

## Evolution of groundwater salinity in the unconfined aquifer of Bou-Areg, Northeastern Mediterranean coast, Morocco

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Received: 10 November 2006 / Accepted: 1 May 2007 / Published online: 22 June 2007  
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**Abstract** The Bou-Areg plain in the Mediterranean coast at the North-eastern of Morocco is characterized by a semi-arid climate. The aquifer consists of two sedimentary formations of Plio-quadernary age: the upper formation of fine silts and the lower one of coarse silts with sand and gravels. The aquifer is underlain by marly bedrock of Miocene age that dips toward the coastal lagoon of Bou-Areg. The hydrodynamic characteristics vary between  $10^{-4}$  and  $10^{-3}$  m/s; and transmissivities range between  $10^{-4}$  and  $10^{-1}$  m<sup>2</sup>/s. The general direction of flow is SW to NE, toward the lagoon. The aquifer is crossed by the river Selouane, which also ends in the lagoon. The groundwater is characterized by a high salinity that can reach 7.5 g/l. The highest values are observed in the upstream and in the downstream sectors of the aquifer. The temporal evolution of the physico-chemical parameters depends on the climatic conditions and piezometric variations. The analysis of the spatio-temporal distribution of the physico-chemical parameters suggests different sources of groundwater salinization: the seawater

intrusion, the influence of marly gypsum-bearing terrains, and the influence of anthropogenic products as the agricultural fertilizers, which cause great nitrate concentrations that vary between 80 and 140 mg/l.

**Keywords** Unconfined aquifer · Groundwater salinity · Seawater intrusion · Nitrate pollution · Lagoon · Morocco · Bou-Areg

### Introduction

The plain of Bou-Areg is on the Mediterranean coast of the North-eastern Morocco. The Moroccan Mediterranean coast lies on a length of 450 km, between Cape of Spartel in the West and the Kiss river estuary in the East, on the frontier with Algeria. It includes numerous alluvial plains (Martil, Smir, Al Hoceima, Bou-Areg, Saïdia...) dominated by the modest altitudes of rifain mountainous massifs (Fig. 1). The Mediterranean plains, although of small extension in comparison with their Atlantic counterparts play an important role in the social–economical development of this part of the country, notably in activities as agriculture, fishing, tourism and drinking water supply.

The resources for fresh water in the Bou-Areg plain are essentially supplied by the river Selouane in the central sector of the plain and by groundwater. Problems of salinization have been already outlined in several previous works (Carlier 1964; Chaouni et al. 1996; Dakki et al. 2000). The origin of this salinization varies, due either to seawater intrusion or to natural continental and anthropogenic factors. The first process is concentrated in the downstream zone, as reported in many Mediterranean coastal aquifers described by several authors: Custodio 1987, and Pulido 2004 (in Spain), El Baruni 1995 (in

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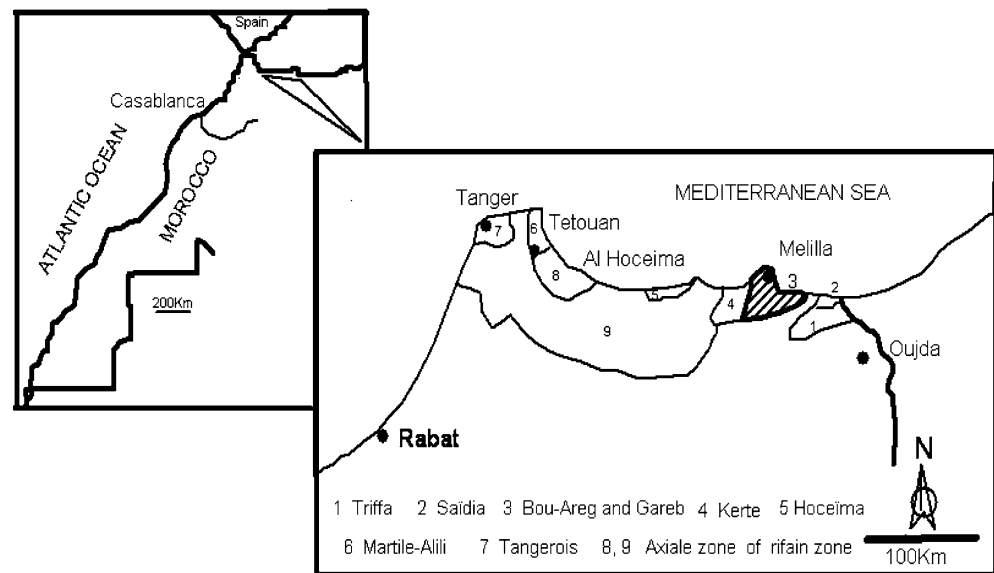
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**Fig. 1** Map location of coastal plains of the Mediterranean Morocco



Libya), Debieche 2002, Mania et al. 1985 (in Algeria), Lambrakis et al. 1997, Petalas and Diamantis 1999 (in Greece), Grassi and Netti 2000, Vincenzo and Giovanna 2003 (in Italy), and Dörfliger 2003 (in France). The second process exacerbated the situation by the increase of the waters salinity (Capacciona et al. 2005; Sanchez-Martos et al. 2002); the nitrate pollution affects most superficial aquifers is accentuated by intense agricultural activities. Indeed, several studies (Dimopoulos et al. 2003; Weil 1990), describe the impact of this pollution of groundwater.

This study was directed to determining the hydrodynamic behavior of the groundwater, to identify the spatial distribution of the physical–chemical characteristics and the nitrate contamination in the aquifer, and to present the hydro-chemical parameters at a scale of the whole plain of Bou-Areg. It was also directed at analyzing the temporal evolution of the piezometric variations, and of the physical–chemical parameters at selected monitoring points in the aquifer. A comparison with other coastal Mediterranean Moroccan aquifers to the east and the west of the Bou-Areg aquifer is also presented.

#### Geographical setting

The coastal plain of Bou-Areg covers 190 km<sup>2</sup>, limited to the northwest and to the west by the massifs of Gourougou and Ibn-Bou-Ifrou and in the East by the chains of Kebdana. In the North, the plain coincides with the arched shape of the lagoon of Bou-Areg, the so-called lagoon of Nador. In the South it is limited by the passageway of Selouane that assures the link with the plain of Gareb. The climate of the region is semi-arid, typically Mediterranean, with an irregular annual rainfall. Average annual precipitation is around 240 mm.

The lagoon of Nador contains salt waters whose average contents vary between 37 and 42 g/l during the 30 last years (Dakki et al. 2000).

The main superficial drainage consists of the Selouane River (“wadi”), which crosses the central plain of Bou-Areg and ends in the Bou-Areg lagoon. The stream water is characterized by a very high salinity; its average electrical conductivity was about 9,000  $\mu\text{S}/\text{cm}$  in 2004.

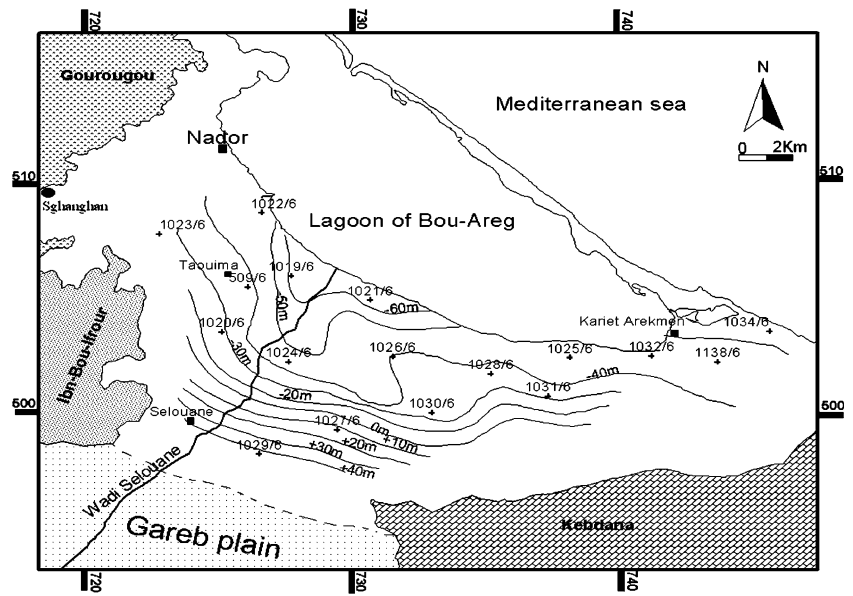
The region presents an important demographic expansion related to a remarkable economic development in the domains of agro-food, textile, chemistry, para-chemistry and steel industries (Sghangan and Ouksan iron mines). In addition, since 1982, different projects of fish and seafood farming (oysters, fish, shrimps, clams) near the lagoon of Nador have been achieved.

#### Geological and hydrogeological setting

The Bou-Areg depression received, during the end of the Pliocene and the beginning of the Quaternary, a very mixed and very thick continental sedimentation extending to a depth of 120 m below sea level. Around thirty boreholes have been done in the plain, showing three distinct sedimentary formations. Every formation regroups a certain number of layers with similar geological features:

- Formation I: constitutes the upper layer and is formed of thin materials, silts, clayey silts, encrusted limestones and marly calcareous tuffs which may contain gravels.
- Formation II: constitutes the bottom of the aquifer reservoir and is formed of coarser elements, pebbles, gravels of volcanic or sedimentary origin and sands.

**Fig. 2** The substratum map of the unconfined aquifer of the Bou-Areg plain



- Formation III: is formed of marls containing gypsum. This formation constitutes the substratum of aquifer, dipping towards the lagoon (Fig. 2). Many boreholes tap this formation.

The plain is surrounded by geological formations with various facies. The Gourougou massif, bordering the plain in the NE and culminating at 887 m a.s.l., is a strato-volcano generated by three types of volcanic eruptions: (1) calco-alkaline (potassic tendency); (2) intermediate (shoshonites: trachytes and latites); and (3) alkaline (basalts to sodium tendency) (Barathon 1989; Gill et al. 2004; Hernandez and Bellon 1985). These volcanic events extend between the Messinien and the Plio-Quaternary (Morel 1985). Although the primary porosity of volcanic rocks is very low, tectonic activity has resulted in secondary porosity (fissured igneous rocks), which gives rise to a significant increase in permeability. Therefore, volcanic rocks are suitable rocks to recharge and store groundwater. Quality waters can be supplied from these rocks in the Bou-Areg plain. Towards the south of the Gourougou massif, the plain is bordered by Ibn-bou-Ifrouf complex (699 m a.s.l.) constituted of Jurassic deposits (limestone, limestone–sandstone and marls) and Cretaceous deposits (schisto-sandstone and volcano-sedimentary). The complex is covered by the Miocene molasse. A part of the massif is crossed by several micro-granodiorite veins, associated to a hydrothermal mineralization (El Bakkali 1995) that explains the wealth of the region in iron ores (Ouchxane jbel).

The eastern boundary is defined by the Kebdana mounts (937 m a.s.l.) consisting of the Jurassic formations covered in discordance by the transgression of the Mio-Pliocene deposits. The Jurassic formations are composed of marls and marly limestones at the base, and at the summit of sandstone,

limestone–sandstone, limestone and dolomite–limestone. These formations are overlaid locally by Miocene materials, including limestone and marls (Bloundi 2005).

Generally the aquifer shows good hydrodynamic characteristics. The higher values of the permeability, reaching  $7 \times 10^{-4}$  m/s, are shown in the vicinity of the lagoon and in the western zone. Lower values are found in the borders of the massif of Kebdana.

Transmissivity values are in the range of  $10^{-3}$ – $10^{-2}$  m<sup>2</sup>/s. The largest values are found in the western part (north of the plain). The lowest are measured at the borders of the massif of Kebdana, probably owing to the accumulation of marls. All along the coast, the transmissivity has values around  $2.5 \cdot 10^{-2}$  m<sup>2</sup>/s.

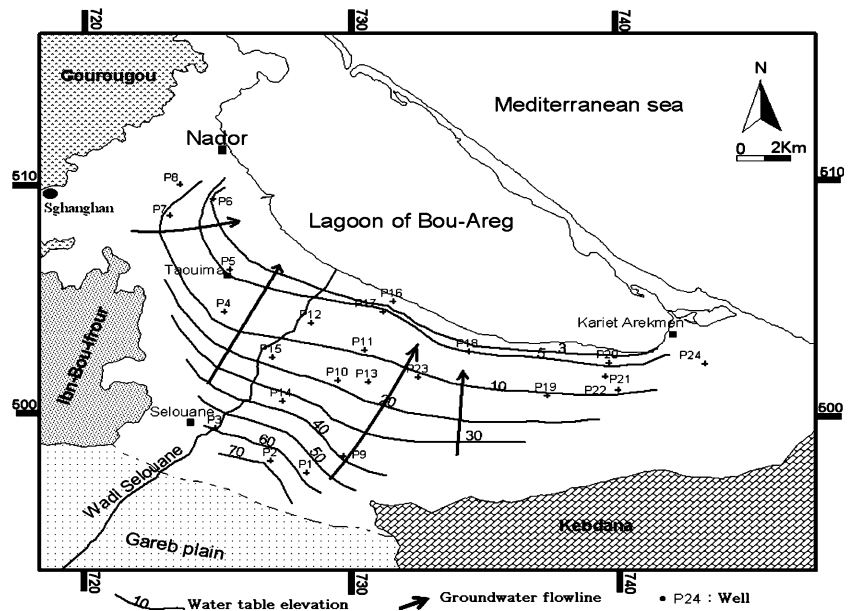
### Methodology

Sampling surveys were undertaken at April 2004. Twenty-four wells representing a homogeneous spatial distribution on the whole aquifer (Fig. 3) were measured following the months of higher precipitation. Samples were collected for cation and anion analyzes. A sample of sea water was also analyzed.

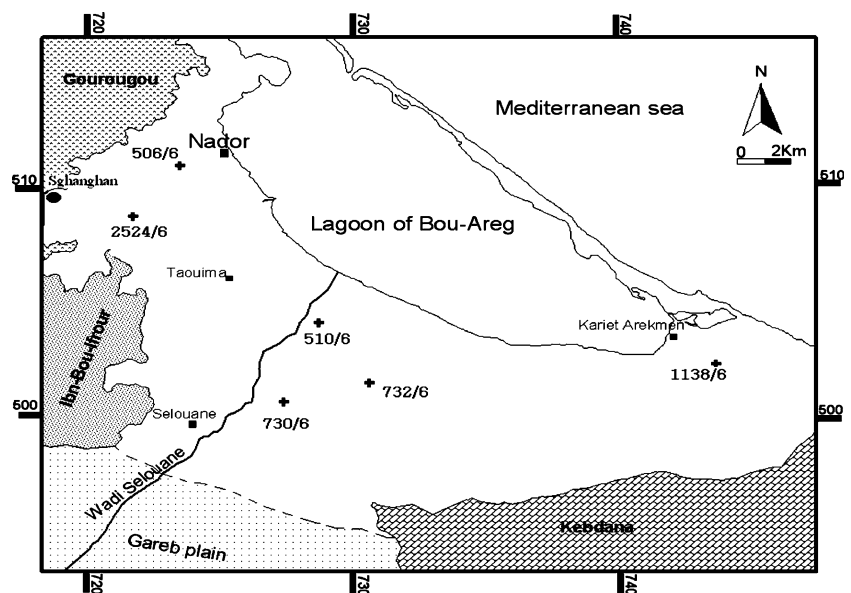
Monitoring of five water points (Fig. 4) performed by the Moulouya River Basin Agency of Oujda during 1992–2003 which offer piezometric and physico-chemical variations were also reviewed.

Temperature, pH and electrical conductivity were measured in the field. The chemical analyzes of the Na, Mg, CO<sub>3</sub>, HCO<sub>3</sub>, Cl, SO<sub>4</sub>, K and NO<sub>3</sub> were done in the laboratory using standard analytical procedures. Chloride, calcium, carbonate, bicarbonate and the magnesium values were collected by titration. Atomic absorption spectro-

**Fig. 3** Piezometric map of Bou-Areg unconfined aquifer (April 2004)



**Fig. 4** Localization map of piezometric and physico-chemical monitoring wells in unconfined aquifer of Bou-Areg



photometry was used to measure the concentrations of the sodium, potassium and the nitrates. Sulphate was measured by the colorimetric method.

To identify the chemical processes evolution in the groundwater, the Stuyfzand method (1986) was used. This method classifies groundwater quality according to Table 1. The deficit in the cation exchange (class-) results from salinization. In the case of freshening, there is an excess in the cation exchange (class +). The cation exchange equilibrium (class 0) indicates a state of chemical balance. The cartography and temporal distribution methods are applied to visualize the variation of piezometric, physico-chemical parameters and nitrate contents and to identify factors modifying this variation.

## Results and discussion

The results of sampling surveys undertaken April 2004 indicate groundwater temperature varies between 17.5 and 21.7°C and pH ranges between 6.4 and 8.4, with an average of 7.5, indicating a slight tendency toward basic composition. The electrical conductivity varies between 485 and 21,600  $\mu\text{S}/\text{cm}$  with an average of 6,720  $\mu\text{S}/\text{cm}$ ; 71% of the samples are between 4,000 and 21,000  $\mu\text{S}/\text{cm}$  and 25% between 2,000 and 4,000  $\mu\text{S}/\text{cm}$ . This indicates the high salinity affecting the groundwater. The chemical analysis results of sampling surveys (Table 2) indicate that salinity is controlled by the predominance of the major ions chloride and sodium; this shows good corre-

**Table 1** Hydro-chemical classification of Stuyfzand (1986)

Classification	Units	Limits	Code
Main type	Cl (mg/l)	< 150	F: fresh
		150–300	Fb: fresh-brackish
		300–1,000	B: brackish
		1,000–10,000	Bs: brackish-salt
Type (total hardness)	Ca + Mg (Mmol)	<1	
		1–2	1
		2–3	2
		3–5	3
Class [(Na <sup>+</sup> +K <sup>+</sup> +Mg <sup>2+</sup> ) <sub>corrected</sub> - √(½Cl <sup>-</sup> )] Cation exchange situation	Meq/l	0 (balance)	0
		>0 (excess)	+
		<0 (deficit)	-

lation with electrical conductivity ( $r^2 = 0.98$  for the chloride and 0.96 for sodium).

The waters are mostly classified as sodium-chloride type, as shown on the Piper diagram (Fig. 6). The sodium-chloride waters are mainly downstream, close to the lagoon. Some different waters, located in the eastern and western zone of the plain, show a net enrichment in sulphate, calcium and magnesium.

Spatio-temporal evolution of groundwater level

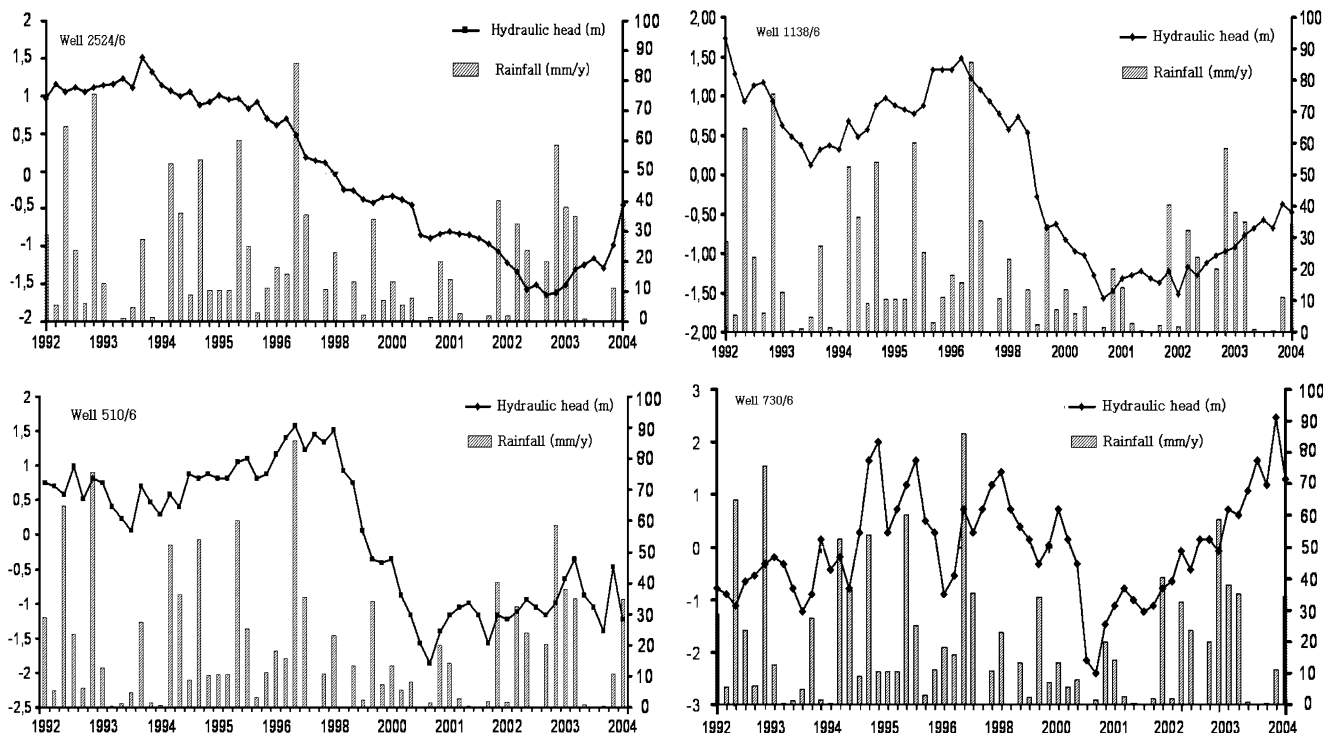
The piezometric map of April 2004 (Fig. 3) shows a general groundwater flow directed SW–NE toward the lagoon, which constitutes the main outlet of the aquifer. Except for the upstream part of the aquifer, the hydraulic gradients are generally low and range from 2 to 5‰.

**Table 2** Physico-chemical results (ionic contents in mg/l) of the water sample analysis of Bou-Areg groundwater (April 2004)

Wells	T (°C)	pH	EC (µS/cm)	Cl	NO <sub>3</sub>	HCO <sub>3</sub>	SO <sub>4</sub>	Na	K	Ca	Mg
P1	21.0	6.8	21,600.0	7,317.7	2.7	427.0	1,415.8	5,000.0	80.0	493.0	702.3
P2	20.7	6.9	8,250.0	2,479.2	38.6	366.0	623.2	1,600.0	34.4	356.7	211.4
P3	21.2	6.4	8,600.0	2,559.2	12.2	463.6	599.8	1,500.0	26.0	472.9	260.0
P4	18.5	8.3	3,250.0	559.8	10.6	671.0	522.2	292.0	22.8	96.2	143.4
P5	17.5	7.7	8,240.0	2,189.3	64.4	610.0	811.9	1,640.0	64.0	188.4	153.1
P6	18.7	7.1	4,020.0	809.7	103.0	512.4	696.7	680.0	18.4	304.6	150.7
P7	21.7	7.7	2,720.0	503.8	78.5	500.2	306.0	435.0	22.8	212.4	72.9
P8	20.4	7.0	3,780.0	624.8	110.0	793.0	306.0	400.0	39.6	320.6	155.5
P9	19.4	7.5	8,240.0	2,313.3	10.0	305.0	765.0	1,800.0	33.2	216.4	199.3
P10	20.1	7.9	2,800.0	479.9	13.8	536.8	504.8	630.0	31.2	108.2	85.1
P11	18.2	8.1	5,420.0	1,045.7	93.3	805.2	943.5	1,560.0	28.0	88.2	89.9
P12	19.3	7.1	6,560.0	1,831.4	34.6	488.0	418.2	1,360.0	32.0	268.5	172.5
P13	20.7	7.9	485.0	664.8	17.5	473.4	455.0	734.8	9.8	39.3	49.6
P14	19.8	7.3	5,600.0	1,480.0	36.0	414.8	368.0	826.4	11.8	200.4	141.0
P15	19.9	7.1	7,090.0	1,989.4	25.3	463.6	448.8	1,270.0	34.4	248.5	213.8
P16	19.1	6.8	18,100.0	6,068.1	14.8	488.0	873.1	4,200.0	48.0	545.1	435.0
P17	17.6	7.4	7,800.0	1,913.4	75.1	671.0	987.4	1,560.0	96.0	300.6	238.1
P18	17.8	8.3	7,520.0	2,174.3	16.8	329.4	795.6	1,500.0	72.0	240.5	303.8
P19	20.3	8.4	2,980.0	489.8	17.5	512.4	415.1	680.0	23.2	104.2	46.2
P20	18.8	8.2	7,870.0	2,099.3	32.5	402.6	696.7	1,840.0	36.0	172.3	138.5
P21	21.6	7.4	8,160.0	2,191.3	14.2	427.0	724.2	1,900.0	34.8	140.3	170.1
P22	18.8	7.8	6,490.0	1,705.5	15.6	549.0	632.4	1,440.0	38.4	180.4	104.5
P23	19.4	8.3	3,800.0	631.8	16.2	622.2	603.8	500.0	30.0	100.2	97.2
P24	19.7	8.0	2,360.0	483.0	8.3	395.3	418.0	549.8	19.2	46.9	36.6
Lagoon	19.1	8.3	53,700.0	20,993.5	9.9	170.8	3,468.0	9,800.0	368.0	741.5	1,234.4

EC electrical conductivity





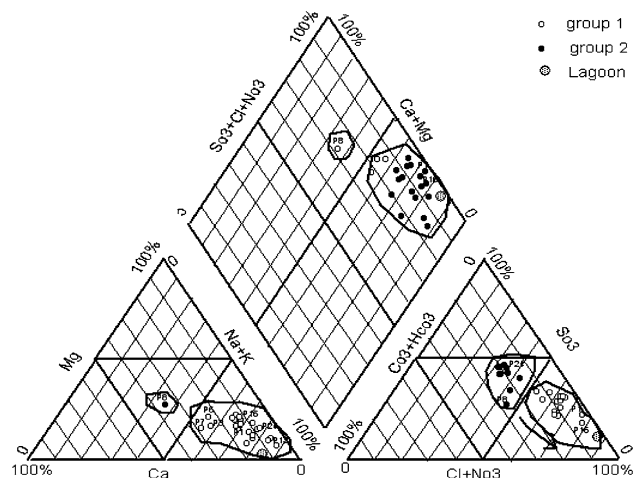
**Fig. 5** Historical piezometric evolution in water points in unconfined aquifer of Bou-Areg

The examination of the hydrographs of four observations wells from 1992 to 2004 (Fig. 5) shows a good correlation between the interannual piezometric variations and rainfall on the whole coastal aquifer. The water table declines during the dry periods, and in the wet period it rises.

Since 1992–1994, the average level of the groundwater has lowered by 0.5–1 m according to the well observations, correlating to precipitation. Afterwards, a very rainy period from 1995 to 1997 completely disrupted the normal pattern and groundwater raised an average of 0.5–2 m. Since 1997, the water table has declined by 1.5 m in the occidental and in the upstream zones following lesser rainfall in 2000. This same downwards trend occurs in the coastal zone (downstream and eastern zone of the aquifer), though the values are higher (2.5 m at well 510/6 and 3 m at well 1,138/6). This decrease due to decline of rainfall is linked to the intensive water demand for domestic and agriculture activities. An increase in groundwater levels is observed during 2002–2004, following the greater precipitation of 2002. Interannual fluctuations of the water levels have been observed in well 730/6 in the upstream zone of the aquifer, probably due to the heaviest pumping for agriculture (Fig. 6)

#### Spatial distribution of the physico-chemical parameters

Visualizing the spatial distribution of physico-chemical parameters, (conductivity, chloride, sulphate and nitrate)



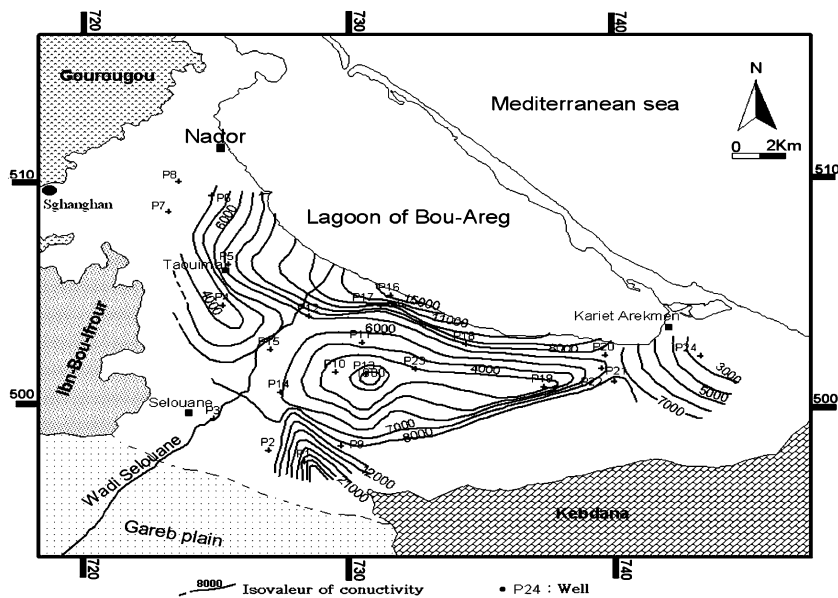
**Fig. 6** Diagram of Piper

during the monitoring survey of April 2004 helps assess the possible origins of the groundwater salinization.

The spatial variability of electrical conductivity (Fig. 7) clearly shows three zones of higher salinity:

- In the SW (upstream zone) the curves of E.C. are brought closer and display elevated values between 7,000 and 21,000  $\mu\text{S}/\text{cm}$ . The increase of the conductivity occurs in the opposed direction of the groundwater flow, which may be explained by the effect of the evaporite-bearing marly outcrops.

**Fig. 7** Spatial distribution map of conductivity (April 2004)



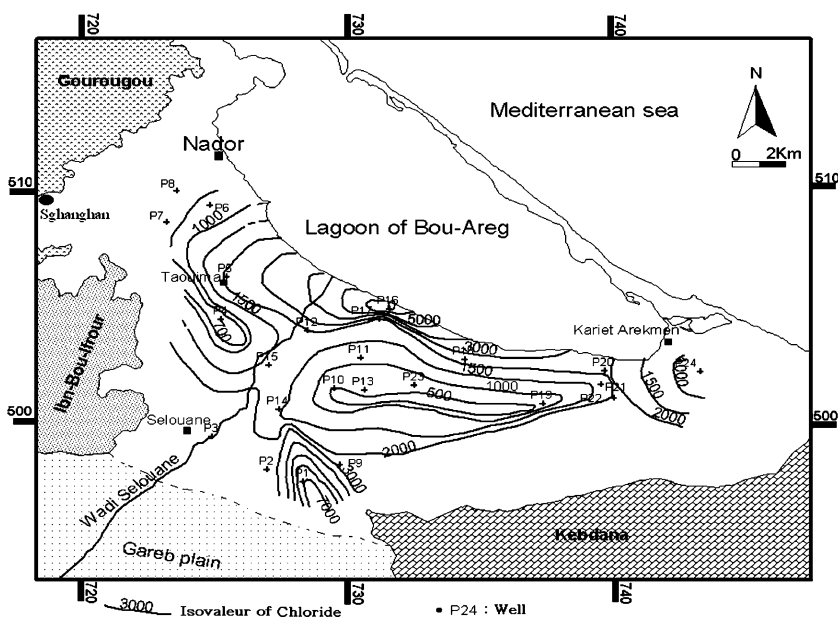
- In the coastal (downstream) zone the gradient of salinity increases towards the lagoon, where the electrical conductivity varies between 8,000 and 18,000  $\mu\text{S}/\text{cm}$ . This suggests the influence of the groundwater contamination by the saltwater intrusion from the lagoon.

The conductivity values remain mostly above 6,000  $\mu\text{S}/\text{cm}$  in the central part of the plain (zone surrounding well P15), which is due to the influence of the Selouane River. However, in the western and eastern zones, the values are less, ranging from 3,000 to 5,000  $\mu\text{S}/\text{cm}$ . These values indicate that the aquifer is recharged by fresher waters coming from the massifs which border the plain.

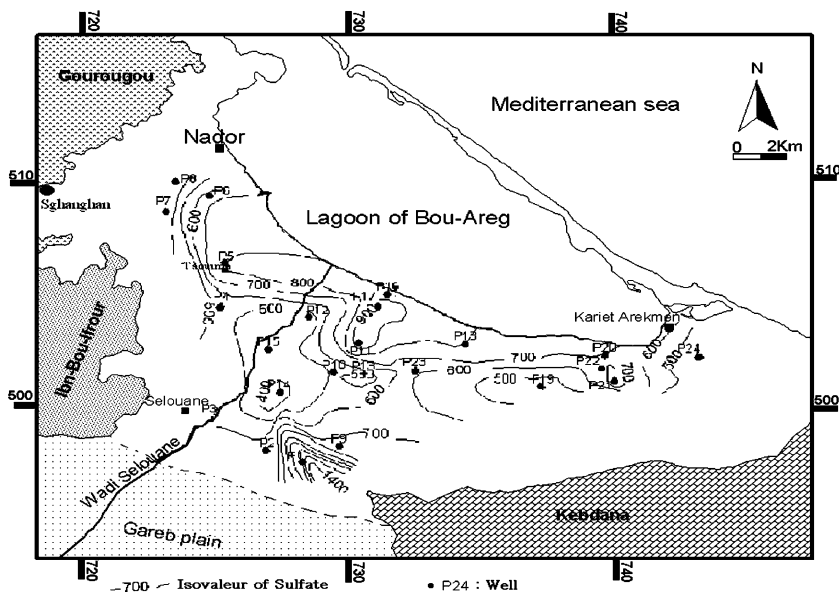
These processes are responsible for the enrichment of the groundwater in chemical elements, notably chloride (Fig. 8), calcium, and magnesium. In this context, and like the neighboring coastal aquifer of Saïdia (Fig. 1) that is located in the easternmost part of Morocco near to the Algeria frontier, (El Mandour et al. 2007), the ionic exchanges can also intervene.

Likewise, the highest concentration of chloride occurs in the regions of high electrical conductivity values. The spatial distribution of chloride (Fig. 8) shows that the maximal concentrations of chloride in coastal zone of the aquifer is 6,068, and 7,317 mg/l in the upstream zone. In the eastern and western regions near the massifs limiting

**Fig. 8** Spatial distribution map of chloride (April 2004)



**Fig. 9** Spatial distribution map of sulphate (April 2004)



the plain, the concentrations of chloride are average (between 1,000 and 3,000 mg/l).

Sulphate concentrations (Fig. 9) varied from 400 to 1,400 mg/l. The highest levels of sulphate were in the upstream zone, concomitant with the raise of the electrical conductivity values, indicating the influence of the marly gypsum-bearing outcrops. Sulphate distribution in the coastal zone of the aquifer in the eastern and western regions presents anomalous zones (500–900 mg/l). The highest concentrations are probably due to additional regional sources of sulphate, such as fertilizers in agriculture.

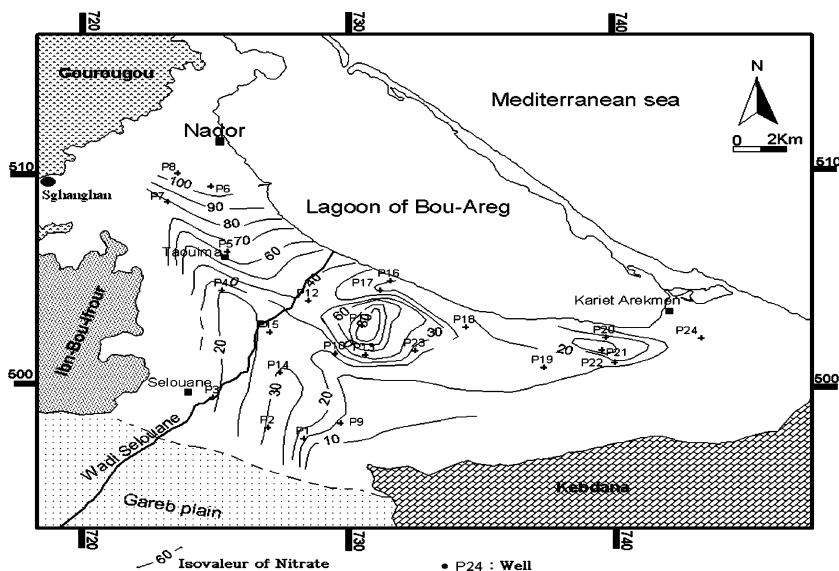
The spatial distribution of nitrate concentrations (Fig. 10) shows that the highest contents occur generally in the western and central zones, with an elevated contents reaching 85 mg/l in the central zone and 105 mg/l in the

western zone. These high concentrations may have several origins. An excess of agricultural fertilizers may be the primary cause in the central zone, and in the western zone waste solids and wastewater from domestic activities and sewage waters are probably the main sources of groundwater pollution (Fig. 11).

The spatial variability of the waters according to the classification of Stuyfzand (1986) is shown in Fig. 1:

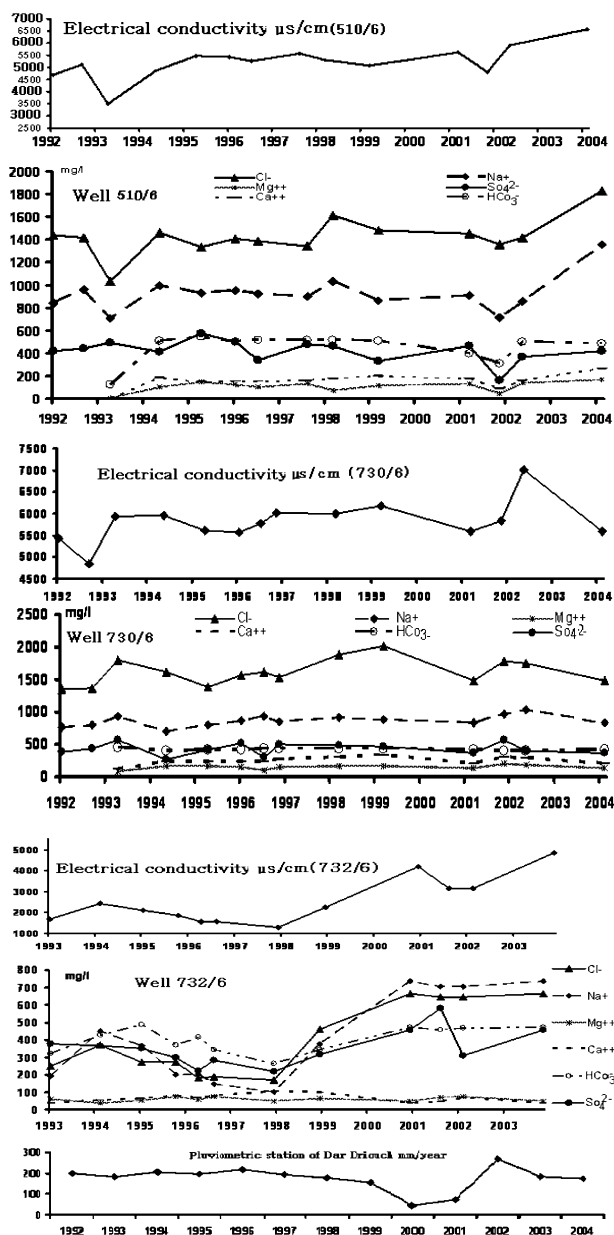
- In the upstream, central and downstream zones of the aquifer, the waters-types are primarily  $Bs_4NaCl$ ,  $Bs_5NaCl$  and  $Bs_6NaCl$ , indicating that the waters are salty brackish types, enriched with chloride and sodium concentrations. This type of water reveals a state of salinization provoked by the seawater intrusion in the zones close to the lagoon and by the contact of the

**Fig. 10** Spatial distribution map of nitrates (April 2004)









**Fig. 12** Physical-chemical trends of monitoring wells 730/6, 510/6 and 732/6 of Bou-Areg aquifer (1992–2004): central, upstream and downstream zones

In the western part (well 506/6), concentrations of major ions from 1992 to 2004 fluctuate (Fig. 13).  $Mg^{2+}$  contents vary between 19 and 160 mg/l and  $Ca^{2+}$  rises from 36 to 320 mg/l. The bicarbonates concentrations fluctuate between 292 and 793 mg/l and slightly exceed the chloride concentrations. The enrichment of these ions is owed to the infiltration of sewage and wastewater. The noticeable rise of  $Ca^{2+}$  and  $Mg^{2+}$  may also be related to recharge from the massifs limiting the plain.

### Temporal evolution of nitrate

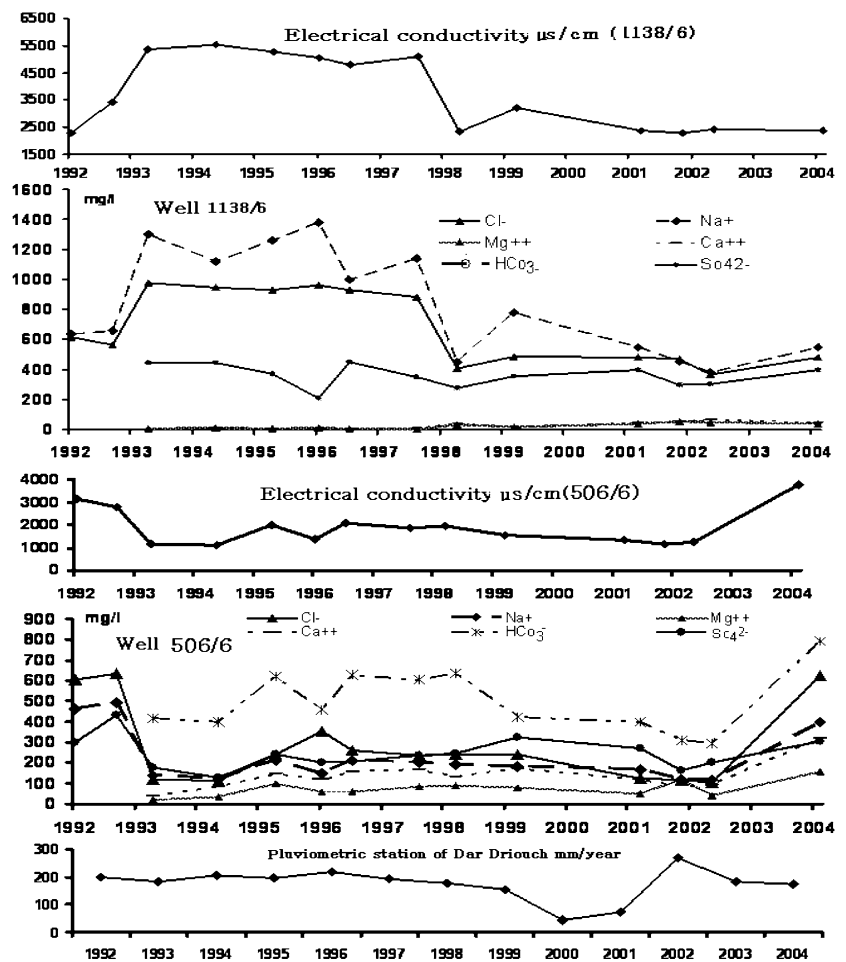
The time series of the nitrate concentrations during the observation period 1992–2004, indicates nitrate contents have risen during the rainy periods and declined during the dry periods. Nitrate concentration graphs (Fig. 14) demonstrate nitrate contamination in the western and central zones, where concentrations exceed the allowed limits (50 mg/l) of the World Health Organization (WHO).

In the western zone, nitrate concentrations increase from 50 to 140 mg/l during an important rainy period of 1992–1998, and are 120 mg/l in 2004. The rainiest period during 2002, coincided with a drop in nitrate concentrations to 10 mg/l. This decrease may be explained by the reduction of pollution and increased evacuation to the lagoon in this rainy period. In the central zone (well 730/6 and 510/6), the interannual variation of nitrate did not exceed 30–70 mg/l during 1992–2000. Maximal peaks in nitrate were only observed during the rainy period of 2002. Then the maximal contents reached 80 mg/l, probably due to an excess of agricultural fertilizers.

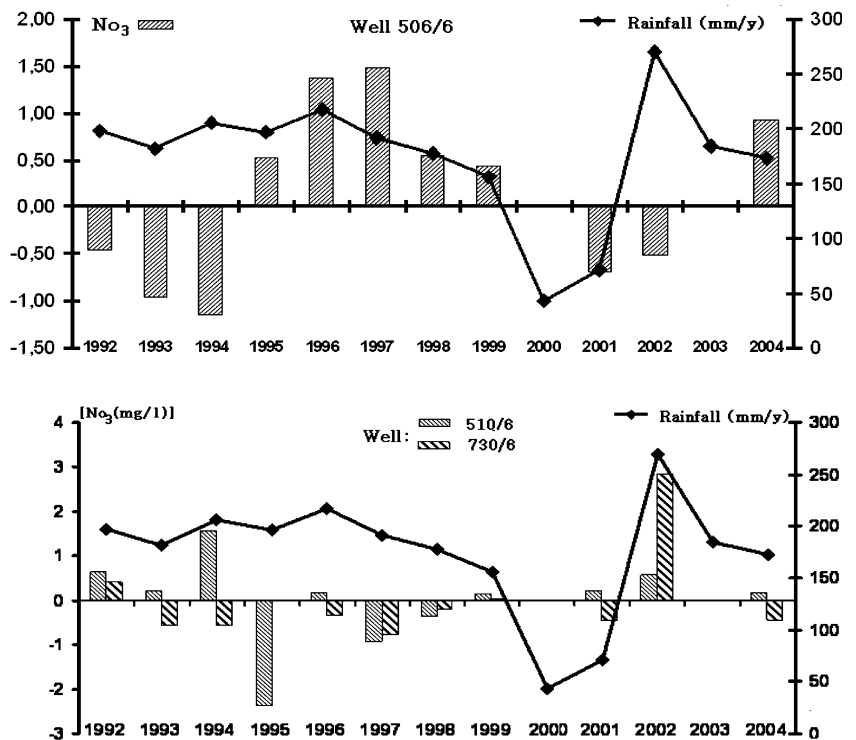
### Moroccan Mediterranean coastal aquifers salinity

The groundwater of Bou-Areg plain has been affected by salinization during the last decades. Sources of salinization are similar to a variety of coastal Mediterranean aquifers within Italy (Capacciona et al. 2005; Vincenzo and Giovanna 2003) and Spain (García-Aróstegui et al. 2003). Seawater intrusion, natural and the anthropogenic factors have caused aquifer quality to deteriorate. Similar examples have been recorded from Mediterranean Morocco in both the eastern and the western Bou-Areg aquifer. Smir and Martil-Alila detrital aquifers (El Morabiti and Pulido Bosch 1993; Stitou and Pulido Bosch 1995) located to the north of the Tetouan town (Fig. 1), are mainly sodium chloride type. Salinity is generally high, with a conductivity average of 2,030  $\mu S/cm$ , but less than Bou-Areg groundwater. Increased salinization is a result of human activities (discharge of solid and liquid urban waste and agricultural surpluses), by seawater intrusion and by natural causes such as evaporation of surface waters. In the eastern Bou-Areg area, groundwater of Saïdia detrital aquifer (El Mandour et al. 2007), is highly saline, (electrical conductivity averages 13,800  $\mu S/cm$ ), more than Bou-Areg groundwater (Table 3). The causes of this salinization are similar to those of Bou-Areg plain and linked to geological, hydrogeological and geochemical contexts of the plain, seawater intrusion, and other phenomena, such as ionic exchange and dissolution of gypsum indicated by high sulfate concentrations.

**Fig. 13** Physical–chemical trends of monitoring wells 506/6 and 11,138/6 of Bou-Areg aquifer (1992–2004): eastern and western zones



**Fig. 14** Temporal evolution of nitrate in the unconfined aquifer of Bou-Areg (1992–2004)



**Table 3** Simple statistics variation of the physico-chemical parameters in the both aquifers of Bou-Areg and Saïdia: of eastern Moroccan Mediterranean coast

	Bou-Areg				Saïdia			
	Min	Max	Mean	SD	Min	Max	Mean	SD
C.E ( $\mu\text{S}/\text{cm}$ )	485	21,600	6,718.95	4,735.32	1,600	55,200	13,800	16,050
pH	6.43	8.39	7.55	0.56	7.3	9.6	8.24	0.62
Cl (mg/l)	479.85	7,317.73	1,858.53	1,675.56	319	21,396	4,727	6,305
SO <sub>4</sub> (mg/l)	306	1,415.8	638.8	255.73	19	1,117	433	289
HCO <sub>3</sub> (mg/l)	305	805.2	509.45	130.8	244	1,830	539	283
Ca (mg/l)	39.28	545.08	226.87	137.74	25	892	255	176
Mg (mg/l)	36.6	702.27	182.09	142.77	62	1,798	388	399
Na (mg/l)	292	5,000	1,412.42	1,116.7	166	12,420	2,564	2,659
K (mg/l)	9.78	96	36.91	21.25	10	469	117	134

SD standard deviation

## Conclusions

The groundwater of Bou-Areg plain is affected by significant salinity. The average conductivity is 6,718  $\mu\text{S}/\text{cm}$ , varying between 485  $\mu\text{S}/\text{cm}$  (fresh water) and 21,600  $\mu\text{S}/\text{cm}$  (almost salt water). The groundwater is mainly sodium-chloride type. Where the sulphate facies are more pronounced, there is influence from the marly gypsum terrains.

Sampling from the monitoring wells of the plain show decreasing water quality over time. The spatio-temporal distribution of the physico-chemical parameters, notably chloride, one of the characteristic parameters of sea water (Richter and Kreitler 1993), indicates saltwater intrusion in the downstream part of the aquifer and accentuated salinization in the upstream due to contact of groundwater with the marly gypsum formation.

Nitrate pollution has also affected groundwater quality over the decades. The primary sources are increased use of agricultural fertilizers (Gardner and Vogel 2005; Vandenberghe and Marcoen 2004), and leakage of domestic and industrial waste waters. Wastewater nitrate contribution in the western zone is characterized by discharge from urban areas, such as the City of Nador. Nador operates a wastewater treatment station, but its output is only 70% (Dakki et al. 2000). The other urban areas discharge their wastewaters to the Selouane River which crosses the plain of Bou-Areg and exits directly into the lagoon. This practice also contributes to the rise of groundwater salinity.

In comparison with other aquifers of the Moroccan Mediterranean coast, salinization of groundwater follows a general eastward increasing trend, from the aquifers of Martil-Alilla and Smir (average conductivity of 2,030  $\mu\text{m}/\text{cm}$ ), to Saïdia aquifer with 13,800  $\mu\text{S}/\text{cm}$ . Groundwater of the Bou-Areg coastal aquifer is characterized by an intermediate value and has an average conductivity of 6,718  $\mu\text{c}/\text{cm}$ . High salinity both in the coastal aquifers of

Saïdia and Bou-Areg is related to the influence of geological formations rich in gypsum and also to seawater intrusion from increased pumping.

The high salinity that affects the northeastern region of Morocco both in the coastal and the continental sides (El Mandour 1998; El Mandour et al. 2007), as well as the problems of deterioration and rarefaction of groundwater resources, require multidisciplinary hydrological and geochemical approaches to assess the origins and the evolution of salinity in both water and soil. Gathering accurate and timely data will constitute first step toward a regional action plan for reducing salinity and improving water quality.

**Acknowledgments** Thanks are addressed to Mr. B. El Haouadi from the Agency of Moulouya River Hydraulic Basin and to the COSTE (Oriental Center of Water Sciences and Technology), Oujda, Morocco. The participation of J. B. is in the framework of the EC Contract ICA3-CT2002-10004 (INCO Program).

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