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Study of The Water Recharge Problematic in a Semi-Arid Zone (Climatic and Anthropic Impacts) : The Case of the Essaouira Aquifers System (Mogador, Morocco)

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Abstract

The piezometric map of the Essaouira synclinal basin (Morocco) was realized. Different water samples have been collected from drillings, sources and wells belonging to the plioquaternary and turonian aquifers of the studied region. Their electric conductivity as well as 18O, 2H and 3H concentrations were measured. A meteoric local line was determined and compared to the world meteoric line. The radiocarbon ages of the studied aquifers were evaluated. The recharge of the main aquifers of the studied region was investigated.
Keywords: Plioquaternary and turonian aquifers, 18O, 2H, 3H and 14C isotopes, aquifer recharge.

Introduction

Due to the population growth and climate change (causing long periods of drought) in the world, many countries have intensively increased their use of water sources for supplying potable water to population and for their agricultural (irrigation) and industrial developments. Due to the lack of surface waters, people exploit mainly underground water reservoirs. So, it is necessary to study and characterize these water reservoirs to avoid any excess of exploitation. All waters have fingerprints of naturally occurring isotopes that provide information about their origin. Among the most powerful fingerprinting tools are the ratios of stable isotopes of hydrogen-deuterium to hydrogen (2H/1H) and of oxygen 18 to oxygen 16 (18O/16O) (Bourg et al., 2001; D'Alessandro et al., 2004). Naturally occurring radioactive isotopes provide information about the age of ground waters, which refers to the last time the water was in contact with the atmosphere.

In the present work, we use stable and radioactive isotopes for characterizing water resources in the arid and semi-arid coastal zone of Essaouira (Morocco).

Methods

The studied region, called Essaouira synclinal zone, belongs to the Essaouira basin. With a surface of about 300km², it is bordered by the Ksob river in the north, Tidzi river in the south, Tidzi diapir in the east and Atlantic Ocean in the west (Fig. 1). This region is less fractured and is characterized by low hills with a less dense hydrographic network. The Essaouira synclinal zone is one of the Moroccan semi-arid areas with mean annual rainfalls not exceeding 300 mm per year. The mean temperature is of about 20°C, the temperature gap between January and August may reach 17°C (Bahir, 2001).In this region, underground water resources are contained in two main reservoirs: the plioquaternary and turonian aquifers. The plioquaternary aquifer hosted by grey limestone marl rocks shows a primary hydraulic conductivity by porosity and contains an important free water table with a wall formed in the syncline structure, by the senonian marls (Fig.2). This aquifer is exploited for irrigation and potable water supply. The turonian contains a rapidly captive aquifer confined under the senonian marls in the syncline structure and likely in direct contact with the plioquaternary on the edges of this structure, near the Ksob river in the north, the hidden diaper of Essaouira in the west and the Tidzi diapir in the south and east. Many deep drillings have been done on this aquifer during the eighties of the twentieth century in order to supply drinking water to the city of Essaouira and some neighbouring towns. The structures of the studied area are represented by the Tidzi diapir in the east and south. Directed NNE-SSW (on 20km) from the Ksob river to the Tidzi river where it tooks an east-west direction and by the Essaouira anticlinal with a triasic core, hidden by the plioquaternary recoverings. We also notice an intensive fracturation of N110 general direction which cuts up the carbonated cretaceous formations. The piezometric map of the plioquaternary aquifer realized in March, 2004 (Fig.3) shows a general flow direction from SE to NW, imposed by the tilting of its substratum. However, waters diverge to avoid the Essaouira downstream hidden anticlinal which is directed WE-SW. The aquifer is divided into two compartments : the northern compartment which has current lines directed similarly as the global flowing, whereas the southern one shows a flowing directed from the east to the west. The piezometric level is at 180m altitude upstream where the hydraulic gradient is strong, about 2%, due to the high tilting of the aquifer wall due to the rising of the Tidzi diapir. The hydraulic gradient decreases towards the zone core where it does not exceed 0.3%. then, it increases towards downstream to reach 2% vertically to the hidden anticlinal which reduces the aquifer surface (Mennani, 2001).

Different gauging, realized during the 1990-1991 hydrologic cycle and confirmed in 2004, permitted to assess that 42l/s waters are infiltered from the Ksob river to the plioquaternary aquifer with a flow rate of 42l/s (Fekri, 1993).

The passage of this river in canyons, where it outcrops the turonian aquifer, causes water losses of 64 l/s in favour this aquifer.

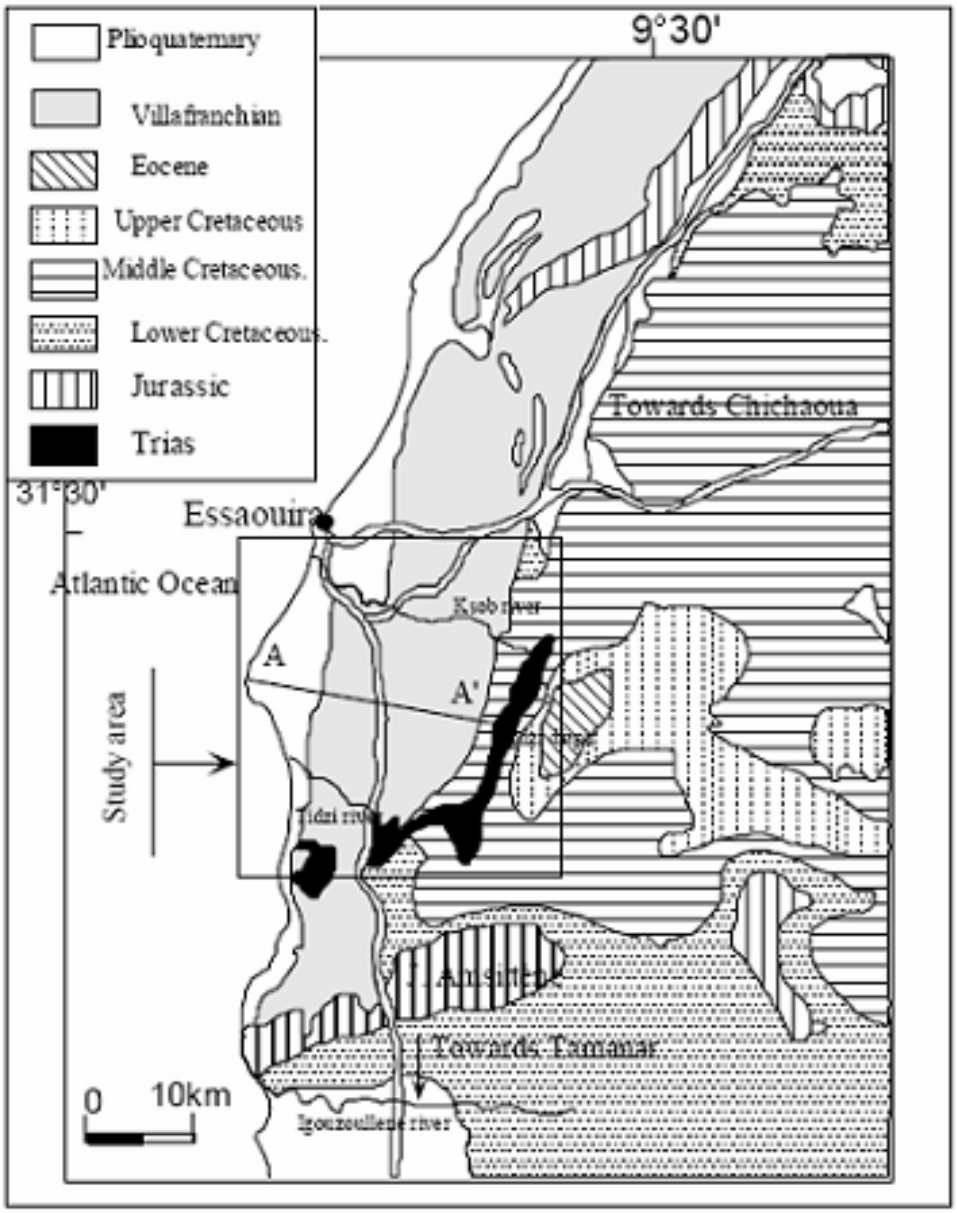

Fig. 1, Map showing study area (after the geographic map of Marrakech, 1/50000)

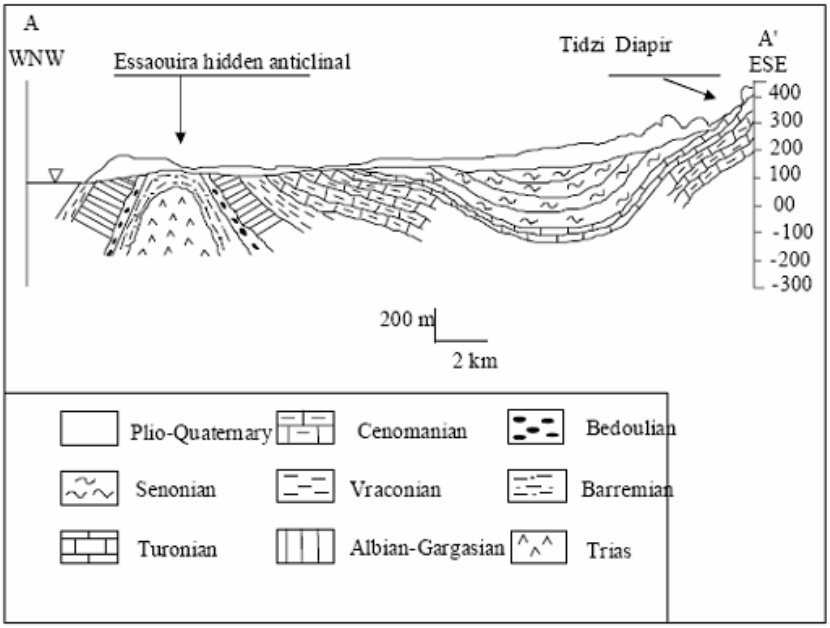

Fig. 2. Geological cutting of the Essaouira synclinal

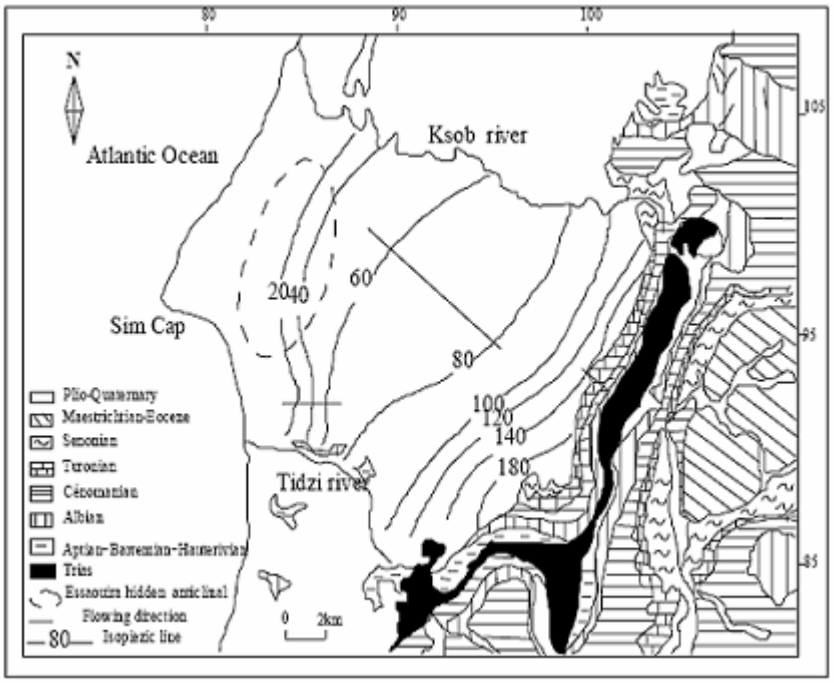

Fig.3. The piezometric map of the plioquaternary aquifer of the Essaouira synclinal zone (March 2004).

Results and discussions

A water sampling from forty wells, drillings and sources belonging to the plioquaternary and turonian aquifers was realised. The electric conductivity and temperature were measured on the ground. Waters belonging to the plioquaternary aquifer present very variable electric conductivities from 1590µs/cm (well M5) to 5040 µs/cm (well18/51)(Table 1).

Table.1. Data obtained for the plioquaternary aquifer for the 2004 campaign

point 1	149/51	85,1	105,8	40	36	4	3280	23,4	7,28	Plio-Quat.
point 2	132/51	89,75	98,25	99	26.2	72.8	1260	18,6	8,47	Plio-Quat.
Piont 4	M98	89	100	125	84	41	2330	22,2	7,34	Plio-Quat.
Ech.5	15/51	86	97	70	5	65	3240	18,7	7,46	Plio-Quat.
Ech.6	11/51	80,45	96,45	8	3	5	1940	21,7	7,25	Plio-Quat.
Ech.14	21/51	89,4	91,4	89,6	62,6	27	6940	22	7,05	Plio-Quat.
Ech.15	380/51	89,35	91,8	135	75	60	2180	21,6	8,09	Plio-Quat.
Ech.29	327/51	88,8	88,8	130	21.1	108.9	2390	22,6	7,58	Plio-Quat.
Ech.30	27/51	95,5	91,3	208	28	180	798	22,6	7,54	Plio-Quat.
Ech.31	M24	95	91,5	200	174	26	4660	27,7	7,5	Plio-Quat.
Ech.32	28/51	97,2	91,8	225	177	48	1080	23,1	7,99	Plio-Quat.
Ech.33	140/51	87,3	103,6	60	8,5	51,5	2010	23,7	6,82	Plio-Quat.
Ech.34	148/51	85,7	102,05	60	14	46	1590	20,4	7,35	Plio-Quat.
Ech.36	Upstream river	86	106	20		river	2160	20,9	8,01	Upstream river
Ech.37	389/51(M65)	91,6	96,8	105	64	41	4600	24,2	7,35	Plio-Quat.
Ech.38	134/51	91,65	97,6	101	37	64	3040	23	7,5	Plio-Quat.
Ech.39	53/51	92,7	104,18	75	61	14	1490	21,6	7,26	Plio-Quat.
Ech.40	93/51	92,37	101,9	98	70	28	1750	23	7,39	Plio-Quat.
Ech41	Private well	97,6	101,2	108	87,5	20,5	1890	21,2	7,18	Plio-Quat.
Ech.42	Downstream river	100,5	100,4	111		river	1840	25,8	8,8	Downstream river
Ech.44	272/51	97,17	100,76	105,5	36	69.5	2000	21,2	7,43	Plio-Quat.

In spite of this variability, they form the same family and are characterized by sodium-chloride facies. There exists, however, a good correlation between the electric conductivity and chloride and sodium contents. The lower electric conductivities are situated in the NE quarter immediately in the south of the Ksob river; they regularly increase towards SW to reach a maximum near the hidden diapir of Essaouira in the south-west quarter. Outside this structure, towards the west, the observed electric conductivity decrease except for well N° 11/51 which is situated in the Atlantic Ocean borders where marine water intrusion was confirmed by measuring 18O concentration. The map of chlorides (Fig.4) confirms this evolution; it reveals a supplying zone by losses of the

Ksob river in NE with moderated chloride concentrations. These concentrations increase approximately with the flowing direction until a zone where the plioquaternary aquifer is in contact with the evaporitic grounds of the hidden Essaouira diapir.

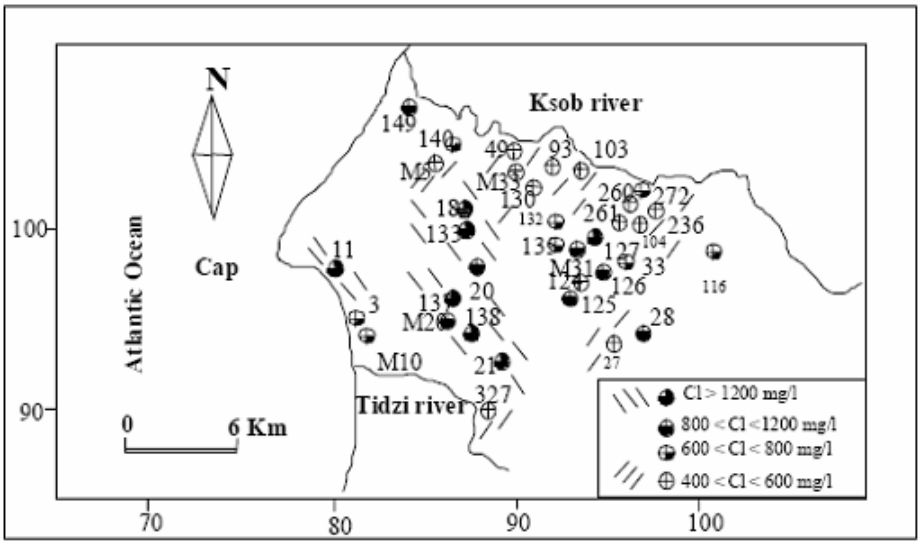

Fig. 4. Distribution of chlorides for water of the plioquaternary aquifer (January 2004 campaign)

Thus, the water chloride mineralization is obtained in contact with the detritic grounds of the plioquaternary aquifer containing leached elements from the triasic relief in the east and this as a function of residence time on one hand, and indirect contact with the Essaouira hidden diaper evaporates (Jalal, 2001), on the other hand.

Unlike the plioquaternary aquifer, turonian waters show homogeneous electric conductivities ranging between 2000µs/cm and 2500µs/cm(Table 2). Waters from the turonian aquifer present the same sodium-chloride chemical profile as that of the plioquaternary waters. It is then difficult to distinguish between the turonian and plioquaternary waters according to only the mineralisation.

Table.2. Data obtained for the turonian aquifer of the coastal zone of Essaouira.

Water sample	N°IRE	X	Y	Z(m)	N.P(m)	H(m)	CE(µs/cm)	T°C	pH	Aquifer
Point3	386/51	92	98,65	105	30	75	2240	17,3	7,66	Turonian
Ech.28	363/51	89,75	88,2	150	60	90	2410	19,9	7,71	Turonian
Ech.35	157/51	86,55	105,3	30		source	1950	23,6	7,42	Turonian
Ech.43	390/51	97	100	105,5	26,2	79,3	1820	27,5	7,15	Turonian
Ech.45	346/51	97,25	100,7	105	26	79	1950	26,5	7,16	Turonian.

Globally, results of the 2004 campaign for the turonian aquifer confirm the homogenisation of the electric conductivities in the 1800µs/cm more than 2400µs/cm, proving the little effect of the drought happened in this region due to the captive effect of this aquifer. We noticed that the electric conductivity increases regularly to reach 7000µs/cm. This is due to both the demographic growth and drought in this region (Bahir, 2002). It is to be noticed that nitrate concentrations of the plioquaternary waters are larger than the WHO(World Health Organisation of 50mg/l) whereas those of the turonian waters are smaller than this limit.

In the studied zone, the hydrodynamic behaviour is influenced by the structure of the ground (folds and faults) which steers the flowing water and determines the out puts. In such a context, stable isotopes constitute a good tool for determing the origin and history of waters, recharge surfaces and relationships between the aquifers. Results obtained for the oxygen 18 (18O) and deuterium (2H) are shown in Table 3.

Table.3. Isotopic data obtained for the plioquaternary aquifer (2004 campaign) and upstream and downstream of the Knob river.

Water sample		$\delta^{18}O$ (‰)	$\delta^{2}H$
point 1	149/51	-3.68	-21.9
point 2	132/51	-3.70	-17.6
Plont 4	M98	-4.03	-23.7
Ech.5	15/51	-3.84	-16.9
Ech.6	11/51	-3.43	-17.0
Ech.14	21/51	-4.53	-23.8
Ech.15	380/51	-4.57	-26.5
Ech.29	327/51	-4.00	-4.00
Ech.30	27/51	-4.86	-4.86
Ech.31	M24	-4.47	-4.47
Ech.32	28/51	-4.85	-4.85
Ech.33	140/51	-4.63	-4.63
Ech.34	148/51	-4.06	-4.06
Ech.36	389/51	-3.28	-3.28
Ech.37	134/51	-4.29	-4.29
Ech.38	53/51	-3.69	-3.69
Ech.39	93/51	-4.35	-4.35
Ech.40	Puit/51	-2.52	-2.52
Ech41	272/51	-2.85	-2.85
Ech.42	Upstream river	-3.06	-3.06
Ech.44	Downstream river	-2.17	-2.17

The isotopic concentration of the plioquaternary waters ranged from -3.7□‰ to -4.7□‰ except the sample 11/51 situated in the ocean borders which is affected by marine intrusion. Results obtained at the Nuclear and Technologic Institute of Lisbon (Portugal)for the plioquaternary waters during the 2004 campaign are shown in Table 3. Water samples N° 18 and N° 19 collected from well situated near the IddaouGard town and well 272/51 supplying potable water to the city of Essaouira , respectively, show

values of 18O varying from -2.52 □‰ to -2.85 □‰ closer to those of the upstream Ksob river with a value of -3.06 □‰ confirming that these wells are supplied by that river. Indeed, this is confirmed by the fact that these waters show practically similar electric conductivites: 216 µs/cm, 2000µs/cm and 1890 µs/cm, respectively.In its downstream part, during the resurgence of the Sidi Yassine sources, waters of the Ksob river are 18O enriched with a value of - 2.17□‰ . Otherwise 18O values vary from -3.20 to -4.80□‰ . 18O values vary from -4.88 to -5.25 □‰ and they are centred around the lowest value of -5 □‰. This difference persists despite seasonal variations observed in the plioquaternary aquifer. This may be due to the difference of altitude of the recharge zones; the turonian is outcropping between 400m and 500m altitude near the Tidzi diapir outcrops, whereas the mean altitude of the plioquaternary implivium is situated between 300 m and the sea level. Values of 18O for the 2004 campaign are comprised between -4 □‰ and -4.5 □‰ and are centred around -4.5 □‰, showing by this a higher recharge, especially on the Tidzi diapir outcrops (Table4).

Table.4. Isotopic data obtained for the turonian aquifer.

N°IRE	X	Y	Z(m)	N.P(m)	H(m)	CE(µs/cm)	T °C	pH	Aquifer	Oxygen 18
386/51	92	98,65	105	30	75	2240	17,3	7,66	Turonian	-4.03
363/51	89,75	88,2	150	60	90	2410	19,9	7,71	Turonian	-4.46
157/51	86,55	105,3	30		source	1950	23,8	7,42	Turonian	-4.49
390/51	97	100	105,5	26.2	79.3	1820	27,5	7,15	Turonian	-4.07
346/51	97,25	100,7	105	26	79	1950	26,5	7,16	Turonian.	-4.20

This is confirmed by electric conductivity values close to each other around 2200µs/cm. For water sample 386/51 collected from a drilling performed in the Essaouira aerodrome, electric conductivity higher values could be due to a probable contact with the plioquaternary aquifer, confirmed by a depth of about 100m. The Leroux source 157/51 confirms its turonian origin with a value of -4.5 □‰. Data obtained for the deuterium analysis permitted to determine on the 18O -2H correlation diagram a meteoric local line of equation : □2H=7.95□18O+11.3 (n = 11, r = 0.97) close to the world meteoric water line (WML) of a slope of 8 with a deuterium excess close to 10 (Craig, 1961). This meteoric local line characterizes oceanic precipitations.The equation of this meteoric local line was determined without taking into account the three water points (65/51, 272/51 and Ksob river) which are identified as evaporated because they are placed bellow the meteoric line. The other water samples analysed are situated on the meteoric line showing that these two aquifers and more specifically the turonian one are rapidly supplied without evaporation. Tritium analysis was performed for thirteen water points supplied by the different aquifers of the Essaouira coastal zone. Data obtained are shown in Table 5. Tritium values vary from a minimum value smaller than 0.8 UT and a maximum value of 4.2 UT. We notice from results shown in Table 4 that recent waters of the Essaouira coastal zone

Table.5. Data obtained for the physical parameters and radioisotope concentrations for the underground waters of the coastal zone of Essaouira

^{14}C	Nature	Origin	Altitude	Depth (m)	T (°C)	C.E µs/cm	pH	Alc. méq/l	^{3}H *UT*	^{14}C pcm	^{13}C °/°°
272/51	Well	Plio-Q	105,5	38,4	20,6	1660	7,65	3,30	3,9+/-0,5		
21/51	Well	Plio-Q	135	29	21,7	5170	7,13	2,80	2,0+/-0,5		
327/51	Well	Plio-Q	130		22,2	3880	7,23	4,03	3,2+/-0,4		
65/51	Well	Turon	15	20,3	22,5	2870	7,48	4,64	2,8+/-0,5	88,9+/-0,5	-9,8
390/51	Drilling	Turon	95	200	26,7	1995	7,35	4,94	<2	32,5+/-0,4	-9,4
386/51	Drilling	Turon	105	100	23,2	1828	7,56	4,26	4,2+/-0,5	84,8+/-0,6	-10,3
380/51	Drilling	Turon	135	194	26,1	2280	7,54	4,67	<2	3,0+/-0,5	-9,0
M98	Drilling	Bar-Apt	90	100	22,0	2380	7,59	3,55	<2	79,6+/-0,6	-9,3
A.Aghbalou	Drilling	Bar-Apt	80		23,1	2720	7,50	3,58	<2	72,0+/-0,4	-10,0
216/51	Source	Por-Ber	160		23,1	1663	7,28	4,53	<2		
218/51	Source	Por-Ber	308		22,5	1620	7,29	4,24	<2	68,5+/-0,6	-9,9
361/51	Drilling	Lias	382	90	23,5	1780	7,22	4,45	2,0+/-0,4		
203/51	Drilling	Callov	14	50	22,7	5330	7,11	4,26	3,8+/-0,4		

present tritium concentrations comprised between 2 and 4 UT. It is notably the case of 65/51, 27/51, 327/51 and 386/51 water points, confirmed by higher 14C activities for some of them.

Water having tritium concentrations smaller or equal to 2 UT are considered as being old such as those belonging to the 21/51, M98/51, 218/51, 361/51, 380/51, 390/5 and Ain Aghbalou points. 14C was analysed in some of these waters to confirm or show up the weakness of this hypothesis. Tritium was analysed in May 2004 in water samples belonging to water points supplied by the main aquifers used for supplying potable water to the Essaouira city (Table 6). Measurements were realised at the Sacaven Institute of Technology of Lisbon (Portugal). Tritium concentration varies between a minimum value smaller than 1.1UT. It is to be noticed that recent waters of Essaouira coastal zone show tritium concentrations larger than 2 UT. It is the case of water points 272/51 and 386/51 called Idda ou Gourd drillings and the aerodrome drilling which supply water respectively to Essaouira and Idda ou Gourd in agreement with results obtained in 1996. Then, one can say that the 2004 campaign has definitively confirmed the recent recharge of these water points. On the other hand,

waters showing tritium concentrations smaller or equal to 2 UT are considered as ancient, such as water points 261/51, 390/51, 6/51 and M98.

Table.6. Data obtained for tritium dating of the main water points which supply potable water to the city of Essaouira (May 2004 campaign)

N°IRE	X	Y	Z (m)	N.P (m)	H (m)	CE (µs/cm)	T°C	pH	Aquifer	Tritium (UT)
261/51	96,42	99,25	124	46	88	1900	23,2	7,40	Plio-Quat.	1.4+/-0.6
390/51	97	100	105,5	26.2	79.3	1890	25.9	7.15	Turon.	2.0+/-0.6
386/51	92	98,65	105	30.7	74.30	2260	18,5	7,70	Turon.	2.5+/-0.7
272/51	97,17	100,76	105,5	36	69.5	1917	20,9	7,42	Plio-Quat.	4.2+/-0.7
6/51	86,1	105,4	25	25		2780	23,4	7,01	Turon..	1.4+/-0.7
346/51	97,25	100,7	105	26	79	1830	26,5	7,24	Turon.	1.5+/-0.6
363/51	89,75	88,2	150	60	90	2600	24,5	7,14	Turon.	1.2+/-0.8
380/51	89,35	91,8	135	55	80	2180	21,10	8,26	Plio-Quat	0.9+/-0.7
M98	89	100	125	80	45	2460	21,5	7,47	Plio-Quat	1.1+/-0.6
149/51	85,1	105,8	40	36.2	3.8	2800	23,3	7,83	Plio-Quat	0.2+/-0.8

The turonian aquifer supplying 50% of potable water to the city of Essaouira, notably drillings of more than 300 m depth (346/51 and 390/51), and the 6/51 source show tritium concentrations smaller or equal to 2UT (Bahir, 2001). One can conclude from data obtained from tritium for the 2004 campaign that the recharge is low or non-existing for drillings performed in the plioquaternary aquifer, notably the 261/51 one which supplies the city of Essaouira with a flow rate of 6l/s. this is corroborated by its portion for from the Ksob river, which when rising supplies the neighbouring water points. The 14C radioisotope were utilized for dating ancient waters with very low tritium concentrations. To assess unitial 14C activities of underground waters of the coastal zone of Essaouira many models were tested (Table 7). These different models may take into account of the 14C chemical dilution, isotopic exchanges and isotopic mixtures with isotopic exchange. From the analysis of data given in Table 5, 6 and 7 one can deduce that: Two water points, among those studied presenting significant tritium concentrations and 14C percentage larger than 85% should be considered as recent. Among these two water points one can notice well number 65/51 situated near the Ksob river which supplies potable water to the Essaouira city with a flow rate of 6l/s (5% of the total water supply). This well supplied by the turonian aquifer shows an 18O concentration of -4.53 □‰. This value is intermediate between the isotopic concentrations of -4 □‰ of the plioquaternary waters and that of the turonian ones

Table.7. Data obtained for the initial activity of ^{14}C and radiocarbon ages of the underground waters of the Essaouira coastal zone.

Water point	Tamers		Pearson		Fontes Garnier		AIEA		Evans	
	Age (y)	A0 (pcm)	Age (y)	A0 (pcm)	Age (y)	A0 (pcm)	Age (y)	A0 (pcm)	Age (y)	A0 (pcm)
65/51	present	53,6	present	46,7	present	46,4	present	76,5	present	44,6
390/51	4267	54,5	2646	44,8	2558	44,3	6445	70 ,9	2128	42,0
386/51	present	53,0	present	49,0	present	48,9	present	79,9	present	47,0
380/51	23739	53,0	21984	42,9	21891	42,4	25829	68,2	21443	40,1
M98	present	52,8	present	44,3	present	44,0	present	72,9	present	42,2
A.Aghbalou	present	53,4	present	47,6	present	47,4	624	77,6	present	45,5
218/51	present	55,3	present	47,1	present	46,8	994	77,3	present	45,1

which is of -5□‰, indicating a drainage of the plioquaternary aquifer. The second water point consists of the 386/51 drilling, impounded by the turonian aquifer waters and supplying potables waters to the aerodrome of Essaouira. The M98 drilling which has no detectable tritium and has a 14C concentration of 80%, has been supplied before the 1952-1963 nuclear tests and its radiocarbon age does not exceed some hundred years independently of the model utilized. The 390/51 drilling impounded by the turonian aquifer waters, supplies the Essaouira city with a flow rate 60l/s representing 50% of the water needs. This drilling has a radiocarbon age of about 6500 years according to the IAEA model, a little lower but still always of reveral thousand years according to the other models. This means that there exist very ancient waters we are surexploiting. This could present a risk of lack of water to supply the Essaouira city. The 380/51 drilling impounded by the turonian aquifer which supplies potable water to the Si Ahmad ou Hmad town (5000 inhabitants), is also surexploited. It has a radiocarbon age greater than 20,000 years independently of the model utilized indicating a low recovering rate of the turonian aquifer. The present 14C activity (around 70%) of the Aghbalou source impounded by the Barremian-Aptian aquifer which supplies water to a population of 10,000 inhabitants and their livestock with a flow rate of 30l/s. This water source presents a tritium concentration smaller than 2 UT. Its supplying was then before the nuclear tests and its radiocarbon age is of some thousand years, independently of the model utilized. The Igounitene source, impounded by the portlandian - Berrisian aquifer with a flow rate of 0.5l/s, shows a 14C activity around 70% and a tritium concentration smaller than 2UT. Its supplying was then previous to the nuclear tests and its radiocarbon age is of some hundred years. Finally, dating of the turonian aquifer waters could be very ancient, must be taken into account in managing this aquifer and in future development projets.

Conclusion

Potable water supplying the Essaouira city and its neighbouring rural agglomerations is presently based on exploiting underground waters, notably those of the plioquaternary aquifer. This aquifer is submitted to several constraints. Less deep, this aquifer is sensitive to drought episodes, more frequent in Morocco; the most severe one was happened in 1995. It has been shown by this study that the recharge rate of the deep turonian aquifer is too low. This may cause a lack of water for supplying the Essaouira city and its region. Nevertheless, if we return to the drought context of the past years as
prevented by the present world tendency, Moroccan authorities must envisage to build small dams on the Ksob river for a better management of flooding waters which are presently thrown in the Atlantic ocean.

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دراسة إشكالية إعادة تزويد الفرشات المائية في المناطق الشبه الجافة : مثلا حوض الصويرة بالمغرب

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أنجزت خريطة مستويات الفرش المائية بحوض الصويرة المقعر لعدة سنوات. وفي هذا الإطار أخذت عينات مـــن الماء من الآبار العادية والعيون والآبار العميقة التي تزود المدينة والقرى التابعة لها بالماء الصالح للـــشرب. وقـــد درســـنا التوصيلات الكهربائية لمعرفة مدى ملوحة المياه ومعرفة تركيز الأوكسجين O_{18} والدوتريوم H_2 والتريسيوم H_3 وكذلك الكاربون C_{14}. تفيد هذه الدراسة مصدر تزويد الفرشات المائية وكذلك عمر هذه المياه تبين أن عمر مياه الفرشة المائيـــة تيرونيان والتي تشكل أكثر من 50% من مجموع مياه الإقليم يتجاوز 20 ألف سنة مما يطرح إشكالية التجديد في المناطق الشبه الجافة وكذلك الاستمرار في تزويد الساكنة.

وتفيد الدراسة، ومن أجل المحافظة على نسبة واستمرارية الأجيال القادمة بالماء الصالح للشرب، يستوجب مـــن السلطات المعنية تدبير و عقلنة استعمال مياه هذه الفرش مع التفكير في مصادر أخرى كتحلية ماء البحر.