

## Study of Hydrochemical Characteristics in the Middle Moulouya Basin of Morocco

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### ABSTRACT

This study analyzes the effects of dry land salinity, climate severity, and pollution on groundwater quality in the Middle Moulouya basin. Our research provides insights into certain pollutants and their sources and discusses the impact of saline soil and dry weather. A comprehensive understanding of these factors is essential for managing water resources and promoting sustainable resource use in the area. In fact, the use of a database relating to the major elements, viz. potassium ( $K^+$ ), calcium ( $Ca^{2+}$ ), sodium ( $Na^+$ ), magnesium ( $Mg^{2+}$ ), bicarbonates ( $HCO_3^-$ ), sulfates ( $SO_4^{2-}$ ), nitrates ( $NO_3^-$ ), chlorides ( $Cl^-$ ) has proved to be effective to assess the hydrochemical features of groundwaters and their suitability for both aims (i.e., irrigation and drinking). The Middle Moulouya basin's subterranean water is slightly acidic to basic, with a pH range of 6.8 to 7.66 and mild to brackish water at specific sites. Furthermore, in line with the hydrochemistry diagrams, groundwater can be classified into three main types: Ca-Cl, Ca- $HCO_3$ , and Ca-Mg-Cl type. Moreover, the results pertaining to the overall quality of groundwater regarding Moroccan control standards guidelines indicate that: (i) 32.43% of the groundwater samples are of excellent quality, (ii) 24.32% of the collected water points are of good quality, (iii) 32.43% have medium quality, (iiii) and only 10.82% are of poor and very poor quality (i.e., 5.41% for each class). Finally, based on the Wilcox method, a significant percentage of groundwater sites are suitable for farming.

**Keywords:** Middle Moulouya basin, groundwater quality, hydrochemistry, groundwater, diagrams, Wilcox method.

### INTRODUCTION

The groundwater has become the basic vehicle for the best part of industrial and rural development around the world as it gives rise to livelihoods and employment. In this vein, it continues to be a vital water source for diverse purposes, including irrigation, drinking, and industry, due to high demand. At this point, its quality could be extremely critical before any particular utilization. In light of this, chemical composition can probably be amongst the relevant clues that determines water's cleanliness. As surely, in most cases, the chemical constituents turn out to be toxic and harmful while exceeding a certain threshold whereas they could be

nutritious and beneficial in smaller quantities (Das et al., 2021; Pervez et al., 2021). Against this background, in Morocco, particularly within its dry and semi-dry areas., the presence of groundwater meeting acceptable standards quality has become a controversial subject across the overwhelming majority of its expanse, and more precisely in the Middle Moulouya basin in view of the various plumes, viz. pollution potential dry land salinity, and climate severity have rendered this resource more likely vulnerable. Therefore, it was imperative to appraise the quality and pinpoint the sources of groundwater pollution in the Middle Moulouya basin. Considering that, Hydrochemical studies have proven to be beneficial and highly valuable

in identifying the physico-chemical traits of the water bodies within the basin. In fact, the findings from this assessment could serve as a valuable management strategy, particularly in areas affected by contamination. Indeed, an integrated study, via the combination of the Geographic Information System, field investigations, along with geochemical analyses, were conducted on samples gathered from scattered water points (sources, boreholes, and wells), not only that, covering approximately the whole Middle Moulouya basin. The analysis as well as the interpretation of the results of the geochemical analyses are provided by different treatments using both hydrochemical and statistical software. This survey involves assessing water quality in the district by: (1) specifying water facies, (2) detecting pollution and quantifying it, (3) and finally creating a groundwater quality map for the study area, the Middle Moulouya basin.

## STUDY AREA

### Geographic location

The Middle Moulouya basin, covering a large area reaching 16800 km<sup>2</sup>, encompasses a fairly large segment of the Moulouya river, about 150 km, the latter belongs to one of the largest catchments of Morocco, Moulouya basin. Generally, in view of the geographic coordinates, the Lambert coordinates, the study area is lodged within the coordinates of X = 580,000 to X = 776,000 and Y = 220,000 to Y = 370,000 (Figure 1).

### Geological background

In the study region, the extensive stratigraphic exposures consist of Paleozoic basement, separated by an angular unconformity from subsequent deposits spanning the Triassic to the Quaternary period. Throughout Morocco, the Triassic deposits encompass almost the same trilogy of facies. The geological formations of Lower and Middle Liassic, mostly denoted by carbonate formations, have facies segmented into depth-restricted zones. A sedimentation hiatus took place during the Upper Domerien period. The Cretaceous deposits rest on angular unconformity on the various outcrop formations of the Middle and Upper Jurassic. The evolution of the Cretaceous series over time has three stages depicting a wide-ranging sedimentary cycle. The most striking feature of the Cenozoic

is the sea withdrawing from the district, favoring the emergence of a continental environment well known for its own sedimentary evolution.

### Hydrogeological background

Hydrogeologically, this zone generally presents an abundance of groundwater because it incorporates many hydrogeological units, precisely seven units, which fall into three categories (i.e., deeper water tables, water tables, alluvial aquifer), widely exploited by the population. In addition to all the underground sources that flow in the basin, this exploitation is materialized by the creation of wells and boreholes intended to meet all kinds of needs (irrigation, drinking, industry). Indeed, around sixty groundwater springs are inventoried in the district, the foremost is Tissaf as its high flow rate which is about 180 l/s. Climatologically, the Middle Moulouya basin is characterized by a semi-arid climate, with an annual average rainfall of approximately 150 mm downstream of the catchment, specifically between Outat El Haj and Bouyaakobat, and it can reach 600 mm on the summits of the Middle Atlas. The rainy periods are recorded in September, October or November and April or May while the dry period generally lasts for 6 months (Figure 2a). Generally, the majority of precipitation falls during the autumn and winter seasons, while low precipitation falls during the spring and summer seasons (Figure 2b).

## MATERIALS AND METHODS

### Master data

Before gathering data, especially groundwater samples (Figure 1), we carefully followed guidelines to ensure well-distributed sampling locations in the basin. Various data types, like topographic and geological maps, were used to address groundwater deterioration. ArcGIS and Google Maps aided in creating visual aids for locating sampling points and verifying accuracy, saving time and covering most aquifers in the Middle Moulouya basin. Figure 1 shows the geographical distribution of all sampling points.

### Description of the analyses carried out

In hydrogeological researches, as concerns the quantity and quality of water resources, field

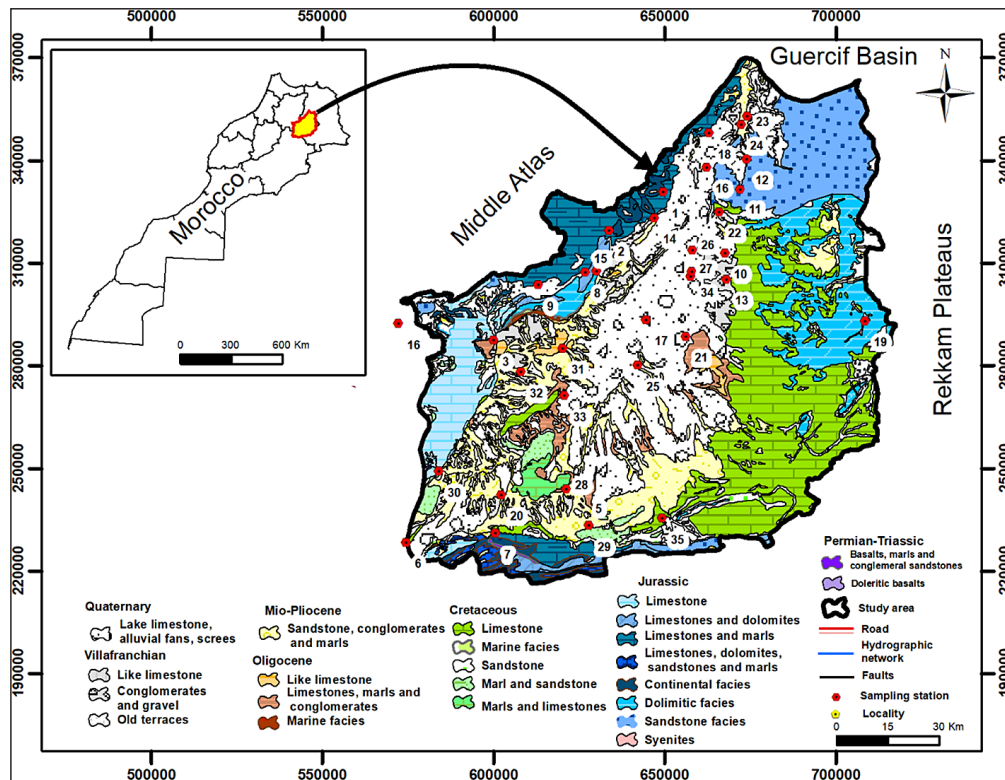


Figure 1. Geographical situation of the studied area and geological maps (Geological map of Rabat, sheet Oujda, at 1:500.000 scale, 2021)

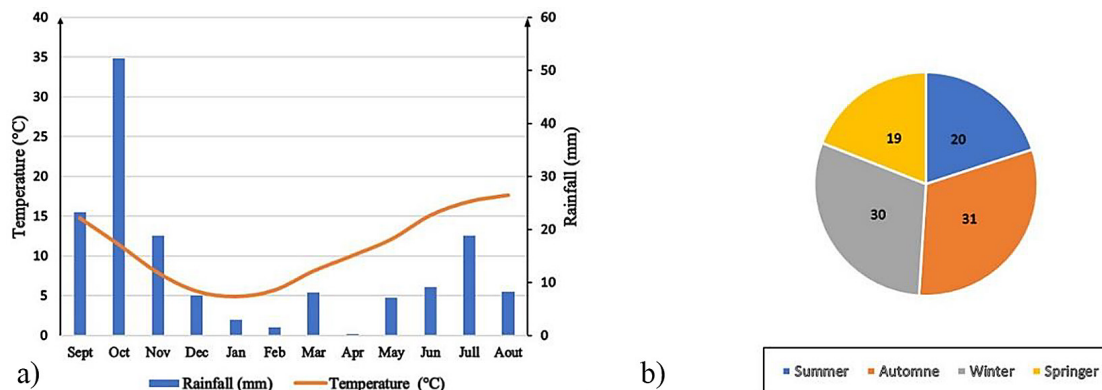


Figure 2. (a) Average temperatures and precipitation graph, (b) and the seasonal distribution of precipitation and its percentages from Outat El Haj station (1995/2013)

observations remain mandatory to determine their state (Beecham & Razzaghamanesh, 2015). Hence, it was absolutely essential to schedule more than a few field missions; five field missions for the purpose of gathering numerous water samples for laboratory analysis. Furthermore, discrete analyzes performed for each sampling location involve two main phases: (1) on one hand, the reliable physico-chemical parameters that are stated to be measured in situ namely electrical conductivity, pH, and water temperature, (2) on the other hand, the collected groundwater samples, which have been labeled carefully and transported to

the laboratory for such accurate chemical analysis relating to the major elements, viz. potassium, bicarbonates, magnesium sulfates, sodium, nitrogen dioxide, nitrates, calcium, and chlorides.

### Geochemical analysis

Typically, according to the types of analyses aimed, all water samples were carefully distributed in various bottles (i.e. polyethylene bottles of different capacity). The first set was gathered without any additional preservative (i.e. anion analyses) whereas the second set was acidified

with nitric acid to  $\text{pH} < 2$  (i.e. cation analyses). So that, the prepared bottles were sorted at  $5\text{ }^\circ\text{C}$ , low temperature, till laboratory analysis.

### Data processing method

The basic approach consists of using hydrochemical and geostatistical methods for processing data collected on groundwater in the Middle Moulouya basin. In addition, other objectives such as the classification of hydrochemical data (i.e., classification of groundwater samples into groups) as well as their interpretations require the use of leading hydrochemical software such as DIAGRAMMES 6 (Raco et al., 2021). With this in mind, a statistical analysis was carried out through the use of a database, drawn up from data relating to scattered water sites, which is structured around various variables (i.e., hydrogen ion concentration (pH), temperature ( $T\text{ }^\circ\text{C}$ ), electrical conductivity (EC), potassium ( $\text{K}^+$ ), calcium ( $\text{Ca}^{2+}$ ), sodium ( $\text{Na}^{2+}$ ), magnesium ( $\text{Mg}^{2+}$ ), bicarbonates ( $\text{HCO}_3^-$ ), sulfates ( $\text{SO}_4^{2-}$ ), nitrates ( $\text{NO}_3^-$ ), chlorides ( $\text{Cl}^-$ ), and suspended solids (mg/l). For more precision, the results pertaining to chemical analyzes have been compared with national standards for drinking water, not influenced by various actions done by people (i.e. human activities), prescribed through the Moroccan Industrial Standardization Service, 2008. Typically, the use of all aforementioned techniques allow the highlight of mechanisms that are responsible for the mineralization of the groundwaters of the Middle Moulouya basin.

### Method of assessing the risk of soil salinization

Usually, since plants do not tolerate saturated soils, it is important to evaluate the risk of soil salinization. Therefore, Wilcox's plot, which was among the earliest water classification systems for irrigation could be used to make a decision about the suitability of water for irrigation. Generally, the Wilcox classification depend on percent sodium, electrical conductivity and boron concentration. The percent sodium is defined by the Eq. 1 (Batarseh et al., 2021):

$$\% \text{Na} = \left( \frac{\text{Na}^+ + \text{K}^+}{\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^+ + \text{K}^+} \right) \times 100 \quad (1)$$

where: every ionic concentration must be expressed in terms of meq/l.

Furthermore, the water quality for agricultural use was also evaluated through Riverside diagrams. This plot relies to these two criteria: (i) sodium adsorption ratio (SAR) since it is a measure of sodium/alkali risk to harvests, hazard agricultural yields, (ii) and electrical conductivity (EC) that reflects the total dissolved solids (TDS) in water, as the most important standard for the classification of farming water. The SAR is denoted by the Eq. (2) (Boufekane & Saighi, 2019):

$$(\text{SAR}) = \left( \frac{\text{Na}^{2+}}{\sqrt{(\text{Ca}^{2+} + \text{Mg}^{2+})/2}} \right) \quad (2)$$

## RESULTS AND DISCUSSIONS

In Table 1, the results of the different physico-chemical analyze conducted on the groundwater of the Middle Moulouya basin are shown. The subsequent discussion will depict the significance of these outcomes within the context of: (i) origin of water chemistry, (ii) water-rock interactions, (iii), water types, and (iiii) groundwater origin.

### Chemical characteristics of groundwater

The pH in groundwater samples is largely in the neighborhood of neutrality. Truly, pH values fluctuate from 6.88 to 7.66 which indicates lightly acidic toward lightly basic, with an arithmetic average of 7.16. In the district, the electrical conductivity (EC) ranges from 264 and 3320  $\mu\text{cm}$ , with an average of 1225.97  $\mu\text{cm}$ . Moreover, in 8.33% of the groundwater samples, the salt enrichments are high ( $\text{EC} > 2700\text{ } \mu\text{cm}$ ), 33.33% of samples are medium ( $1300 < \text{EC} < 2700\text{ } \mu\text{cm}$ ), and 58.33% of samples are low ( $\text{EC} = < 1300\text{ } \mu\text{cm}$ ). In fact, a higher value of electrical conductivity (EC) could be attributed to human activities (i.e., anthropogenic contamination linked to septic tanks, domestic sewage, and farming activities) and the dissolution of minerals, triggering increases in ionic concentration. Furthermore, it is worthy of note that the high values are observed in the regions of Missouri and Ksabi. The mineralization is primarily based on (1) the leaching of stratigraphic series (i.e., the geological formations), (2) groundwater travel time, (3) ion exchange, (4) evaporation, (5) sediment dissolution, (6) rainwater infiltration, etc. The maximum electrical conductivity (EC) value that is allowed, as reported by the Moroccan standards of drinkable

**Table 1.** Results of physicochemical analyzes of groundwater in the Middle Moulouya basin

Parameter	Unit	Maximum	Minimum	Mean	Standard deviation	Moroccan control standard	Number of observations over Moroccan control standard	Maximum allowable (WHO 2004)	Most desirable limits (WHO 2004)
EC 25 °C	µ/cm	3320	264	1225.97	818.27	≤ 1300	14	-	1400
(pH)	-	7.6	6.88	7.16	0.18	6.5–8.5	0	8.5	5
T	° C	47.5	8.5	19.13	6.98	< 25	5	-	-
Mg <sup>2+</sup>	mg/l	196.34	4.86	72.70	46.04	≤ 50	23	150	50
Ca <sup>2+</sup>		448.89	27.29	93.63	81.46	≤ 200	3	200	75
K <sup>2+</sup>		14	0.4	2.93	2.77	10 -15	0	20	-
Na <sup>2+</sup>		640	1	77.58	109.20	≤ 20	28	200	-
SO <sub>4</sub> <sup>2-</sup>		830.28	16.72	245.58	192.70	< 250	16	400	299
Cl <sup>-</sup>		873.72	5.67	129.06	159.93	< 300	2	600	200
CO <sub>3</sub> <sup>-</sup>		1830	115.9	286.53	274.22	≤ 518	1	300	-
NO <sub>3</sub> <sup>-</sup>		50.87	0.336	8.11	12.62	10-25	4	50	-

water, is 2700 µS/cm. Consequently, groundwater samples of Middle Moulouya basin are consistent with the national standards (Service of Moroccan Industrial Standardization, 2008). Generally, the temperatures of the groundwater samples remain under the threshold defined by Moroccan control standards (2008) and World Health Organization (2004). With the exception of the sites (P10, P11, P21) that are moderately high in comparison with different groundwater samples that represent a temperature rate above the threshold (25°C) allowed by Moroccan control standards, and the groundwater point (P17) which may be considered as hydrothermal as its water's temperature reaches 47.50 °C which is the greatest value recorded.

The nitrate concentration (NO<sub>3</sub><sup>-</sup>) was fairly high in certain groundwater samples (i.e., Sites N° 16, 27,30, 31), especially in the South-West of the catchment. In fact, in the area studied in this paper, farming activities are largely related to the groundwater resources. A fairly high nitrate concentration is regarded alongside the Moulouya river, whether forward or backward, which could be on account of the infiltration of irrigational water from agricultural lands where chemical fertilizers are used in a random manner by farmers toward increasing crop yield. The high nitrate concentration in the vicinity of Outat El Haj and Missouri towns is in relation to the sewage water that is over flowing.

Usually, water with a high chloride content (i.e., > 250 mg/l) tastes salty. Chloride limits were set more in terms of taste than the harmful effect on human health. In view of human suffering from hypertension, it is highly desirable that the

chloride concentration ought to be lesser. Drinking standards allow for a maximum permissible concentration that is about 300 mg/l according to the Service of Moroccan Industrial Standardization, 2008. Hydrogeologically, the isochlor map which represents the distribution of chloride ions, is suitable for determining the direction of groundwater flow, as a rule the chloride concentration rise in the direction of flow (Kessasra et al., 2021). The analyses conducted on the groundwater samples indicate that the chloride concentration values are between 5.6 and 873.72 mg/l in groundwater sites N° 22 and 15, respectively. Chloride's concentrations in the groundwater sites of the Middle Moulouya basin remain below the threshold established by Moroccan standards, except for the site N° 15 and 24 which does not comply with national standards. These sites show very high concentration of chlorides (i.e., 873,72 and 401,88 mg/l, respectively) (Service of Moroccan Industrial Standardization, 2008). In addition, the rise in chloride concentration springing from: (i) cross-flow of saline water from underlying Triassic saliferous deposits, (ii) evaporation of the water specifically in areas that show fewer depths (iii) leaching of soil via farming water, (iiii) and supplementary input of chloride from abundant uses of fertilizers and rock weathering.

Regarding water-soluble salts, in particular the sulfate component, Moroccan control standards guidelines for drinking water allow a maximum concentration which oscillates between 200 and 250 mg/l. Correspondingly, there is a moderate increase in sulphate concentration at 44.44% of groundwater samples (i.e., sites N° 2, 5 and

11). In addition to the dissolution of gypsum, well known for its own chemical formula (i.e.  $\text{CaSO}_4 - 2\text{H}_2\text{O}$ ), other processes are responsible for the input of this chemical element (the ion sulfate solute ( $\text{SO}_4^{2-}$ ) in the water and contribute to change of the groundwater sulfate concentration namely: (i) the oxidation of mineral sulfides (i.e., sphalerite ( $\text{ZnS}$ ), galena ( $\text{Pbs}$ ), chalcopyrite ( $\text{CuFeS}_2$ ), and pyrite ( $\text{FeS}_2$ )), (ii) and agricultural runoff, which is one of the most common sources in farming areas, highly rich with fertilizers (Li et al., 2022).

The concentration of bicarbonate ( $\text{HCO}_3^-$ ) oscillates between 115.9 and 408.7 mg/l in the study area, representing the most preponderant solute compared to the others. In fact, it is possible to elucidate the relation between the higher bicarbonate concentration and the dominance of the mineral dissolution. That is to say, the greater the mineral dissolution, the higher the concentration is, and vice versa. The carbonates, existing in carbonate rocks, are able to be dissolved in the course of (i) groundwater flow, (ii) rainfall infiltration, (iii) irrigation, and will subsequently be added to the underground water system through the process of water recharge (Singh et al. 2012). Therefore, when considering the high values of ( $\text{HCO}_3^-$ ), they are explained via the water flowing which is supposed to be highly rich with carbonic acid and carbon dioxide broken up in the Jurassic aquifers, since the latter are dominated by carbonate formations.

### Hydrochemical classification of waters

The sound evaluation of the hydrochemical data could be achieved by plotting: (1) hydrochemical sections, (2) hydrochemical diagrams, and (3) hydrochemical maps. Hydrochemical facies is an expression adopted in this paper to refer to the groundwater solutions' diagnostic chemical aspect taking place in hydrologic systems that are often complex. The aforementioned term, facies, reflects the chemical processes' response acting within the host rocks (i.e. inside the lithologic frame) as well as the water flow pattern (Yang et al., 2021). In addition, in hydrochemical pattern diagrams, the variation in the hydrochemical features of groundwater could be exhibited through plotting diagrams (i.e. Collins' Bar Diagrams, Stiff's Diagrams, Scholler's Diagram, Hill-Piper diagram). The aim of hydrochemical diagrams is to illustrate the relative or absolute concentration of various anions (i.e.,  $\text{Cl}^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{HCO}_3^-$ ,  $\text{CO}_3^-$ )

and cations (i.e.  $\text{Na}^{2+}$ ,  $\text{K}^+$ ,  $\text{Mg}^{2+}$ ,  $\text{Ca}^{2+}$ ) which are expressed by meq/l or mg/l while reporting values concentration: Typically, the hydrochemical data analysis of the of Middle Moulouya basin has been plotted in different hydrochemical pattern diagrams, especially Schoeller, Piper diagrams as illustrated in Figures 3 and 4.

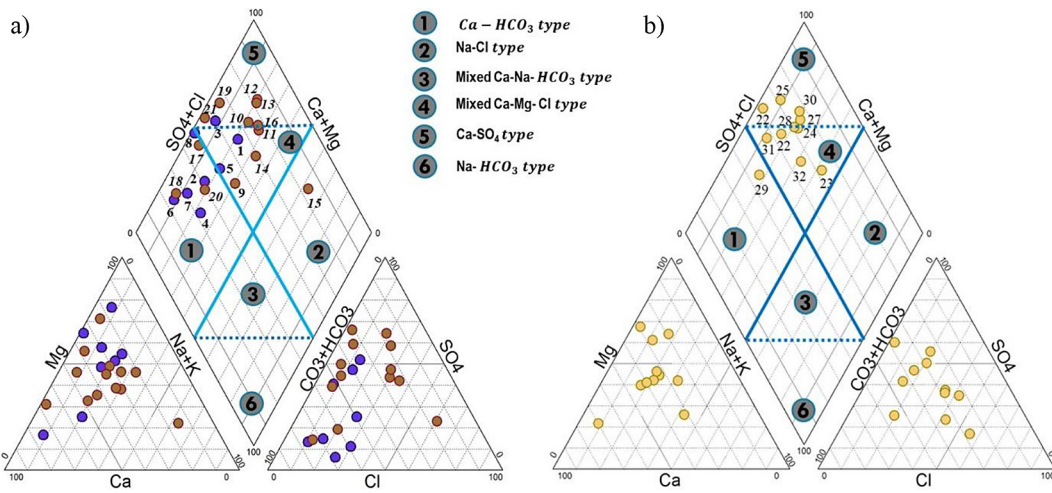
### Piper diagram

One of the chief drawbacks of Piper's diagram is that it exhibits the relative concentration of various solutes and not their proper absolute concentration (Chenaker et al., 2018). Besides, it has the utility of indicating changes in water quality due to mixing two extreme water's types, viz. the mixture of sea water and fresh groundwater as well as the base exchange effect. Furthermore, the diagram offers the advantage of representing the analytical data of many water samples in a single diagram. This diagram is widely used for the classification of water samples into different hydrochemical types based on the relative concentration of the main anions (i.e.  $\text{Cl}^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{HCO}_3^-$ ,  $\text{CO}_3^-$ ) and cations (i.e.  $\text{Na}^{2+}$ ,  $\text{K}^+$ ,  $\text{Mg}^{2+}$ ,  $\text{Ca}^{2+}$ ). In the study area, the hydrochemical classification of groundwater samples with respect to Piper's diagram (Figure 3) discloses that in most samples no ion (i.e., anion or cation) exceeds 45%, except  $\text{HCO}_3^-$  which reaches 52% in the Upper Miocene aquifer presented by samples numbered from 22 to 32 (Figure 3 b). However, the main anions are  $\text{HCO}_3^-$  (weak acids) and  $\text{Cl}^-$  (strong acid) for both aquifers (i.e., Jurassic and Miocene. In addition, regarding cations, the  $\text{Na}^{2+}$  and  $\text{Mg}^{2+}$  are the main ones with regard to Jurassic aquifers (Figure 3a) while for the Upper Miocene aquifer,  $\text{Ca}^{2+}$  and are the major cations.

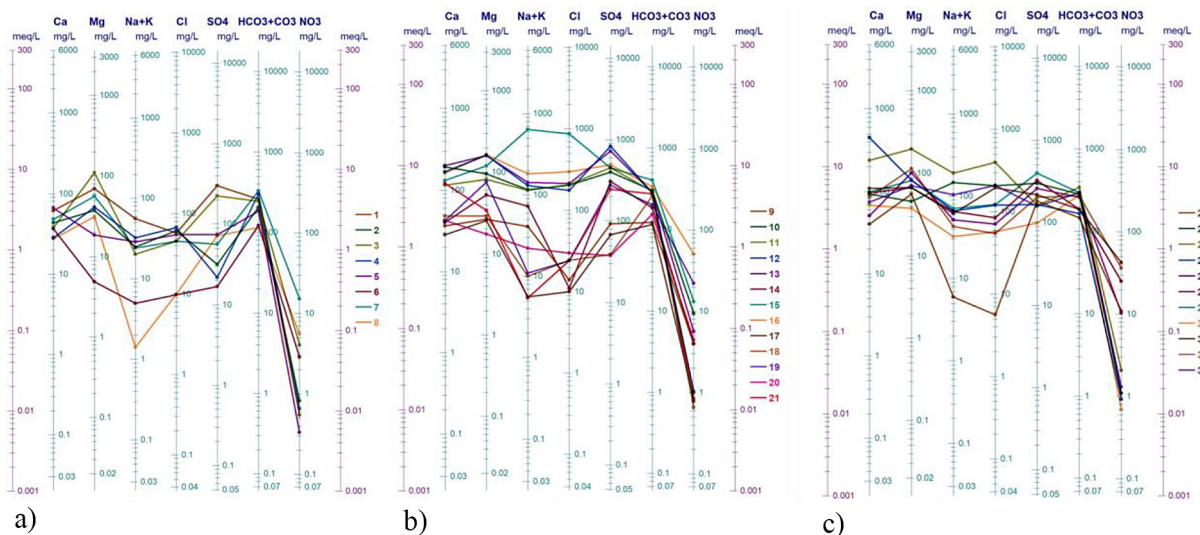
Generally, in the Middle Moulouya basin, 37% of the groundwater samples appertain to the Ca-Cl type, 31% of the groundwater samples appertain to the Ca- $\text{HCO}_3^-$ , 28% of the samples appertain to the mixed Ca-Mg-Cl type, and 3% of the groundwater samples appertain to the Na-Cl type. The presence of the aforementioned types in our district could be attributed to: (i) prolonged contact of water with host rocks (residence time) (ii) ion exchange, (iii) water velocity, (iiii) as well as the type of rocks (i.e., the lithology).

### Schoeller's diagram

The Schoeller's diagram known as a semi-logarithmic graphic on which the various anions



**Figure 3.** Report of chemical analysis results on the Piper diagram, (a) the Jurassic water points, (b), the Upper Miocene water points



**Figure 4.** Schoeller diagram of groundwater in the Middle Moulouya basin, (a) Lower Jurassic aquifer, (b) Middle Jurassic aquifer, (c) Upper-Miocene aquifer

and cations are listed at equidistance in the following order:  $\text{HCO}_3^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{Cl}^-$ ,  $\text{Na}^+$ ,  $\text{Mg}^{2+}$ , and  $\text{Ca}^{2+}$  from the right to the left on the abscissa axis, as reported by (Mir et al., 2017). The value pertaining to each of these solutes in terms of meq/l or mq/l is plotted over the y-axis on the logarithmic scale. The plots, gotten through the projection of value pertaining to each ion (i.e.,  $\text{HCO}_3^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{Cl}^-$ ,  $\text{Na}^+$ ,  $\text{Mg}^{2+}$ , and  $\text{Ca}^{2+}$ ) in the diagram, are connected through straight segments (Figure 4). Furthermore, this graphical representation is advantageous because one or more analyzes could be plotted effortlessly at a single diagram. At that time, the hydrochemical features of different samples would be easily comparable. There

are also possibilities to compare the reports of various components from the lines' slope linking the plots of neighboring anions or cations, viz.  $\gamma\text{SO}/\gamma\text{Cl}$ ,  $\gamma\text{Mg}/\gamma\text{Ca}$  and others. Obviously, waters of a similar composition should be drawn in the form of almost parallel lines. In fact, the analysis of the obtained diagram, Schoeller's diagram (Figure 4), gave us permission to sort out the groundwater samples studied of the deeper-water tables (Lower and Middle Jurassic aquifers) into two classes, each of which is of as-near parallel curves. The first class consists of the following groundwater samples pertaining to the points N<sup>o</sup>: 10, 11, 12, 13, 15 and 16, while the second class consists of the rest of the samples numbered from

1 up to 21 and which are not listed in the first class (Table 3). The concentration of magnesium, calcium, chlorides, and sulfates are more notable in the first class.

Genetically, both classes depict widely the effect of the rock sequences, the lithology, besides the water flowing over the Jurassic carbonate and Triassic evaporite series across the study area. Nevertheless, there is a wide chemical variability of the groundwater samples which could be explained by hydrochemical processes, viz. mixing and the interconnection between the profound Jurassic aquifers and the surface water bodies. In addition, regarding the Upper-Miocene aquifer, the groundwater points of this aquifer (i.e., samples N° 22 up 32) are gathered into a sole mass of parallel lines displaying that these samples derive from the same aquifer according to the Schoeller's diagram (figure 4). The latter allows us to infer that all the samples mostly exhibit identical chemical profile for  $\text{NO}_3^-$ ,  $\text{CO}_3^-$ ,  $\text{HCO}_3^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{Mg}^{2+}$ , and  $\text{Ca}^{2+}$  elements, apart from the water point N°22 outlined through low concentrations of both ions  $\text{Cl}^-$  and  $\text{Na}^{2+}$  (their concentration is about 5.67 and 4 mg/l, respectively), and the sample N° 24 that is characterized by the greatest amounts of sodium, magnesium, bicarbonate, and chlorides as compared to the other samples.

### Overall water quality of the Middle Moulouya basin

#### Evaluation of the overall quality of groundwater

Groundwater encompasses numerous chemicals both man-made and naturally occurring. Among them, some exist in huge amounts while others occur by means of trace concentrations (Luu et al., 2009). Some are extremely small and are then dissolved chemically in water, while larger particles are usually suspended. The subsequent

sections depict each of the chief chemicals found in Middle Moulouya basin, how these differ from place to place, and what this informs us regarding the effect of land uses or aquifer dynamics. In other words, the evaluation of the quality of the groundwater is done on the basis of the study of main pollution parameters (i.e., nitrates  $\text{NO}_3^-$ , chloride ions ( $\text{Cl}^-$ ), electrical conductivity (CE). The achievement of the overall quality required the use of the basic grid (Table 2) which encompasses the three aforementioned parameters which are considered among the main causes of pollution. On the one hand, the electrical conductivity (EC), as one of the electrical properties of rocks, and the chloride ions ( $\text{Cl}^-$ ) that comes from rock weathering and extensive use of fertilizers, fully reflect the mineralogical quality of the water (Perrin et al., 2008). On the other hand, nitrate ( $\text{NO}_3^-$ ) concentration is among the chief indices of water pollution as its presence in large concentrations presents ecological and human health risks (Pathak & Bhandary, 2020).

The water analyzes for sites N ° 10, 11, 12, 13, 23, 27, 28, 27, 30, 31, 33 and 36 show that the overall water quality is medium due to the electrical conductivity value which exceeds 1430  $\mu\text{S}/\text{cm}$  in all the aforementioned sites, with the exception of sites N ° 27, 31 which have good electrical conductivity values (1189 and 834  $\mu\text{S}/\text{cm}$ , respectively) but their nitrate contents are average (25.32 and 36.50 mg/l, respectively) which allows these two points (i.e. No. 27, 31) to be attributed to the medium class with regard to the overall underground water quality. And the point N° 30 has both a large quantity of nitrate (i.e. 42.62 mg/l) and a medium electrical conductivity that oscillates between 1300 and 2700  $\mu\text{S}/\text{cm}$  (Table 3). Nevertheless, with regard to the chloride's concentration, the overall quality of the groundwater is generally excellent and good in most cases (i.e., 94.59%), with the exception of the site N °

**Table 2.** Simplified grid for assessing the overall quality of groundwater (Service of Moroccan Industrial Standardization, 2008)

Quality	Pollution parameters		
	Nitrate (mg/l)	Chloride (mg/l)	Electrical conductivity ( $\mu\text{S}/\text{cm}$ )
Excellent	< 10	< 200	100–750
Good	10–25	200–300	750–1300
Medium	25–50	300–750	1300–2700
Bad	> 50	750–1000	2700–3000
Very bad		1000–6000	3000–7000



**Table 3.** Overall quality of groundwater in the Middle Moulouya basin

Aquifers	N° samples	Electrical conductivity (µS/cm)	Chlorides (mg/l)	Nitrates (mg/l)	Overall quality
Lower-Jurassic	1	1050.00	56.98	0.55	Good
	2	517.00	60.98	0.82	Excellent
	3	911.00	44.99	4.07	Good
	4	736.00	66.98	0.65	Excellent
	5	610.00	54.98	0.34	Excellent
	6	443.00	9.91	2.89	Excellent
	7	673.00	44.99	15.23	Good
	8	423.00	10.00	5.59	Excellent
Middle-Jurassic	9	417.00	14.00	3.99	Excellent
	10	1596.00	204.94	9.41	Medium
	11	1990.00	206.94	0.65	Medium
	12	1430.00	176.95	1.06	Medium
	13	1782.00	213.93	5.63	Medium
	14	264.00	11.00	4.01	Excellent
	15	3320.00	873.73	13.25	Very Bad
	16	1895.00	299.91	50.86	Bad
	17	395.00	10.00	0.84	Excellent
	18	513.00	24.39	0.99	Excellent
	19	622.00	23.99	22.16	Good
	20	355.00	29.96	4.45	Excellent
	21	1000.00	23.99	0.78	Good
Upper-Miocene	22	635.00	5.67	10.97	Good
	23	1720.00	207.84	1.10	Medium
	24	3270.00	401.88	2.09	Very Bad
	25	2910.00	119.96	0.93	Bad
	26	1006.00	70.98	10.30	Good
	27	1189.00	84.97	25.32	Medium
	28	1550.00	121.96	1.10	Medium
	29	872.00	56.98	0.70	Good
	30	1531.00	194.94	42.62	Medium
	31	833.00	54.98	36.50	Medium
	32	1470.00	209.94	1.31	Medium
	Alluvial-Quaternary	33	1780.00	234.93	1.1 18
Others	34	791.00	73.98	0.53	Good
	35	440.00	129.96	1.35	Excellent
	36	2410.00	213.93	1.01	Medium

15 which presents a very poor quality combined with the dissolution of saline rocks. Nevertheless, the sites N° 2, 4, 5, 6, 8, 9, 17, 18, 20 and 35 have shown excellent quality (Table 3, Figure 7). Furthermore, the groundwater samples pertaining to sites N° 1, 3, 7, 21, 22, 26, 29 and 34 turned out to be of good water quality (Table 3). This state of quality is due to: (i) chloride’s concentration that is excellent, less than 200 mg/l (ii) nitrate’s concentration that is also excellent, less than 10

mg/l, except for site N° 7 and 22 where the concentration has shown 10.97 and 15.34 mg/l values, respectively. The latter oscillates between 10 and 25 mg/l (i.e., good quality) (iii) electrical conductivity (EC) values that has a maximum noted value of about 1050 µS/cm (i.e., good quality).

The histogram (Figure 5) is an additional tool that represents the overall quality of water (Service of Moroccan Industrial Standardization, 2008). In fact, in the Middle Moulouya

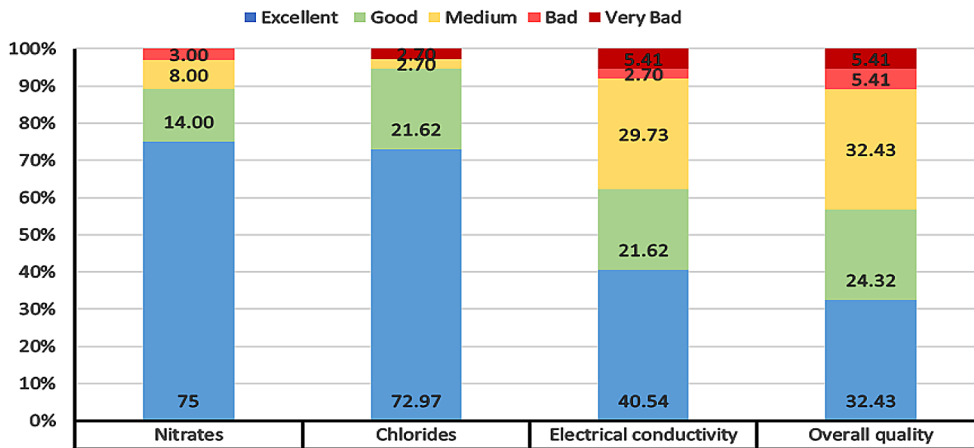


Figure 5. Graphical representation of the groundwater quality in the Middle Moulouya basin in line with the Service of Moroccan Industrial Standardization, 2008

basin, it indicates that: (i) 32.43% of the groundwater samples are in favor of the class of excellent quality, (ii) 24.32% of the collected water points are of good quality, (iii) 32.43% are attributed to medium quality, (iiii) and 10.82% are of poor and very poor quality (i.e., 5.41% for each class for these last two classes). Moreover, aquifer structure is a significant parameter related to the aquifer’s quality. Typically, the deeper aquifers (i.e., older water) are under slight hazards as compared to shallow aquifers (i.e., younger water). Generally, the latter are at the broader level of land use’s contamination. Thus, in most cases, the shallow aquifers are more susceptible to water’s quality deterioration than the deeper aquifers as chief variations in groundwater quality firstly cropped up in the unsaturated zone or soil, directly over the water table, and are lastly driven through biochemical processes. In the study area, the groundwater belonging to the deeper aquifers (Lower and Middle Jurassic) are chemically suitable, as the Lower-Jurassic

aquifer presents just two classes of high groundwater quality (the excellent of about 62.50% and the good of about 37.50%), whereas the Middle-Jurassic aquifer exhibits a decrease in the values related to these last two classes (42.86% and 14.29%, respectively), with the appearance of other classes (i.e., medium 28.57%, bad and very bad, with 7.14% for each class).

But when it comes to the Upper-Miocene aquifer, we note the disappearance of the excellent class with a fairly large increase in the value related to the medium class (54.55%), and a slightly increase in values pertaining to both classes (i.e., bad and very bad) which raised of about 2% for each class (Figure 6).

### Classification of water through the Wilcox method

Wilcox diagram was developed by Wilcox in the 1955’s and is one of the oldest irrigation waters classification systems. It is also based on:

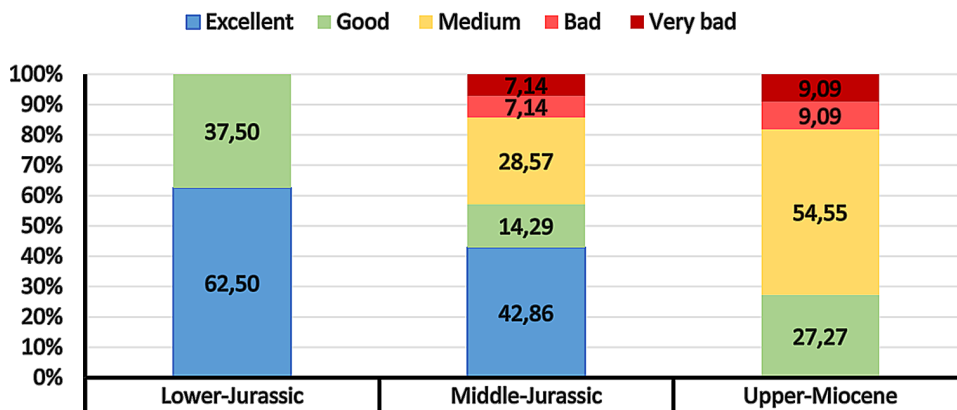


Figure 6. Graphical representation of the water quality classes for each aquifer

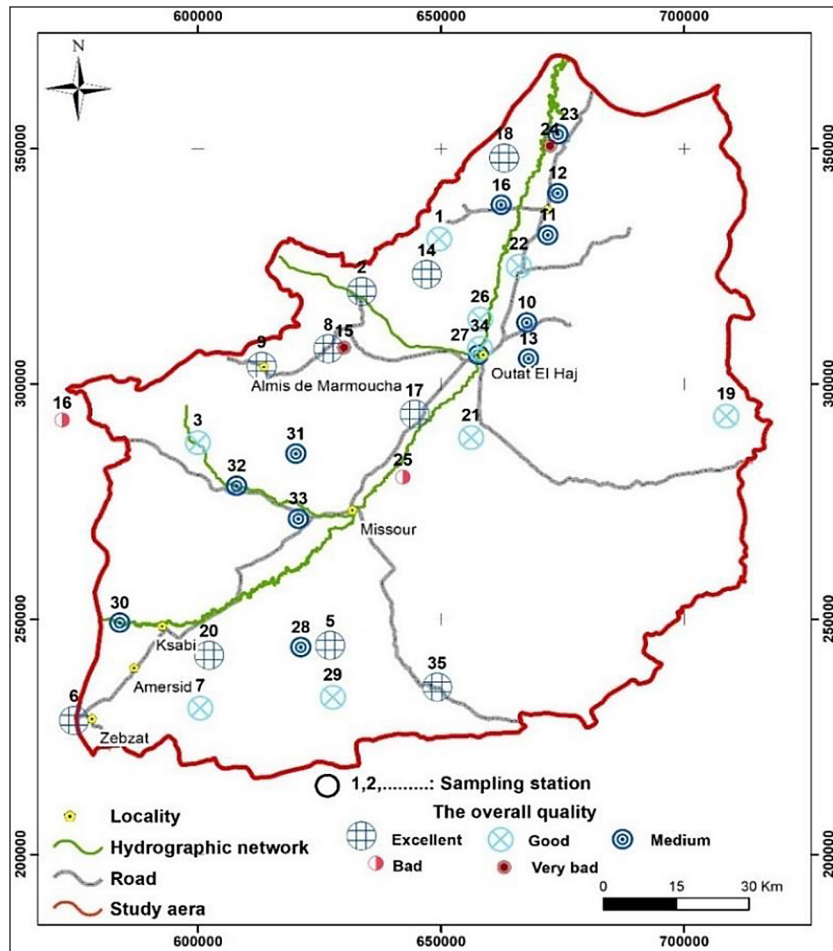


Figure 7. The overall groundwater quality map in the Middle Moulouya basin

(1) the percentage of sodium (%Na), (2) the electrical conductivity, and (3) the amount of boron. The latter is beneficial in minor concentration for the ordinary growth of some kind of plants. Nevertheless, it turns out to be toxic in larger amount depending upon the nature of plants (Yermiyahu et al., 2008). The percent sodium is stated in Equation (1). In our study area, the portrayal of the different groundwater samples treated with the support of Wilcox diagram (Figure 8) depict those waters of Middle Moulouya basin fit in four classes, excellent, good, poor and bad. Each of these classes have the following percentages: 40.62%, 50%, 3.12%, 2.32%, respectively. It should be borne in mind that the percentages of poor and bad classes are so rare in the district compared to the other two classes

(i.e., excellent and good). Consequently, It is worth noting that waters and soil of the Middle Moulouya basin have a low risk of salinization. Besides, by applying the Richards classification (i.e. Riverside diagram), the graphical representation of the groundwater samples collected confirms that both aquifers, Jurassic and Upper Miocene, fall into zones having low sodium hazard (SAR) in most cases (Figure 8, Table 4). From this classification, it can be noted that the majority of waters analyzed have low risk of alkalization except for point 15, and thereby water of both aquifers is suitable for use in irrigation. Furthermore, the Riverside diagram allows classifying underground water in well-defined intervals according to the hazard of salinization and alkalization.

Table 4. Groundwater quality intervals according to riverside diagram

Quality intervals	C <sub>2</sub> -S <sub>1</sub>	C <sub>3</sub> -S <sub>2</sub>	C <sub>4</sub> -S <sub>1</sub>	C <sub>4</sub> -S <sub>3</sub>
Jurassic aquifer (%)	57	38	0	5
Upper Miocene aquifer (%)	9	73	18	0

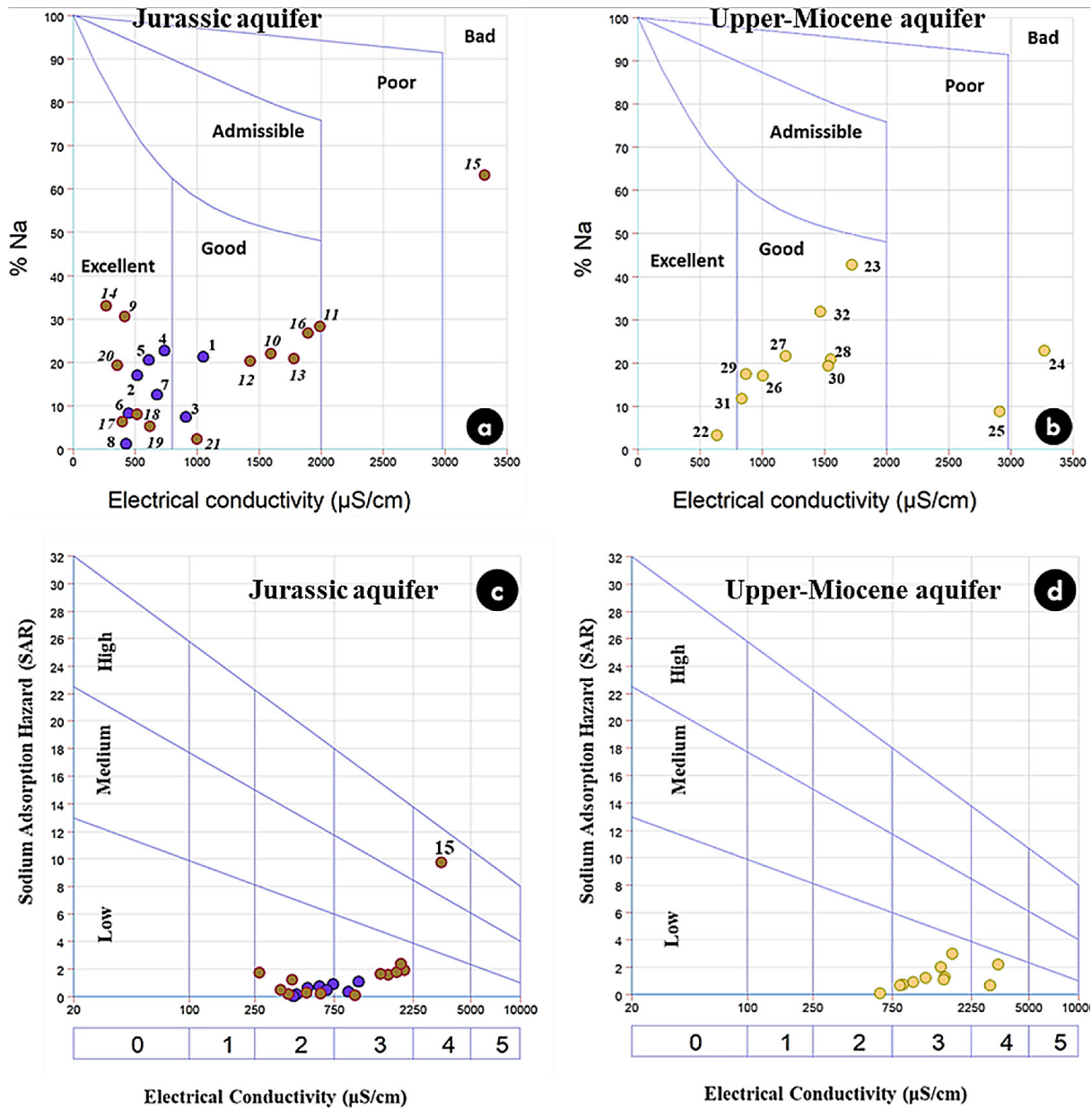


Figure 8. Water classification according to Riverside diagram Wilcox (a) and b), water classification according to Riverside diagram (c and d)

### CONCLUSIONS

The purpose of this paper was the evaluation of the groundwater quality of the semi-arid Middle Moulouya basin. This evaluation had not been considered in earlier bodies of research and needs to be measured for more further thorough investigations. In this light, the parameters and diagrams used in this research, which turned out to be metric, enable for the evaluation of the prevalent occurring processes like: origin of water chemistry, water–rock interactions, water types, and groundwater origin into the Jurassic and Upper Miocene aquifers. Generally, the analysis of

the overall water quality revealed that most of the sampling localities are chemically suitable in view of Moroccan control standards guidelines, stating in the same time that this groundwater is expected to be used with specific management in the case of sensitive irrigation crops and any other human uses. In turn, it is worthy of note that some localities exhibit an unsuitable quality that is often linked to the geogenic sources such as the effect of Miocene marly-gypsum formation and Triassic saliferous deposits. This quality deterioration is rarely anthropogenic, whether upstream or downstream of the basin and/ or on either side of the Moulouya river except in the areas where

the evacuation of wastewater of different compositions from the resident water took place.

In conclusion, the results from thirty-six water points localities contribute to the identification of the chemical status of the groundwater aquifers (i.e., Jurassic and Upper Miocene) of the Middle Moulouya basin regarding major ions. This quality baseline will be of great value in the upcoming studies to evaluate if variations might arise in the chemical composition of water. We intend to conduct isotopic research on groundwater to understand its recharge processes and ascertain its absolute age in the near future.

### Acknowledgements

This work was undertaken within the framework of PhD Thesis, did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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