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Isotopic Tool and Problematic of Recharge in Semi-Arid Area: The Case of the Coast Zone of Essaouira Basin (Morocco)

Hamid Chamchati[1]* Mohammed Bahir[1] Salah Ouhamdouch[1] Paulà Carreira[2]
Abdelmalek Goumih[1]

1.Laboratory of Geosciences and Environment (LGE), ENS-Marrakech, Morocco

2.Centro de Ciências e Tecnologias Nucleares, IST/CTN,Universidade de Lisboa, Portugal

Abstract

The Essaouira coastal zone is one of the Moroccan semi-arid areas with annual rainfall not exceeding 300 mm/year. This area contains several main aquifers such as: The Plio-quaternary aquifer consisting of sandstones, the Turonian aquifer composed of chalk-dolomitic rocks, the Barremian-Aptian aquifer content in calcareous clay formations, fossil limestone and sandstone and the Hauterivian aquifer housed formations of marl clay alternating with hard siliceous limestone and calcareous marl. The study had framework on the most important aquifers of the Eassouira coast zone, while having as principal objectives the dating of underground waters of the region and the sampling of main water points that supply drinkable water to the city as well as to the rural agglomerations. Different water samples were collected from drillings, sources and wells belonging to the Plio-quaternary, Turonian, Barremian-Aptian and Hauterivian aquifers of the studied region. Their electric conductivity, pH and temperature were measured in situ and water samples were collected for ^{18}O, ^{2}H and ^{3}H determinations. A meteoric local line was determined and compared to the world meteoric line.The apparent radiocarbon ages of the studied aquifers were evaluated. The recharge to the main aquifers of the studied region was investigated. It has been shown by this study that the recharge rate to the deep Turonian aquifer is very low. This may cause a shortage in water supply to the Essaouira city and its surrounding region. Among the concerned aquifers, the Turonian provides more than 50 % of drinkable water to Essaouira city and rural villages and must therefore be subject to a rational and durable exploitation of the groundwater resources.

Keywords: Essaouira basin, semi-arid, ^{18}O, ^{2}H, ^{3}H and ^{14}C isotopes, aquifer recharge

1. 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's 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. 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).

The studied region, belongs to the Essaouira basin. With a surface of about 900 km², limited by the Ksob river in the north, Igouzoulene river in the south and Atlantic Ocean in the west (Fig. 1). This region is less fractured and characterized by low hills with a less dense hydrographic network. The coastal zone of Essaouira basin is one of the Moroccan semi-arid areas with mean annual rainfalls not exceeding 300 mm per year (Ouhamdouch, 2016).

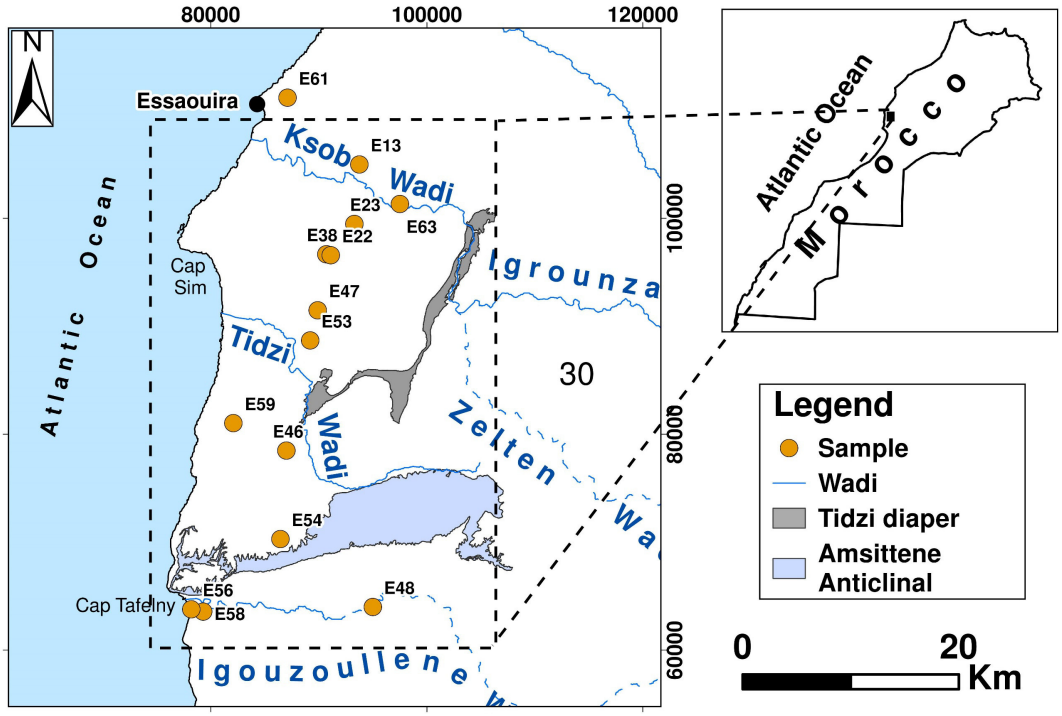

Figure 1. Location of study area.

The mean temperature about 20°C, the temperature gap between January and August may reach 17°C (Bahir, 2014). In this region, underground water resources are contained in four main reservoirs: The Plio-Quaternary, the Turonian, the Barremian-Aptian and Hauterivian aquifers. The Pliocene-Quaternary 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 Senonian marls. This aquifer is exploited for irrigation and potable water supply. The Turonian contains a rapidly captive aquifer confined under Senonian marls in the syncline structure and likely in direct contact with the Pliocene-Quaternary on the edges of this structure, near the Ksob river in the north, the hidden diapir of Essaouira in the west and the Tidzi diapir in the south and east. The Barremian-Aptian generally formed of alternating marl, marl and limestone and fossil fractured limestone and sandstone, contains a generally confined aquifer which is formed of mature Hauterivian marl. As to Hauterivian aquifer is constituted by marl and silty clays more or less altered, alternating with fractured siliceous limestone and is home to a water table sometimes, sometimes captive whose wall is formed by the Valanginian marl.

Different gauging, realized during the 1990-1991 hydrologic cycle and confirmed in 2004, showed that waters infiltrated from the Ksob river into the Pliocene-Quaternary aquifer at a flow rate of 42 l/s. The Ksob river traverses canyons, where the Turonian aquifer crops out, causing water losses of 64 l/s in favor of this aquifer (Bahir, 2013).

2. Methods

In order, to determine the age and recharge zone in the coastal area of Essaouira basin, fourteen groundwater samples have been collected along at the coast and have the measure of the contents of environmental stable (^{18}O and ^{2}H) and radioactive (^{3}H and ^{14}C) isotope.

3. Results and discussion

A water sampling from fourteen wells, drillings and sources belonging to the Plio-Quaternary, Turonian, Barremian-Aptian and Hauterivian aquifers was realised. The electric conductivity and temperature were measured on the field. Waters belonging to the Plio-Quaternary aquifer present very variable electric conductivities from 547µs/cm to 4670 µs/cm. In spite of this variability, they form a same family and are characterized by sodium-chloride facies. Lower electric conductivities are situated in the NE quarter immediately to the south of the Ksob River; they regularly increase towards SW to reach a maximum near the Essaouira hidden diaper in the south-west quarter. Outside this structure, towards the west, the observed electric conductivities decrease (Chamchati, 2013).

In the studied zone, the hydrodynamic behavior is influenced by the structure of the ground (folds and faults)

which steers the flowing water and determines the outputs. In such a context, stable isotopes constitute a good tool for determining the origin and history of waters recharge surfaces and relationships between the aquifers. The isotopic concentration of the four aquifers ranged from - 3.77 ‰ to -5.59‰ and -21.27‰ to -32.37 in ^{18}O and ^{2}H respectively (Table 1 and Fig. 2). Water samples E63 and E23 collected from well situated near the Ksob river, show a low value of 18O confirming that these wells are supplied by that river power source aquifer system.

Table 1. Isotopic data obtained for coast zone of Essaouira basin (2007 campaign).

Water sample	^{18}O (‰)	^{2}H(‰)
E47	-5.02	-27.34
E38	-4.79	-28.12
E61	-5.46	-27.83
E53	-4.78	-24.69
E23	-4.53	-27.02
E13	-5.59	-32.79
E63	-4.60	-26.33
E22	-3.77	-21.27
E59	-4.59	-22.16
E46	-4.53	-25.61
E54	-4.49	-22.49
E58	-3.93	-22.21
E56	-4.02	-21.53
E48	-3.92	-23.04

This difference persists despite seasonal variations observed in the Plio-Quaternary aquifer. This may be due to the difference of altitude of the recharge zones; the Turonian is outcropping between 400 m and 500 m altitude near the Tidzi diaper outcrops, whereas the mean altitude of the Plio-Quaternary implivium is situated between 300 m and the sea level. As for Barremian-Aptian and Hauterivian aquifer, the altitude of recharge is around 650m and 400m respectively. Values of ^{18}O for the 2007 campaign are comprised between -3.77 ‰ and -5.02 ‰ and are centred around -4.5 ‰, showing by this a higher recharge, especially on the Tidzi diaper outcrops. The Barremian-Aptian and Hauterivien show a slight homogeneity in the content of ^{18}O and ^{2}H.

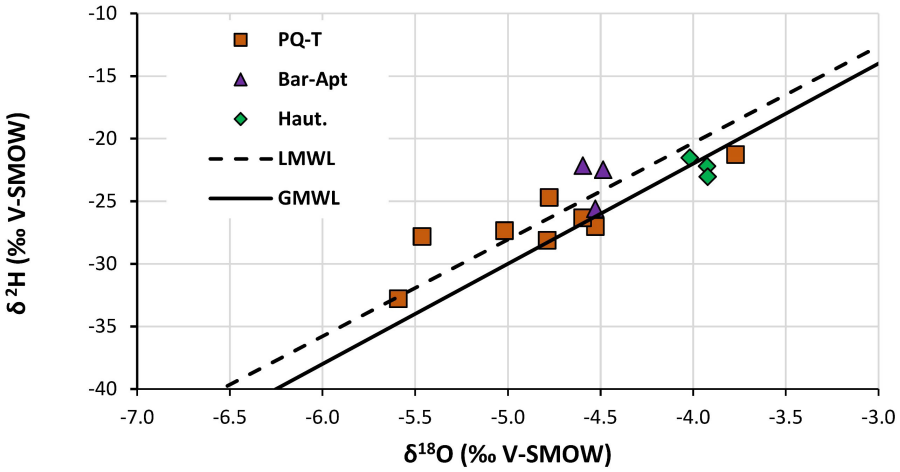

Figure 2. Plot of δ ^{18}O versus δ ^{2}H for groundwater samples from Essaouira basin.

Tritium was analysed in 2007 in water samples belonging to water points supplied by the main aquifers used for supplying potable water to the Essaouira city (Table 2). Measurements were done at the laboratories of IAEA-IHS (International Atomic Energy Agency - Isotope Hydrology Section) in Vienna, Austria.

Table 2. Data obtained for tritium of coast zone of Essaouira basin (2007 campaign).

Water sample	EC (µs/cm)	T (°C)	pH	Aquifer	3H(TU)
E47	2530	25.8	7.6	Turonian	0
E38	1930	26.9	7.65	Plio-Quat.	*
E61	547	19.8	7.45	Plio-Quat.	3.4
E53	2270	24	7.1	Plio-Quat.	*
E23	1700	22.4	7.2	Plio-Quat.	2.02
E13	2430	23.5	6.9	Plio-Quat.	1.7
E63	1920	27	6.8	Plio-Quat.	1
E22	4670	24.9	7.15	Turonian	*
E59	2770	23.6	6.9	Bar-Aptian	1
E46	1620	24.2	6.95	Bar-Aptian	1.2
E54	3230	23.5	6.7	Bar-Aptian	0.8
E58	3710	23.3	7.1	Hauterivian	2.2
E56	1170	22.2	7.05	Hauterivian	1.8
E48	3290	24.1	6.8	Hauterivian	1.3

Tritium concentrations vary between a minimum value smaller than 1 TU and a maximum value of 3.4 TU, to be noticed that recent waters of Essaouira coastal zone show tritium concentrations larger than 2 TU, and it's the case of water points E58 and E61. On the other hand, waters showing tritium concentrations smaller or equal to 2 TU are considered as ancient, such as water points E13, E46, E48, E54, E56, E59 and E63. The Turonian aquifer supplying 50% of potable water to the city of Essaouira, notably drillings of more than 300 m depth show tritium concentrations smaller or equal to 2 TU (Bahir, 2001). We can conclude from data obtained for tritium, for the 2007 campaign, that the recharge is low or non-existing for drillings performed in the Plio-Quaternary aquifer. This is corroborated by her portion from the Ksob river, which when rising supplies, the neighboring water points. The ^{14}C radioisotope was utilized for dating ancient waters with very low tritium concentrations. To assess initial ^{14}C activities of underground waters of the coastal zone of Essaouira many models were tested (Table 3). These different models may take into account the ^{14}C chemical dilution, isotopic exchanges and isotopic mixtures with isotopic exchange. Two water points among those studied presenting significant tritium concentrations and ^{14}C percentage larger than 70% should be considered as recent. Among these two water points one can notice well number E23 situated near the Ksob river. This well shows an ^{18}O concentration of -4.53 ‰. This value is intermediate between the isotopic concentration of -4 ‰ for the Pliocene-Quaternary waters and that of the Turonian ones which is of -5 ‰, indicating a drainage of the Pliocene-Quaternary aquifer. The second water point consists of the E22 drilling, impounded by the Turonian aquifer waters and supplying potable waters to the aerodrome of Essaouira. The samples whose content of 3H<2 TU are supplied before the 1952-1963 nuclear tests and his radiocarbon age does not exceed some hundred years independently of the model utilized.

Based on the model of Tamers, Pearson, IAEA, Evans and Fontes Garnier & the water age in the coastal area of Essaouira varies the current to about 3030 BP (Table 4).

Table 3. Data obtained for radioisotope concentrations for the underground waters

Water sample	^{3}H (TU)	^{14}C pcm	^{13}C ‰
E47	0	*	*
E38	*	*	*
E61	3.4	*	*
E53	*	*	*
E23	2.02	72.07	-8.42
E13	1.7	42.37	-7.70
E63	1	*	*
E22	*	70.93	-6.26
E59	1	*	*
E46	1.2	*	*
E54	0.8	*	*
E58	2.2	*	*
E56	1.8	*	*
E48	1.3	*	*

Table 4. Data obtained for the initial activity of 14C and radiocarbon ages of the underground waters of the Essaouira coastal zone.

	Tamers		Pearson		Fontes & Garnier		AIEA		Evans	
	A0 (pcm)	Age (year)	A0(pcm)	Age (year)	A0(pcm)	Age (year)	A0(pcm)	Age (year)	A0(pcm)	Age (year)
E13	61.1	3033.1	36.7	actuel	35.6	actuel	59.7	2831.9	36.0	actuel
E22	56.8	actuel	29.8	actuel	28.7	actuel	48	actuel	26.7	actuel
E23	56.7	actuel	40.1	actuel	39.5	actuel	65.9	actuel	37.8	actuel

4. Conclusion

It has been shown by this study that the use of stable and radioactive isotopes is a good tool for determining the origin, story and recharge zones of the main aquifers of the studied area. Indeed, potable waters supplying the Essaouira city and his neighboring rural agglomerations is presently based on exploiting underground waters, namely those of the Pliocene-Quaternary 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 happened in 1995. It has been shown by this study that the recharge rate of the deep Turonian aquifer of the studied region is very low.

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