Nature Environment and Pollution Technology
An International Quarterly Scientific Journal
p-ISSN: 0972-6268
e-ISSN: 2395-3454
Vol. 19 No. 1 pp. 17-28 2020

Original Research Paper **Open Access**

Assessment of Seasonal and Spatial Variation of Groundwater Quality in the Coastal Sahel of Doukkala, Morocco

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Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 09-04-2019
Accepted: 02-07-2019

Key Words:
Groundwater quality
Variability
Sahel of Doukkala

ABSTRACT

The current research is set in the context of the impact of climate change at the regional level, particularly focused on seasonal variations and their influence on the physico-chemical characteristics of groundwater in the rural and urban areas of coastal Sahel of Doukkala. The main objective of this study was to evaluate the quality to explain the phenomena at the origin of the mineralization of groundwater. Two measurement campaigns of sampling were carried out on 30 wells, in 2016 and 2018 (dry and wet season). The water points were piezometrically surveyed. In situ, the same water points were measured for temperature, pH, and electrical conductivity, using a multiparameter conductivity meter and a pH meter. The chemical analysis was carried out at the Laboratory of Geosciences and Environmental Technics using volumetry (Ca^{2+}, Mg^{2+}, Cl^- and HCO_3^-) and spectrophotometry methods (SO_4^{2-}, Na^+ and K^+); total dissolved solids (TDS) were computed by multiplying the EC by a factor (0.55 to 0.75), depending on relative concentrations of ions. Total hardness (TH) was calculated by taking the differential value between Mg^{2+} and Ca^{2+}. For the reliability of the results obtained, we proceeded to the application of the ionic balance. The obtained water quality data was subjected to multivariate statistical techniques to evaluate homogeneity and heterogeneity between sampling water and to differentiate water quality variables for temporal variations.The elements are all significantly different among seasons. The dry season was positively associated with EC, TDS, Cl^-, Na^+, SO_4^{2-} and K^+ and negatively associated with temperature, and pH. The wet season was in contrast associated with high values of NO_3^- and pH. These results show that the majority of well water in the study area represents strong mineralization that far exceeds standards, especially during the dry period, with an average EC of 416.04 µS/cm, while the wet season is lower at 382.6 µS/cm. The hydrochemical classification of water from the Piper diagram revealed only one hydro facies, which is the chlorinated sodium facies. In conclusion, the variability of groundwater quality could be explained by the fact that in the dry season, there is concentration and in the wet season, there is ionic dilution and may also reflect the effect of anthropogenic activity.

INTRODUCTION

The challenge in the coming years is undoubtedly to ensure the sustainable management of water resources without hindering economic and social development. Globally, groundwater is one of the most precious sources of natural resources. Groundwater contributes to 80% of rural domestic water needs and 50% of urban water needs. According to World Health Organization (2011), 80% of diseases in human beings are caused by water. Problems associated with groundwater exploitation include the following: declining water tables, wells running dry (seasonality) increasing pumping costs, competitive deepening of wells, groundwater subsidence, loss of wetlands and flowing springs and rivers, salt water intrusion, groundwater degradation from natural toxins (fluoride and arsenic, spreading or leaking of anthropogenically used substances from point and non-point sources (FAO 2003, Richardson et al. 2004).

In fact, this vital resource no longer seems to meet today's growing population demand and development needs. This water deficit is caused in particular by the growth in water needs and its irrational use, as well as climate change (UNESCO 1987). In addition, these climatic variabilities have led to a disruption in the frequencies and intensities of precipitation and periods of drought (Berdai 1997). The succession of extremely loss-making and/or extremely surplus years (high and rapid rises) favours soil erosion and subsequently accelerates the transfer of surface pollution to watercourses and then to underground aquifers, which in turn deteriorates water quality. This water problem is therefore aggravated by the almost regular decrease in rainfall over the past fifty years, seasonal irregularities, the rapid increase in desertification and the progressive degradation of environmental factors (Ahoussi et al. 2012). In fact, estimates made by UNESCO in 2003 indicate that globally groundwater provides about 50% of current potable water supplies,40% of the demand of self-supplied industry and 20% of water use in irrigated agriculture. Groundwater is the most realistic water supply option in much of Africa to meet dispersed rural demand (Foster et al. 2000).

In a country with limited water resources, such as Morocco, where the hydrological context is marked by spatial and temporal variability, the water problem is becoming increasingly worrying (Agoussine & Bouchaou 2004). In addition, groundwater is a very slow-running reservoir and its use for drinking water supply and irrigation purposes may lead to its depletion.

At the regional level, a number of studies on groundwater with respect to drinking and irrigation purposes have been carried out in the different parts of the region (Ambroggi & Thuille 1952, Gigout 1952,1955, Ferre 1969, Ferre et al. 1975, Chtaini 1987, Fakir 1991, Fakir et al. 2003, DRPE 1992, DRHT 1994, Souhel et al. 2000, El Achheb 2002, El Achheb 2003, Chofqi 2004, Hilali 2002, El Hasnaoui et al. 2006, Kaid Rasou 2009, Oulaaross 2009, El Hasnaoui et al. 2011, Fadili et al. 2012), but little work on the effect of seasonal changes on the qualitative aspect of groundwater has so far been done in the rural and urban area of coastal Sahel of Doukkala.

Human activities in our study area are constantly increasing, increasing water consumption and consequently hindering polluting discharges. In agricultural areas, the need to increase production in order to meet food needs requires the intensification of irrigation and the use of agricultural products (fertilizers and pesticides...). This promotes the leaching of excess products from the products used and their transfer to groundwater (El Achheb 2002). The multiplication of industrial activities, for its part, generates multiple pollutants of very varied nature and severity (toxic substances, heavy metals, etc.), thus threatening the sustainability of environmental systems as a whole (El Hasnaoui et al. 2006), especially since the region is considered for the coming years to be Morocco's second largest industrial centre. The industrial image of this region is characterized by the weight of the chemical (Jorf Lasfer OCP complex), agri-food (e. g. sugar factories, dairy and pharmaceutical units) industries (Souhel et al. 2000).

A more complete diagnosis of the current situation of the contamination and a rigorous follow-up of its evolution, are of great necessity for the safeguarding of this resource. It is with this in mind that our work aims to assess the seasonal quality of well water in the Doukkala coastal Sahel, in order to explain the phenomena that cause the mineralization of these waters.

The goal of this study is to assess the spatiotemporal variation of physico-chemical water quality parameters within the aquifer of the Sahel coastal of Doukkala, especially since in this area the population is mainly rural, increasingly turning to well water (most of which is damaged or abandoned) and using it for domestic needs, ignoring the quality of these resources.

According to this study we hypothesized that during the dry season when the input of water is low, most water quality chemical parameters would have higher concentrations (as compared to the wet season) due to resuspension, absence of dilution, and increased evaporation. We also hypothesized that water quality would vary spatially throughout the aquifer, with the highest concentrations of terrestrially derived pollutants (like nitrate, sulphate...) are found near the agricultural areas, the controlled landfill and both the industrial area which are the main sources. So, these spatiotemporal variations are essentially caused by the intensification of agricultural, climate variability, industrial and domestic activities.

It is essential to have a good knowledge of the nature and the chemistry of groundwater variations that can occur as a result of physical processes and anthropogenic activities. It is expected that this type of study will guide proponent's groundwater development projects, especially in the developing countries, point the need for intensified efforts to cope with the different types of imbalances.

MATERIALS AND METHODS

Study Area Description

The study area is part of the coastal Sahel basin of Doukkala which belongs to the Western Moroccan Meseta. It lies between latitudes 33°2.451' and 33°15.798' N and longitudes 8°29.150' and 8°39.082' W. The area is bordered southwest by the municipality of Sidi Abed, south east by the municipality of Sebt des Oulad Aissa and on the northwest by the Atlantic Ocean. This region covers an area of 195 km^2, includes an urban area (the city of El Jadida) and an industrial complex (Jorf Laasfar) (Fig. 1).

Climatic Setting

Climate is semi-arid with minimum temperature of 18°C in winter and maximum temperature of 23°C in summer. The average rainfall is 380.08 mm.

According to unpublished data of the regional direc-

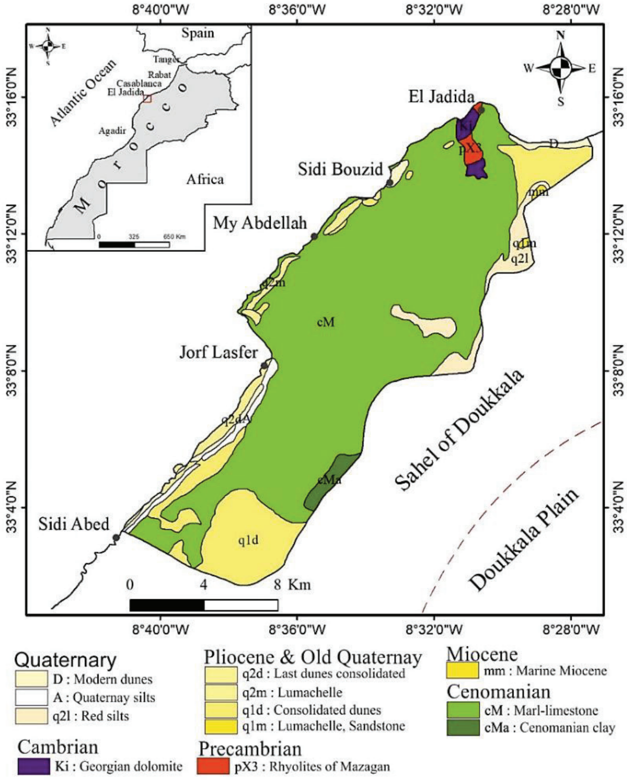

Fig. 1: Location and geology simplified map of the study area (Ferré & Ruhard 1975, Oulaarous 2009).

torate of agriculture, from the year 2016-2018, the average annual rainfall in El Jadida station was 400 mm with a minimum of 0 mm recorded in June, July and August respectively in 2016 and 2017. The maximum monthly rainfall (139 mm) was occurred during March. In terms of the regional rainfall variability, 2018 is a rainy year compared to 2016. Seasonal fluctuations in water levels during 2016-2018 correspond to rainfall (DRH 2016-2018) (Fig. 2).

Geological and Hydrogeological Setting

The study area consists of highly varied geological formations such as of limestone and marl formations of Cenomanian (Cretaceous) age (Fig. 3), resting in angular discordance on the basal Palaeozoic monoclinal dolomites (El Achheb 2002).

Rainfall is the main recharge source for groundwater in the area. The Cenomanian formations represent the most extensive aquifer at the study area (Ferré & Ruhard 1975). The calcareous layers form a fractured and karstic aquifer which is up to 100 m thick.

Test pumping in the vicinity of El Jadida revealed permeability values in the range of 5×10^{-6} to 10^{-5} m/s for the studied aquifer (Souhel & El Achheb 2000).

Experimental Setup and Methods

Groundwater samples collected from 30 dug wells in June during a period of two years 2016 and 2018, covering both wet and dry periods (Fig. 4), these water points are located in urban and rural areas characterized by different activities (agricultural, industrial...). The water samples were taken according to Rodier's techniques (1984), collected in prewashed (with detergent, diluted HNO_3 and double de-ionized distilled water, respectively). Prior to sampling, all the sampling containers were rinsed thoroughly with the groundwater, filled with refusal (to avoid the formation of air bubbles) and kept at low temperature (2-4°C).

Field samples were analysed immediately for hydrogen ion concentration (pH), temperature and electrical conductivity (EC), using a HACH multiparameter conductivity meter, model 44 600 and a WTW pH meter, pH 522 with combined electrode.

Other parameters were later analysed in Laboratory of Geosciences and Environmental Techniques of Chouaïb Doukkali University. These parameters include important

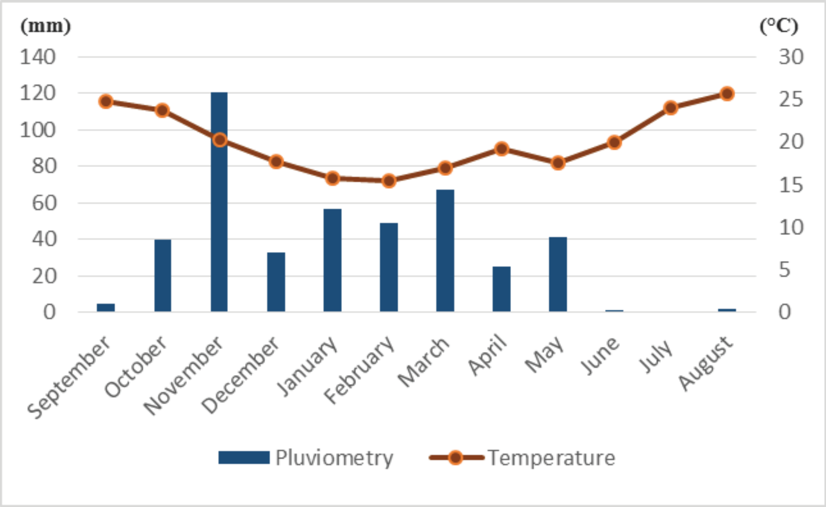

Fig. 2: Monthly variation of pluviometry and temperatures at El Jadida station between 2015 and 2018 (C.P.M).

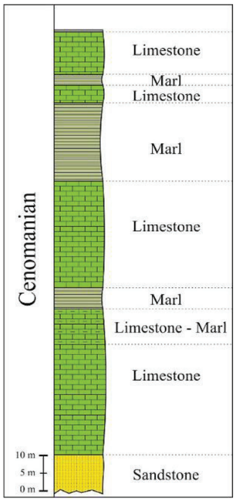

Fig. 3: Portion of the synthetic stratigraphic log of the Cenomanian of the study area (D.R.H 1990).

cations such as calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), potassium (K^+) as well as anions such as bicarbonates (HCO_3^-), chlorides (Cl^-) and sulphates (SO_4^{2-}). Total dissolved solids (TDS) were computed by multiplying the EC by a factor (0.55 to 0.75), depending on relative concentrations of ions (Sudhakar et al. 2013). Total hardness (TH) was calculated by taking the differential value between Mg^{2+} and Ca^{2+} (ISO 1984), these two elements were analysed titrimetrically, using standard EDTA. Sodium (Na^+) and potassium (K^+) were measured, using a flame photometer. Bicarbonate (HCO_3^-) were estimated by titrating with H_2SO_4. Chloride (Cl^-) was determined titrimetrically by standard $AgNO_3$ titration. Sulphate (H_2SO_4) and nitrate (NO_3^-) were analysed, using spectrophotometer. All parameters are expressed in milligrams per litre (mg/L) and milliequivalents per litre (meq/L), except pH (units) and EC. The EC is expressed in microsiemens per centimetre (µS/cm) at 25°C.

For the reliability of the results obtained, we proceeded to the application of the ionic balance (taking the relationship between the total cations and the total anions) and an error of 10% was accepted (Domenico & Schwartz 1998, Rodier 2009).

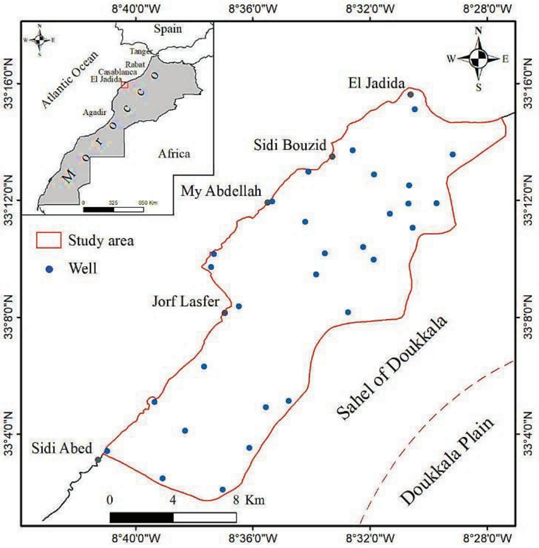

Fig. 4: Location of sampling points in the study area

The processing of the collected physico-chemical data was carried out using multivariate hydrochemical and statistical methods. The hydrochemical method required the use of the Piper diagram for hydrochemical classification. The statistical approach that has been used to study the phenomena underlying water mineralization, water aggregation and identify the factors responsible for these aggregations is based on multivariate statistical techniques. The statistical analysis was carried out on 30 descriptors and all parameters (13 variables) in wet and dry periods. Concentration differences for each water quality variable between the wet and dry season were examined using the Mann-Whitney U test, and differences among seasons were examined using one-way ANOVA, both at a significance level of $p < 0.05$.

The box plot analysis was used to assess temporal variability in water quality parameter concentrations based on the median, minimum, maximum, and 25th and 75th percentile values (Dou et al. 2016). The reservoir water quality variables were also subjected to multivariate statistical techniques using principal component analysis (PCA), which is one of the most commonly used multivariate statistical techniques. Its purpose is therefore to establish a relationship between the various physico-chemical parameters and to better assess the effect of anthropogenic activities on the quality of the groundwater sampled (Quinn & Keough 2002). The statistical analysis was performed using Statgraphics 16.1 software and IBM SPSS statistics 20.

The application of all these different methods made it possible to assess seasonal quality in order to explain the phenomena responsible for variations in groundwater mineralization in our study area.

RESULTS

From Table 1, the results of the physico-chemical analyses of water samples are shown and the WHO prescribed guideline used in the description of groundwater quality characteristics in the study area.

Spatial descriptive statistics result of the analysed parameters showed that there are parameters that express significant changes during the study period, indicating spatial variability of chemical composition among sampling sites (Table 1) for wet and dry seasons, respectively.

83.33% of the water analyses carried out in two seasons have an ionic balance of less than 5%, so these analyses are satisfactory. However, 16.67% of the analyses carried out on groundwater have an ionic balance of between 5 and 10%, so these analyses are of acceptable quality.

WHO- World Health Organization, SD- Standard deviation, CV- Coefficient of variation, WT- Water temperature TH- Total hardness, EC- Electrical conductivity, TDS- Total dissolved solids

The pH values of groundwater varied from 7.2 to 8.65 during dry season and 7.1 to 8.3 during wet season. EC values ranged from 101.9 to 955 μS/cm during dry season whereas during wet season it was 82-86.1 μS/cm. Respective minimum and maximum TDS values observed were

Table 1: Descriptive characteristics of physico-chemical parameters of groundwater quality for wet and dry seasons in the study area.

	WHO standards	Dry season					Wet season				
Parameters		Min	Max	Mean	SD	CV	Min	Max	Mean	SD	CV
pH	6.5 - 9.5	7.2	8.65	7.77	0.33	4.31	7.1	8.3	7.69	0.34	4.42
WT (°*C*)	< 25	21.4	24.8	22.7	0.92	4.04	19.4	24.1	21.87	1.33	6.08
TH (mg/L)		2.5	129.14	37.06	25.5	68.81	10.5	114.25	35.68	23.67	66.33
EC (*µS/cm*)	> 400	101.9	955	416.04	215.46	5178.7	82.8	86.1	382.6	196.96	5147.77
TDS (mg/L)		50.95	477.5	208.02	107.73	2589.4	41.4	429.95	191.30	98.47	5147.77
Ca^{2+} (mg/L)	< 100	16	372	128.57	83.21	64.72	28	420	165	99.51	60.31
Mg^{2+} (mg/L)	< 50	1.2	460	100.77	99.06	98.31	3.6	296.4	76.96	72.85	94.67
Na^{+} (mg/L)	< 150	220	3066	695.17	623.47	89.68	81	1500	541.84	335.28	61.88
K^{+} (mg/L)	< 12	3.8	31.5	12.47	6.66	53.38	5.1	75	18.9	14.25	75.44
HCO_3^- (mg/L)		158.6	890.6	443.43	163.01	36.76	183	671	370.88	115.81	31.22
Cl^- (mg/L)	< 200	221.9	2644.75	1061.45	689.47	64.95	272.75	2502.8	994.58	616.02	61.93
SO_4^{2-} (mg/L)	< 250	25.64	454.59	112.42	91.89	81.73	41.61	714.54	264.19	190.23	72
NO_3^- (mg/L)	< 50	6.76	165.93	52.02	37.04	71.2	9.6	383.62	69.97	76	108.62

41.4 and 477.5 mg/L during wet season and 50.95-429.95 mg/L during dry season. The total hardness ranged from 2.5 to 129.14 mg/L during the dry season and 10.5 to 114.25 mg/L during wet season. During both seasons, concentrations of major elements exceed the permitted limits (WHO). For nitrate, the highest value was 383.62 mg/L during the dry season and 165.93 mg/L during the wet season. The results of analyses show that the highest concentration of Cl^- was recorded at dry season with a value of 2644.75 mg/L and with a minimum of 221.9, but in the wet season, concentrations fluctuate between 272.75 and 2502.8 mg/L. In the case of sulphates, the variations in concentrations are in the order of 25.64 to 454.59 during the dry season, and 41.6 to 714.54 mg/L during the wet season.

Groundwater has highly variable sodium concentrations during two seasons. In wet season, they range from 81 mg/L to 1500 mg/L with an average concentration of 541.84 mg/L, but in dry season, it varies between 220 and 3066 mg/L with an average of 695.17 mg/L.

The distributions of pH, EC, TDS, TH, the major elements in both seasons are presented as a projection graph resulting from the analysis of the principal component (Figs. 5 and 6).

Analyses of the Principal Component

During the wet season, the principal component analysis extracted 80.24% of the variance of that season's data (Fig. 5a). Of this, the first factor (PC1) extracted 57% of the variance and was correlated positively with all variables (CE, TDS, Cl^-, TH, Mg^{2+}, Na^+) with a lesser degree of NO_3^- and K^+. In its negative part, PC1 is controlled by the variable WT, HCO_3^- and pH. The group of variables Ca^{2+}, Mg^{2+} reflects the calcium and magnesium mineralization acquired as a result of water-rock interactions. On the other hand, the group of variables K^+ and NO_3^- seems to characterize a change that would occur near the soil surface. These variables have a superficial origin and reflect anthropogenic pollution. The grouping of these variables in the positive part of the PC1 factor means that these chemical variables are acquired after a slow residence time. This grouping expresses mineralization related to agricultural activities. The factor PC1 is determined by the variable SO_4^{2-} in its positive part to which the pH is opposed and to a lesser degree the temperature (T°C). The PC1 factor is considered as a mineralization axis of both natural (water-rock contact) and anthropogenic origin.

The second factor (PC2) explained 22% of the variance (Fig. 5a), positively correlated with HCO_3^-, Mg^{2+}, NO_3^-, K^+ and pH. The most correlated variables are NO_3^- and K^+ which represent the surface parameters that are found at depth due to infiltration. Indeed, these parameters would come mainly from fertilizers used in agricultural activities.

However, factor PC2 provides information on the spatial origin of ions through direct infiltration of surface water and both anthropogenic degradation from agricultural sources, then the PC2 is an indicator of surface inputs.

The projection of individuals in the factorial plane PC1-PC2 (Fig. 5b) shows 3 classes. Class 1 takes into account all highly mineralized waters in the study area. Class 2 includes all waters with low mineral content and high pH content. Class 3 contains waters rich in bicarbonates and sulphates.

During the dry season, the representation of the data

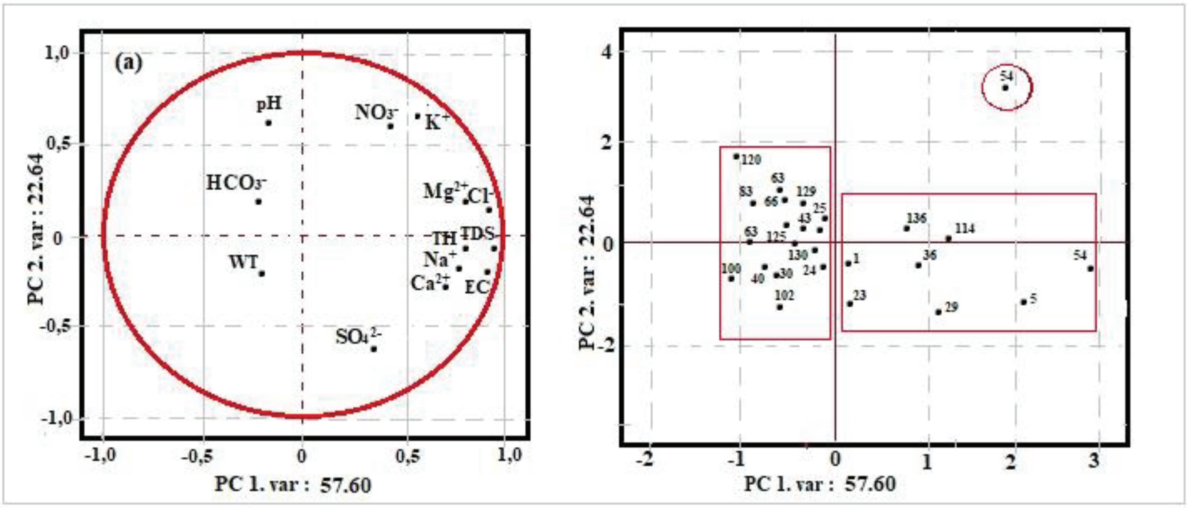

Fig. 5 (a): Wet season PCA analysis and (b) a graph of statistical units in the PC1-PC2 factorial design of study area.

in the factorial plane PC1-PC2 expresses 81.01% of the total variance of the point cloud including 53.79% for the factor PC1 (Fig. 6a). The physico-chemical parameters: CE, TDS, Mg^{2+}, TH, Cl^- and K^+ are well correlated with each other and have a significant weight in the prevalence of the phenomenon represented by PC1. The CE and TDS elements are characteristic of the natural mineralization of water in its host (Murdey & Blavoux 1986), while Cl^- and Mg^{2+} reflect induced mineralization. In this case, this axis expresses the residence time of the elements; it is an indicator of mineralization (Hani et al. 1997).

PC2 explained 27% and was determined by NO_3^- but also by HCO_3^- and Na^+. These parameters are inversely correlated to Ca^{2+} and SO_4^{2-}. The factor PC2 reflects the environmental conditions and their influence on the chemical variations of the water and represents the surface inputs. It is also an indicator of natural (HCO_3^-) and induced (NO_3^-) mineralization (Fig. 6a).

The projection of individuals in the factor plane PC1-PC2 (Fig. 6b), shows three classes. Class (1) is composed of a single water point rich in nitrates and characterized by a low sulphate content. Class (2) consists of highly miner-

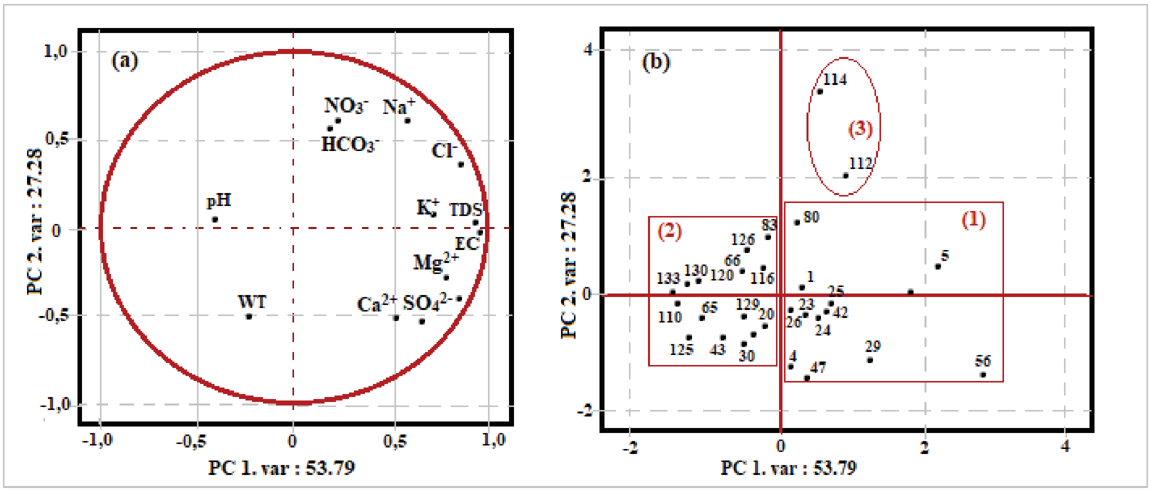

Fig. 6 (a): Dry season PCA analysis and (b) a graph of statistical units in the PC1-PC2 factorial design of study area.

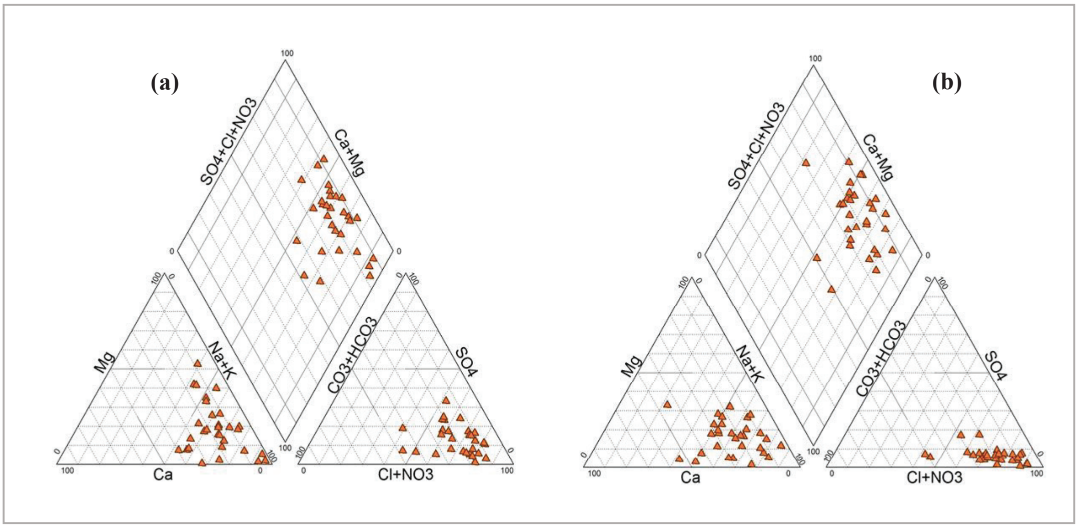

Fig. 7: Classification of well water using the Piper diagram in the dry (a) and wet (2) season.

alized waters whose ionic acquisition is under the control of mineralization-residence time. Class (3) is located in the negative part of factor 1 and includes waters with low mineral content.

Hydrochemical Classification

In order to determine the chemical facies of the waters of the studied aquifer, we used a Piper diagram (Eblin 2014) which indicated that hydrochemical classification of the groundwater sampled (Figs. 7a and 7b) shows only one facies: the chlorinated sodium facies.

DISCUSSION

We found that there was a distinct seasonal pattern in water quality of the study area. The most parameters were higher during the dry season in contrast to the wet season.

Water temperature: The variations in water temperature show that in the wet season the temperature of groundwater is lower than in the dry season (Fig. 8a). This observed increase in the dry season is most likely associated with an elevation in surface water temperature due to the higher air temperature.

Temperature variations are strongly influenced by environmental conditions related to the geographical location of the locality, the geology of the terrain crossed, the hydrology of the ecosystem and especially the climate (Rodier 1984). In both, the dry and wet seasons, the lowest temperature values were obtained either early or late in the day. Indeed, previous studies by Reggam et al. (2015) in Algeria and Makhoukh et al. (2011) in Morocco have shown high temperature values during the dry season and the lowest during the wet season.

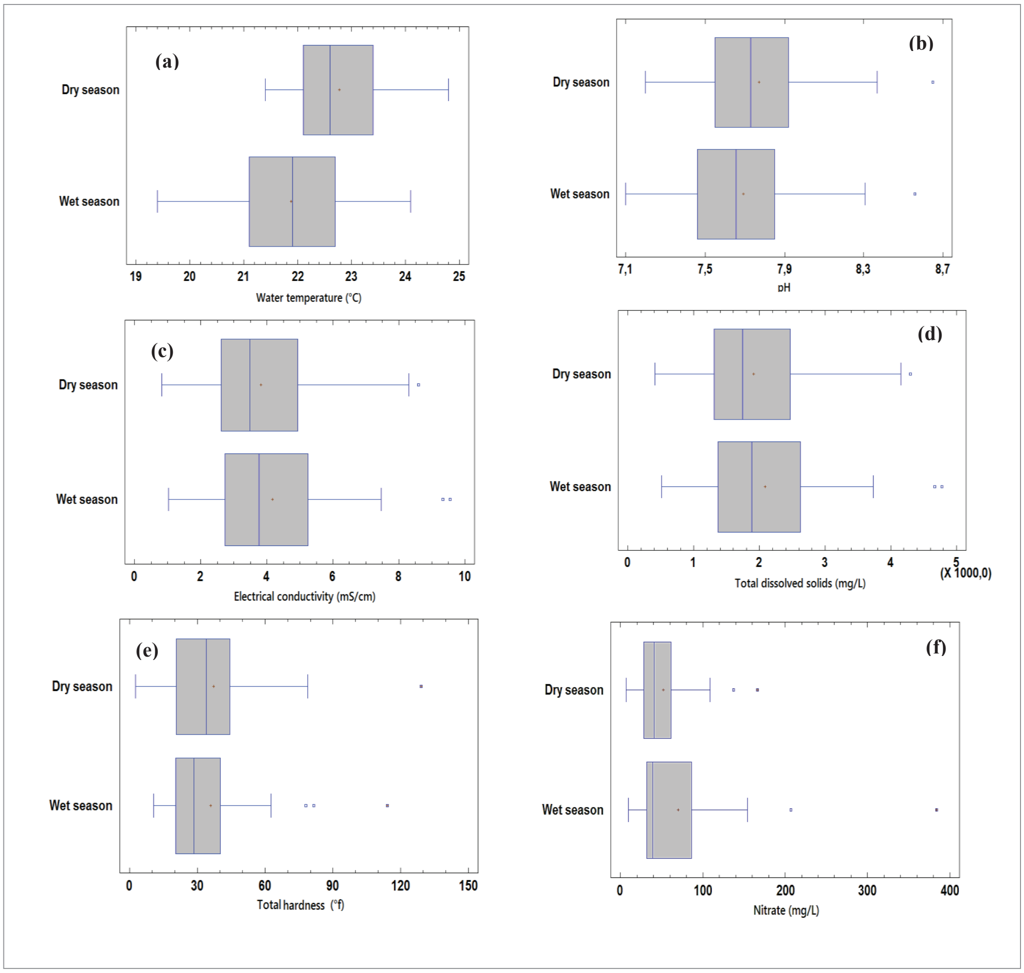

Fig. 8: Box and whisker plot of seasonal variation of water quality parameters. Water temperature (a), pH (b), Electrical conductivity (c), Total dissolved solids (d), Total hardness (e), Nitrate (f), Small red squares represent the median values, boxes represent the interquartile range, plus signs represent the extremes, small blue dots represent the outliers, and range bars show the maximum and minimum values.

Therefore, the water temperature must be determined because it is used as a good measure of contamination because it has a marked effect on bacteria and chemical reaction rates in the water (Mink 1964, Dixey 1972, Hutton 1983).

pH: The measurement of pH is one of the most frequently used tests in water chemistry (Hem 1985). The results of analyses of water samples show pH of groundwater is all within the WHO allowable limit of 7-9.2.

The high pH value during the dry season (Fig. 8b) could be due to the low water level during the dry season causing a concentration of base cations, or an excess of primary productivity over respiration during that season, consuming CO_2 and reducing H^+. Further, the study area also encompasses extensive agricultural fields. Another reason for the observed low pH values could be thus related to the use of acid producing fertilizers like ammonium sulphate and super phosphate of lime as manure for agriculture use (Raghunath et al. 2001), especially that the study area also includes extensive agricultural fields is particularly important (El Adnani et al. 2018).

Electrical conductivity (EC): The EC mean values were observed to be statistically highest in dry season, in contrast to the wet season. The distribution of EC values is presented in Fig. 8c.

The occurrence of high EC values in the study area might also be due to addition of some salts through the prevailing agricultural activities (El Achheb 2002). Comparatively zones with low EC values (<100µS/cm) are due to dilution of soluble salts by rainfall (Raghunath et al. 2001).

The EC of most of the groundwater samples showed decreasing trend in wet season (Fig. 8c) and magnitude of decrease might have been influenced by rainfall characteristics, geology, soil and land use activities, topography of the area and its drainability (Laluraj et al. 2006).

Total dissolved solids (TDS): The concentration of total dissolved solids in groundwater are noted to be higher in wet season than in dry season (Fig. 8d). This is consistent with the findings of Bowell et al (1996) and Efe et al. (2005).

During the dry season, the increased concentration of TDS may be associated with evaporation and the absence of a dilution effect, while the lower values during the wet season are hypothesized to be due to dilution from the tributaries.

The low mineralization of groundwater during the rainy season is due to dilution by rainwater input as the majority of wells are not constructed and receive runoff directly (Laluraj et al. 2006), or it could be due to the hydrogeological properties of rocks (a strong influence on the extent of water/rock reaction). Zones with high groundwater-flow velocities usually will have relatively low dissolved solids because of the shorter groundwater- rock contact time and high water/rock ratios, and vice-versa (Langmuir 1997).

EC and TDS were common for both wet and dry (Figs. 8c and 8d). There was a highly significant positive correlation of TDS with EC both in the wet and the dry season ($r = 0.99$ at $p < 0 .01$).

Total hardness (TH): The seasonal variation shows that hardness is lower during wet season (Fig. 8e), probably due to strong dilution, which can be explained by the solvent action of rainwater coming in contact with soil and especially with the rocks characterizing our study area such as limestone and marl limestone formations (Fig. 3) (Souhel et al. 2000) rocks is capable of dissolving calcium and magnesium that promote water hardness.

Although, water harness has no harmful on human health except that it can react with ordinary soap to form scum, plume solvent, scale formation in boilers and in hot water systems (Maxwell et al. 2012).

Nitrate: It is evident that concentration of nitrate was quite variable from season to season. The high values of NO_3^- during the wet season (Fig. 8f) returns to the high rate of precipitation that facilitate infiltration of the amount of fertilizer applied.

The spatial variation in nitrate content in groundwater might be due to different degrees of evaporation/recharge, amount of fertilizer applied, anthropogenic activities, microbial reactions, nature of vegetation cover and adsorption/desorption processes in the soil system (Datta et al. 1996, 1997, Martin et al. 2006).

Chloride: The seasonal variations of chloride show an increase during the dry season compared to the wet season (Fig. 9a) which can be attributed to the local environment of the wells or the chemical composition of the groundwater is strongly affected by excess fertilizer spread over the last 20 years, in particular, chloride (from potassium fertilizers) (El Adnani et al. 2018).

The weakness of chlorides in the wet season is mainly related to the extent and intensity of precipitation during that season. Chloride levels in open pit and borehole waters indicate that seawater in the region has a significant influence on the salt content of groundwater resources, particularly the leaching of salt crystals from aerosols and sea spray (Younsi et al. 2001). The chloride content of water is an indication of the intrusion of seawater. The levels of chloride in open-well and borehole waters indicates that

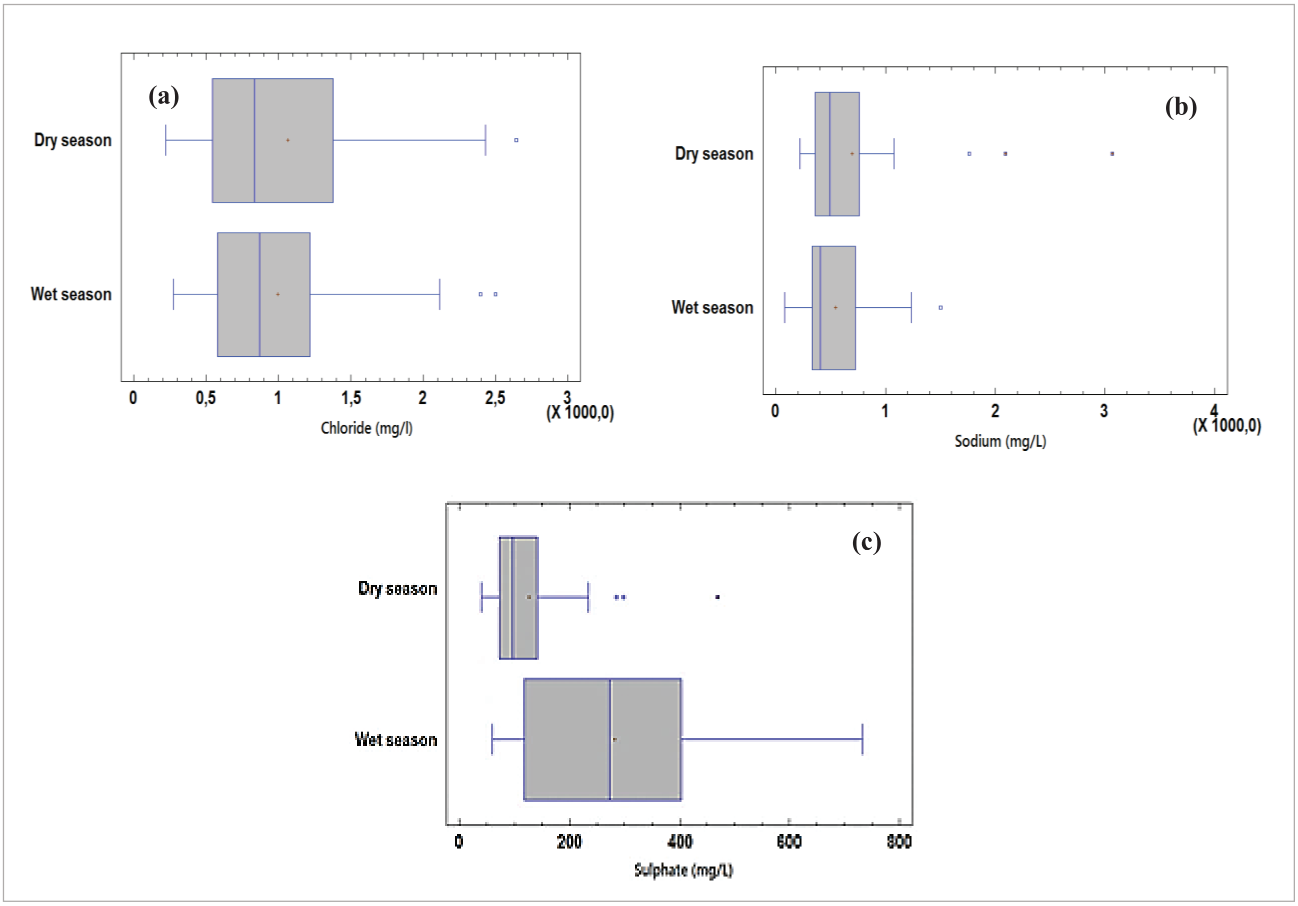

Fig. 9: Box and whisker plot of seasonal variation of water quality parameters. Chloride (a), Sodium (b) and Sulphate (c).

sea water within the area has a great influence on the salt content of the underground water resources (Efe et al. 2005, Maxwell et al. 2012).

Sodium: The reduction in the current study of the concentration of sodium during the wet season (Fig. 9b) may be associated with dilution by rainwater.

As noted above, the potential source of the Na+ in water may be related to leaks of leachate from CET to studied water (El Adnani et al. 2018), or other sources can be cited, such as leaching of NaCl crystals from sea spray with over-concentration by the possible effect of evaporation, recirculation of saline drainage waters in agricultural sectors (Younsi et al. 2001).

Sulphate: The results of analyses show that the highest concentration of SO_4^{2-} was recorded at the wet season (Fig. 9c). A significant difference in sulphate concentrations was observed for both seasons which can be explained by the fact that rainwater seems to contain more sulphates than water from wells and boreholes. This may result from high level combustion of sulphur-containing hydrocarbon emissions in the study area, specifically in the vicinity of the industrial area (El Hasnaoui et al. 2006, 2011). Oxidation of sulphur containing compounds after rainwater water has been charged to ground water resources may increase the acidity and toxicity of open-well and borehole water resources.

The study of the mechanism for acquiring water chemistry in the study area using multivariate statistical analysis methods made it possible to observe, in a first approach, three main mechanisms responsible for the evolution of groundwater mineralization in the study area. The three main mechanisms are: mineralization, residence time and spatial origin of ions.

The acquisition of ions is essentially through rock-water interactions, which is the important phenomenon in water mineralization. The limestones and marls of the formations dominate the geology of the region and characterize the

Cenomanian aquifer, which explains the dominant Ca^{2+} contents for cations in groundwater.

The acidity of the waters and the abundance of precipitation cause a very intense and complete alteration of the primary minerals of the parent rock by hydrolysis (Eblin et al. 2014). This hydrolysis is, therefore, important in both the rainy and dry seasons. Indeed, in both the rainy and dry seasons, the mineralization of the waters studied is of both natural (water-rock contact) and anthropogenic origin.

In view of the findings revealed by this study, it is recommended that there is necessary to place two meteorological stations in the area for local measurement of precipitation, temperature and evapotranspiration. The risk of contamination by seawater must be controlled, it would therefore be necessary to set up a network of monitoring piezometers (with continuous recording), in order to control the fluctuation of the piezometric surface and to regularly monitor the quality of the groundwater to preserve these resources; to conclude, authorities must be required to authorize the use of low-flow pumps and the generalization of economic irrigation methods such as drip irrigation. Propose changes in agricultural practices and especially monitor effluent treatment at landfills and industrial areas.

CONCLUSION

In this study, the measured parameters showed a seasonal fluctuation, with concentrations mainly higher during the dry season than during the wet season. This assessment provided information on the characteristics of groundwater in the coastal zone of the Sahel of Doukkala. Physico-chemical analyses show that the water is highly mineralized with an average electrical conductivity of 382,6 µS/cm in the wet season and 416,04 µS/cm in the dry season. Multivariate statistical analysis methods indicate that the different processes responsible for the acquisition of groundwater chemistry studied are: the residence time of the water in contact with the rock, the infiltration of substances related to anthropogenic activities (agricultural fertilizers, household and industrial waste...) and the intensity of rainfall.

REFERENCES

Agoussine, M. and Bouchaou, L. 2004. The major problems of water management in Morocco. Science and Planetary Changes/Drought, 15(2): 187-194.

Ahoussi, K.E., Koffi, Y.B., Kouassi, A.M., Soro, G., Soro, N. and Biemi, J. 2012. Physico-chemical and bacteriological characterization of the water resources of localities located near the Ébrié Lagoon in the commune of Marcory (District of Abidjan, Ivory Coast): case of the village of Abia Koumassi. European Journal of Scientific Research, 89(3): 359-383.

Ambroggi, R. and Thuille, G. 1952. Abada-Doukhala. In: Hydrogéologie du Maroc. Notes et Mémoires. Services Géologique Maroc, N° 97.

Berdai, H. 1997. Synthesis of work carried out in Morocco on nitric pollution of groundwater. Studies Division, Testing Experiments and Standardization Service, Rabat.

Bowell, R.J., McEdonney, S., Warren, A. and Bwankuzo, M. 1996. Biogeochemical factors affecting groundwater quality in central Tanzania. Geological Society, London, Special Publications, 113(1): 107-130.

Chofqi, A. 2004. Highlighting the mechanisms of contamination of groundwater by leachate from an uncontrolled landfill (El Jadida-Maroc). Geology, hydrogeology, geoelectric, geochemistry and epidemiology, pp. 184.

Chtaini, A. 1987. Hydrogeological Study of the Doukkala Sahel (Morocco). Doctoral Dissertation, Joseph Fourier University (Grenoble), pp. 157.

D.R.H . 1990. Projet de réalisation des sondages à l'air sur la région des Doukkala, Rabat, Maroc.

Datta, P.S. and Tyagi, S.K. 1996. Major ion chemistry of groundwater in Delhi area: Chemical weathering processes and groundwater flow regime. J. Geolog. Soc. India, 47(2): 179-188.

Datta, P.S., Deb, D.L. and Tyagi, S.K. 1997. Assessment of groundwater contamination from fertilizers in the Delhi area based on 18O, NO_3^- and K^+ composition. Journal of Contaminant Hydrology, 27(3-4): 249-262.

Dixey, F.A. 1972. A Practical Handbook on Water Supply. 2nd edition, Thomas Murby & Co, London.

Domenico, P. A. and Schwartz, F.W. 1998. Physical and Chemical Hydrogeology. Vol. 1, Wiley, pp. 506.

Dou, M., Zhang, Y. and Li, G. 2016. Temporal and spatial characteristics of the water pollutant concentration in Huaihe River Basin from 2003 to 2012, China. Environmental Monitoring and Assessment, 9: 188-522.

DRHT 1994. Elaboration d'un schéma d'exploitation des eaux souterraines du Sahel (Maroc). Rapp. Projet : DRPE-FAO. TCP/MOR/2251.

DRPE 1992. Etude par prospection électrique : Région des Abda et des Doukkala, (21 Mars 1990-10 Juillet 1990, 08 octobre 1992-15 novembre 1992). GEOATLAS. Tome 1: texte et planches.

Eblin, S.G., Soro, G.M., Sombo, A.P., Aka, N., Kambiré, O. and Soro, N. 2014. Hydrochimie des eaux souterraines de la région d'Adiaké (Sud-Est côtier de la Côte d'Ivoire). Larhyss Journal, 17: 193-214.

Efe, S.I., Ogban, F.E., Horsfall, M. and Akporhonor, E.E. 2005. Seasonal variation of physico-chemical characteristics in water resources quality in western Niger Delta region, Nigeria. Journal of Applied Science and Environmental Management, 9(1): 191-195.

El Achheb, A. 2002. Contribution à l'étude de la minéralisation et identification des sources de contaminations des eaux souterraines, application au système aquifère du Bassin Sahel Doukkala (Maroc). Thèse d'état, Univ Chouaïb Doukkali, El Jadida, pp. 206.

El Achheb, A., Mania, J. and Mudry, J. 2003. Mécanismes d'acquisition de la minéralisation des eaux souterraines dans le bassin Sahel des Doukkala (Maroc Occidental). Approche par des traceurs hydrogéochimiques. IGME. Madrid, pp. 113-123.

El Adnani, I., Younsi, A., Ibno Namr, K., El Achheb, A. and Irzan, E.M. 2018. The influence of anthropogenic activities on groundwater quality of southwest region of El Jadida city (Sahel of Doukkala, Morocco), European Journal of Scientific Research, 151: 96-111.

El Hasnaoui, B., Garmes, H., Younsi, A., Mountadar, M. and Mouhab, I. 2006. Problèmes de contamination fluorurée en zone industrielle (Cas du Jorf Lasfar, Maroc). Approche pluridisciplinaire dans le Colloque Internationale, Mines: Exploration, Exploitation et Impact environnementale (M3E), Bouznika, 20-21 Avril, pp. 53.

El Hasnaoui, B., Younsi, A., Mountadar, M., Garmes, H. and Mouhab, I. 2011. Impacts négatifs d'une zone industrielle sur les eaux souterraines et sur le cheptel (Cas du Jorf Lasfar, Maroc): Approches pluridisciplinaires. Déchets sciences techniques, N°59, 2945.

Fadili, A. 2014. Etude hydrogéologique et géophysique de l'extension de l'intrusion marine dans le sahel de l'Oualidia (Maroc): Analyse statistique, hydrochimie et prospection électrique. Thèse Doct, Univ. Chouaib Doukkali, El Jadida, Maroc., pp. 289.

Fakir, Y. 2001. Caractérisation hydrogéologique et hydrochimique des aquifères côtiers du Sahel de Safi à Oualidia (Méséta côtière- Maroc). Thèse 3éme cycle. Univ. Cadi Ayyad, Marrakech, pp. 143.

Fakir, Y. and Razack, M. 2003. Hydrodynamic characterization of a Sahelian coastal aquifer using the ocean tide effect (Dridrate Aquifer, Morocco). Hydrological Sciences-Journal-des Sciences Hydrologiques, 48(3).

FAO (Food and Agriculture Organization) 1997. Seawater Intrusion in Coastal Aquifers: Guidelines for Study, Monitoring and Control. FAO Water Reports 11. Rome Italy: FAO; 163 p.

Ferre, M. 1969. Hydrologie et hydrogéologie des Abda- Doukkala. Thèse du Docteur Ingénieur- Nancy.

Ferre, M. and Ruhard, J.P. 1975. Les bassins des Abda-Doukkala et du Sahel de Azemmour à Safi. In: Ressources en eau du Maroc. Notes mém. *S*erv. Géol Maroc, 2(231): 261-298.

Foster, S., Chilton, J., Moench, M., Cardy, F. and Schiffler, M. 2000. Groundwater in rural development: Facing the challenges of supply and resource sustainability. World Bank Technical, Washington. Paper No 464.

Gigout, M. 1952. Les ressources en eau souterraine des Doukkala et Abda (Maroc occidental). Rapp. Inéd. Seconde thèse.

Gigout, M. 1955. Enseignement de trois forages sur la stratigraphie du Crétacé des Doukkala. Notes mém. Serv. géol. Maroc, t. 11(123): 44-55.

Hani A, Djarbri L, Mania J. 1997. Etude des caractéristiques physico-chimiques du massif cristallophyllien de Séraïdi (nordest Algérien). Hard Rock Hydrosystems (Proceedings of Rabat Symposium S2 1997). IAHS Publ., N°.241: 41-59.

Hem, J.D. 1985. Study and Interpretation of The Chemical Characteristics of Natural Water. 3rd edition, US Geological Survey water-supply, paper 2254.

Hilali, M. 2002. Hydrogéologie et modélisation de l'intrusion marine dans les aquifères côtiers de Martil et du Sahel-Maroc. Thèse de Doctorat. Ecole Mohammadia d'Ingénieurs Rabat.

Hutton, L.G. 1983. Field testing of water in developing countries. Water Resources Center, Unwin Brothers Limited, Britain. 125 pp.

ISO 1984. Total Hardness of Water by Photocolorimetry, Standard Methods 2340C Hardness. Hach Company/ Hach Lange GmbH, 2015. Edition 1, 1-13.

Kaid Rassou, K. 2009. Etudes des interactions entre les eaux souterraines et les eaux de surface dans le bassin côteir d'Oualidia, These doctorat es science Univ. Marrakech, pp. 193.

Laluraj. C. M. and Gopinath Girish 2001. Assessment on seasonal variation of groundwater quality of phreatic aquifers-a river basin system. Environmental Monitoring and Assessment, 117: 45-57.

Langmuir, D. 1997. Aqueous Environmental Chemistry, Prentice-Hall, Inc., New Jersey, pp. 600.

Makhoukh, M., Sbaa, M., Berrahou, A. and Clooster, V.M. 2011. Contribution à l'étude physico-chimique des eaux superficielles de l'oued Moulouya (Maroc oriental). Larhyss Journal, 9: 149-169.

Martin, C., Molénat, J., Gascuel-Odoux, C., Vouillamoz, J.M., Robain, H., Ruiz, L., Faucheux, M. and Aquilina, L. 2006. Modelling the effect of physical and chemical characteristics of shallow aquifers on water and nitrate transport in small agricultural catchments. Journal of Hydrology, 326: 25-42.

Maxwell, I.O. and Ahola, O. 2012. Seasonal variation in physico-chemical characteristics of rural groundwater of Benue State, Nigeria. Journal of Asian Scientific Research, 2(10): 574-586.

Mink, J.F. 1964. Groundwater temperatures in tropical island environment. Journal of Geophysical Research, 66: 5230-5250.

Murdey, J. and Blavoux, B.1986. Utilisation de l'analyse en composantes principales (sur variables centrées réduites) pour l'étude du fonctionnement hydrocinématique de trois aquifères karstiques du Sud-Est de la France. Hydrogéologie, n° 1: 53-59.

Oulaaross, Z. 2009. Etude climatologique, hydrogéologique et géophysique du Sahel Côtier des Doukkala (Maroc). Apport de l'analyse statistique et de l'inversion des données géoélectriques à l'étude du biseau salé de la lagune de Sidi Moussa Thèse Doct, Univ. Chouaib Doukkali, El Jadida, Maroc. pp. 279.

Quinn, G.P. and Keough, M.J. 2002. Experimental Design and Data Analysis for Biologists. United States of America by Cambridge University Press, New York, pp. 553.

Raghunath, R. Sreedhara, Murthy, T. R. and Raghavan, B. R. 2001. Spatial distribution of pH, EC and total dissolved solids of Nethravathi river basin, Karnataka state, India, Pollution Research, 20(3): 413-418.

Reggam, A., Bouchelaghem, H. and Houhamdi, M. 2015. Qualité physico-chimique des eaux de l'Oued Seybouse (Nord-Est de l'Algérie): caractérisation et analyse en composantes principales. J. Mater. Environ. Sci., 6(5): 1417-1425.

Richardson, S., Evans, R., Middlemis, H., Ross, J., Howe, P., Hiller, J. and Dyson, P. 2004. Guiding Principles for Sustainable Groundwater Management. IAH Background Paper, MDBC (Murray- Darling Basin Commission), REM (Resource & Environmental Management Pty Ltd.), Australia.

Rodier, J. 1984. L'analyse de l'eau : eaux naturelles, eaux résiduaires, et eau de mer. 7ème édition, Dunod Technique, 1136 pp.

Rodier, J. 2009. L'analyse de l'eau. 9ème édition. DUNOD, Paris, France.

Souhel, A. and El Achheb, A. 2000. Cadre géologique des principaux aquifères de la plaine des Doukkala. Actes de la 2ème session de L'université de printemps des Doukkala-Abda. Université. Chouaïb Doukkali, El Jadida, (Maroc), 3: 71-73.

Sudhakar, A. and Narsimha, A. 2013. Suitability and assessment of groundwater for irrigation purpose: A case study of Kushaiguda area, Ranga Reddy district, Andhra Pradesh, India. Pelagia Research Library, Advances in Applied Science Research, 4(6): 75-81.

UNESCO 1987. Groundwater Problems in Coastal Areas. United Nations Educational, Scientific and Cultural Organization, pp. 582.

UNESCO 2003. Water for People: Water for Life. 1st edition. The United Nations' world water development report, Berghahn Books, 543 pp.

WHO 2011. World Health Statistics. WHO Department of Health Statistics and Informatics of the Innovation, Information, Evidence and Research Cluster, France, pp. 162.

Younsi, A., Mania, J., Lhadi, E.K. and Mudry, J. 2001. Incidences de pluies exceptionnelles sur un aquifère libre côtier en zone semi-aride (Chaouia, Maroc). Revue des sciences de l'eau, 14(2): 115-130.