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ISOTOPIC TOOLS FOR GROUNDWATER MANAGEMENT IN SEMI-ARID AREA: CASE OF THE WADI OUAZZI BASIN (MOROCCO)

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ABSTRACT

Climate aridity and intensive exploitation due to uncontrolled pumping for irrigation have caused a drastic decrease in the piezometric level aquifers of ouazzi basin plain, and have seriously degraded groundwater quality. Overexploitation of coastal aquifers and pollution vulnerability are among the main problems related to groundwater resources assessment and management in arid and semi-arid regions threatened by desertification being the only source for agricultural and public water supply.
The overall objective of this study is to identify the possible human impact on groundwater quality, and the elaboration of a conceptual circulation model of Essaouira coastal aquifer (W Morocco).
A study was conducted, having as main goal the characterization of the groundwater evolution from the chemical and isotopic point of view from the recharge areas towards the coast line. Groundwater samples from Plio-Quaternary and Turonian aquifers were collected and analysed: i) variable electric conductivity from 900 µs/cm to 3880 µs/cm with similar Cl-Na facies; ii) carbon-14 varies from30 to 60 pMC, with3H levels (Ouazzi Basin) below the detection limit, SW of Essaouira city, tritium content range between 1.5 and 3 TU.

Keywords: Wadi Ouazzi, Arid climate, Groundwater resources, Environmental isotopes, Morocco.

INTRODUCTION

The countries of North Africa have long had the challenge of providing sustainable livelihoods for their populations in the fragile ecosystems of semi-arid and arid areas, facing the challenging issues of water scarcity, drought, land degradation and desertification (Bahir et al., 2001; Re et al., 2013;Warner et al., 2013).

Climate change is already a reality in North Africa and it places additional constraints on its fragile ecosystems and limited natural resources. Aquifers represent an important source of renewable freshwater in most coastal plains, and are largely exploited to respond to human needs. In coastal regions, salinization and pollution in groundwater systems is generally associated to the effects of seawater intrusion and ascribed to anthropogenic activities such as domestic wastes, agriculture and industry, which have marked effects on local and regional economies and livelihoods (Re et al. 2013; Qin et al, 2013).

The Essaouira basin is located between Jbel Amsittène in the south and Jbel Hadid in the north (Fig. 1). The basin is a vast syncline open to the Atlantic Ocean with about 6000 Km^2 and it is characterized by limited and discontinuous water resources units.

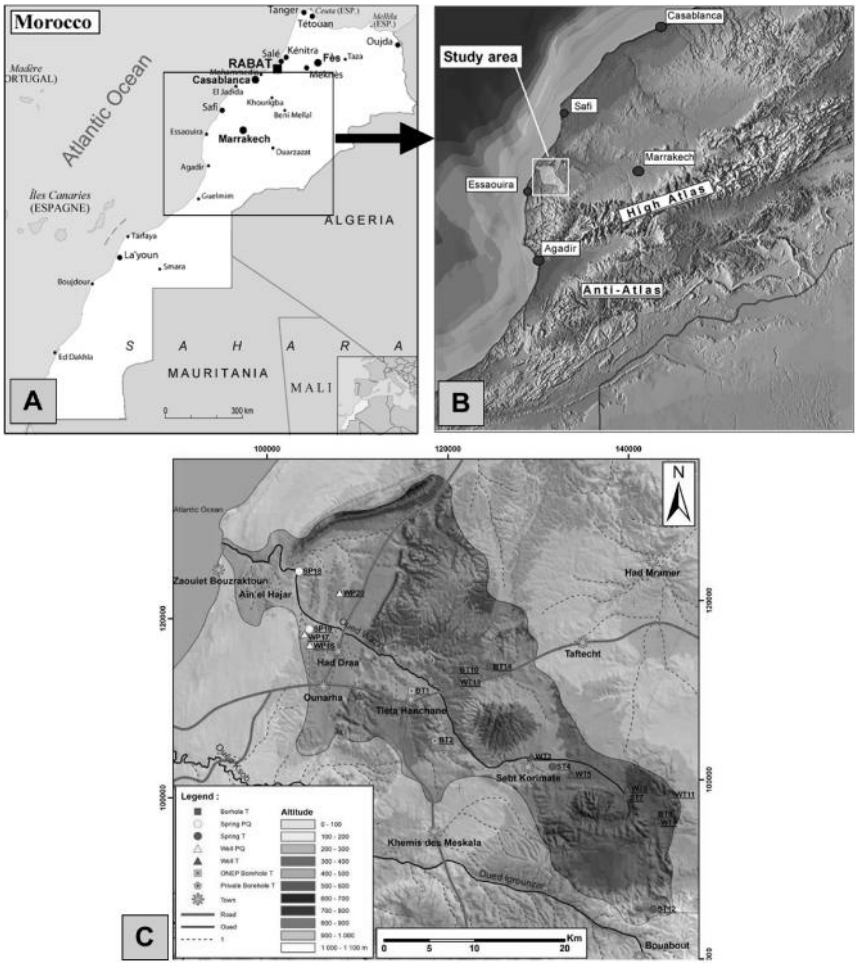

Figure 1: A- Map of Morocco, B- Localization of study area, C-Localization of samples water point in Ouazzi basin.

One of the major concerns of the coastal aquifers in arid regions over the last years has been the sustainability and groundwater management, because of the increasing water stress, mainly in coastal areas. These areas and Essaouira is no exception, are also experiencing an increase in population, due to the combined action of internal migration and demographic growth, causing a rise of water demand. As a consequence, in arid and semi-arid regions, where the alluvial aquifers are tapped by a large number of wells, abstraction rates often exceed natural replenishment rates, leading to over-exploitation.

The main objective of this study was to characterize the groundwater sustainability and management by way of the application of chemical and isotopic techniques: i) to determine the possible interconnections between aquifers in the coastal zone of Essaouira (Plio-quaternary aquifer) and the

aquifers in the Meskala region (Turonian aquifer); ii) quantify the percentage of mixing between the different aquifers systems within the Meskala region; furthermore to estimate the apparent groundwater age in the coastal zone and in Meskala region aquifers, through carbon-14 measurements. The overall objective of this study is to identify the possible human impact on groundwater quality and identify mixing between aquifer units.

The value of water represents an economic and intrinsic value to the region development. The economic value includes not only the value of water to users, but also, the net benefits of return flows (recharge of groundwater), the net benefits from indirect use (improvement in health), and adjustment for societal objectives (poverty alleviation, employment generation). Similarly, water pricing should reflect the scarcity of water. The recommended approach would be to define the water basis of the full cost of supply, it includes operating and management cost, capital charges, opportunity cost, economic and environmental externalities.

Moreover, salinization of soils and groundwater resources is one the most widespread processes of particular relevance in coastal areas, by degradation of water-quality and endangers future water exploitation in particular in arid and semi-arid regions (Re et al., 2011). The extent and importance of salinization as a global threat has been greatly underestimated. In the unsaturated zone, natural salinization can either be due to the presence of evaporate minerals, or be associated with marine aerosols. In particular, marine sprays (either transported as liquid drops or evaporated materials) and airborne marine salts that can contribute to the base cation content in coastal soils.

Drinking water supplying the Essaouira city and its neighbouring rural agglomerations is presently based on exploiting underground waters, notably those of the Plio-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 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.

The water balance of the Essaouira aquifers is irregular, because of the high climatic variability, but in recent decades, this balance has become in continuous deficit, due to the overexploitation of this aquifer, especially in its downstream part, the quality and renewal of water resources in this semi-arid region. As many African urban and rural areas lack adequate and accurate information on both quality and quantity of water resources (Showers 2002), and as the demand on freshwater resources is rapidly growing, there is an urgent need to linker search with improved water management.

Several studies have been already performed in the region (Bahir et al., 1999; 2000; 2001) the authors were focused on the whole Essaouira basin watershed. These studies have partially identified some of the main mechanisms causing degradation of water quality in some areas of this watershed, through the

application of geochemical and isotopic tools. They have also shown that most of the natural recharge in the watershed of Essaouira basin comes from the High Atlas, which receives a significant rainfall, especially in its upstream part.
The identification of the main sources of pollution, and thus the aquifer vulnerability, is essential to provide a sound basis for the implementation of long-term geochemically based water management plans within Essaouira basin. On the other hand, the continuous over exploitation of coastal aquifers increases the groundwater mineralization and produces a decline in the water quality, with important drawbacks on agricultural development and on the population's health. Groundwater salinization is a common problem for both developing and developed countries. This work can contribute at the provision of geochemical and isotopic data in the frame work of the assessment of groundwater quality at the regional level and as a basis for constructing geochemical and isotopic-based programs for water management and international level.

STUDY AREA

Geographical and climatic setting

The study area is located in the upper zone of the Essaouira basin, it is bounded in the Ouest by Mramer Wadi basin, in the north by Igrounzar Wadi crystalline massive in the east.
Essaouira climate is controlled by the dual influence of the Atlantic Ocean and continental processes forced by the relative position of the Azores anticyclone and the North African anticyclone, the mean annual rainfall rate presents a large spatial and temporal variability, ranging from 400 to 560 mm in the High Atlas to approximately 280 mm/yr in the plain. The average of potential evaporation is around 780 mm in the mountains and 920 mm near the Atlantic coast, in the plain, for the period 1998-2000 (ABHT).
In the study area severe and widespread dry conditions occurred, especially in 1998, 1999 and 2000 (Figure 2). The decrease of winter precipitation along 3 consecutive years may have resulted in a degradation of the soil moisture content and depletion of the groundwater levels.
The climatic pattern in this area is frequently characterized by a relatively "cool" dry season, followed by a relatively "hot" dry season, and ultimately by a "moderate" rainy season. In general, there are significant diurnal temperature fluctuations within these seasons. Quite often, during the "cool" dry season, these diurnal temperature fluctuations (Figure. 3) restrict the growth of plant species.

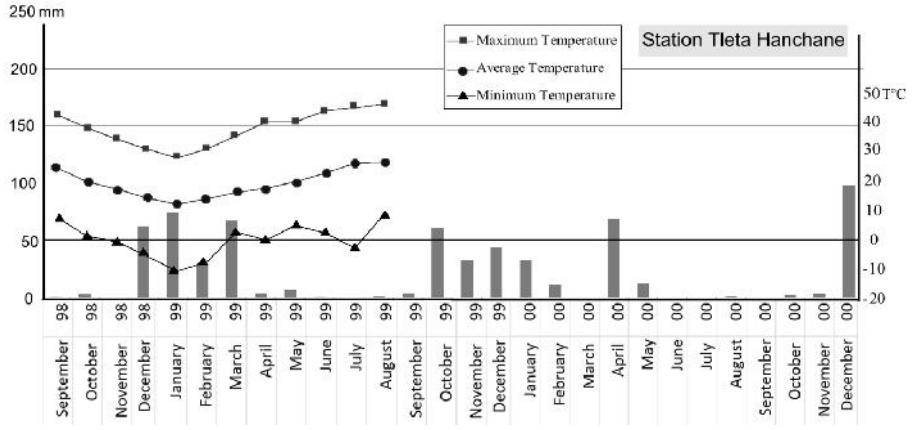

Figure 2: Precipitation annual values (mm) and monthly mean values at Tleta Hanchane Station (1998 to 2000), average temperature per month in Igrounzar station (1998 to 1999).

Geology and hydrogeology

Two main aquifers constitute the system. The Mio-Plio-Quaternary aquifer provides the bulk of the water supply and is mainly composed of sand, sandstone and conglomerates. The Cenomanian-Turonian aquifer is mainly Calco-dolomitic. The Cenomanian was recently drilled for supply for the city of Essaouira.In geological terms, the Essaouira synclinal zone is less rugged, with a lower relief (Figure. 1), characterized by low hills and shaped by a sparse water system. The Plio-Quaternary and Turonian are the main reservoirs of groundwater in the Essaouira Basin. The Plio-Quaternary, with a matrix of sandstone or limestone marine dune has a hydraulic conductivity primary porosity and contains a large free surface whose wall is formed in the synclinal structure, by the Senonian marls, flayed the ante-Pliocene shows that the Plio-Quaternary can be in direct contact with the Triassic and Cretaceous other levels (Laz, 1959; SCP, 1959). It is operated in rural areas and provides drinking water, domestic needs and a lesser extent irrigates farmland (Bahir et al. 2000).
As above mention in the region we can consider the existence of two main aquifers: i) the karstic aquifer is composed by the Cenomanian and Turonian limestones and dolomitic limestones formations. The base of the system corresponds to lower Cenomanian grey clays and the top to the Senonian white marls (Figure 5). The structure of the basin is marked by a succession of anticlines and synclines, affected by folded structures and deep faults (Figure 4) under the influence of Atlas tectonic and Triassic salt diapirs.
The Plio-Quaternary aquifer consists of sands, sandstone and conglomerates and provides the main part of the water supply to the region.

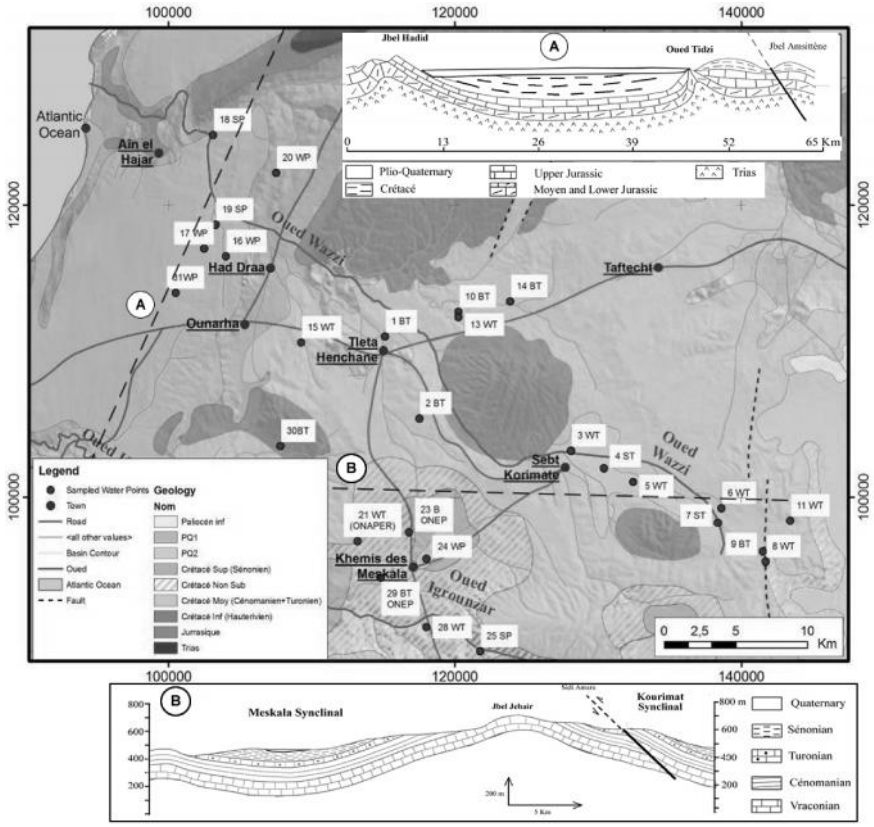

Figure 4: Geological map of study area. With Schematic section A: showing the geological limits of aquifers in the South-East of OuedOuazzi Basin. And B the aquifers post Jurassic (Ambroggin, 1963).

MATERIALS AND METHODS

In order to discriminate between different sources of contamination in the region of Essaouira, twenty groundwater samples have been collected along the at the coast, the samples were collected in springs, dug wells and boreholes issuing from the coast to the wadi upstream (Figure. 1). Water samples were collected for physic-chemical and isotopic analyses. All samples have been subjected to physical analyses.

The stable isotope analyses, $\delta^{2}H$ and $\delta^{18}O$ are reported in ‰ to V-SMOW (Vienna Standard Mean Ocean Water) and $\delta^{13}C$ results are also reported in ‰ to V-PDB (Vienna-PDB).

The stable isotopic measurements were performed by mass spectrometry while and the radiocarbon (^{14}C) content in the groundwater samples were carried out in the Total Dissolved Inorganic Carbon (TDIC) and the results reported as percentage modern carbon (pMC). All the isotopic analyses were performed in

the laboratories of IAEA (International Atomic Energy Agency - Isotope Hydrology Section, Vienna).
The 20 groundwater samples and surface water sampling points were chosen (Figure 1, Table 1).

Table 1: Isotopic parameters of groundwater in study area.

Code	pH	EC («S/cm)	$\delta^{18}O$ (‰)	$\delta^{2}H$ (‰)	^{3}H (UT)	$\delta^{14}C$ (pMC)	$\delta^{13}C$ (‰ PDB)	Age
BT1	6.9	2092	-5.39	-31.39	1.25	67.40	-10.44	
BT2	7.28	2600	-4.71	-26.57	0.42	-	-	
WT3	7.24	1500	-5.43	-31.42	1.86	-	-	
ST4	7.5	998	-5.69	-32.67	3.43	-	-	
WT5	7.39	1065	-5.68	-33.32	1.69	60.5	-10.82	2300
WT6	7.69	994	-5.32	-31.57	2.02	-	-	
ST7	7.64	3880	-5.43	-34.32	0.43	-	-	
WT8	7.6	1600	-5.59	-34.23	-	-	-	
BT9	7.11	2750	-5.88	-35.71	-	86.0	-5.12	
BT10	7.8	900	-5.29	-29.13	0.18	-	-	
WT11	7.10	1900	-5.63	-35.14	1	-	-	
ST12	7.65	3740	-5.48	-34.26	-	-	-	
WT13	7.40	1220	-5.25	-29.76	-	-	-	
BT14	7	2300	-4.9	-28.87	-	-	-	
WT15	7.35	2540	-3.82	-20.69	-	-	-	
WP16	6.90	2500	-6.21	-38.37	-	60.0	-7.41	2300
WP17	6.9	2800	-4.7	-24.54	-	-	-	
SP18	6.75	3100	-4.81	-27.57	0.76	74.4	-8.45	
SP19	6.65	2700	-4.9	-27.89	-	67.7	-9.18	
WP20	7.35	2970	-4.2	-23.69	-	-	-	

Based on the hydrochemical facies and on the hydrogeological conditions found in the different sectors of the Plio-Quaternary and Turonian aquifers at Essaouira basin.
The different isotopic techniques associated with the hydrochemistry of major and trace elements have been applied in order to investigate the pollution sources affecting groundwater quality. The evaluation of the groundwater data was carried out by geochemical and isotopic methods were used to establish the processes controlling the groundwater chemistry. The concentrations of major ions in groundwater can be correlated based on underlying physical and chemical processes.
The evolution of geochemical processes in groundwater depends on the equilibrium between mineral phases and water and is commonly discussed by

saturation indices. A positive value of saturation indices computed with respect to solid phase, following Garrels and Christ (1965), indicates an oversaturated state. In our case, saturation indices have been calculated from most common minerals encountered in the aquifer formation meant calcite, dolomite, halite and gypsum using DIAGRAM software (Appelo and Postma 1996).
Also, stable isotopes (^{2}H and ^{18}O) have been used as an integral component of hydrogeological and geochemical methodology in order to identify possible recharge processes, groundwater salinization mechanisms and mixing within aquifer systems (Fontes, 1980; Rozanski, 1985; Edmunds et al., 1992; Clark and Fritz 1997).

RESULTS AND DISCUSSION

Geochemical processes

The evolution of geochemical processes in groundwater depends on the equilibrium between mineral phases, i.e. by all the water-rock interaction processes. These results obtained helped to identify the different terms of the regional water balance and to characterize their changes over time, although major uncertainties remains and our results may contradict previous interpretations or calculations. The groundwater of Plio-Quaternary and Turonian is characterized by the recorded conductivity varies from 900 μScm^{-1} to more than 3,500 μScm^{-1}, with an average of 2,000 μScm^{-1}.

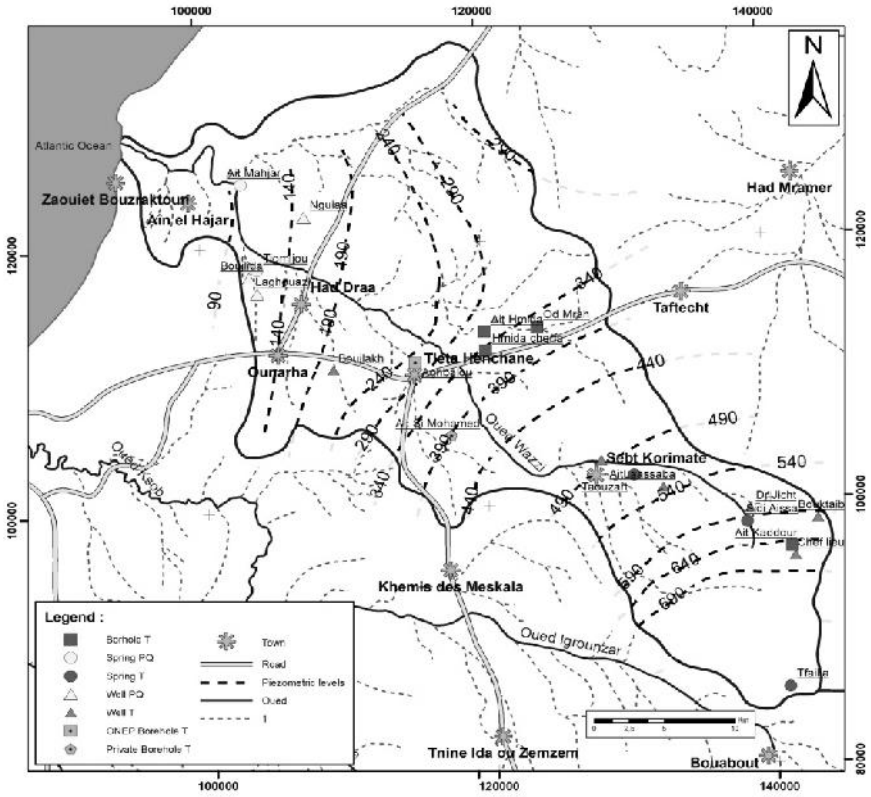

Figure 5: Location of sampled points and piezometric contour map.

If the intensification of agriculture through irrigation in the basin of Ouazzi Wadi helped quickly and significantly to the increase in agricultural production, it is responsible for its share of diffuse pollution and deterioration (Table 1).In this area we mainly retain the pesticides and fertilizers. Among the chemicals used in agriculture are cited, inorganic nitrogen compounds that are essential for plant growth. After erosion and leaching from agricultural land, courses and reservoirs are enriched in nitrates and phosphates. The immediate consequence of these releases is eutrophication.

Isotope results

Laboratory results for δ^2H and $\delta^{18}O$ analyses of 20 samples from Ouazzi Wadi Basin (Table 1) were reviewed by applying a Linear - regression model to the complete dataset (excluding the 3 quality-assurance replicates). The interpretation of this the results (oxygen and hydrogen isotope data) allows the separation of the two aquifer units the Plio-Quaternary from the Turonian aquifers, which was not obvious by using only the chemical parameters, namely

the major element interpretations and correlations. The Plio-Quaternary groundwater samples are more enriched in both isotopes than the samples from the Turonian.

The combination of these review tools helped to identify samples that may have been impacted by secondary processes such as partial evaporation of the sample during storage in the rain gage, or by site-specific environmental conditions at the sample location.

This difference persists despite the perceptible seasonal variations of the Plio-Quaternary aquifer. It may be related to the difference in altitude of recharge areas.

The Turonian recharge area is located between 500 and 1000m in altitude, occurring on the outcrops of the Jbel Kchoula, whereas the average altitude of Plio-Quaternary layers can be found between sea level and 400 m altitude. The difference in almost 500 m observed in the recharge areas altitude of these two aquifers, is reproduced in the isotopic composition of the groundwater samples, i.e. the Turonian water samples infiltrated at higher altitudes display an isotopic depletion when compared with the Plio-Quatenary samples (Dansgaard, 1964; Rozanski et al, 1993; Araguás-araguás, et al, 2000).

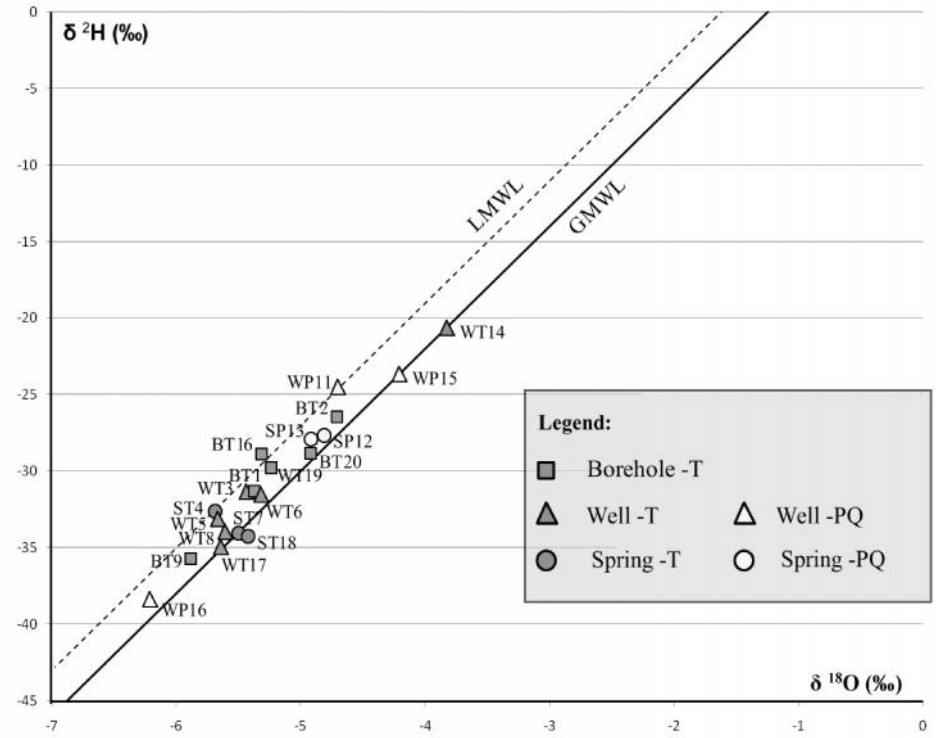

Figure 6: The **δ ²H (‰)** and **δ ¹⁸O (‰)** relation for the groundwater samples collected from the study area. The Global Meteoric Water Line (GMWL) and Local Meteoric Water Line (LMWL) are also shown.

The local meteoric line: H = 7.95 × ^{18}O + 13 (n = 11, r^2 = 0.97) parallel to the meteoric water line (MWL): 6,2 H = 8,6 × ^{18}O + 10 (Craig, 1961). This line characterizes the oceanic precipitation.

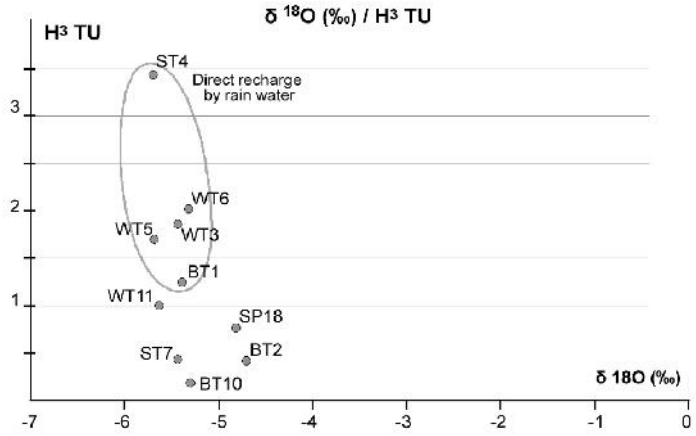

Figure 7: Analysis of δ^{18}O and H^3 (TU).

A weak correlation has been found in the groundwater samples between the isotopic composition (stable isotopes) and the borehole depths (r=0.01; n=20). This trend is pointing to the lack of relation between these parameters.
Tritium values are between 0 and 1TU, from the analysis of Figure 7 it is possible to say that the ^{18}O data is suggesting a direct infiltration of the precipitation, since no evaporation is observed and the higher tritium values are pointing to relatively recent rain water. A few exceptions involving higher stable water isotopes and tritium values included samples collected near the Ouazzi Wadi and suggesting the contribution of the Wadi which were subject to evaporation. On the other hand, from the analyses of the tritium content when plotted in a regional map (Figure 6), the regional decrease of ^{3}H content are supporting the piezometric map contours (Figure 5), with higher values at SE of Sebt Korimate and smaller values near the coast.

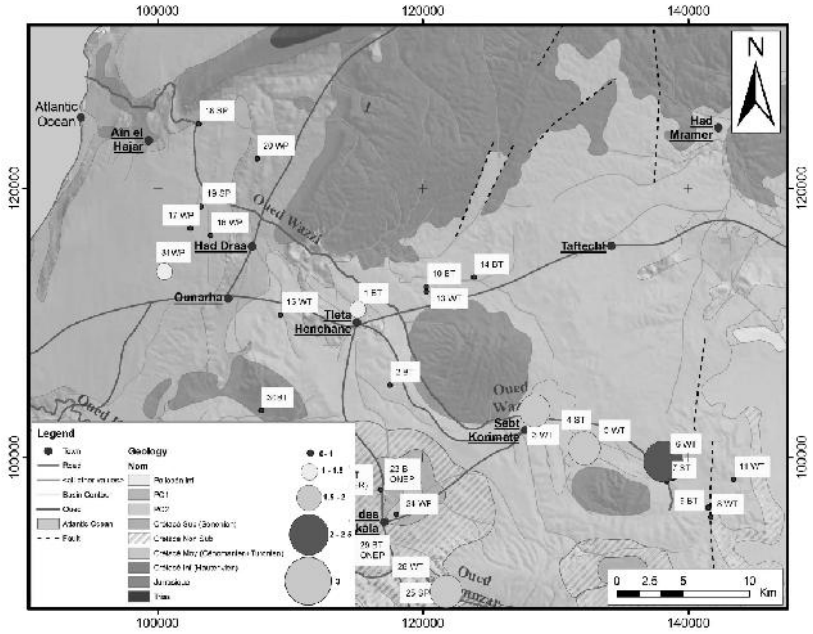

Figure 8: Map of results the tritium analysis.

Code	H^3TU	$\delta^{14}C$ (pMC)	$\delta^{13}C$ (‰ PDB)
SP18	0.76	74.36	-8.45
SP19	-	67.65	-9.18
WP16	-	60	-7.41
BT1	1.25	67.43	-10.44
WT5	1.69	60.5	-10.82
BT9	-	86	-5.12

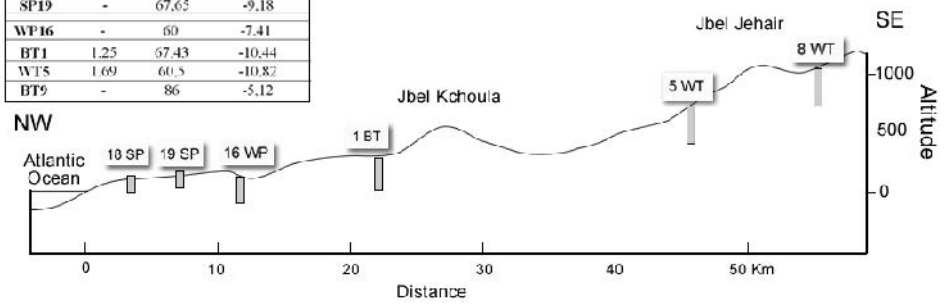

Figure 9: Isotopic values with altitude in the Ouazzi Basin

The age of groundwaters is an average time spent between the moment they have been infiltrated and the moment they are caught at a spring, a well or a borehole. Because of its capacity to date groundwater that is up to 30,000 years old, and due to the ubiquitous presence of dissolved inorganic carbon (DIC) in groundwater, ^{14}C is the most widely used radiogenic dating technique in regional aquifers (Edmunds, 2009). The simultaneous use of the ^{14}C and ^{13}C content measured in the TDIC (Total Dissolved Inorganic Carbon) enable us to interpret recharge modes and to estimate the residence time of the groundwaters.
Plotting the ^{14}C (pmC) *versus* the ^{18}O (‰) measured in 6 groundwater samples from the Turonian aquifer, a relationship can be observed between these two

isotopes, i.e., the samples with the lower ^{14}C content have the most depleted ^{18}O values, with the exception of the sample BT9. The trend could be ascribed to a paleoclimatic signal (colder climate) being the aquifer an archive of past climatic events /changes.

CONCLUSION

The goal of this study was to delineate and characterize the major geologic structures so as to describe the Turonian limestone aquifer in the Ouazzi Basin, through interpretation of isotopic data and isotopic investigation of the groundwater from the different water resources is the principal tools for the management in countries that are already severely water stressed faces new challenges. In addressing this uncertain future it is critical to draw as much strength as possible from the lessons of the past, particularly to ensure that the approach chosen, is coherent and clearly articulated to reflect the varied responsibilities and disciplines involved in successful water resources management.

Most previous studies in the region considered only the hydrodynamic aspect, but were not able to reach an operative level. The comparison with other approaches (hydrochemistry and isotopic in particular) enabled substantial progress in the surface hydrology of the upstream catchment, in the groundwater dynamics of the Ouazzi Basin. In this case of Essaouira basin this work is showing clearly the importance of systematic collection of information on water resources and their dissemination is essential for comprehending and management of water resources. Which involve a combination of human activities and environmental responses, affect both internal and boundary conditions over a large range of time scales. The construction of management models is therefore risky when information is not available at sufficient density.

The balance deficit predictable was already reached, due to combined effect of drought and aquifer overexploitation. The rain water storage in excess periods allows regulating the temporal disproportion between the differences in water demand and those of its availability, pre-venting loss of water to the ocean, to avoid risk due to evaporation of water storage in reservoirs, to alleviate piezometric decreases and improve water quality.

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