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title: **Groundwater salinisation of the agricultural plains located in the Northeastern Mediterranean region of Morocco**

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INTRODUCTION

The north oriental Mediterranean coast of Morocco (Figure 1) is characterized by the juxtaposition of small plains, Triffa, Saïdia, Gareb, Bou-Arreg and Kerte, localized between the mounts of Beni Snassen and Gourougou at the south and the Mediterranean sea at the north. The rainfall is weak, with an average of 245 mm/year in the plains. It can reach 300 mm/year nearby the Mediterranean sea and 500 mm/year on the mountains. The variation and the scarcity of the rainfall and the geological nature of the lands cause a big variability of groundwater and surface water resources between the Mediterranean and Atlantic sides of Morocco. The Mediterranean coast (500 km long) is indeed characterised by smaller aquifers and shorter rivers than the ones of the Atlantic coast (3000 km long).

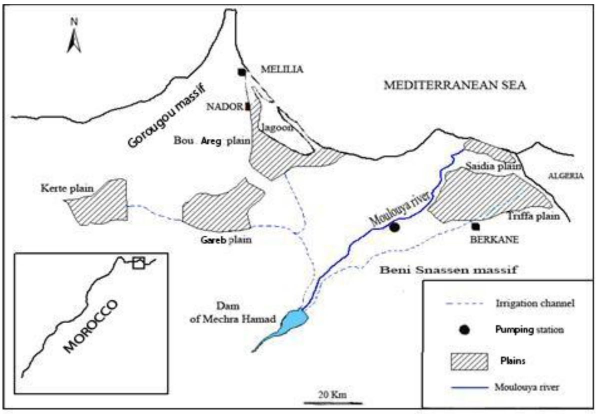

Figure 1. Location of the study area.

The groundwater is widely used for irrigation and drinking water supply. Two dams, located in the massif of Beni Snassen, are used for the irrigation of 60000 ha in the plains of Triffa, Bou-Areg and Kerte.

The exploited Plioquaternary aquifers, formed of detritical deposits of Quaternary age resting on a marly substratum of Mio-Pliocene age (Carlier,1971), show medium to good hydraulic potentialities. However, they are affected by problems of salinity and nitrates contamination.

CLIMATIC DATA AND SURFACE RUNOFF

Tens of pluviometric stations are installed in the plains and the reliefs of Beni Snassen and Gourougous. The rainfall average values are 250 mm/year in the plains and 500 mm/year in the mounts. The evolution of rainfall over a period of 70 years in the Triffa plain shows a big variability. The highest and lowest recorded values are respectively 800 mm in 1962 and 120 mm in 1965.

From west to the east, the study region is crossed by the following rivers: Kiss, Moulouya, Selouane, Kerte and Nakor. The Moulouya is the biggest river; it is 600 km long and brings about 900 millions of m^3/year as average flow. Its watershed is located in the High and Middle Atlas, contrary to the other rivers of the study region, coming from the Rif reliefs. Two dams are installed on the Moulouya river, with a capacity of 410 million of m^3. These dams play an important role in drinking water supply for the cities of Berkane, Zaïo and Nador as well as in the irrigation of the perimeter of the Bas-Moulouya (Triffa, Bou-Areg, and Gareb) with an area of 60,000 ha.

GEOLOGY AND HYDROGEOLOGY

The majority of the plains are generally filled of quaternary deposits constituted by alluvions and silts (Figure 2), resting on a marly substratum of Mio-Pliocene age.

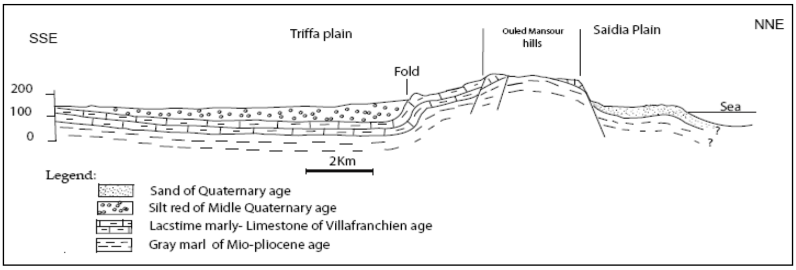

Figure 2. Geological cross section of Triffa and Saidia plains.

The groundwater constitutes an important component of the water resources system. It presents, in comparison with the surface water, the advantage of its regularity and its low costs of mobilization. Two main aquifers are targeted: the superficial aquifer and the deep aquifer which is exploited only at the margins of the plains, near the mountains.

The aquifers of the plains of Kerte, Gareb, Bou-Areg and Triffa generally have good hydraulic potentialities, thanks to the predominance of silts with conglomerate deposits. The pumping tests show transmissivities ranging from $3 \cdot 10^{-2}$ m^2/s to $4 \cdot 10^{-5}$ m^2/s. The low values are related to the marly limestone of the north part of the Triffa plain and the silts of Gareb (El Mandour, 1998).

HYDROCHEMISTRY, SALINISATION AND POLLUTION

The analyses of the hydrochemical data concern 250 samples taken from wells, boreholes and springs of the concerned aquifers. The electrical conductivity varies from 1.3 ms/cm to 55 ms/cm and the values of nitrates from 1 mg/l to 160 mg/l. In spite of the variation in the salinity, the groundwaters present similar chemical facies and are characterized, up to 90% of the samples, by a sodium-chloride water type. A good correlation exits between the electric conductivity and the contents in chloride and sodium.

The degree of salinity measured in the plains is very different (Tab. 1). The coastal plains of Saidia and Bou-Areg are affected by a salinisation related to the seawater intrusion (El Mandour and al., 2008; El Yaouti and al., 2009) and also by ion exchange between the groundwater and the salty marl and gypsiferous deposits of the Mio-Pliocene and Messinean, forming the aquifer's substratum. The continental plains of Triffa, Gareb and Kerte are also affected by a salinisation but less important than the coastal plains. The origin of this salinity is on the one hand the infiltration of the evaporated irrigation water and on the other hand the ion exchange with the Mio-Pliocene and Messinean deposits of the substratum.

Table 1. Chemical variation of groundwater.

	Saïdia			Triffa			Bou Arreg			Kerte			Gareb		
	Min	**Max**	**Moy.**	**Min**	**Max**	**Moy.**	**Min**	**Max**	**Moy.**	**Min**	**Max**	**Moy.**	**Min**	**Max**	**Moy.**
C.E. (mS/cm)	1.60	55.20	13.80	1	13.39	4.1	2.55	21	6.79	1.08	12.3	5.15	1.5	20.1	6.5
pH	7.3	9.6	8.24	7.05	8.5	7.3	7.3	8.5	7.8	6.23	7.7	7.15	6.5	7.6	7.12
Cl^- (mg/l)	319	21396	4727	97	4180	984	448	7797	1828	109	3389	1037	1477	7990	4733
SO_4^{2-}(mg/l)	19	1117	433	57.3	756	336	76	1473	795	69	2029	894	68.5	1288	678
HCO_3^-(mg/l)	244	1830	539	129	488	290	25	854	544	183	1329	400	229	456	342
Ca^{2+}(mg/l)	25	892	255	90	676	205	32	649	180	80	581	319	101	537	320
Mg^{2+}(mg/l)	62	1798	388	16.7	477	154	20	797	142	22	464	136	59	580	319
Na^+(mg/l)	166	12420	2564	144	1334	420	400	3000	1237	40	2500	651	116	3583	850
K^+(mg/l)	10	469	117	8	25	12	7	250	29	1	18	5	7	39	23
NO^{3-}(mg/l)				4	151	65	0.4	95	34	1	145	17	0.5	88	45

The groundwater of Triffa and Saidia plains shows in addition a stratification of the mineralization (Figure 3 and 4) (El Mandour 1998 and El Mandour and al., 2008). The measurements of electric resistivities in the saturated zone of the wells and boreholes of the plain of Triffa (Figure 3) and the application of the Stuyfzand classification (1986) on the waters of the plain of Saidia, (Figure 4) show an increase of the salinisation from the top to the bottom of the aquifers. Concerning the aquifer of Saidia, the existence of a paleo-salinity has been advanced to explain the brines encountered in the Southern limit of the aquifer.

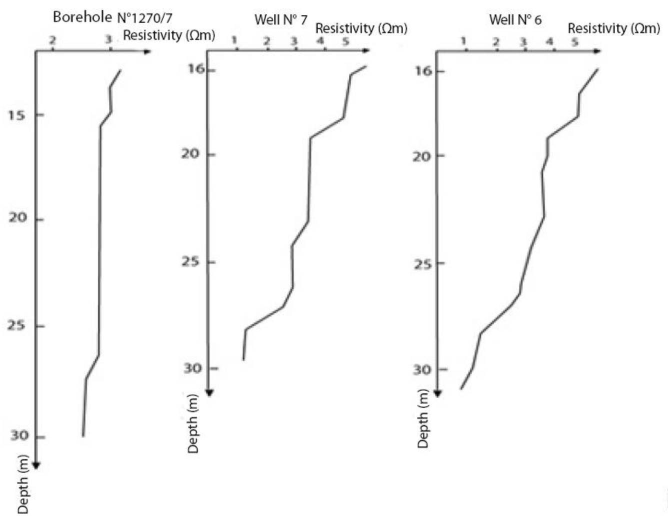

Figure 3. Electric resistivities in the saturated zone of the wells and boreholes.

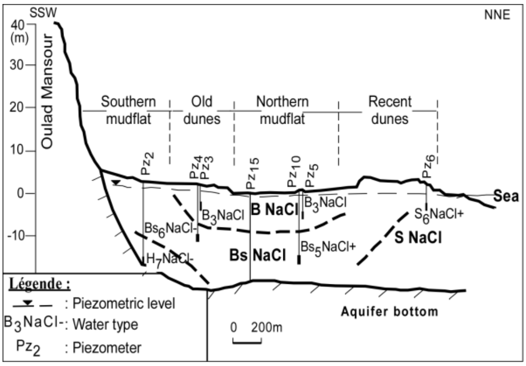

Figure 4. Vertical distribution of hydrochemical water types.

On another hand, the high levels of nitrates (up to 150 mg/l) in the groundwater of the plains of Triffa (Figure 5), Bou Areg and Kerte, indicate the existence of a heavy agricultural pollution.

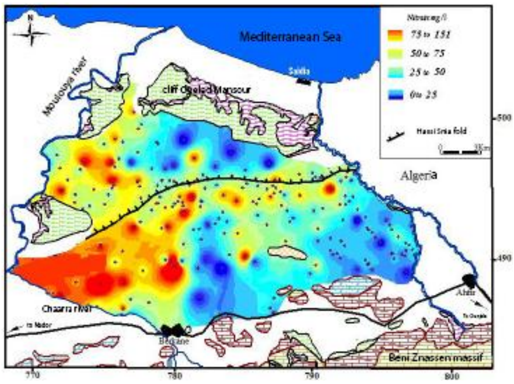

Figure 5. Map of distribution of nitrates in Triffa plain.

CONCLUSION

The sustainable management of Machrar Hamadi dam supplying presently the plains of irrigation water, would contribute to reduce the salinisation of the aquifers.

The construction of new dams on the tributaries of Moulouya river (Cherra and Agbal on the right bank and Kerte on the left bank) will reduce the use of the groundwater and will enhance the aquifers recharge and improve their quality. This should be accompanied by the use of water saving techniques of irrigation, such as drip irrigation which is still not widespread in the study area.

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