

Evolution of groundwater quality in intensive agricultural zone: case of Chtouka-Massa Aquifer, Morocco

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Abstract The Chtouka-Massa area in Southern Morocco has shown an increase in water scarcity during the last decades, caused mainly by withdrawal of water resources aggravated by agricultural intensification and climate change impacts. To better understand the changes of groundwater quality, a sampling campaign was conducted in many wells during March 2015 and compared to historical chemical data from the hydraulic basin agency, as well as previous studies performed at Ibn Zohr University. All data were used to assess the spatial-temporal evolution of nitrate and salinity relevant to the recent sampling. This paper describes the current state of groundwater quality in the Chtouka-Massa zone with an overview of different sources of water mineralization and the nitrate evolution in an agricultural area. Our results indicate a general increase in mineralization from the north to the south, and from the east to the west. The plain, dominated by farms, shows a relatively high conductivity (up to 2000 $\mu\text{S}/\text{cm}$), while in both coastal area and Anti-Atlas Mountain the water salinity shows a gradient increase from the north to the south. However, the highest electrical conductivity is observed along

the Massa River. The water type is bicarbonate, chloride, and sodium for farm samples, while from the other parts, it is mostly dominated by chloride and sodium. The spatial-temporal analysis of nitrates generally shows an increasing trend. However, the levels remain overall lower than the limit. The temporal evolution of control points set by the hydraulic agency shows a decreasing trend decline that can be explained by the improvement of agriculture practices, including the conversion towards drip irrigation mode. Different chemical tracers highlighted some processes involving the changes of mineralization of groundwater (e.g., irrigation water return, marine intrusion, and water/rock interaction). The results will be used to improve water management in this area showing water quality degradation.

Keywords Chtouka-Massa · Agriculture · Spatial-temporal evolution · Nitrate · Quality · Mineralization

Introduction

During recent decades, water quality continues to deteriorate as a result of climate change and human pressure, especially in arid zones (Fedrigoni et al. 2001). The aquifers in urban, agricultural, and coastal areas show particular aspects due to their context (Pixie and Dennis 1995; Trabelsi et al. 2005; Jalali 2008).

The influence of arid and semi-arid climate on mineralization of groundwater particularly in areas where agricultural activity is quite large and has widely studied the origins of groundwater salinity and the impacts of agriculture on groundwater quality was already examined by many studies over the world (Cossier et al. 1990; Ghazali and Zaid 2013; Kim et al. 2004; Lgourna et al. 2013; Warner et al. 2013).

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As well, several studies have been conducted in the basin of Souss-Massa that englobes Chtouka-Massa basin, in order to assess the quality of groundwater (Gw) resources and understand the origins of their mineralization (Boutaleb et al. 2000; Hsissou et al. 2002; Dindane et al. 2003; Bouchaou et al. 2008). These studies attributed the deterioration of water quality to several origins (mineralization, geology, intrusion, anthropogenic impacts (agriculture, wastewater)). In addition to that, Ahkhouk et al. (2003) and Tagma et al. (2009) have highlighted the impact of agricultural fertilizers and the type of irrigation on the quality of groundwater in irrigated areas of Chtouka. Krimissa et al. (2004) has related a degradation part mainly to high chlorides contents caused by the dominance of schist in the southern part of the area near the dam of Youssef Ibn Tachfine and along the Massa River.

Nevertheless, the succession of drought years, the intensification of agriculture, and the continuous demographic growth considerably affect the availability of Gw resources as well as their quality. In fact, surface water is nearly absent in the area and, the Gw of Chtouka-Massa constitutes the main source of water for various uses (i.e., drinking, irrigation, etc.) with a recourse to retained water from the dam Youssef Ibn Tachfine in some communes of the area. This overexploitation leads to a depletion of water resources and quality degradation for both human consumption and agricultural activities.

In order to control the evolution of the Gw quality in the area, the hydraulic basin agency of Souss-Massa (A.B.H.S.M.) installed a monitoring network that has been operational since 1990 and whose measurements are usually carried out once a year by a private company.

The main objective of our study is to further identify the origins of mineralization, to characterize its spatial-temporal evolution using some indicators, and to highlight the processes controlling the changes in water quality.

Study area context

The Chtouka-Massa area is located in the southern part of the Souss-Massa region in the West-south of Morocco (Fig. 1). It is a plain which belongs to the Souss-Massa basin with an average altitude of 200 m above sea level (a.s.l) and extends on a surface of 1260 km² (ABHSM 2006).

The Chtouka-Massa basin is located in an arid region where precipitation are generally low and do not exceed 200 mm/year. The geography of the region is mainly characterized by three components: the limits with the Anti-Atlas Mountain, the proximity of the Atlantic Ocean, and the border with the Sahara. The combination of these factors and their association with the hydrogeological context influence the development of activities in the region (Aghzar et al. 2002). However, in spite of these natural constraints, agriculture occupies more than 50 % of

activities in the area, making it an important agricultural pole at the regional and national level (HCP 2013).

The Chtouka-Massa plain is formed mainly by Plio-Quaternary deposits with very diverse facies, depending on the nature and deposition conditions. These formations are (i) marl and limestone based directly on Acadian age schist that outcrop especially in the South and East of the plain (Choubert 1963); (ii) conglomeratic deposits encountered mainly in the bed of the Massa River; (iii) alluvial deposits, mainly sands and silts that belong to the recent Quaternary; and (iv) lacustrine limestones of a very large extension. The sandy formations are encountered in two forms: (a) a well-consolidated sandstone dunes with a marine facies and presences of clays. They extend over 70 km long and 5–7 km wide with a thickness exceeding 50 m (Ahkhouk 2004), and (b) sandy dunes made of very small size of sand less consolidated and frequently subjected to the effects of wind (Fig. 2a). The Paleozoic schist presents a significant salinity due mainly to high chloride contents (Krimissa et al. 2004).

From a structural point of view (Fig. 2b), several studies highlighted a series of major faults oriented approximately north-south at the piedmont of the Anti-Atlas Mountains (Ahkhouk in C.A.G. 1964). These faults affect Paleozoic formations, which quickly sink in successive releases in deep northern Chtouka. In the same region, located approximately in the north of the line-Ait Amira-Biougra, the cretaceous breakdown in “stair.”

The Chtouka-Massa aquifer is limited by the Souss plain formation to the north, and to the south by the Acadian age schist and constitutes the substratum of a part of the plain aquifer and at the east side, it is limited by the Paleozoic formations of the Anti-Atlas (ABHSM 2008). According to the different studies carried out by the hydraulic department, we summarized in Fig. 3 the schematic functioning of the Chtouka system. The Chtouka aquifer shows a flow path of groundwater from the east towards the Atlantic Ocean in the West. The system is recharged mainly from underground water coming from the Anti-Atlas Mountains formations (mainly the karstic ones of Cambrian). A component of recharge is also highlighted from the lacustrine limestone which drained water from the mountains (Bernert 1968). The coastline is the major natural outlet of the system as well as the pumping rate for irrigation and drinking uses.

Methodology

Sampling campaign

In order to assess the current quality of Chtouka Gw, a sampling campaign was carried out in the study area with an

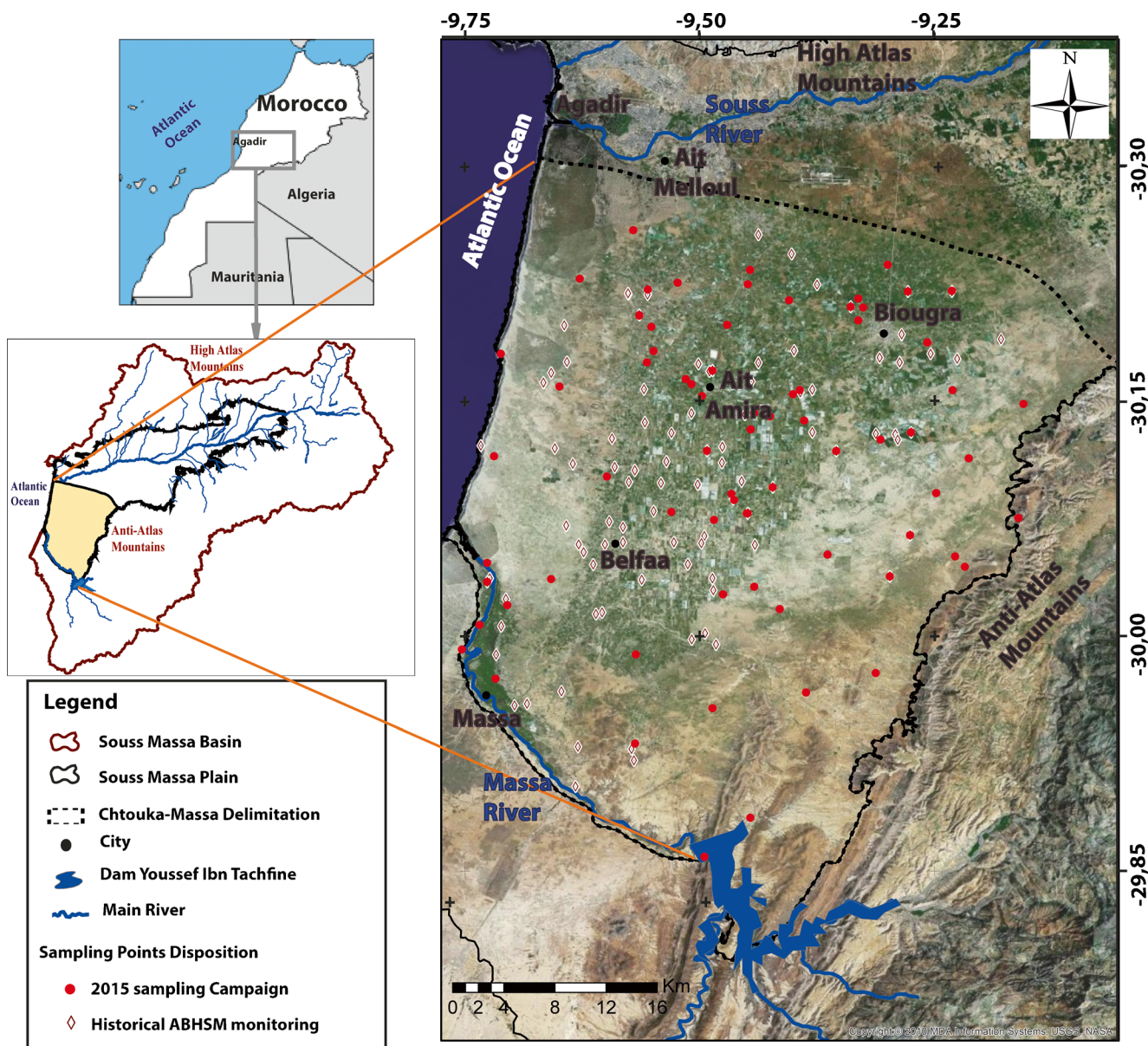


Fig. 1 Location map of the study area, with the spatial distribution of sampling points differentiated by years

adoption of a multi-criteria approach to collect water samples from wells (Fig. 1). These criteria depend on the different uses of the wells (irrigation/drinking), their position in relation to the different parts of the area (coastal area, border with the Anti-Atlas Mountains, south part (along the Massa River) and the plain (dominated by farms), and different agglomerations). The samples were taken directly from wells being purged during March 2015.

Forty-seven samples were selected for chemical analysis. They were shipped to the Applied Geology and Geo-Environment Laboratory (LA. G.A.GE.) at Ibn Zohr University in double-capped polyethylene bottles. Physical and chemical parameters (electrical conductivity (EC), pH, temperature, oxygen and potential RedOx), and

alkalinity (titration method) of Gw were measured in situ. Major anions and cations were determined in the laboratory by titration using the volumetric method. Ca, Mg, Cl, NO_3^- , and SO_4^{2-} were measured by absorption spectrophotometry using UV-visible spectrophotometer while Na and K were determined with the flame spectrometer.

Saturation indices (S.I.) and water type classification were performed by a free software which projects chemical analysis data on a Piper diagram using major element water chemistry (Smiler 2005).

In addition, historical data for chemical analysis performed at the laboratory LAGAGE from 1998 to 2013 were used to assess the temporal evolution of Gw quality of the Chtouka-Massa basin.

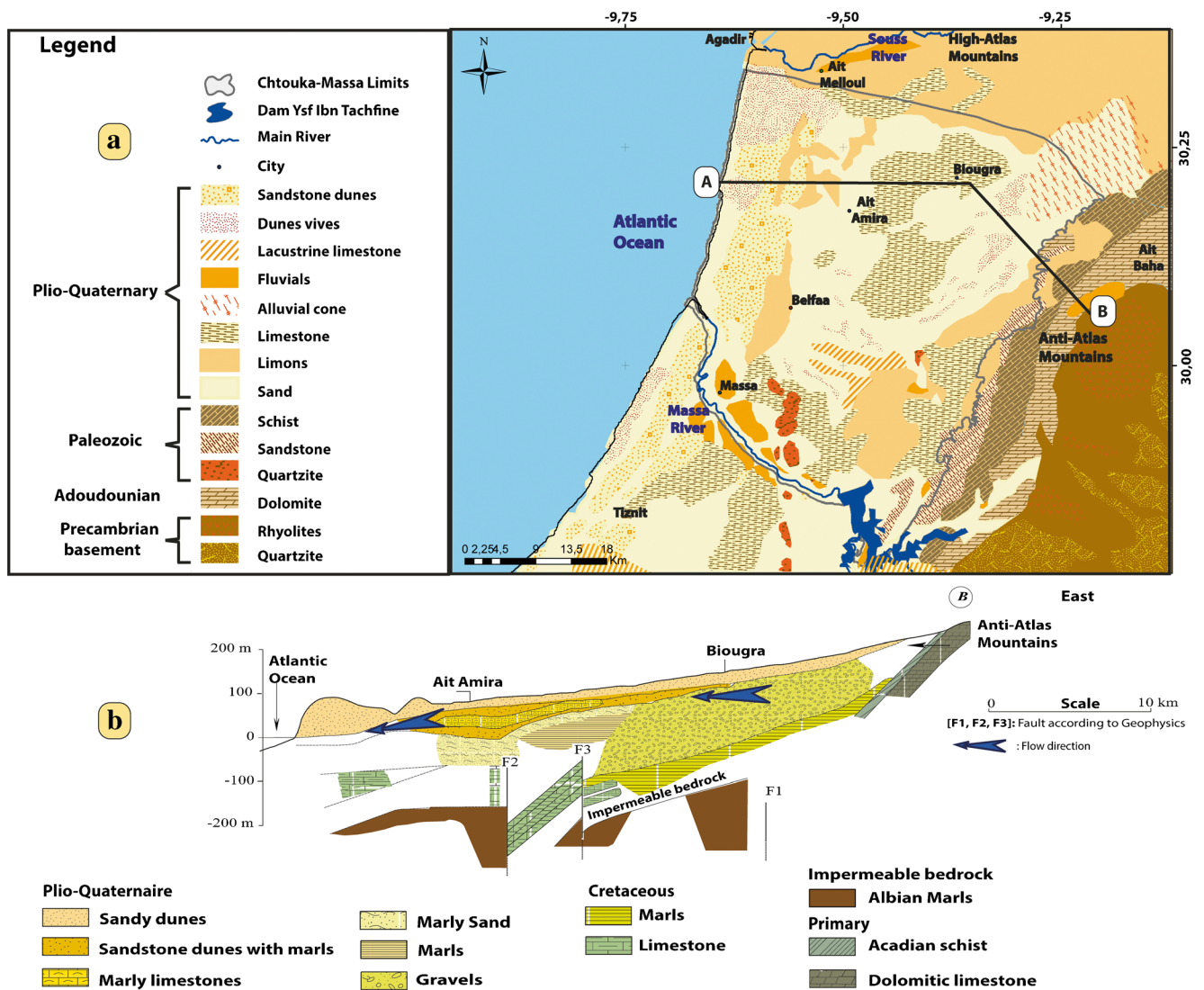


Fig. 2 a Geological map of the Chtouka-Massa area (based on esquisse géomorphologique de l'Anti-Atlas occidentale au 1:500,000, 1972). Modified b Geological section of the Chtouka plain from the Anti-Atlas Mountains to the Atlantic Ocean (Ahkouk et al. 2003)

Results

Chemical characterization of groundwater

According to the results of the recently collected samples (Table 1), water, pH, and temperature do not show a large spatial variation. pH values are ranging between 6.85 and 8.32; water temperature ranges between 16.6 and 27.7 °C.

The mineralization of Chtouka Gw varies from one part to another of the area. Indeed, the plain which is occupied by farms, shows a relatively high EC ranging from 2000 to 3000 $\mu\text{S}/\text{cm}$ in the entire area, while in the coastal area and Anti-Atlas Mountains, we noted that water salinity shows a gradual increase from the north to the south. It ranges between 1478 and 2540 $\mu\text{S}/\text{cm}$ and from 782 to

4480 $\mu\text{S}/\text{cm}$, respectively. The highest EC is observed along the Massa River. In fact, the mineralization gets higher from the east to the west; it reaches 9660 $\mu\text{S}/\text{cm}$ near the Youssef Ibn Tachfine dam. In general, the mineralization of Chtouka Gw increases from the north (irrigated plains) to the south (mountains), and from the east (irrigated plain) to the west (coastal area).

The most abundant cations in the water samples are sodium and magnesium, whose concentrations vary from 32.2 to 2010 mg/l and from 6.9 to 285.6 mg/l, respectively. Also, calcium, potassium, and ammonium are found in the Gw with variable concentrations, depending on the location.

The most abundant anions are bicarbonate, chloride, and nitrate. Anion concentrations are highly variable and range from 91.6 to 677.1 mg/l for bicarbonate, 0.25 to

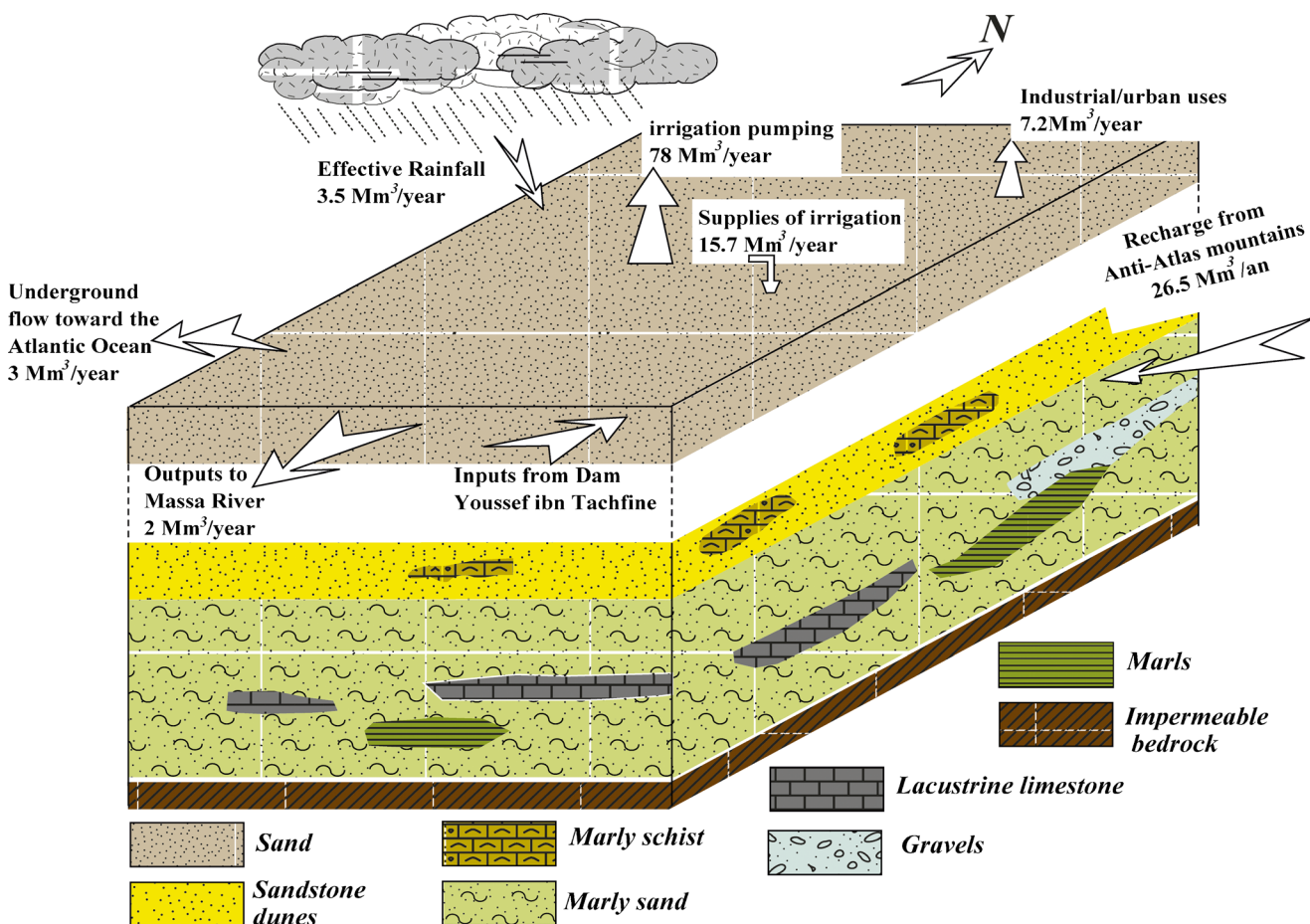


Fig. 3 Schematic representation of inputs and outputs of the Chtouka-Massa System (based on Ahkouk 2004, modified)

138.6 mg/l for nitrate, and 49 to 3195 mg/l for chloride. High nitrate concentrations, up to 50 mg/l, which is the limit based on World Health Organization standards, are registered in 34 % of the samples. The highest values are found in samples from the area along the Massa River, in the southern Chtouka area. The sulfate values range from 7.67 to 412.3 mg/l. The highest values of 325 to 412.3 mg/l are measured in some samples along the Massa River (Table 1).

Piper diagram

The use of Piper diagram highlights the impact of geology on water quality; it also provides the estimation of chemical element percentages and their classifications (Belghiti et al. 2013; Schoeller 1964).

In Chtouka Gw, the water type is bicarbonate, chloride, and sodium-magnesium for farm samples, while for other samples from the coastal area, Anti-Atlas Mountains, and along the Massa River, Gw is mostly dominated by chloride, sodium, and potassium (Fig. 4).

Discussion and interpretation

Origins of groundwater mineralization: water/rock interactions

Relationship between TDS and major elements

To better understand and determine the origin of Gw mineralization, we use the correlation between chemical concentrations and total dissolved solids (TDS), which could be considered to be a reliable indicator of water mineralization.

The plots for the water samples show a good correlation between major ions and TDS, especially for sodium, calcium, and chloride (Fig. 5a–c)). This correlation implies that Gw mineralization is mostly related to the dissolution of minerals that contain these major ions. Correlation between EC and nitrate is very low (Fig. 5d, e), which implies that nitrate is not responsible for the rise of EC in some parts of the study area; a slight increase trend is observed for samples along the Massa River. The same observation could be made about bicarbonates (Fig. 5f).

Table 1 Results of physical and chemical measurements and major ion analysis of 47 groundwater samples from Chtouka groundwater

Code	T (°C)	pH	Cond. (us/cm)	TDS (mg/l)	Ca ²⁺ (mg/L)	Mg ²⁺ (mg/L)	Na ⁺ (mg/L)	K ⁺ (mg/L)	HCO ₃ ⁻ (mg/L)	Cl ⁻ (mg/L)	SO ₄ ²⁻ (mg/L)	NO ₃ ⁻ (mg/L)	Br/Cl
Plain (farms)													
P8	26.8	7.36	802	602	40	49	64.4	3	298.9	99.4	45.4	0.254	-
P23	25.2	7.24	1343	991	71.7	73.6	148.35	3.5	292.8	228.97	65.21	103.9	0.0044
P12	27.2	7.5	669	475	28.8	42.72	33.35	2	292.8	51.47	16.31	7.87	-
P13	23.7	8.08	774	598	31.2	58.56	58.65	2.5	298.9	90.52	47.5	10.56	-
P5	23.7	7.38	688	534	34.9	39.6	55.2	2	292.8	85.2	10.84	12.17	-
P14	18.8	7.64	1917	1319	70.7	55.8	322	9.3	323.3	497	23.9	13.89	-
P11	16.6	7.84	782	649	56.7	48.8	52.9	2.5	366	81.65	16.53	23	-
P19	18	7.42	781	580	54.2	54.6	39.1	2.5	335.5	60.35	7.67	25.54	-
P20	27.7	7.42	781	584	40.2	48	37.95	2.5	359.9	58.57	15.89	21.31	-
P15	17.8	8.08	1143	1041	40	76.8	139.15	8	500	214.77	32.12	29.89	-
P3	24.5	7.34	952	747	47.6	53.7	105.8	2.5	329.4	163.3	20.32	22.56	0.0030
P21	23	7.32	727	635	40	42.4	63.25	2.1	353.8	97.62	12.94	22.74	-
P1	25.3	7.3	893	713	45.1	49.7	92	2.3	341.6	142	16.53	22.41	0.0040
P17	21.6	7.52	1056	836	65.7	63.3	95.45	2.1	341.6	147.32	40.97	78.39	-
P18	26.6	7.32	767	649	54.8	48.8	47.15	2	378.2	72.77	16.31	27.99	-
P32	26	7.1	957	747	63.9	56.8	89.7	2.3	359.9	138.45	25.39	8.98	0.0042
P2	23.9	7.25	1331	951	56	58.3	143.75	2.4	359.9	221.87	50.45	55.58	0.0046
P16	20.7 °C	8.15	1204	860	23.2	72.48	139.15	3	298.9	214.77	28.96	61.42	0.0068
P42	22.7	8.32	265	303	18.3	6.9	63.25	2.7	97.6	97.62	11.68	4.13	-
P22	21.5	7.64	1389	983	52	51.3	150.65	2.4	378.2	232.52	70.68	42.82	0.0032
P34	24.7 °C	7.14	2610	1568	28.8	64.32	356.5	2.7	225.7	550.25	216.3	40.98	0.0030
P40	19.9	7.84	1262	1052	49.4	28	212.75	2.2	317.2	328.37	38.65	71.96	0.0057
P41	18.5 °C	7.73	1295	941	55.2	47.52	161	2.1	347.7	248.5	42.45	49.51	0.0034
P39	24.8	7.28	1934	1782	91	76.3	345	3	600	532.5	77.85	52.63	-
P35	24.5	7.4	3020	2086	81.9	63.3	453.1	3	677.1	699.35	45.82	58.94	-
Coastal area													
P38	22.4	7.62	1478	1083	72.9	71.3	212.75	3.4	317.2	328.37	44.76	29.68	-
P26	21	8.05	2540	1624	81.6	58.5	415.15	20.5	146.4	640.77	114.5	128.5	-
P4	22.2	7.35	1557	1079	53.6	59.5	181.7	2.1	353.8	280.45	116.4	29.31	-
P27	19.5	7.72	2350	1563	67.3	71.3	327.75	5.3	402.6	505.87	134.3	41.76	-
Anti-Atlas Mountains													
P45	22.4	7.75	782	749	57.6	40	92	2.1	378.2	142	17.58	18.94	-
P47	22.5	7.45	923	1481	61.6	39.1	345	2.4	347.7	532.5	22.85	128.2	-
P46	24.5	7.22	2110	1378	114	64.8	264.5	4.6	475.8	408.25	15.26	28.22	-
P33	19.3	7.52	2410	1697	128	56	433.55	2.5	250.1	669.17	42.87	112.4	-
P10	23	7.69	2830	1918	140	66.24	495	3.3	207	809.4	61.41	131.4	0.0027

Table 1 (continued)

Code	T (°C)	pH	Cond. (us/cm)	TDS (mg/l)	Ca ²⁺ (mg/L)	Mg ²⁺ (mg/L)	Na ⁺ (mg/L)	K ⁺ (mg/L)	HCO ₃ ⁻ (mg/L)	Cl ⁻ (mg/L)	SO ₄ ²⁻ (mg/L)	NO ₃ ⁻ (mg/L)	Br/Cl
P9	23	6.85	4480	2882	250	138.5	609.5	6.2	450	940.75	340.6	138.6	-
P6	24	8.3	2660	1519	64.2	57.2	326.6	3.6	256.2	504.1	176.9	127.3	-
P36	24	7.56	1359	865	55.1	25.8	218.5	3.2	152.5	337.25	51.72	17.93	0.0029
Along the Massa River													
P30	17.4	7.84	282	217	18.7	7.5	32.2	3	91.5	49.7	10.62	2.94	-
P31	25.5	7.68	9660	6578	272	285.6	2010	18.3	335.5	3195	412.3	27.17	0.0030
P29	24.5	7.2	6480	4433	306	183.1	1150	14.9	378.2	2014.6	322	49.83	0.0028
P43	24.5	7.1	5370	3800	206	182	1035	2.8	262.3	1704	325.5	65.16	0.0029
P37	24.2	7.51	4280	2728	122.7	99.1	793.5	9.5	256.2	1224.7	190.6	19	-
P44	19.3	7.92	3330	3456	155.1	162.5	989	3	164.7	1526.5	313.9	126.9	0.0025
P25		7.45	2370	1604	94.4	91.2	377.2	4.8	300	582.2	114.3	40.05	-
P7	23.9	8.21	1612	1146	66.6	51.3	227.7	4.6	262.3	351.45	43.29	136.7	-
P2	4	26.5	7.1	777	60.5	53.9	89.7	2.4	341.6	138.45	56.57	31.93	0.0033
P28	23	7.2	4860	3432	161.5	168.2	954.5	11.8	305	1473.2	278.1	63.58	0.0026

In order to better understand the origins of different ions affecting the mineralization of Chtouka-Massa Gw, we define the eventual relation between dominant ions and the environment of groundwater circulation.

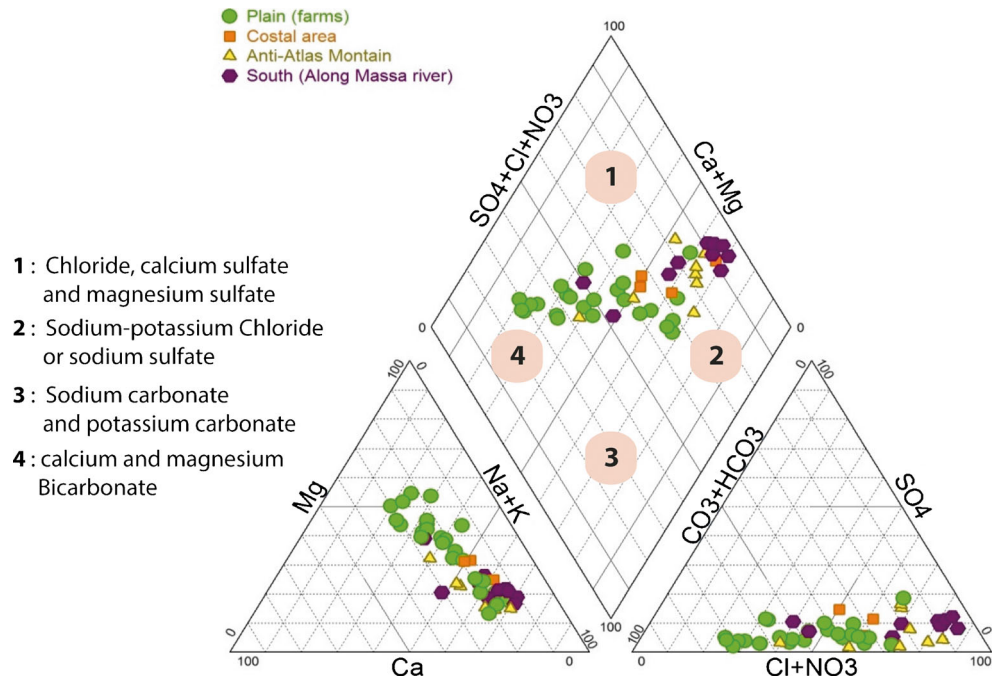
Relationship between ions

Sodium and chloride The presence of Na in water is generally associated with chloride. This interdependence is illustrated by the good alignment of water samples with the dissolution line of halite (Na = Cl) particularly for samples from the southern part around the Massa River (Fig. 7a). This means that these ions could originate from the halite dissolution. However, geological studies conducted in the Chtouka-Massa area revealed the absence of evaporates, and, regarding the general structure, Anti-Atlas aquifers are likely to supply the groundwater of Chtouka-Massa. Thus, the water with high contents of sodium can be originating from the dissolution of evaporate rocks. Additionally, the dominance of agricultural activities in the area could lead to consider the leaching of agricultural amendments as a potential source of NaCl (Ahkook 2004).

The spatial distribution of chlorides is variable in Chtouka-Massa Gw. In fact, they are moderate in the northern part of the area, and get higher in the direction of the ocean (Fig. 6). The highest values are observed in the Massa perimeter, along the river and in the schist area around the Youssef Ibn Tachfin dam, where the aquifer is thin and located in the superficial altered zone. This could be explained by the leaching of chemical fertilizers used in agriculture such as potassium chloride (Fakir et al. 2001). A further source of chloride-sodium ions can be considered in this part of the area, which is the leaching of schist bedrock usually reached by sampled wells. The study made by Krimissa (2005) strongly supports this remark by analyzing rock and water. In fact, using mineralogical composition of schist removed from this area as well as chemical and isotopic tracers, the study revealed that the chloride levels are very high and reach up to 40,000 ppm, which is a likely cause of the high levels of chlorides in sampled Gw.

In the downstream Chtouka, high chloride concentrations are more likely related to marine influence and the contribution of aerosols and sea spray loaded with salt particles from the Atlantic Ocean. This phenomenon was already highlighted in the area using several tracers such as Cl⁻, Br⁻, ¹⁸O to highlight the impacts of marine influence (aerosols and sea spray) on Souss Gw Hsissou (1999). This phenomenon is aggravated by the succession of drought years and increase of evaporation within the irrigated soil. The depletion of water level caused by the intensification of pumping can induce locally

Fig. 4 Piper diagram illustrates the major ion geochemistry of all water samples. Samples were sorted according to different areas sampled in the study



inverse flow path mainly in the coastal area which can promote marine intrusion.

Calcium et magnesium Correlation between the magnesium, calcium, and bicarbonate ((Mg + Ca) vs. $\text{HCO}_3^- + \text{SO}_4$) is

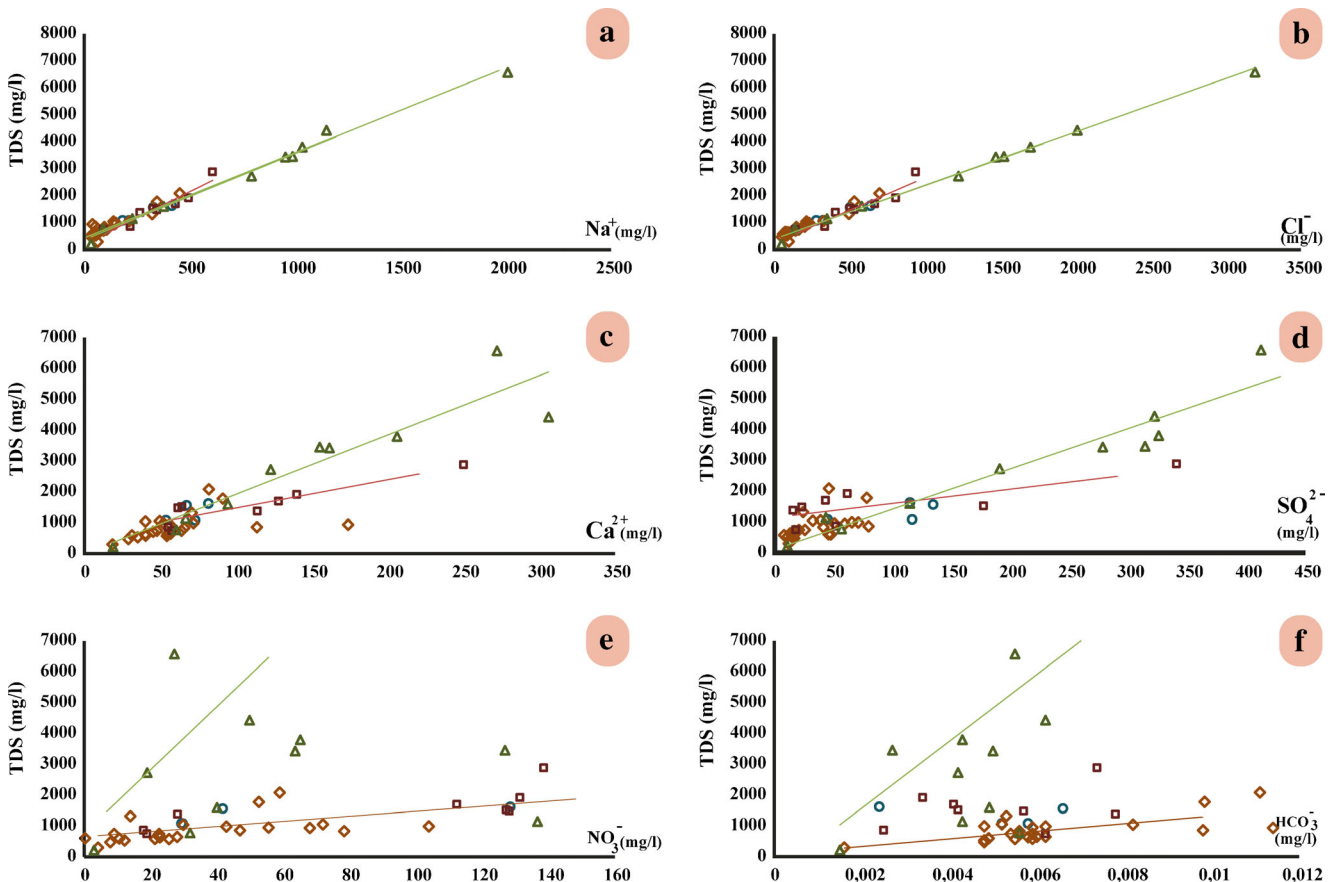


Fig. 5 Variations of major element concentrations (mg/l) versus TDS (mg/l) of Gw samples, sorted according to the spatial distribution of wells considered in the study

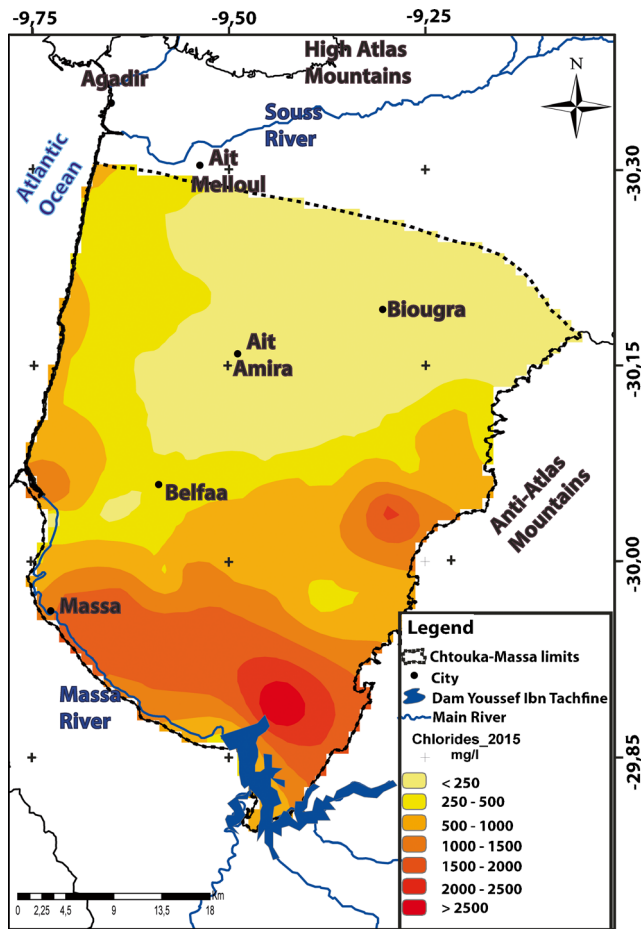
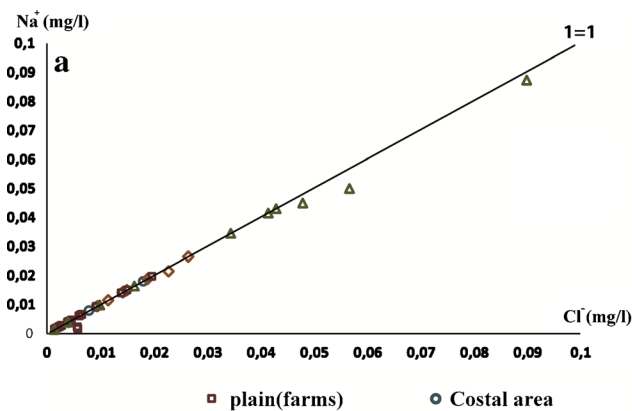


Fig. 6 Spatial distribution of chlorides in Chtouka Gw for the year 2015

often adopted to conclude whether the dissolution of calcite, dolomite, or gypsum is causing the presence of these ions in water (Zocovic 1965).

In Chtouka-Massa Gw, samples from group A (Chtouka plain, as well as the majority of those from the Anti-Atlas mountains and coastal area) are located under the diagonal line which indicates the carbonate dissolution such as calcite CaCO_3 , while samples from group B (taken along the Massa River) are above the diagonal line, showing excess of calcium



and magnesium which originate from the dissolution of dolomite.

According to Chtouka-Massa geology, the presence of calcium and magnesium is related to the dissolution of Plio-quaternary and Paleozoic carbonates. The leaching of these formations in the recharge areas (Anti-Atlas Mountains and plain) contributes greatly to the groundwater mineralization (Fig. 7b).

Saturation indices

All water samples are undersaturated with respect to gypsum and halite ($\text{SI} < 0$); the lowest SI are those of halite ($\text{SI} < -8$). While for calcite and dolomite, only a few water samples from the deep aquifer are undersaturated. In fact, 95 % of samples go from balanced ($\text{IS} \approx 0$) to oversaturated ($\text{SI} > 0$) with carbonate minerals, primarily calcite and dolomite (Fig. 8). This indicates that the Gw has the capacity to dissolve gypsum and halite along the flow paths so that the concentrations of calcium, sulfates, sodium, and chlorides in solution could increase down gradient. These results may confirm that mineralization of Chtouka-Massa Gw is related to the solubilization of carbonates which dominate the area and evaporates noticed within the Paleozoic schist. A significant additional mineralization can be attributed to human activities (agriculture, wastewater) and marine impacts.

Chtouka-Massa Gw salinity

Spatial distribution of salinity in 2015

In order to assess the state and the evolution of Chtouka-Massa Gw salinity, we developed, by the spatial analysis tools, a salinity map (Fig. 9a) using results of the analysis conducted on March 2015 as well as results of the campaign conducted by the ABHSM on November 2014.

The spatial distribution of salinity, determined by the total dissolved solids (TDS) of Chtouka-Massa Gw, shows that it is

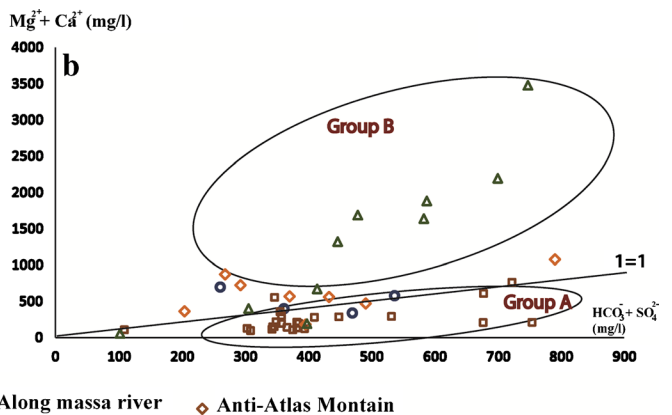
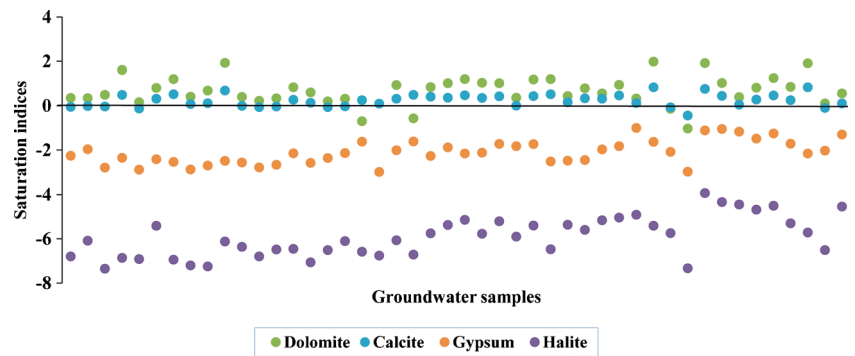


Fig. 7 Relationships between major ions concentrations of sampled Gw in the study area

Fig. 8 Saturation indices of Gw samples with respect to calcite, dolomite, gypsum, and halite



generally characterized by a large variation. In fact, the majority of the area presents a moderate salinity (TDS < 2200 mg/l). However, high values are registered in the irrigated perimeters of Massa and along Oued Massa (3600–6000 mg/l). In the center of the area around Biougra, Ait Amira, and Belfaa, salinity remains very low and does not exceed 1000 mg/l.

The comparison between the spatial evolution of salinity in 2015 (Fig. 9b) and chlorides (Fig. 6) emphasizes the relation between the two parameters. In fact, areas with high concentrations of chlorides are those that present high salinity and this confirms the observation made about the correlation between chlorides and TDS (Fig. 5b). Overall, chlorides increases from the north to the south, and their origin are attributed to the influence of agricultural activities (leaching of chemical fertilizers), influence of geology (leaching of schist bedrock), and marine influence (contribution of aerosols and

sea spray loaded with salt crystals from the Atlantic Ocean) (Morsli 2007).

The marine intrusion is not clearly pronounced in the area. However, we noticed, by using Br/Cl ratio indicators, the presence of marine intrusion signal in some samples (P22, P32, P34, P40, and P41) located mainly in the plain area (Table 1). This could be related to the influence of sea spray as mentioned before by the study made by Hsissou (1999) in Souss plain aquifer.

Temporal evolution of salinity from 2000 to 2015

The study of the temporal evolution shows that, in general, global salinity remains moderate in the northern part of the area (<1600 mg/l) with a significant localized increase in some areas. In fact, the salinity clearly increases in the southern part,

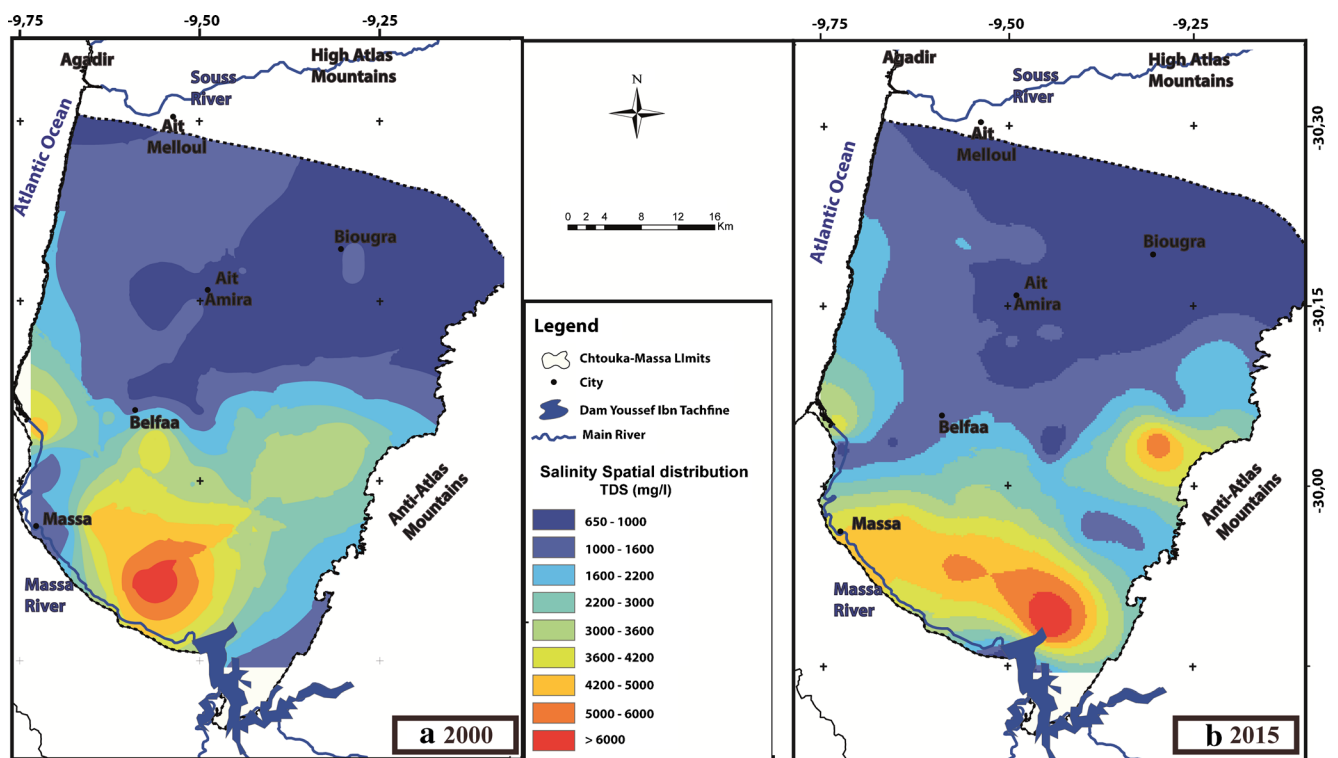


Fig. 9 Spatial distribution of salinity in Chtouka-Massa Gw for the years 2000 (a) and 2015 (b)

particularly along the Massa River as well as in the coastal area. This rise could be directly related to the marine influence (presence of aerosols) enhanced by the proximity of the Atlantic Ocean and aggravated by the local decline of the piezometric level. This accentuation of salinity can be recognized as a result of water resources overexploitation, especially by intensive agricultural activity in the southern part of the study area, where the irrigation water return affected by the practice of fertilization could also constitute an origin of Gw mineralization (Ahkoui 2004; Hsissou et al. 1999; Hsissou et al. 1997; Tagma et al. 2009) (Fig. 9a, b). Furthermore, we notice a decrease in salinity in the northern part around Biougra and Ait Amira. This is mainly related to a water table level depression caused by the intensification of pumping. Water sampled from this area in the northern part of Chtouka plain can be explained by the contribution of freshwater coming from the Souss aquifer recharged mainly from the High Atlas Mountains (Bouchaou et al. 2008). Figure 10 shows a clear decrease in electrical conductivity as the depth of the sampled wells increases. This remark supports the possibility for pumped water in this area to come from a deep aquifer.

The Eastern part also displays an increase in salinity, particularly at the boundary of the Anti-Atlas Mountains where the soils are mainly made by carbonates and altered schist. However, we should mention the existence of an anomaly of 2882 mg/l in the sampled well P9 (Table 1). In fact, the hydrochemical results show high values of major elements comparing to samples from the neighbor area. This anomaly is confirmed by a second analyze performed in the Laboratory of Bonn University in Germany, by ionic chromatography. This anomaly could be related to a local pollution caused by domestic releases particularly that the well is a private abandoned and stagnated well located in a small village without a sanitation connection.

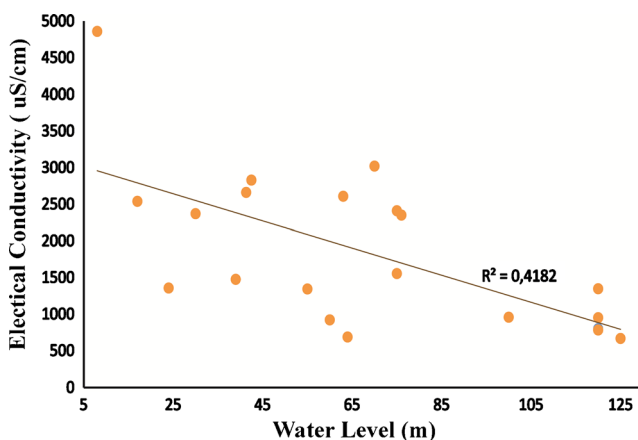


Fig. 10 Plot of EC distribution and variation of water level of Chtouka Gw

Anthropogenic items

Spatial distribution of nitrates in 2015

Chtouka basin is an arid area experiencing high water scarcity where Gw nitrate pollution has become widespread, causing a number of issues including the reduction of available freshwater resources, poor sanitation, as well as impacting the general well-being of the regional and national socio-economic development. The problem worsens with the intensification of anthropogenic activities, such as agriculture, which contributes more with nitrogen compounds as a result of the increased use of fertilizers.

The spatial distribution of nitrate concentrations in the study area for the years 2000 and 2015 is shown in Fig. 11a, b, respectively. The examination of nitrate contents of Chtouka-Massa Gw for the year 2015 shows that the majority of the area (71 %) ranges between 20 and 40 mg/l while, just 21 % of samples exceed the limit of 50 mg/l established by the World Health Organization standards (WHO 2006).

The highest nitrate concentrations are observed in the western and southwestern parts of the study area, especially in the irrigated perimeter of Massa and around Belfaa where agricultural activities involving nitrogen compounds are intensively used with a dominance of sprinkler and flood irrigation. These results are consistent with studies made by Ahkoui et al. (2003) and Tagma et al. (2009) that demonstrate the relationship between the mode of irrigation and nitrate levels.

On the other side, in spite of the high and intensive agricultural activity of the area around Biougra and Ait Amira, nitrate contents remains lower than the limits (50 mg/l), which could be attributed to the adoption of drip irrigation as well as the exploitation of deep freshwater that is not contaminated by high salinity.

Temporal evolution of nitrates from 2000 to 2015

In order to assess the temporal evolution of nitrates from 2000 to 2015, we will use the maps performed with the current data of March 2015 and the historical data of the hydrological agency as well as the laboratory LAGAGE from 1998 to 2014. The comparison between the spatial distributions of nitrates in 2000 and 2015 shows a significant increase in concentrations. In fact, in the year 2000, 78 % of the area has a concentration lower than the limit, with 72 % of the studied samples ranging from 0 to 30 mg/l, which indicates high water quality. On the other hand, for the year 2015, the quality dropped and only 56 % of the study area has nitrate concentrations between 0 and 30 mg/l (Fig. 11a, b).

On the other hand, some distinct spots of nitrate pollution are localized in the coastal area and the border of the Anti-

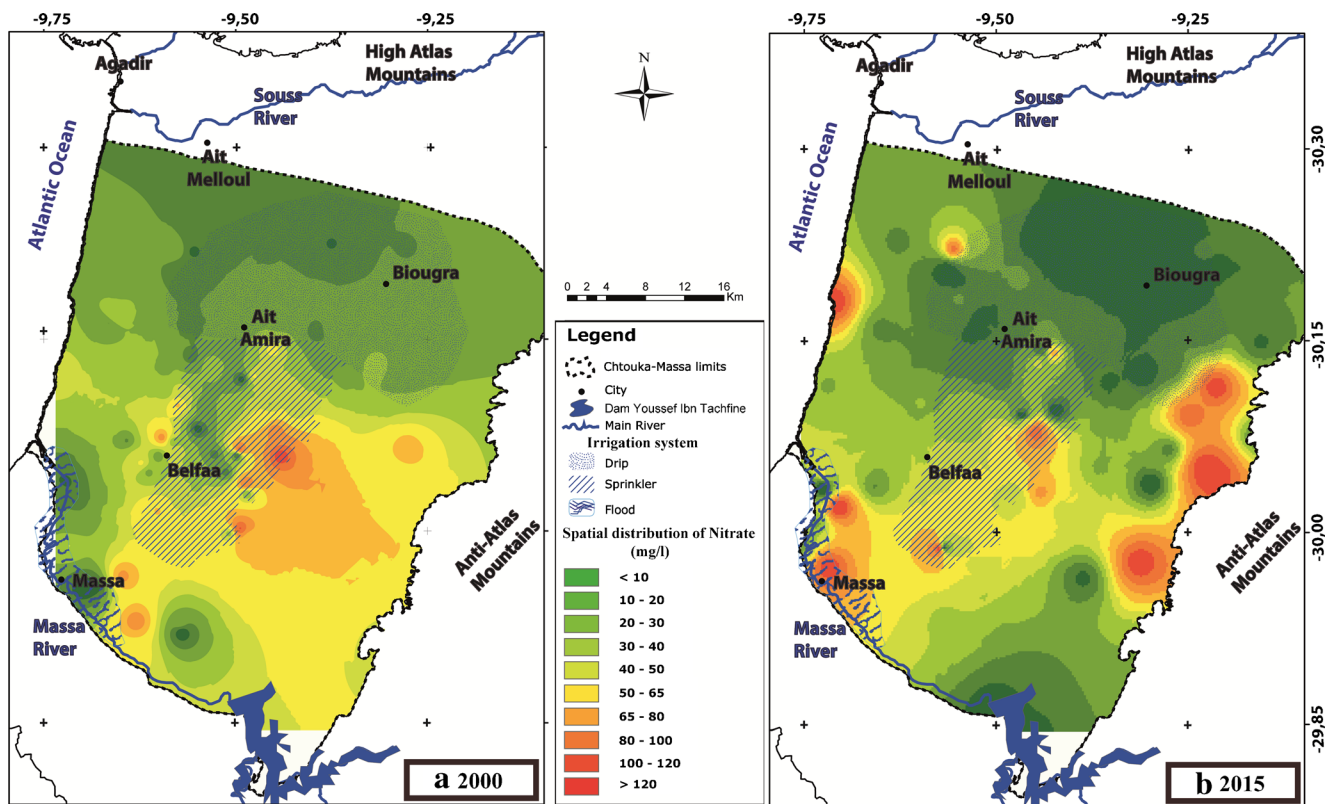


Fig. 11 Spatial distribution of nitrates in Chtouka Gw for the years 2000 (a) and 2015 (b) with differentiation of the three modes of irrigation adopted in the area

Atlas Mountain where agriculture activity is absent. This rise could be related to the presence of septic tanks and sewage discharges, especially since these points are located in a place

with a high population density. This is further aggravated by the absence of a sanitation network, causing the majority of effluent to be released directly into natural waterways.

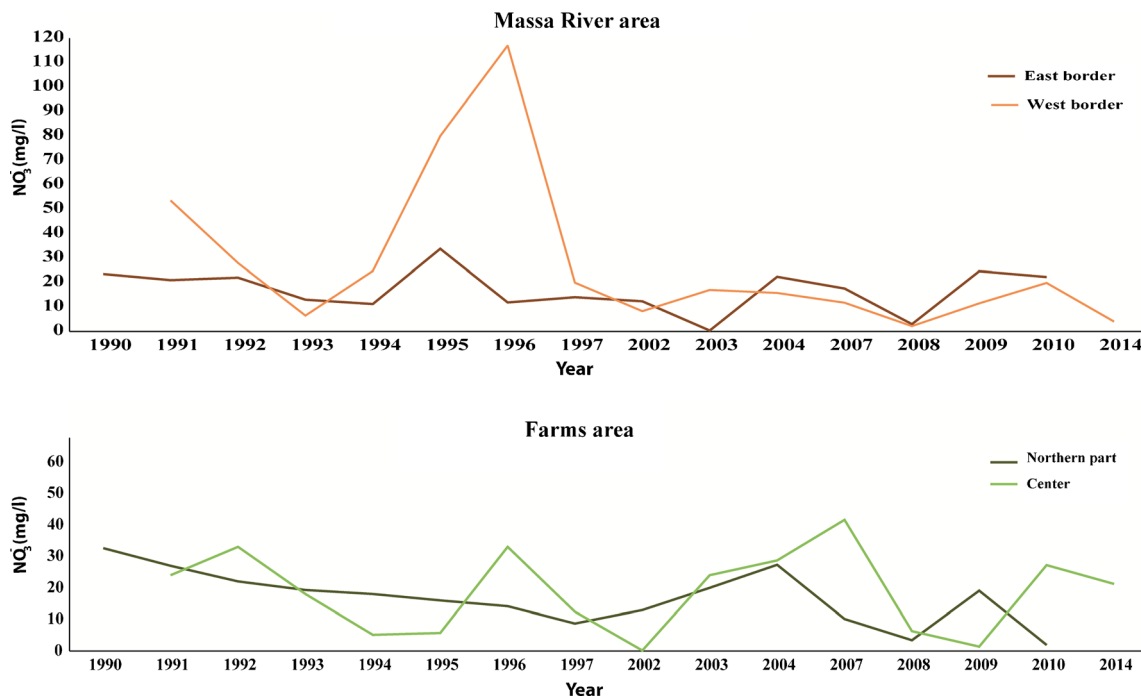


Fig. 12 Temporal evolution of monitoring control points from 1990 to 2014 based on hydraulic basin agency data

Furthermore, based on the monitoring network of the ABHSM, the temporal evolution was plotted within the area (Fig. 10), especially along the Massa River and in the northern part of the area around Biougra. The plotted points indicate that nitrate concentrations experience lighter fluctuations but remain below the standard with a general downward trend. The high value observed for 1995–1996 can be attributed to an extreme rain event that occurred during this period. The rain value of 800 mm largely exceeded the average annual value of 200 mm/year for that area. Consequently, this excessive rainfall can induce leaching of nitrates through the unsaturated zone towards the aquifer on one hand and a general dilution of TDS on the other hand. Moreover, until 1996, the majority of farmers use traditional flooding irrigation, which can also affect these fluctuations. In addition, these temporal variations can be impacted by the seasonal precipitation (Fig. 12).

In the same point of view, several studies have been made in different areas facing the same conditions: natural constraints (arid climate, succession of drought years, absence or limitation of water resources) and anthropogenic effects (agricultural activities, wastewater). These studies used chemical and isotopic tracers to highlight the impact of these conditions on water resources and the origin of Gw mineralization (Fedrigoni et al. 2001; Jalali 2008; Kouzana et al. 2009; Grassi and Cortecchi 2004; Martos et al. 2001; Olobaniyi and Owoyemi 2006; Trabelsi et al. 2005). Results of these studies have generally linked Gw salinity the downward recharge from rainwater, with the leaching of high nitrates contents, the upward recharge from the deep aquifer by relatively more mineralized waters, which is encouraged by the intensive use of the water table and the effect of marine intrusion.

Conclusion

This study aims to assess the spatial distribution of salinity and nitrate pollution of Chtouka-Massa Gw as a result of intensified agriculture. It presents the results of chemical tracers used to highlight the main processes influencing the changes of mineralization and causes of the degradation of Chtouka-Massa Gw quality.

The spatial distribution of salinity for 2015 revealed a high salinity rate encountered mainly at the coastal area due mainly to the marine influence, as well as geologic factors along the Massa River and around the Youssef Ibn Tachfine Dam, where the water circulates in contact with this element, which leads to their contamination by the chlorides present in abundance in the area of the schists (Krimissa et al. 2004).

Nitrate distribution of 2015 remains moderate, even though there is an increase from 2000 to 2015. The global rate is still moderate and does not exceed the set established by the World Health Organization (WHO) standards. However, there are a

few areas where the concentration of nitrate is higher than 50 mg/l. These variations and distributions depend mainly on the type of irrigation: The low values were observed in places where drip irrigation is used, while high concentrations were measured in areas using gravity irrigation. This confirms the results in Tagma et al. (2009), which show a relationship between an increase in nitrate pollution and the type of irrigation. These results improve the scientific database about Gw pollution in the region, and will assist policymakers to improve water management strategies.

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