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

Imane EL Adnani†, Abdelkader Younsi, Khalid Ibno Namr, Abderrahim El Achheb and El Mehdi Irzan
Laboratory of Geosciences and Environment Techniques, Chouaib Doukkali University, Faculty of Sciences, Ben Maachou Road, B.P. 20 Avenue des Facultés, El Jadida, Morocco
†Corresponding author: Imane EL Adnani

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 (Ca²⁺, Mg²⁺, Cl⁻ and HCO₃⁻) and spectrophotometry methods (SO₄²⁻, 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 Mg²⁺ and Ca²⁺. 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⁺, SO₄²⁻ and K⁺ and negatively associated with temperature, and pH. The wet season was in contrast associated with high values of NO₃⁻ 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.


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 km², 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-
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 $5 \times 10^{-6}$ 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 HNO₃ 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 analyzed 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 analyzed in Laboratory of Geosciences and Environmental Techniques of Chouaïb Doukkali University. These parameters include important
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$_2$SO$_4$. Chloride (Cl$^-$) was determined titrimetrically by standard AgNO$_3$ titration. Sulphate (H$_2$SO$_4$) 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).
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.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>WHO standards</th>
<th>Dry season</th>
<th>Wet season</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>6.5 - 9.5</td>
<td>7.2- 8.65</td>
<td>7.77- 8.39</td>
</tr>
<tr>
<td>WT (°C)</td>
<td>&lt; 25</td>
<td>21.4- 24.8</td>
<td>22.7- 24.1</td>
</tr>
<tr>
<td>TH (mg/L)</td>
<td>&gt; 400</td>
<td>101.9- 955</td>
<td>416.04- 5178.7</td>
</tr>
<tr>
<td>EC (μS/cm)</td>
<td>&gt; 400</td>
<td>101.9- 955</td>
<td>416.04- 5178.7</td>
</tr>
<tr>
<td>TDS (mg/L)</td>
<td>&gt; 400</td>
<td>101.9- 955</td>
<td>416.04- 5178.7</td>
</tr>
<tr>
<td>Ca²⁺ (mg/L)</td>
<td>&lt; 100</td>
<td>16- 372</td>
<td>128.57- 64.72</td>
</tr>
<tr>
<td>Mg²⁺ (mg/L)</td>
<td>&lt; 50</td>
<td>1.2- 460</td>
<td>100.77- 296.4</td>
</tr>
<tr>
<td>Na⁺ (mg/L)</td>
<td>&lt; 150</td>
<td>220- 3066</td>
<td>695.17- 623.47</td>
</tr>
<tr>
<td>K⁺ (mg/L)</td>
<td>&lt; 12</td>
<td>3.8- 31.5</td>
<td>12.47- 53.38</td>
</tr>
<tr>
<td>HCO₃⁻ (mg/L)</td>
<td>158.6- 890.6</td>
<td>443.43- 163.01</td>
<td>183.01- 370.88</td>
</tr>
<tr>
<td>Cl⁻ (mg/L)</td>
<td>&lt; 200</td>
<td>221.9- 2644.75</td>
<td>1061.45- 698.47</td>
</tr>
<tr>
<td>SO₄²⁻ (mg/L)</td>
<td>&lt; 250</td>
<td>25.64- 454.59</td>
<td>112.42- 91.89</td>
</tr>
<tr>
<td>NO₃⁻ (mg/L)</td>
<td>&lt; 50</td>
<td>6.76- 165.93</td>
<td>52.02- 37.04</td>
</tr>
</tbody>
</table>

Nature Environment and Pollution Technology • Vol. 19, No. 1, 2020
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\(^\circ\)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
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-
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.

![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.](image-url)
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 CO₂ 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 NO₃⁻ 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...
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 SO₄²⁻ 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

---

**Fig. 9: Box and whisker plot of seasonal variation of water quality parameters. Chloride (a), Sodium (b) and Sulphate (c).**
Cenomanian aquifer, which explains the dominant Ca²⁺ 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


