Physicochemical characterization of the unconfined water-table aquifer of the Fez-Meknes basin.

Rabia El Fakir[1,] , *El Mostafa* Mili[1], *Ali* Essahlaoui[1], *Mohammed* El Hafyani[1] and *Zakaria* Ammari[1].

[1]Laboratory of Geoengineering and environment, Department of Geology, Faculty of Sciences, Moulay Ismail University, B.P11201, Zitoune, Meknès, Morocco

Abstract. This paper aims to determine the hydrogeochemical characteristics of the Fez-Meknes free water table thought the monitoring of the physicochemical analyses of nine samples during the year of 2013, 2016, and 2019. This water table, which circulates in the plio-quaternary formations, is generally supplied by rainfall infiltration, irrigation water returns and also the lateral inflow of the unconfined liasic water table of the Middle Atlas Tabular. Analyses were performed for electrical conductivity (EC), potential hydrogen (pH), temperature and major elements: Cl^-, $NO3^-$, SO_4^{2-}, Na^+, Mg^{2+}, Ca^{2+}, HCO_3^- , K^+. The results of the projection of the samples on the Piper diagram for the three companies showed a hydrochemical carbonate, calcic and magnesian facies for the majority of the samples with the exception of samples 1161/15 and 352/21 for the year 2013. Then, to understand the origin of the mineralization, as well as the processes related to the dissolution of the carbonate country rock, a principal component analysis (PCA) was performed.

Keywords: Fez-Meknes unconfined water table, physicochemical analysis, pH, EC, major elements, PCA.

Résumé. La présente étude a été menée sur l'analyse des paramètres physico-chimiques durant les années 2013, 2016, et 2019, afin de déterminer les caractéristiques hydrogéochimiques des eaux souterraines de la nappe libre du bassin Fès-Meknès. Celle-ci circule essentiellement dans les formations lacustres du Plio-Villafranchien. Elle est généralement alimentée par infiltration pluviale, par le retour des eaux d'irrigation et par l'influence des apports latéraux de l'eau à partir de la nappe liasique libre du Causse moyen atlasique. Les paramètres physico-chimiques à propos desquels les analyses des eaux souterraines ont été portées sont les ions majeurs Cl^-, NO^{3-}, SO_4^{2-}, Na^+, Mg^{2+}, Ca^{2+}, HCO^{3-} , K^+, la conductivité électrique, le pH et la température. Le suivi de leur évolution par leur projection sur le diagramme de Piper, a permis de mettre en évidence une stabilité de leur faciès chimique carbonaté calcique et magnésien. En parallèle, une analyse statistique basée sur la méthode ACP a permis de visualiser simultanément les corrélations entre les paramètres physico-chimiques étudiés et de comprendre les processus qui peuvent être à l'origine de la minéralisation, et qui sont essentiellement liés probablement à la dissolution de l'encaissant carbonaté.

Mots clés : Bassin Fès-Meknès, paramètres physico-chimiques, ACP, eaux souterraines, nappe libre.

1 Introduction

Groundwater is an essential resource of continental freshwater. It is a limited, fragile, and precious resource essential to the various uses (agricultural, domestic, industrial-commercial, and energy) whose man is responsible for deteriorating their qualities [1].
Morocco is one of the countries suffering from chronic water stress [2]. This nomination sets off alarm bells, according to presential assessments carried out by the World Bank since 1994. It is inspired by the fact that the country suffers from long periods of drought. Therefore, it appears essential to monitor the treatment of groundwater resources to predict the evolution of their quality systematically [3].
On a global scale, previous works such as those carried out by [4], [5], [6], [7], [8], [9], [10], [11], [12], [13], have been interested in the study of the physicochemical characterization in relation with the origin of mineralization in groundwater, as well as the impact of the deterioration of their quality.
The aim of this study is to determine the hydrogeochemical characteristics and the origin of the mineralization of the Fez-Meknes free water table thought the monitoring of the physicochemical analyses of nine samples during the year of 2013, 2016, and 2019. In addition, the Paper diagram and the PCA were used in this purpose.

1.1 Geomorphology and geology of the study area

The basin of Fez-Meknes corresponds as a whole to a vast asymmetrical syncline of East-West direction, which occupies the median part of the southern rift. It's bordered in the North by the prefectural wrinkles, in the South and South-East by the Causse of the Middle Atlas. In the East the basin is limited by the valley of Sebou, and the valley of Beht and its affluents inf the West.

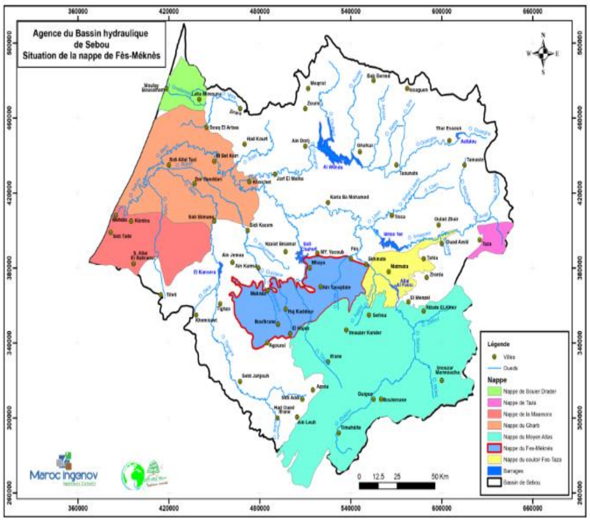

Figure 1: Situation of the Fez-Meknes water table in the Sebou basin (ABHS, 2017).

The regional synthetic log of the basin shows a vertical lithostratigraphic variability. The series corresponding to the bedrock presents a succession that starts with shales and flysch of the Paleozoic and passes to the Triassic trilogy (red clay formations with intercalation of basalts), surmounted by limestones and dolomites of the Lower Jurassic. the substratum is surmounted by the formations of the Neogene which are constituted by sands with carbonate matrix, grey marls and fawn sands [14], [15], [16]. Nevertheless, the roof of the series is composed of deposits of Quaternary age known by their heterogeneities [17], materialized by tawny silts, oncolythic limestones, and ocholytic sands [18], [19].

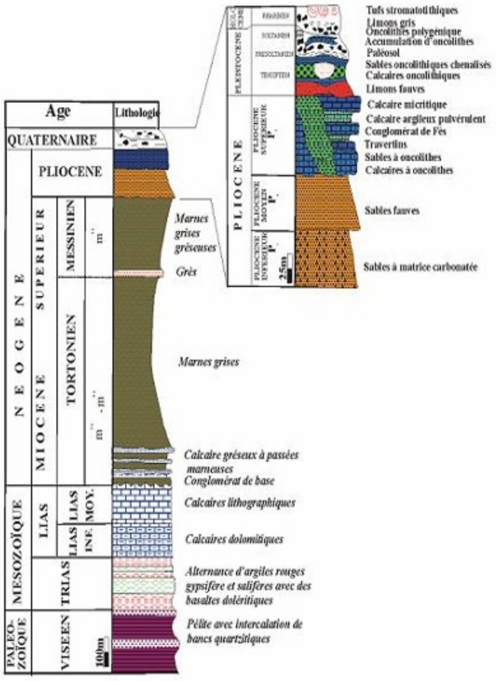

Figure 2: Synthetic lithostratigraphic log of the Fez-Meknes basin (Essahlaoui, 2000).

1.2 Hydrogeology

From a hydrogeological point of view, there are two crucial aquifer reservoirs of unequal interest in the Fez-Meknes basin. These are the free surface water table that spreads in the Plio-Villafranchian formations [19] and the water table that circulates in the dolomitic limestone of the Lias. The latter is free at the level of the Middle Atlas Causse and then sinks under the thick series of impermeable marls of the Miocene, which put it in charge under the plain and constitutes the captive water table. These two aquifers intercommunicate in places either directly through flexures and faults, or indirectly through upward drainage.
The free water table, which will be the subject of our study, is supplied by the direct contributions of the free part of the Liasic water table [20], [21], [22] by the return of irrigation water, and by rainfall infiltration.

2 Materials and methods

In order to achieve the objectives of this study, a physicochemical analysis was carried out for the free water table by the hydraulic basin agency of Sebou and the Public Laboratory of Tests and Studies (LPEE). Thus, three companies were made in 2013, 2016, and 2019 for two periods in the year (Summer and winter). The analysis was made for the pH, EC, temperature, anions (HCO_3^-, SO_4^{2-}, Cl^-), cations (K^+, Mg^{2+}, Ca^{2+}, Mn^{2+}, et Na^+), as well as nutritive elements (NO_2^-, NO_3, NH_4^+), the sampling is well presented spatially.

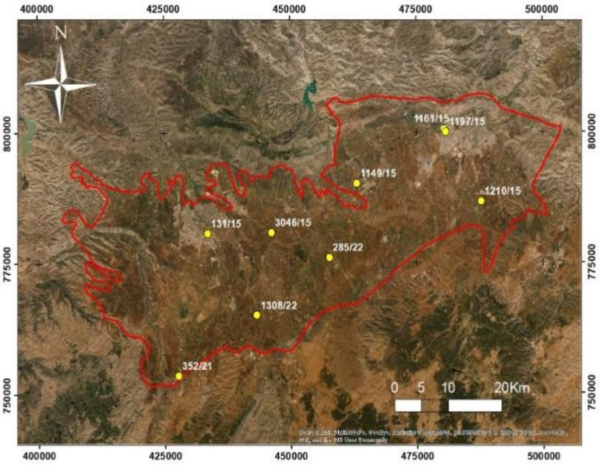

Figure 3: Distribution map of water points sampled in the Fez-Meknes basin located on a satellite background.

Piper's diagram (1944) was used to identify the chemical facies and to analyze the evolution of the studied groundwater. It is composed of two triangles representing respectively the distribution of anions and cations, and a diamond representing the synthetic distribution of major ions. The software Diagram (Roland SIMLER Hydrogeological Laboratory of Avignon, version 6.7, 2020) was used for the graphic. The PCA an exploratory multivariate analysis tool widely used to interpret hydrochemical data. It allows to visualize simultaneously the main trends between a large number of variables, and the distribution of the boreholes (individuals), taking into account their physicochemical parameters. For this purpose, XLSTAT software (Addinsoftet version, 2016) was use.

3 Results and discussion

3.1 Piper diagram

Among the cations (NH_4^+, K^+, Na^+, Ca^{2+}, Mg^{2+} et Mn^{2+}) studied during 2013, 2016, and 2019 in the free groundwater, Ca^{2+} ions are the most abundant in these waters, followed by Mg^{2+} ions, as for the anions we find that HCO_3^- ions are the most important in this category, followed by Cl^- ions. The graphical representation of the results on the Piper's diagram, allows us to distinguish a single family of waters in all the drillings from the hydrochemical point of view. It is mainly calcic and magnesian bicarbonate, except for the waters of the 1161/15 borehole, which presents calcic and magnesian sulfate facies. The water from borehole 3458/15 shows an evolution from calcic and magnesian carbonate facies to chloride and calcic and magnesian sulphate facies.

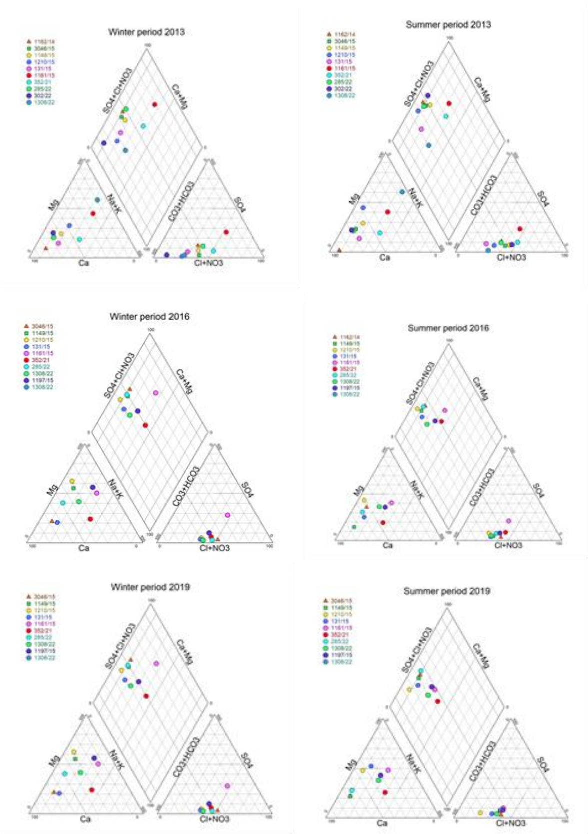

Figure 4: Piper diagram of summer and winter periods 2013, 2016 and 2019.

3.2 Descriptive statistics

Boxplots were used to better identify the variability of the analyses performed on the major elements common to the different boreholes. The horizontal line inside each box corresponds to the median of the values. At the same time those beyond the boxes represent the maximum and minimum values.

3.2.1 Summer period

By comparing the different diagrams of the companies made during the summer periods, we can see that we can see that the median of the majority of the parameters is moderately placed below the zone, which makes the moustache box asymmetrical; from this fact, one deduces an asymmetry of the overlying distribution of the analysed data that allows saying that this distribution is unlikely to be expected. This remark can be reinforced by the presence of several points indicated by aberrant asterisks. During the summer 2013 period, these outliers are not displayed either within the box, or at the whiskers for Ca^{2+}, and Na^+.

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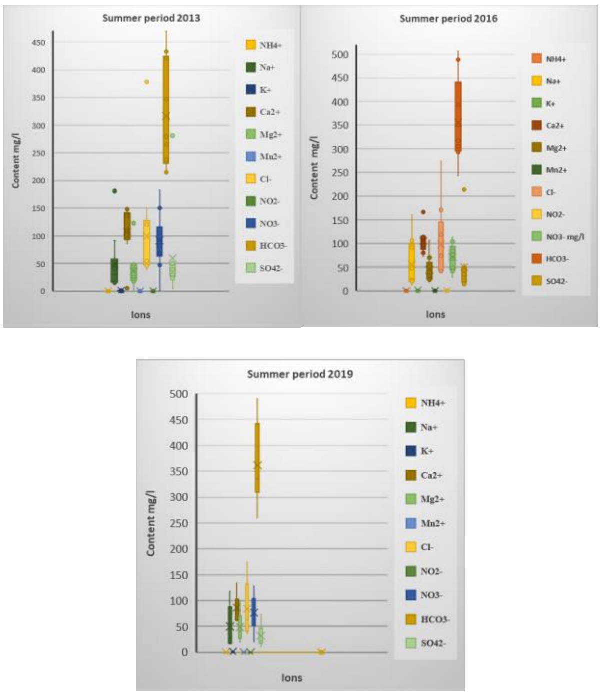
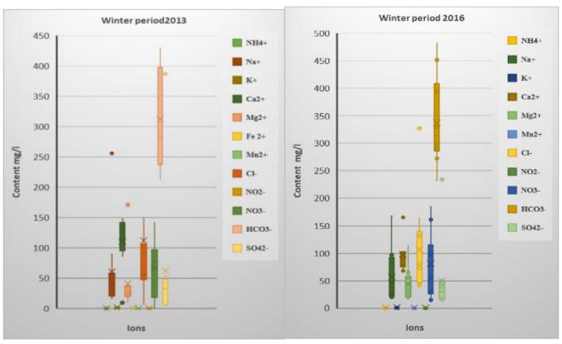


Figure 5: box plots from the 2013,2016, and 2019 summer periods.

3.2.2 Winter period

Like the previous period, this period does not present a significant difference in the location of the median within the box, which allows us to note such an abnormal distribution of the analyzed data. This can be proved by the presence of outliers during the years analyzed for the elements SO_4^{2-}, Cl^-, Mg^{2+}, Ca^{2+}, et Na^+. These values placed outside the boxes and outside the whiskers must be examined, to know if they are due to mistakes during the input, if they are suspicious, or if they are real outliers. As an example, if we treat carbonates the winter period in 2019: we note that 50% of the samples present 281.8 mg/l of this element, while the minimum and maximum values are respectively 175.7 mg/l, 493 mg/l. Concerning the quartiles that present the edges of the box, we notice that 25% of the samples contain 271mg/l, and 75% when it contains 344 mg/l. So, any value lower than 271 and higher than 344 is considered an outlier.



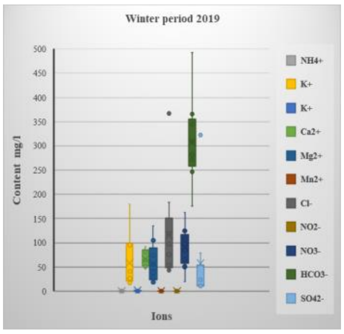


Figure 6: box plots from the 2013,2016, and 2019 winter periods.

3.3 Principal component analyses

In the principal component analysis, the first two factors (F_1 and F_2) were retained, which accumulated a total variance, between (68.92-77.99%) during the summer periods, and (69.68-75.05%) during the winter period. The particular graph of the PCA is the correlation circle shown in the figures below. During all the summer period, the F_1 axis has a cumulative variance it varies from 46.04 to 53.72%, while for the winter period it varies from 30.42 to 51.89%. This axis includes EC, Cl^-, SO_4^{2-} , and Na^+, HCO_3^-, Mg^{2+}, K^+. These ions are strongly correlated on the positive side. This allows us to consider the F_1 axis as an axis that marks the mineralization of groundwater in the different samples. This is reflected in the common origin of the Mg^{2+} and HCO_3^- ions. Indeed, their presence can be attributed to the dissolution of Quaternary formations and Jurassic dolomitic limestones, during the recharge of the Plio-Quaternary aquifer, mainly by direct inflow from the free Liassic aquifer. However, the good correlations at the level of Na^+ and Cl^- ions can be explained by their common origin from an agricultural, industrial uses, and the wastewater infiltration.

As for the F_2 factor axis, it shows the cumulative variance (19.88 to 24.59%) during the summer period, and (19.09 to 23.16%) during the winter period. It shows good correlations between Ca^{2+}, NO^{3-}, and NH^{4+}. This axis expresses the origin of these ions from the organic pollution of the water. Concerning K^+, it can result from the dissolution of chemical fertilizers used excessively by the farmers, while Ca^{2+} is a metal which belongs to the alkaline-earth necessary to the human organism. Its content depends on the nature of the land crossed, and it comes mainly from the limestone rocks constituting the plio-quaternary aquifer. It is present in the form of carbonates. According to [22], the existence of nitrates is due to their origin from soil fertilizers, generally by the decomposition of organic matter by bacterial oxidation of nitrites.

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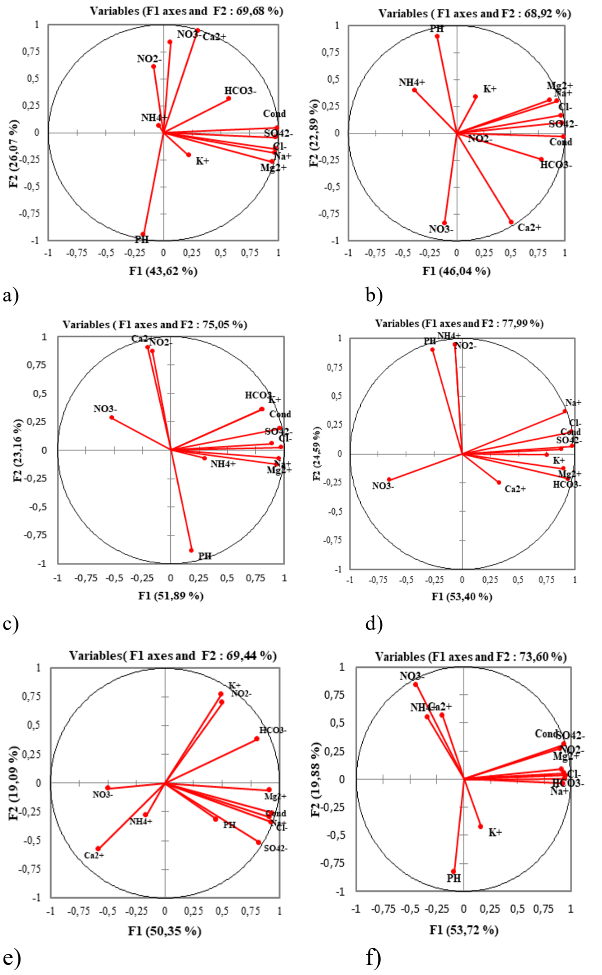

Figure 7: Principal component analyses, a) Winter period 2013, b) Summer period 2013, c) Winter period 2016, d) Summer period 2016, e) Winter period 2019, f) Summer period 2019.

4 Conclusion

This study aims to assess the evolution of the physicochemical parameters of the water table of the Fez-Meknes basin during the years 2013, 2016, and 2019. These parameters, in accordance bye the results obtained by [6], [7], do not present any impact on the water table. The hydrochemical analysis of the results revealed the dominance of carbonates (HCO_3^-, Ca^{2+}), compared to other ions (Na^+, Cl^-, SO_4^{2-}). This reflects the bicarbonate calcic and magnesian facies determined by the Piper diagram of these waters. This is related to the lithology of the aquifer. Indeed, it is the consequence of the dissolution of the plio-quaternary carbonate formations favoured by the ascending and descending circulations of the groundwater.

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