDS, Cl^-, HCO_3^-, SO_4^{2-}, Ca^{2+}, Mg^{2+}, K^+, Na^+ and NO_3^-). Figure 9 represents the principal factors corresponding to the different sources of variation in the dataset. Table 6 summarizes the results of the PCA and the variance induced by each of the principal components. The PCA rendered four principal components contributing to the total variance of over 93.3 % like F1 (59.3), F2 (15.1%), F3 (10.3%) and F4 (8.5%). Table 7 shows significant correlations between EC and elements TDS (0.98), Cl^- (0.73), SO_4^{2-} (0.65), Ca^{2+} (0.77), Mg^{2+} (0.69), Na^+ (0.74), K^+ (0.74), TDS and elements Cl^- (0.73), SO_4^{2-} (0.65), Ca^{2+} (0.77), Mg^{2+} (0.71), Na^+ (0.74), K^+ (0.63), Cl^- and the elements Na^+ (0.98), SO_4^{2-} and the elements Ca^{2+} (0.94), Mg^{2+} (0.57). No correlation is observed between NO_3^- and the other parameters. The first factor F1, of 59.3% of total variance, is related to the electrical conductivity (C.E) and to the concentrations of EC, TDS, HCO_3^-, Cl^-, SO_4^{2-}, Ca^{2+}, Mg^{2+}, Na^+ and K^+. These parameters are associated with the mineralization of water by the phenomenon of dissolution of rocks and evaporites. The factor F1 therefore defines an axis of overall water mineralization. The Ca^{2+}, Mg^{2+}, K^+, Cl^-, Na^+, SO_4^{2-}, HCO_3^- ions (Fig. 9) could result from the hydrolysis of rocks and the decomposition of the minerals present in the area of the Laayoune-

Dakhla from the redox reactions, ion exchange, precipitation, adsorption. This factor is considered to be an axis of mineralization of natural origin (water-rock contact or residence time). The factor F2, which explains 15.15% of the inertia of the representative point cloud, is determined by nitrates (NO_3^-). The presence of NO_3^- ions could have a mainly anthropogenic origin either by discharges of domestic wastewater or by degradation of organic matter.

Table 6. values and percentages expressed for the main axes.

	F1	F2	F3	F4
Eigen values	5.932	1.515	1.029	0.856
Variability in%.	59.316	15.149	10.294	8.559
Accumulated in%	59.316	74.465	84.759	93.317

Table 7. Correlation analysis of the physiochemical parameters for groundwater samples.

Variables	EC	TDS	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	Ca^{2+}	Mg^{2+}	Na^+	K^+
EC	1									
TDS	0.982	1								
HCO_3^-	0.309	0.396	1							
Cl^-	0.729	0.731	0.192	1						
SO_4^{2-}	0.656	0.653	0.320	0.223	1					
NO_3^-	-0.228	-0.240	-0.069	-0.212	-0.283	1				
Ca^{2+}	0.770	0.768	0.471	0.352	0.939	-0.316	1			
Mg^{2+}	0.688	0.710	0.707	0.607	0.575	-0.192	0.710	1		
Na^+	0.742	0.741	0.143	0.984	0.263	-0.224	0.356	0.554	1	
K^+	0.630	0.669	0.566	0.521	0.568	-0.366	0.721	0.791	0.485	1

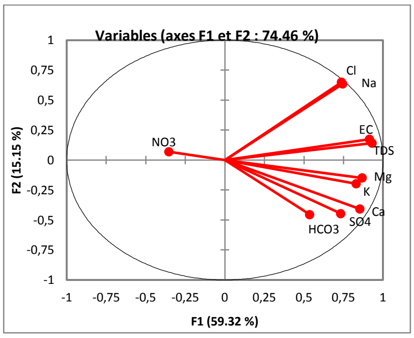

Figure 9. Correlation plot among variables and factor loading.

Conclusion

The quality of the groundwater used for irrigation was assessed in the Laayoune-Dakhla area. The need for this research is justified by the problems encountered by the region such as drought, the evacuation of wastewater, industrial and high demand for water from agricultural activities. The water sources studied were characterized by high concentrations of the parameters studied, in particular the values of the EC and the concentration of Na^+ and Cl^- ions, which would affect the quality of the water as an irrigation source, most of the water was of poor quality for drinking and irrigation. Most of the water studied comes from water with very high salinity (class C4), when it is used for irrigation. In addition, the majority of poor-quality water for salinity values (EC, Cl^-), is not suitable for irrigation. Therefore, if the water is not properly treated before it is used as irrigation water, it can make the soil more alkaline

and eventually lead to clogged soil pores and low crop yield. The interpretation of the hydrochemical analysis reveals that a hydrochemical dominated facies of groundwater are genetic types of water Na-Cl and Ca-SO4. The mineralization of the underground water of Laâyoune-Dakhla is of natural origin, this is confirmed by the multivariate statistical study. Therefore, we recommend periodic monitoring of the region's water resources and the cultivation of salt-resistant plant species, taking into account the use of scientific and modern methods in irrigation operations.

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