Vulnerability and impact of climate change on water resources in semi-arid areas; example of the Essaouira Basin (Morocco)

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Abstract — Essaouira synclinal area is part of the semi-arid areas of Morocco that are subject to the impact of climatic and human pressures. In the case of this coastal area, which includes two main aquifers superimposed; the Plio-Quaternary and Turonian, the resulting vulnerability is compounded by the risk of infiltration navy. The Rainfall in the area does not exceed 300 mm year^{-1}, the average temperature hovers around 20 ° C, the piezometric map of Essaouira synclinal basin was made, different water samples have been collected from October 2009 after exceptional rainfall, all waters are sodium-chloride facies, interpretation of mineralization indicates power by the Ksob Wadi in the northeast and increasing levels of chlorides in the central part generated by the Essaouira diaper hidden. Excessive levels of nitrates have been identified, as well as chlorides after rains of winter 2009. The electrical conductivity and concentrations of ^{18}O and ^{2}H were measured, a local meteoric water line was determined according to the Atlantic origin of precipitation. The Essaouira Basin is more vulnerable to drought because its climate is entirely dependent on recharge meteoric waters.

Keywords — basin of Essaouira; aquifer; semi-arid regions; drought; hydro geochemistry; stable isotopes; recharge

1 Introduction

The relative scarcity of water resources in the Essaouira Basin, their fragility and their uneven distribution give rise to a greater risk of shortage that is growing continually cope with demographic pressures and the growing needs of the socio-economic growth. In the Western High Atlas, Essaouira synclinal area is part of the Essaouira Basin, with an area of 300 km2, bounded by the Ksob Wadi in the north, Tidzi Wadi in the south, the Tidzi Diapir in the East and the Atlantic Ocean to the west (Fig. 1).

The present position of the study area leads to a degradation of water quality caused by rising salinity and the threat of seawater intrusion due to overexploitation of groundwater. The prevailing climate is semi-arid with highly variable rainfall averaging 300 mm year-1, However the annual rainfall varies from 100-630 mm (Fig. 2a) and precipitation of rain within one year shows two seasons, dry from April to September and wet from November to March (Fig. 2b). The average temperature varies between 20 ° C and 21 ° C, the difference between the coldest month (January) and warmest month (August) can reach 17 ° C (Bahir, 2001).

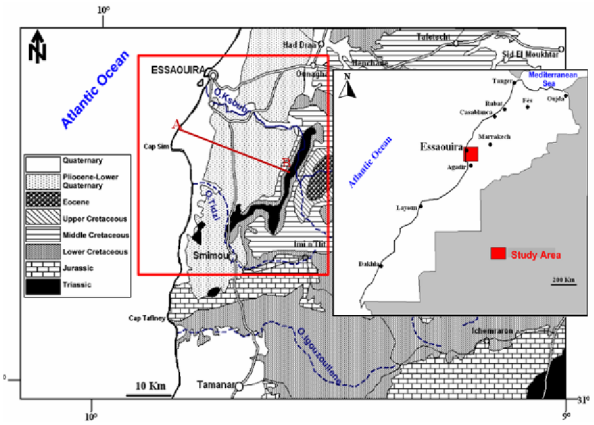

Fig. 1 Geological map (adapted from geological map of Morocco 1 / 1000000. 1985). A–B represents the cross-section location of Fig. 4.

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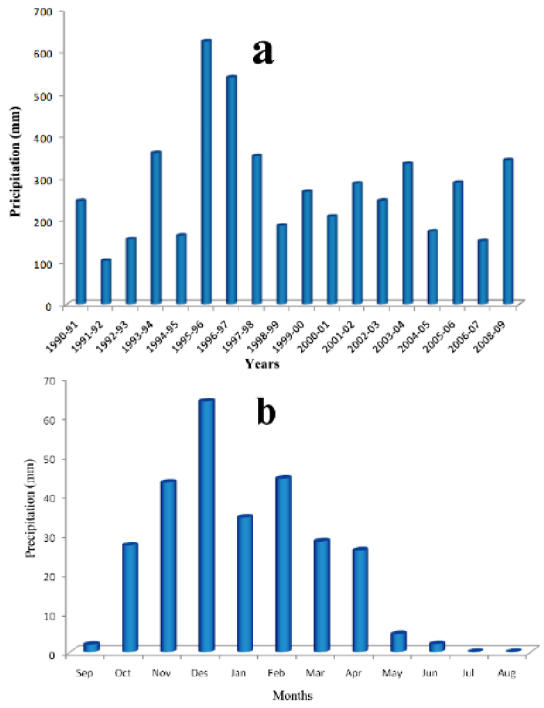

Fig. 2 Precipitation (a) annual values and (b) monthly mean values at Essaouira Station (1990-91 to 2008-09).

The Tidzi diapir oriented NNE-SSW (20 km) from the Ksob Wadi until the Tidzi Wadi where he takes an east-west direction and anticline Triassic heart of Essaouira in the West masked by recoveries Plio-Quaternary (Fig. 3, 4) and identified by geophysical structures. There is also an intense fracturing with a general direction N10 cutting Cretaceous carbonate formations.

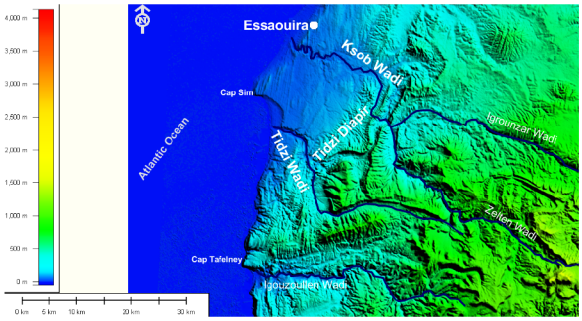

Fig. 3 MNT map of the study area.

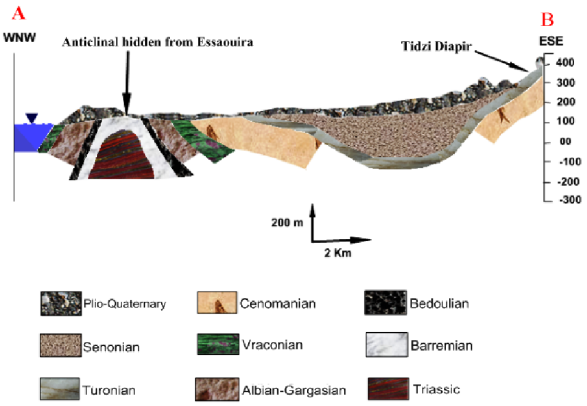

Fig. 4 Geological section of the syncline of Essaouira (after Fekri 1993, modified). For location, see Fig. 1, section AB.

2 PIEZOMETER

The companion measure of the groundwater level Plio-Quaternary conducted in October 2009 allowed us to map the potentiometric (Fig. 5) established for all levels combined to show that the general direction of water flow takes place in South-East to North-West, imposed by the inclination of the bedrock. In the downstream, the waters diverge to circumvent the Essaouira anticline hidden oriented NE-SW.

This over, we note the existence of a line of watershed with a SE-NW direction and influences the direction of flow of water. The groundwater is then separated in two compartments, the first in North streamlines directed in a manner identical to the overall flow, the second in the South, with lines of flow directed from East to West.

The lake is located upstream to 140 m and 10 m downstream. The hydraulic gradient showed variations induced by the pelvic structures and lithology of the reservoir in the upstream part of the study area, the gradient is relatively large, about 2% due to the steepness of the wall the aquifer on the rising Tidzi diapir. At the center, this gradient decreases seven-fold to reach a value of 0.3%.

In the Downstream, the hydraulic gradient increases again to reach an average of 2%. Differential gauging made during the hydrological cycle 1990-1991 and confirmed in 2004 is used to estimate flows infiltrated from the Ksob Wadi to the Plio-Quaternary aquifer at a rate of 42 L s-1 (Fekri, 1993).

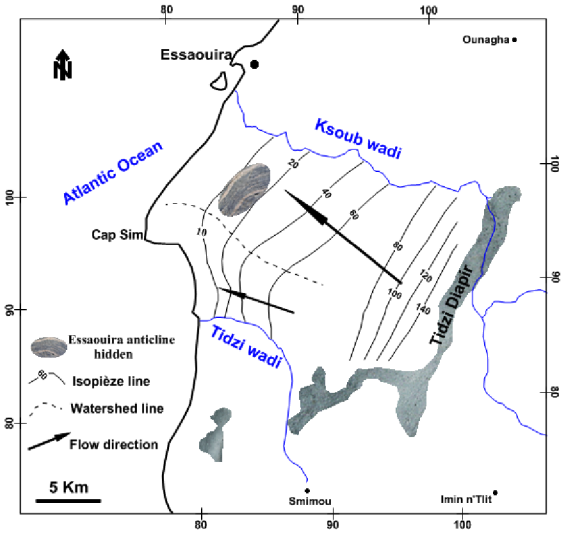

Fig. 5 Essaouira basin piezometric map in October 2009

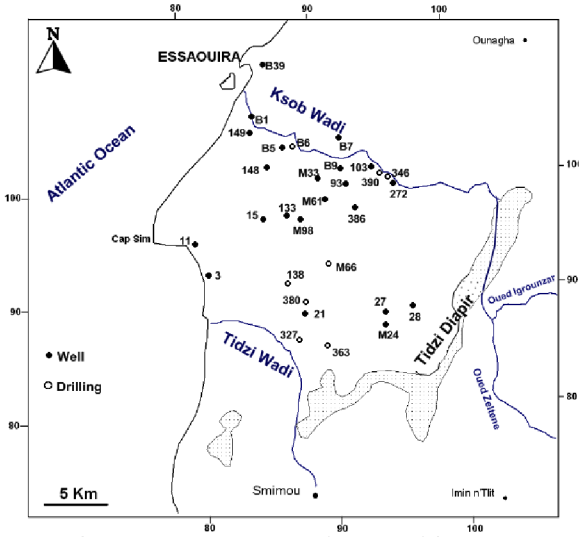

Fig. 6 Distribution of sampled water points in the study area.

The passage of this river in the gorge where the Turonian flow would also result in losses of 64 L s-1 the benefit of the Turonian aquifer.

The year 2008-2009 is noted as a wet year par excellence, following heavy rainfall as experienced Morocco, something that appear to provide a recovery of groundwater level in the Plio-Quaternary aquifer.

3 HYDROCHEMISTRY

The study of the chemistry of water is to identify the chemical facies of waters, their qualities and potability, as well as their suitability for irrigation. It can also track the spatial evolution of physicochemical parameters and estimate their origin, correlating with the geology and groundwater level.

Almost all points of the aquifer are intended to supply drinking water and more modest for the irrigation of farmland. To be used, the water must meet certain standards that vary depending on the type of use. This study is based on physico-chemical analysis of samples taken from the entire basin in October 2009 (Fig. 6).

The temperature, electrical conductivity and water pH were measured in the field (Tab. 1). In the laboratory, analysis focused on the chemical major anions (HCO3-, Cl-, SO42- and NO3-) and cations (Ca2 +, Mg2 +, Na + and K +). The results of major element chemistry laboratories conducted by the National Office of Potable Water (ONEP) and the Office of Regional Development in Agricultural Value Haouz Marrakech (ORMVAH) are presented in Tab. 2.

- Groundwater Plio-Quaternary

The groundwater Plio-Quaternary is characterized by their hydrochemical variability. Indeed, the recorded conductivity varies from 770 ms cm-1 to more than 3,500 ms cm-1 (Fig. 7), with an average of 2,000 ms cm-1. Even with this variability, the waters of the groundwater are grouped in one family and are characterized by the sodium-chloride facies (Fig. 8, 9).

The analysis of maps of the spatial distribution of sodium (Fig. 10), chlorides (Fig. 11) and electrical conductivity show that there is a good correlation between the concentrations of chloride and sodium and that the distribution of these two factors correlate well with the electrical conductivity.Examination of the spatial distribution map of mineralization of water (Figure 7) shows some chemical zonation mainly due to the lithological nature of land crossed.

In the northeast to south of Ksob Wadi, we have the lowest electrical conductivity, they increase fairly steadily to the southwest, with a maximum near the Essaouira diapir hidden in the Southwest. Beyond this structure to the northwest, the observed electrical conductivities are lowered.

Tab. 1 Results of the campaign in October 2009 from the coastal area of Essaouira; aquifers Plio-Quaternary and Turonian.

Sample	X (km)	Y (Km)	Z (m)	N.P/sol (m)	H (m)	PT (m)	c25°C (µs/cm)	T°C	pH	Aquifer
B1=Ksob Wadi	85,5	105,62	22		22		2440	20	7,37	wadi
B2=149-51	85,1	105,8	40	37,2	2,8	33,3	3160	22	6,7	Plio-Quat
B3=138-51	87,85	92,83	109	5	104	26	3520	21	7,31	Plio-Quat
B4=M33	91,15	102,3	78	29	49		2040	20	7,41	Plio-Quat
B5	90,29	102,26	102	48	54	56	2249	19	7,4	Plio-Quat
B6	91,43	102,44	79	22	57	110	1450	21	7,1	Turonian
B7	95,15	104,49	97	27,8	69,2	38	770	20	7,25	Plio-Quat
B8=93-51	92,37	101,9	98	44	54	28,7		21		Plio-Quat
B9	93,41	102,68	114	47	67	50	1763	19	7,41	Plio-Quat
B10=M61	91,2	100,75	90	34	56	40	1720	23	7,5	Plio-Quat
B11=103-51	94,82	102,17	99	22,5	76,5	26,5	1671	21	7,3	Plio-Quat
B12=390-51	96,81	100,93	111		111		1947	23	7,39	Turonian
B13=272-51	97,17	100,76	105,5		105,5	38,4	2180	20	7,15	Plio-Quat
B14=346-51	97,27	100,7	105		105		1969	27	7,17	Turonian
B16=133-51	87,8	98,8	70	38	32	40	2550	22	7,24	Plio-Quat
B17=15-51	86	97,97	70	7	63	8,8	3070	15,5	7,1	Plio-Quat
B18=3-51	81,4	93,4	18	4	14	11	2130	19	7,44	Plio-Quat
B19=M66	90,5	95,5	110	61	49		1911	23,5	7,55	Turonian
B20=21-51	89,4	91,4	89,6	28	61,6	30	3780	20	7	Plio-Quat
B21=380-51	89,35	91,8	135	102	33	184	2340	25	7,69	Turonian
B22=327-51	88,8	88,8	130	24	106	50	2850	21,5	7,3	Plio-Quat
B23=363-51	89,75	88,2	150		150	228	2150	24	7,2	Turonian
B39	84,98	111,08	23	5	18	6	3060	23	7,28	Plio-Quat

The Map of sodium and chloride confirms this evolution, they found a feeding area by the loss of the Ksob Wadi in the northeast with moderate levels of chloride and sodium, these levels increase approximately in the direction of flow until the area where Plio-Quaternary aquifer lies directly on the land evaporitic of Essaouira diaper hidden.

As the mineralization of sodium and chloride of water obtained from a contact with the ground detrital aquifer Plio-Quaternary elements torn from the Triassic of landforms and this is a function of time Living, Moreover, in direct contact with the evaporite of Essaouira diaper hidden.

The Chlorides correlate well with sodium, suggesting a common origin of both elements by dissolution of halite, and the effect of sea spray aerosols and leached by rain seeping into the aquifer. For nitrate (Fig. 12), the minimum contents are saved to the limits of the Ksob Wadi for the remainder of the study area, there is an increase in these levels towards the southwest, the distribution of nitrate shows also the contribution of the Ksob Wadi in the mineralization of groundwater by dilution near this river.

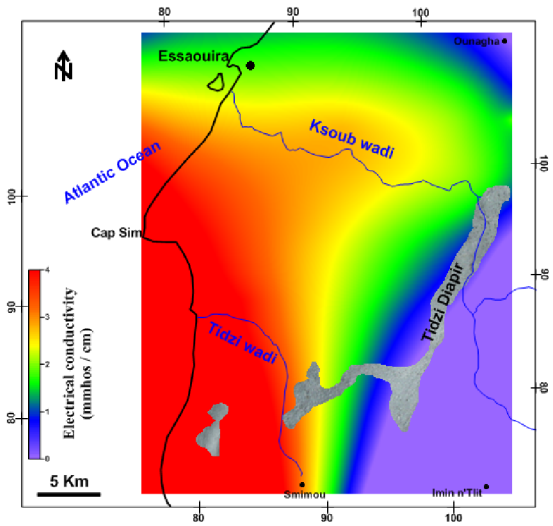

Fig. 7 Spatial distribution of electrical conductivity in the Essaouira basin.

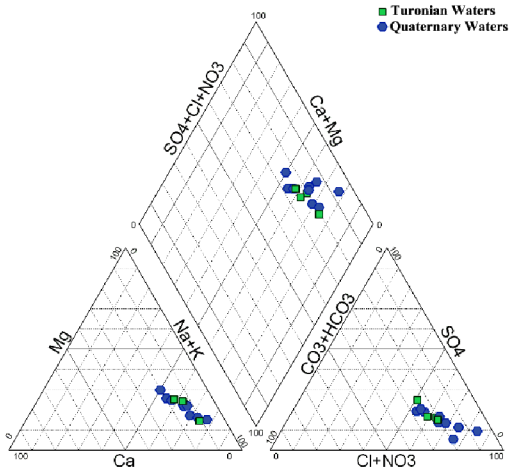

Fig. 8 Piper diagram of Plio-Quaternary water and Turonian water.

The main source of nitrates is associated with traditional withdrawal methods that make a significant portion of water flowing around the well, is quasi-permanent pools which are enriched nitrate by cattle dung during watering.

Also, indoor air pollution from septic systems and septic loss, lack of protection of wellhead, the lack of prevention and environmental programs for the population seriously threatens groundwater resources and led to poor quality supply water (Galego, FP et al., 2005).

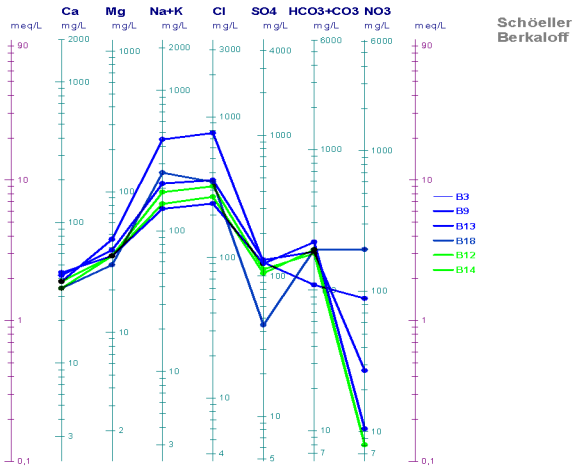

Fig. 9 Facies chemical wastewater Plio-Quaternary (B3, B9, B18 B13et) and Turonian (B12 and B14).

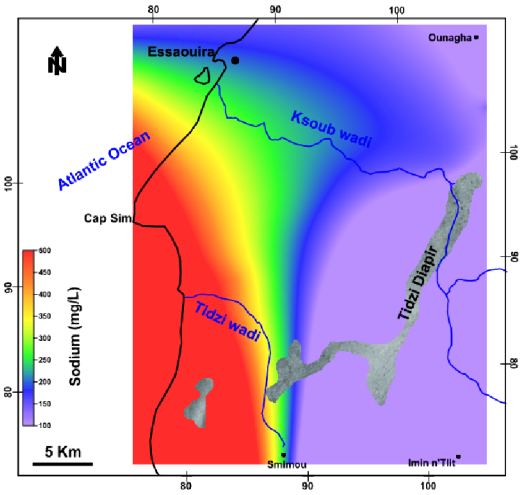

Fig. 10 Spatial distribution of sodium in the Essaouira Basin Syncline.

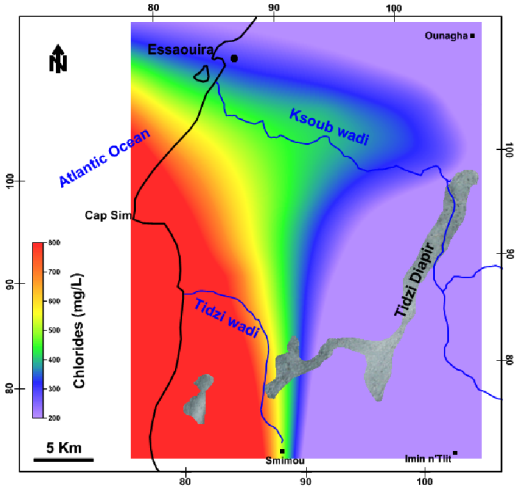

Fig. 11 Spatial distribution of chlorides in the Essaouira Basin Syncline.

Help Regarding safe drinking water and those using the national standards of the Directorate General for Water, we note that the waters of the syncline of Essaouira are medium to poor quality according to the overall mineral content, electrical conductivity and chloride content.

Depending on the concentration of nitrates, they are moderate to poor for 70% of wells surveyed and 55% exceed the WHO standard of 50 mg l^{-1}.

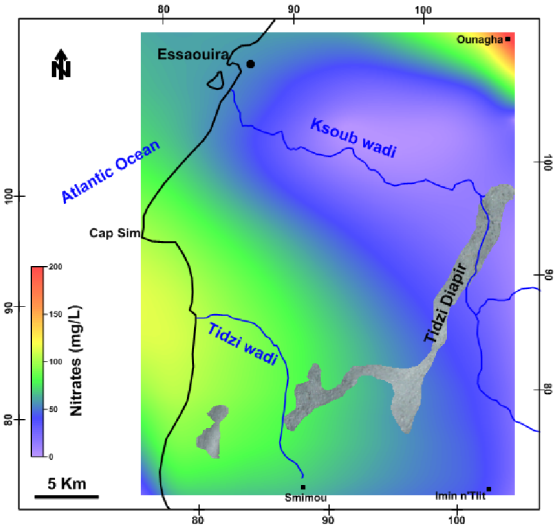

Fig. 12 Spatial distribution of nitrates in the Essaouira Basin Syncline.

- Groundwater Turonian

The small number of water points serving the water Turonian, because of its depth and the high cost operation that demand remains a pickled in understanding the properties of this aquifer. The waters of the Turonian show homogeneous electrical conductivity with a minimum value of 1450 µs cm-1 recorded in wells B6 and a maximum value of 2340 µs cm-1 at the point (B21) (Tab. 1).

The groundwater Turonian have the same chemical profile chloride-sodium like that the Plio-Quaternary water (Fig. 8, 9) and it is difficult to distinguish them only by their mineralization, from shallow or moderately mineralized Plio-Quaternary. The two points studied (B12 = 390-51) and (B14 = 346-51) are the property of the National Office of Potable Water (ONEP) and are intended for the city of Essaouira and around town, showing low levels of nitrate (8.06 mg l-1).

In contrast, higher concentrations of chloride and sodium, respectively, 319.5 mg l-1 and 184.23 mg l-1 for item 390-51 and 270.51 mg l-1 and 149.96 for item 346-51 (Tab. 2). From the point of view of the cleanliness, the levels of chloride and sodium wholes points of the Turonian aquifer exceed the recommendations made by the World Health Organization (WHO). For cons, nitrate levels remain well below this standard.

Tab. 2 Chemical analysis of groundwater; aquifers Plio-Quaternary and Turonian.

Sample	HCO^{3-}	Cl^{-}	NO_3^{-}	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Aquifer
B1= Ksob wadi	146,4	475,7	31	128,64	40	38,64	266,8	5,46	Wadi
B3=138-51	109,8	766,8	89,28	124,8	38	45,96	438,15	10,53	Plio-Quat
B4=M33	207,4	347,9	45,26	104,64	40	30,24	221,95	13,65	Plio-Quat
B5	176,9	390,5	0,62	102,72	42	39,84	207,69	10,53	Plio-Quat
B7	67,1	74,55	100,4	27,36	30	24,12	36,8	3,12	Plio-Quat
B9	219,6	241,4	10,54	121,44	44	35,04	138,69	4,68	Plio-Quat
B10=M61	195,2	255,6	13,64	119,52	46	41,04	127,42	5,46	Plio-Quat
B11=103-51	176,9	217,97	6,82	111,84	38	31,44	135,7	4,68	Plio-Quat
B12=390-51	183	319,5	8,06	111,84	34	35,04	184,23	4,29	Turonian
B13=272-51	189,1	355	27,28	129,6	42	38,64	212,98	4,29	Plio-Quat
B14=346-51	195,2	270,51	8,06	104,64	38	35,04	149,96	5,07	Turonian
B16=133-51	146,4	442,33	50,84	96	40	42,36	236,44	3,9	Plio-Quat
B18=3-51	195,2	344,35	199	44,64	34	30,24	254,38	5,85	Plio-Quat
B19=M66	219,6	264,12	0,62	176,16	34	37,44	167,21	25,35	Turonian
B21=380-51	231,8	420,32	0	133,92	38	30,24	286,35	15,21	Turonian
B39	207,4	372,75	168,6	168,48	66	59,28	219,42	19,5	Plio-Quat

4 ISOTOPIC COMPOSITION

In these conditions and to understand better the functioning of these aquifers and therefore despite the contribution of geological studies carried out in the basin, a combined approach between the methods of hydrodynamic and isotope geochemistry has been followed for many years. It is identified the origin of groundwater and to locate areas of natural recharge and the links between groundwater (seepage exchanges), contribution to explaining the origin of the mineralization, especially in sectors the saltier.

In the Essaouira Basin, the hydrodynamic behaviour is strongly influenced by runoff (CHKIR, N et al., 2008). In this context, stable isotopes are a tool performs to determine the origin and history of water recharge areas and relations between the layers. Analyses were performed at the

Technological Institute of Lisbon Sacavem Department of Environmental and Analytical Chemistry in the context of the Integrated Action between the universities of Lisbon and Marrakesh and funded jointly; the results of these tests are grouped in Table 3.

In the Essaouira Basin, the isotope content of water Plio-Quaternary is between -3.72 and -4.56 ‰ vs. d18O SMOW. These waters are the cloth Turonian between -4.17 and -4.55 ‰ vs. d18O SMOW.

The correlation diagram for deuterium vs. oxygen-18 water in the basin of Essaouira can define a local meteoric right equation: d = 7.72 2H 18O + 10.53 (n = 15, R2 = 0.82) bit different from the global meteoric water (DMM) slope 8 with a deuterium excess around 10. It characterizes the precipitation of oceanic origin; the equation of this line was calculated without taking into account the three water points 390-51, 272-51 and Ksob wadi identified as evaporated because they are placed below right meteoric (Figure 13).

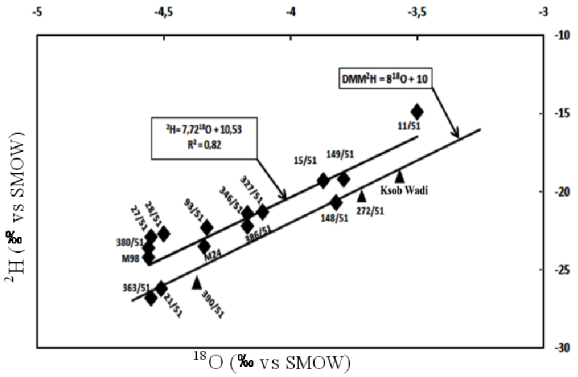

Fig. 13 Relationship 18O – deuterium the groundwater in the area of Essaouira synclinal.

The point marked by 272-51 evaporation Plio-Quaternary aquifer and is in close proximity to the river, which confirms the power of the water in the Ksob wadi already highlighted in a quarter North-eastern sector of the aquifer piezometer. Well 390-51, which captures the Turonian aquifer, it is position on the diagram 18O-deuterium indicates complementary evaporated water from the river for part of the low water.

The other water analyzed aligned right meteoric which means that the power of the two aquifers, and especially of the Turonian aquifer is rapid evaporation without significant if we exclude the point 390-51.

Tab. 3 Contents of stable isotopes ^{18}O and ^{2}H of the waters of Essaouira synclinal (companion of October 2006)

Sample	X	Y	$d^{18}O$ (°/∞)	$d^{2}H$	Aquifer
B2=149-51	85,1	105,8	-3.79	-19.2	Plio-Quat
386-51	92	98,65	-4.17	-22.2	Turonian
M98	89	100	-4.56	-24.2	Plio-Quat
B17=15-51	86	97	-3.87	-19.3	Plio-Quat
11-51	80,45	96,45	-3.50	-14.9	Plio-Quat
B20=21-51	89,4	91,4	-4.51	-26.2	Plio-Quat
B21=380-51	89,35	91,8	-4.56	-23.6	Plio-Quat
B23=363-51	89,75	88,2	-4.55	-26.8	Turonian
B22=327-51	88,8	88,8	-4.11	-21.3	Plio-Quat
27-51	95,5	91,3	-4.55	-22.9	Plio-Quat
M24	95	91,5	-4.34	-23.5	Plio-Quat
28-51	97,2	91,8	-4.50	-22.7	Plio-Quat
148-51	85,7	102,05	-3.82	-20.7	Plio-Quat
Ksob Wadi	86	106	-3.57	-19.0	Plio-Quat
93-51	92,37	101,9	-4.33	-22.3	Plio-Quat
B12=390-51	97	100	-4.37	-25.8	Turonian
B13=272-51	97,17	100,76	-3.72	-20.3	Plio-Quat
B14=346-51	97,25	100,7	-4.17	-21.4	Turonian

5 CONCLUSIONS

The complementary approaches hydrodynamic, hydrochemical and isotopic may lead to the diagnosis of the condition of aquifers vulnerability face the stress of anthropogenic pressures and climate.

On the one hand, the mineralization and concentrations of chloride in the Plio-Quaternary aquifer has to have the power by the Ksob Wadi and the role of Essaouira diapir hidden in the increase of mineralization chloride waters in the central part.

As the excessive levels of nitrates following heavy rainfall in the year 2008-2009, accompanied by elevated chloride, causing degradation of water quality in the region and highlights the vulnerability of abstraction.

On the other hand, the inventory levels of stable isotopes of two aquifers has to differentiate where the water of the Plio-Quaternary shows charging current but is threatened by seawater intrusion due to overexploitation of resources. However, the water Turonian, characterized by significant resources, demonstrates a very low charging current; its vulnerability would be more related to human pressure than changes in climatic conditions.

The development of a rational exploitation strategy may therefore help to enhance water while protecting its long-term potential. As the use of unconventional resources such as desalinated seawater for drinking water or treated wastewater for agriculture must be currently considered as a priority in order to avoid triggering shortages of water.

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