Hydrochemical and Isotopic Study of Water Downstream of the City of Marrakech after the Installation of the Sewage Treatment Plant

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Abstract
The objective of this work is to gauge the impact of the installation of the treatment plant on the water quality of El Azzouzia aquifer. The aquifer of El Azzouzia is located downstream of the Haouz aquifer. The water of this area was threatened by the pollution resulting from the mushrooming houses that proliferated in the region, which culminated in the degradation of the environment. According to hydrochemical analyses, electric conductivity is high in that it varies between 400 and 3200µs/cm. There is also a decrease in the majority of chemical elements in which the rates are inferior or equal to the quality standards, except for chlorides and sodium which can reach a maximum of 2300 mg/l and 1000 mg/l respectively. Another type of study that has been conducted is the isotopic study. This kind of study aims to determine the source of the elements that still mark the waters of this area. The results show that the 18O contents range from -7.89 to -5.21‰ while the 2H contents range from -52.49 to -37.05‰ indicating that the recharge area is located on an altitude that varies between 840 and 1900m, which corresponds to the Permo-Triassic evaporite formations. The degradation of the water quality sources is either from natural pollution (i.e. from the geological contributions of the aquifer recharge basin) or is anthropogenic (i.e. from the seepage of wastewater).
Keywords: Pollution; El Azzouzia groundwater; Haouz; Sewage Treatment Plant; wastewater; isotopic; hydrochemistry; recharge.

1. Introduction

In Morocco, the volume of the wastewater discharged was estimated at 470 million m3/year in 1994 and will reach 900 million m3/year in 2020 (the Ministry of Agriculture and Agricultural Development, Morocco, 1998). More than 7000 ha was irrigated with wastewater ; neverthless, this reuse did not account for sanitary and environmental constraints.

The area under analysis is located downstream of the city of Marrakech, an area of about 1000 ha, irrigated with wastewater for more than 80 years. After this long period of pollution, a treatment plant was installed to treat the wastewater of the city. This problem does not exist only in Marrakech, it is noticed in several other cities in Morocco such as Fez, Settat, Sidi Ifni, to cite but a few; but the city of Marrakech was among the first cities that have known the installation of a sewage treatment plant, which will allows us to assess the role of the latter.

Several studies that have been conducted on the same area (Fig. 1) revealed the existence of many disadvantages wich resulted from irrational use. The epidemiological studies that have been conducted in this area by Habbari (1992) Bouhoum et al (1997) and EL A. Masoudi and S. Ourouadi (2007) showed that the use of wastewater poses serious health problems. We started work in 2009, that is one year after the installation of the treatment plant, our main objective from this work is to check the state of the water ressources in the studied area after the installation of the treatement plant and to determine the relationship between the groundwater and its recharge area on the one hand and the waters discharged from the city of Marrakech on the other hand, not to mention the effect of the recharge area on the chemical elements after the removal of wastewater intake.

Fig. 1: Location of study area "EL AZZOUZIA" downstream of the city of Marrakech

2. Geological and pedological Settings

The contaminated area of Marrakech occupies the north corners of the Central Haouz, presented in the form of a Sedimentary Basin of a tectonic origin with detritic filling produced from the dismantlement of the Atlas chain during its upheaval (Moukhchane 1983).

There is in the contaminated area of El Azzouzia, an accumulation of a Neogene and Quaternary age accumulation on a shistose base of a primary age. This accumulation consists of a significant alluvial Plio-villafranchien formations wich are mainly composed of pebbles and, coarse sand, resulted from the water erosion of the High Atlas of Marrakech.

Along the Tensift wadi, a recent alluvial terrace with low permeability tends to form a barrier that prevents drainage of the groundwater.

The Plio-Quaternary alluvium described as such is the siege of a significantly widespread watertable, which takes part in the perimeter of El Azzouzia.

The pedological study conducted in 1951 at the Haouz of Marrakech revealed the presence of four types of soil: red soil, brown soil, chestnut brown soil, and gray soil, with a texture which is either alluvial, clayey alluvial or sandy alluvial which are divided as follows:

red or red-brown soils developed near the center of Tahanaout, Ourika, and Sidi Rahal and also at the center of the eastern Haouz.

- The chestnut brown soils cover the central and eastern part of the Haouz, the limit of the red soil with the chestnut brown soil passes between Marrakech, Tadert and Tamsloht.
- The gray soils are situated to the west.
- The brown soils are located in the plain area.

3. Climatology

The city of Marrakech is characterized by a continental climate arid to semi-arid, it is characterized by low rainfall of about 170 mm, high evaporation and a high temperature average rising to 39 °C with significant daily and monthly variations.

The hydrology of the city of Marrakech is herefore strongly influenced by this climate, which has a direct impact on the balance sheet and at the same time on water supplies and losses (Abourida 2008).

Temperature variations are characterized by a contrast between the years and months of a year, on the one hand, and between days and nights, on the other hand.

The variational analysis of the monthly and yearly temperature and precipitation indicates the existence of two seasons, one dry and hot and the other cold and rainy.

The maximum temperatures recorded during the months of July and August is of an average of 40 °C. The coldest temperature is generally observed in January and December of an average of 0 °C, and the average temperature is 19 °C.

There is a rainy season between November and April with a peak in March wherein the precipitation rainfall could attain 50mm and a dry season between June and September wherein the lowest precipitations is recorded in the months of July and August.

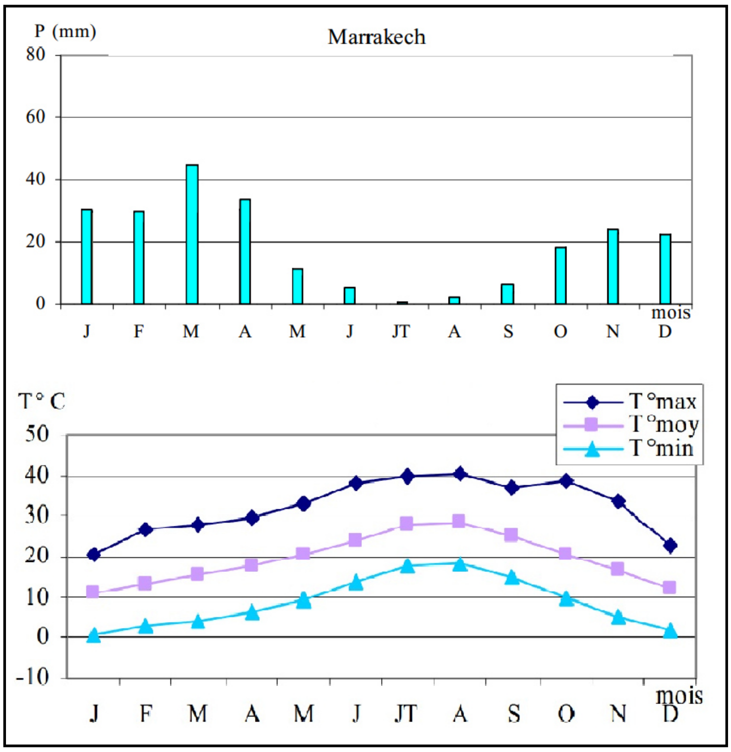

Fig. 2 : Monthly variations of the precipitation and temperature in Marrakech

4. Hydrogeology

The piezometry shows that water discharge take place from the south to the north, i.e, towards the left bank of the wadi, there are outcrops of groundwater in the Oulja, as well.

The drainage of the water table by the Tensift wadi is weak at the eastern side of the studied area as the recent alluvial terraces form a barrier less permeable which prevents the exchanges between the wadi and the water table. On the reverse, by moving backwards to Safi, we find that the absence of such alluvial formation supports the drainage of the water table by the wadi . This parameter will be of paramonnt importance in accounting for the exchanges that take place between the wadi and the water table. (Ouchen, 1994) .

The aquifer at this level has been largely driven by the water for irrigation which is the wastewater of the city of Marrakech, this area is now largely driven by the flood waters of the wadi.

The outputs of the water are essentially pumping for irrigation. During our research we note that the population does not use this water as drinking water. (Fig. 3)

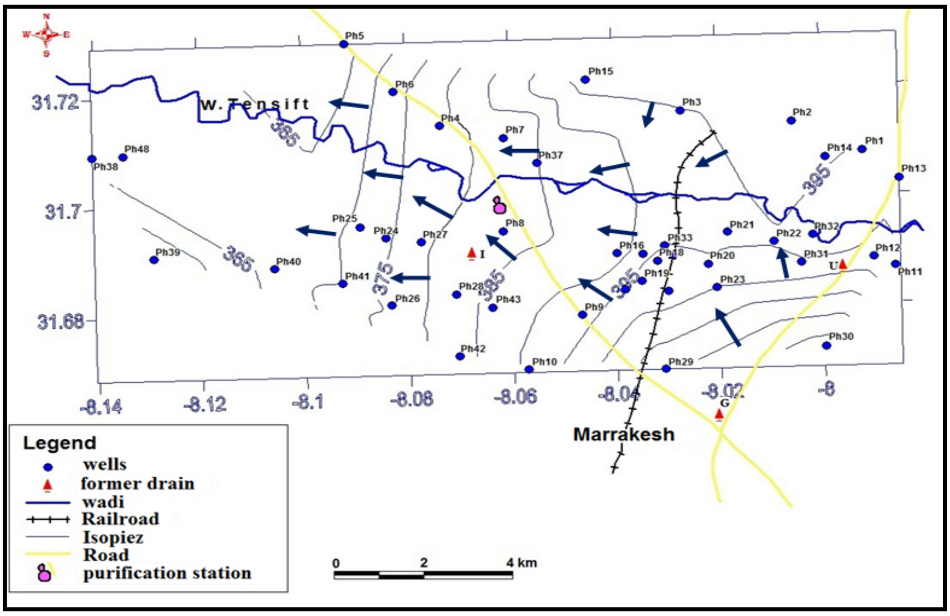

Fig. 3 : piezometric map of the studied area in 2009, with the points surveyed.

5. Physical Chemistry

5.1 Results:

The analysis of the major elements has yielded the results shown in the following table:

Table 1: results of the major elements analyzed downstream of the city of Marrakech in 2009 (meq/l)

Wells	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	HCO_3^-	SO_4^-	NO_3^-	B.I
PH 01	22,14	0,15	11,18	10,29	29,25	7,83	3,79	0,92	2,33
PH 02	11,09	0,15	11,18	3,87	12,02	8,80	1,67	1,65	4,29
PH 03	15,88	0,15	8,78	2,80	14,02	6,72	1,67	1,82	6,49
PH 04	35,93	0,13	11,33	4,11	26,43	10,72	3,06	1,11	-0,80
PH 05	15,44	0,13	7,58	2,14	13,23	6,24	1,69	1,08	6,54
PH 07	15,44	0,13	7,19	16,21	24,00	5,11	2,17	1,32	8,94
PH 08	22,53	0,08	7,73	12,51	24,03	9,69	2,27	1,24	8,45
PH 09	15,88	0,05	10,78	10,45	18,02	9,44	2,04	1,90	8,45
PH 10	13,79	0,10	3,99	1,97	12,02	5,36	1,58	1,06	-0,39
PH 11	34,28	0,31	16,77	19,42	59,29	5,92	4,81	1,79	-0,76
PH 12	43,89	0,28	18,91	20,08	67,30	8,00	4,73	0,94	3,86
PH 13	40,54	0,38	19,96	23,04	54,07	9,77	5,10	2,56	7,96
PH 15	6,70	0,08	4,79	2,80	3,61	6,33	1,25	0,92	8,48
PH 16	17,75	0,31	7,19	5,51	11,23	11,69	4,04	0,10	6,48
PH 17	12,01	0,33	7,19	3,95	8,41	10,16	3,44	0,19	2,76
PH 18	13,01	0,46	6,99	3,95	6,80	10,16	3,16	0,40	8,62
PH 19	16,01	0,23	5,99	2,96	7,62	10,80	3,06	0,27	7,35
PH 20	15,88	0,38	6,94	3,62	8,41	11,19	2,83	0,21	6,70
PH 21	16,01	0,31	8,78	4,36	12,02	10,55	3,37	0,55	5,25
PH 22	18,01	0,26	9,33	3,62	17,23	8,72	3,60	0,74	3,06
PH 23	13,79	0,28	10,53	1,48	7,19	9,92	2,58	0,66	-0,99
PH 24	19,62	0,00	9,58	3,95	18,02	6,72	2,96	0,40	7,59
PH 26	11,70	0,00	7,98	6,09	15,99	5,75	1,39	0,39	4,61
PH 27	19,01	0,03	5,74	4,11	15,23	6,88	3,16	0,42	6,90
PH 28	18,40	0,00	6,39	3,95	17,23	6,16	2,02	0,18	5,82
PH 29	20,05	0,15	6,39	3,54	15,23	9,52	2,96	0,40	3,54
PH 30	20,57	0,18	7,19	7,32	17,23	9,69	2,91	0,52	7,43
PH 31	22,14	0,18	5,59	7,16	17,23	9,60	3,06	0,58	6,98
PH 32	23,84	0,43	9,73	6,42	23,24	12,32	3,08	0,81	3,09
PH 33	20,88	0,18	7,98	5,92	15,23	9,77	3,50	0,63	9,18
PH 34	22,31	0,15	5,59	7,16	14,22	12,00	3,41	0,37	7,97
PH 35	13,35	0,54	7,73	2,63	12,02	8,72	1,79	0,15	4,97
PH 36	21,05	0,43	6,14	5,27	15,23	11,11	2,77	0,60	7,09
PH 38	19,23	0,05	12,77	3,62	23,24	5,52	3,89	0,44	3,70
PH 39	12,14	0,00	5,19	3,79	15,23	5,61	1,81	0,16	-3,92
PH 40	13,05	0,03	5,59	3,13	11,23	6,64	1,92	0,11	4,67
PH 41	10,05	0,03	5,19	3,37	9,62	6,24	1,54	0,10	3,11
PH 42	12,22	0,03	7,98	2,80	11,23	7,19	1,89	0,16	5,76
PH 43	14,48	0,00	8,78	3,54	12,02	9,69	3,02	0,13	3,84

5.2 Discussion:

Electric conductivity : It is highly significant that it varies between 400 and 3200 µs/ cm, but it exceeds 5600µs/cm in the eastern side of the studied area.

Chlorides : the group of wells in the contaminated area shows high values that may reach a maximum of 2300mg/l.

Sodium : The sodium map shows a similar plot to that of chlorides

Potassium : This chemical element contributes only little in water mineralization since the degree of correlation with the conductivity is 0.022 .

Sulfates : The concentration of sulfated ions in the water is generally inferior to 200 mg/l (a recommended Standard). The well PH13 is an exception in that it has a maximum value of about 245 mg/l.

Bicarbonates : The concentration of this chemical element in the contaminated zone varies between 312 and 752 mg/l.

Calcium and Magnesium : while the concentration of the calcium element varies between 80 and 400 mg/l, the concentration of magnesium oscillate between 18 and 280 mg/l .
Nitrate NO_3^- : The data concerning the water content of the NO_3^- ions show that the rate of nitrate in the entire zone does not exceeds the norm in most of the wells except in 30 % of the wells.

5.3 Chemical facies:
Cations diagram: $Na^+/Ca^{2+}/Mg^{2+}$

For the pole Na^+, all the samples present contents superior to 50% and inferior to 70%, while the pole Ca^{2+} shows contents that oscillates between 15% and 45%. The pole Mg^{2+} indicates that the samples present contents that vary between 5% and 45%.

Anions diagram Cl^-/SO_4^{2-} / HCO_3^{2-}

For the pole Cl^-, the contents oscillate between 35% and 85%, while the pole SO_4^{2-} shows that the samples present contents inferior to 20% and the pole HCO_3^{2-} indicates that the contents vary between approximately 10 and 55%.

The static interpretation of the Piper diagram (Fig. 4) shows in this manner that the percentages of Na^+ and Cl^- oscillate between 50% and 70%, and 35% and 85% respectively, which allows for the definition of a single chemical facies : this is a sodium chloride facies which characterizes all the water points of the contaminated zone. This is possibly linked to the existence of a dense series of Permo-Trias, containing evaporite series (Beauchamp 1988).

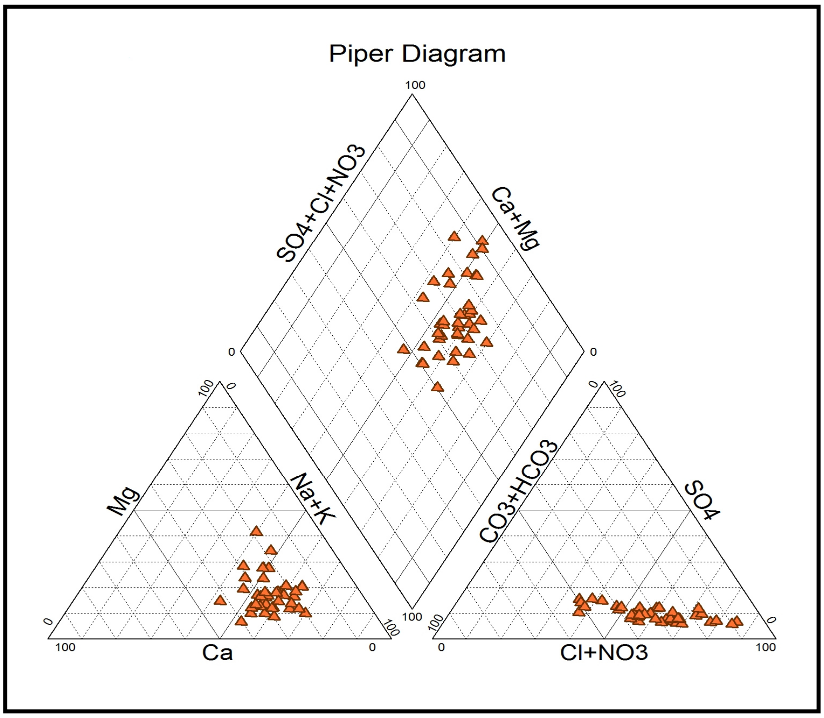

Fig. 4 : Triangular diagram of piper

5.4 Relationship of the electric conductivity and Cl^-, Na^+, SO_4^{2-} and HCO_3^-:
In parallel to the variation of water mineralization, variations with similar chemical elements have been recorded in particular for sodium, sulphate and chloride ions.

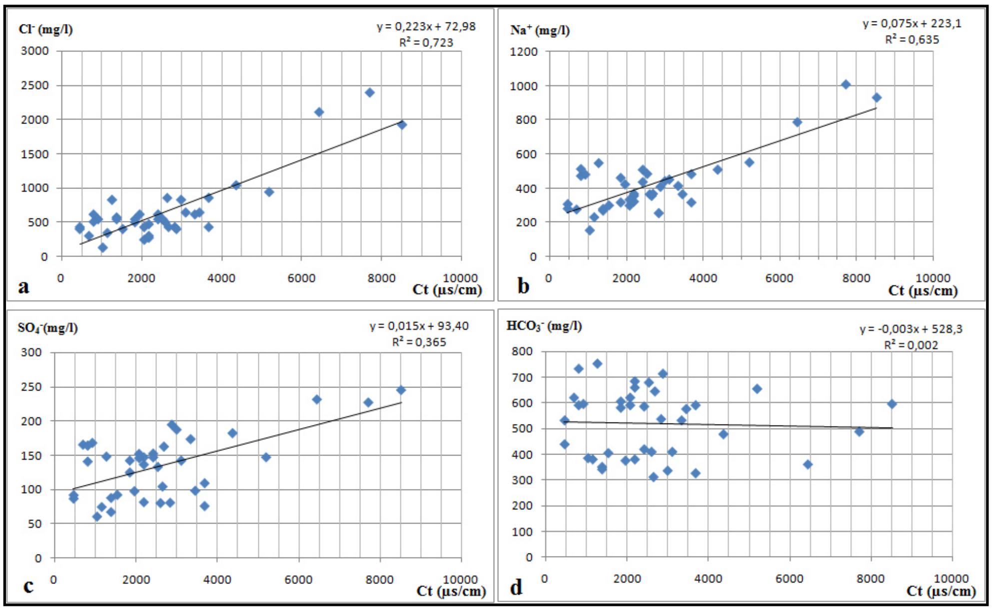

Fig. 5 : Degree of correlation between electric conductivity and the chemical elements
(a : Cl^-, b: Na^{2+}, c : SO_4^{2-}, d : HCO_3^-)

The degree of correlation between these ions and electric conductivity is R2=0.72, R2=0.63, R2=0.36 respectively. As for bicarbonate ions, they do not demonstrate a good correlation R2=0.002 (Fig. 5).

6. Analysis of stable isotopes at the studied area

6.1 Sampling and results:
The samples of this campaign have been the object of analysis of oxygen 18 and deuterium in the laboratory of Alfred-Wegener Institute for Polar and Marine Research, Isotope Laboratory Research Unit Potsdam, Germany. The distribution of the different points of sampled water as well as their contents in oxygen 18 and deuterium are represented in Tables 2, Figure 6.

Tab. 2: Isotopic abundance of the water of the aquifer (Campaign 2009).

Well	Z (m)	$\delta^{18}O$ (‰) vs. SMOW	1	δ^2H (‰) vs. SMOW	1	d excess
PH02	412,00	-5,62	0,03	-39,99	0,55	4,94
PH03	410,00	-5,62	0,03	-39,74	0,24	5,21
PH04	385,00	-5,64	0,03	-42,30	0,45	2,78
PH05	380,00	-5,90	0,02	-38,97	0,58	8,24
PH08	390,00	-6,65	0,03	-49,04	0,35	4,18
PH09	407,00	-6,86	0,01	-51,33	0,31	3,58
PH10	410,00	-7,89	0,03	-52,49	0,24	10,60
PH11	407,00	-6,37	0,03	-43,44	0,28	7,49
PH13	403,00	-5,41	0,03	-40,16	0,31	3,11
PH15	410,00	-6,01	0,02	-38,34	0,44	9,72
PH22	399,00	-6,78	0,05	-46,10	0,08	8,17
PH25	387,00	-6,71	0,03	-47,10	0,39	6,61
PH28	397,00	-7,19	0,04	-49,53	0,29	7,96
PH29	419,00	-6,62	0,04	-47,16	0,32	5,81
PH30	425,00	-6,93	0,03	-48,28	0,25	7,17
PH36	402,00	-6,26	0,04	-46,84	0,29	3,25
PH37	392,50	-5,21	0,03	-39,48	0,30	2,23
PH48	390,00	-5,21	0,02	-37,05	0,63	4,65
PH49	Oued	-7,46	0,03	-44,94	0,47	14,75
PH50	Pluie	-12,48	0,02	-87,95	0,44	11,87

$\delta^{18}O$: contents in oxygen 18 δ^2H : contents in deuterium

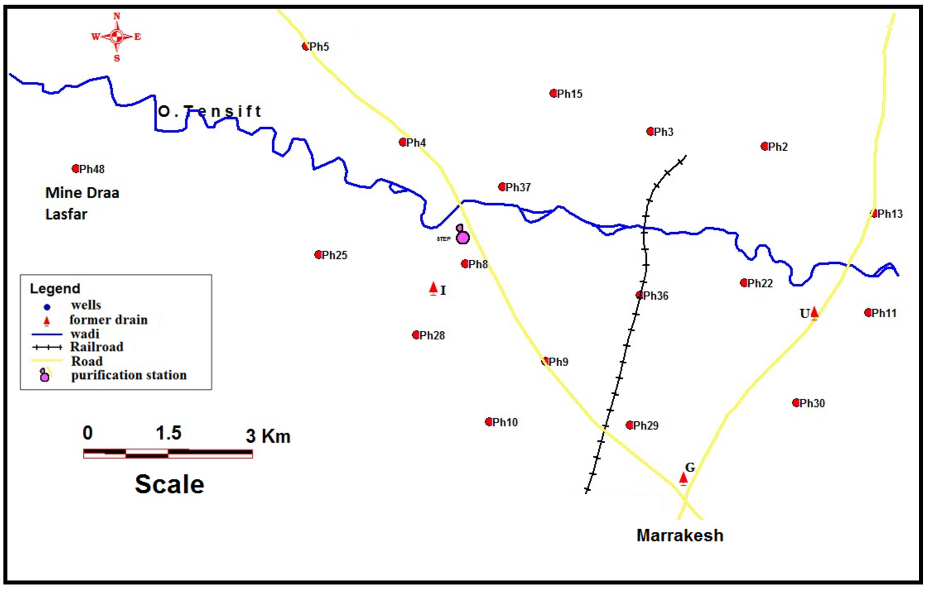

Fig. 6 : Distribution of the differents water sampled points.

6.2 Interpretation of the results:

Relationship between Oxygen 18 and deuterium:

The results obtained give the graph represented in the following figure:

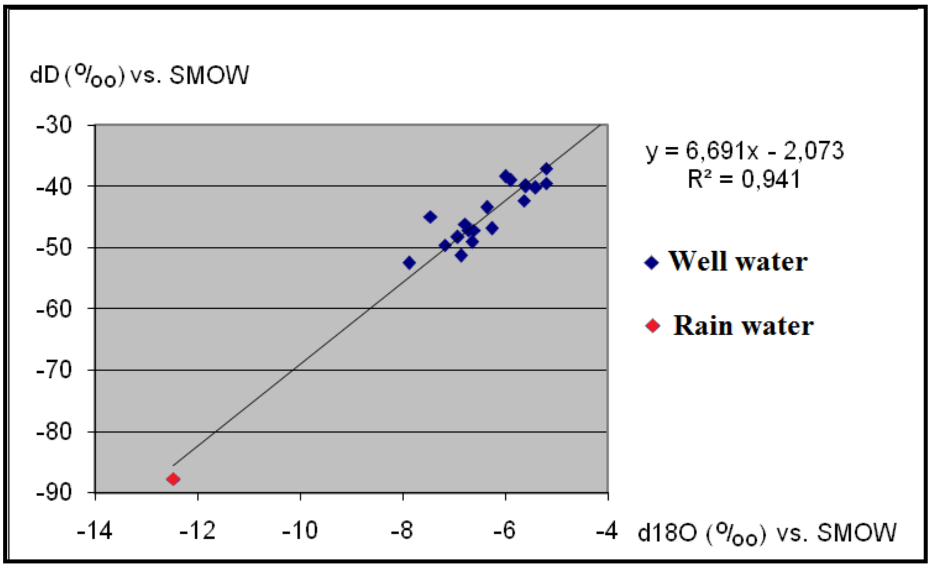

Fig. 7 : contents in Oxygen 18 and deuterium.

We sampled the local rains of Marrakech (PH50), which is situated in the Haouz plain at an altitude of 413 m and which has a semi- arid climate. The ^{18}O and ^{2}H average content, weighted by the rains, is -12.48 and -87.95 ‰ respectively with an excess in deuterium which reaches 11.87 ‰. These values characterize an Atlantic origin of the precepitation that recharges the aquifer. This origin could possibly be confirmed by meteoric lines, as determined by Ouda et al (IAEA, 2005).

The majority of points are located on or close to the sloping line 6.69 which is characteristic of this campaign which denotes the absence of fractionation by evaporation since the fall of rain, but according to a hydrogeological study there are exchanges between the aquifer and the Tensift wadi at the eastern side of the studied area. This exchange, however, remains very weak, and it is for this reason that these points are not far from the line.

6.3 Recharge altitude:
The aquifer recharge altitude could be estimated through stable isotopic contents. The signal of infiltrated water varies within the same area according to the average temperature of the soil of the altitude (Blavoux et al . 1995). In this way, it is possible to calculate the average altitude of the feeding basin from the isotopic composition of water at the outlet. To make this feasible we take the isotopic content of the different sampled points back to the time of this campaign on a regional line of a stable isotope- altitude.

However, the information available in Morocco suggests consistency of this altitudinal gradient. We have therefore synthesized the previous studies (Marcé 1975; Bouchaou et al , 1995; Ouali El 1999; Bahir et al, 2001 , Mennani et al , 2001, IAEA , 2004. . .) and obtained a gradient of - 0.25 ‰ per 100 m for 18O (Abourida 2008) (Fig. 8), with values of 18O going from -4.00 ‰ at the side of the Atlantic to -8.00 ‰ if we go 1600 m in the same direction (Marjoua et al. , 1997)

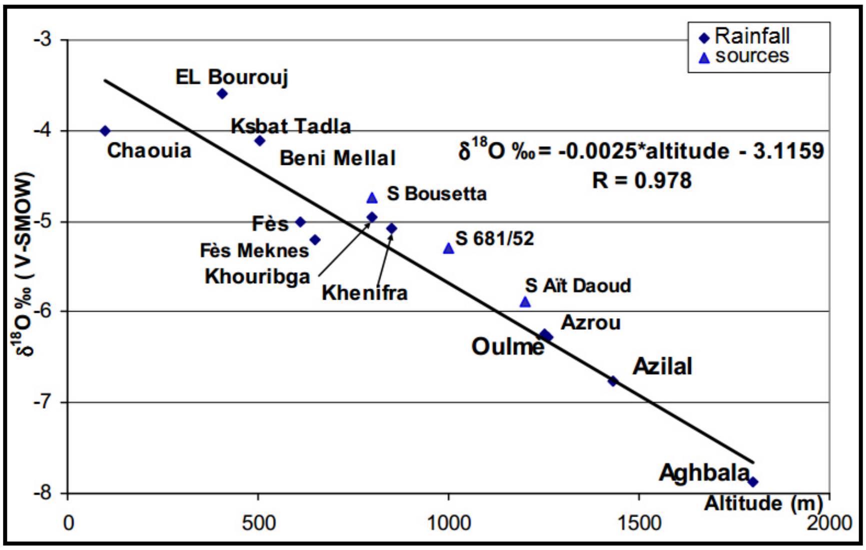

Fig. 8 : an altitudinal synthesized from the variations of the ^{18}O content from the rainfalls and springs in Morocco.

From this line, it is possible to determine the average altitudes of the groundwater recharge of the Haouz by projection isotopic conent of distinct sampled points.

The studied area's altitude range from 380 to 420 m, the a waters fed on the basis of this perimeter should have the 18O contents usually ranging from -7.89 to -5.21 ‰ .

The water points located in the studied area should have in this way a feeding area which should be situated at an altitude between 838 and 1908 m. The central Haouz would be fed by the High Atlas (Abourida et al, 2004).

7. Conclusion

In this part of the study,our main focus draws essentially on determining groundwater recharge areas, which constitues a significant parameter in the hydrodynamics in the aquifer hydrodynamism, of which the utilisation of isotopic techniques is of great interest.

The stable isotopic contents of the waters emanating from the Haouz groundwater as shown in the studied area indicate that these waters come from the rains fallen at an altitude and not having undergone strong evaporative moments before infiltration. This absence of evaporation demonstrates a rapid infiltration and confirms perfectly presupposed typical schema of the groundwater recharge in semi-arid areas.

Contents of major ions reflect well the transit at the levels of Triassic evaporite formations of the Central High Atlas which comprises an altitude that oscillate between 800 and 1900m, although they may be later modified during residence time in the plain's aquifer. The direct infiltration of the water of the Tensift wadi during its inlet to this area is another source of groundwater recharge. This infiltration, however, remains a bit weaker in comparison to that of the recharge area in the central high Atlas which feed the Haouz groundwater. Neverthless, the relative proportion of these two natural recharges has not yet been perfectly determined.

It was said in the previous studies that the state of pollution was at a primary stage and that it has not yet reached the free level as concerns the water table, but at the present time, the major source of pollution has been eliminated in this area thanks to the treatment plant and the stage of pollution has become weaker and weaker.

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