Journal of Environment and Earth Science
ISSN 2224-3216 (Paper) ISSN 2225-0948 (Online)
Vol. 3, No.10, 2013

Potential Hydrogeological, Environment and Vulnerability to Pollution of the Plio-Quaternary Aquifers of the Coastal Basin of Essaouira (Morocco)

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Abstract
The Essaouira synclinal area is part of the semi-arid areas of Morocco which are subject to the impacts of climate and anthropogenic pressures. It is also expected to experience an important agro-industrial development. Water requirements are important for the development of all these activities. Although the situation is not yet alarming, the fact remains that the quality of groundwater resources is constantly put to the test because of the growth sources as diffuse pollution that point. To prevent pollution of groundwater, one approach is the knowledge of especially vulnerable areas. It is for this reason that this study was initiated to produce a map of intrinsic vulnerability of aquifers in the region. The method used to make the card is the numerical rating DRASTIC method (Aller et al. 1987). 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 results indicate that the region is dominated by the class of high vulnerability (61%) followed by the class of very high vulnerability (20%), then the class medium vulnerability (15%) and the class of low vulnerability (4 %). Class very high vulnerability is located in the western coastal area. The center of the basin is dominated by the class of high vulnerability to the east, past the middle and low class. Almost throughout the Oued Ksob is particularly dominated by the class of high vulnerability.
Keywords: basin of Essaouira; aquifer; semi-arid regions; hydro geochemistry; stable isotopes; recharge; vulnerability, pollution, DRASTIC, management, protection of water resources

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).

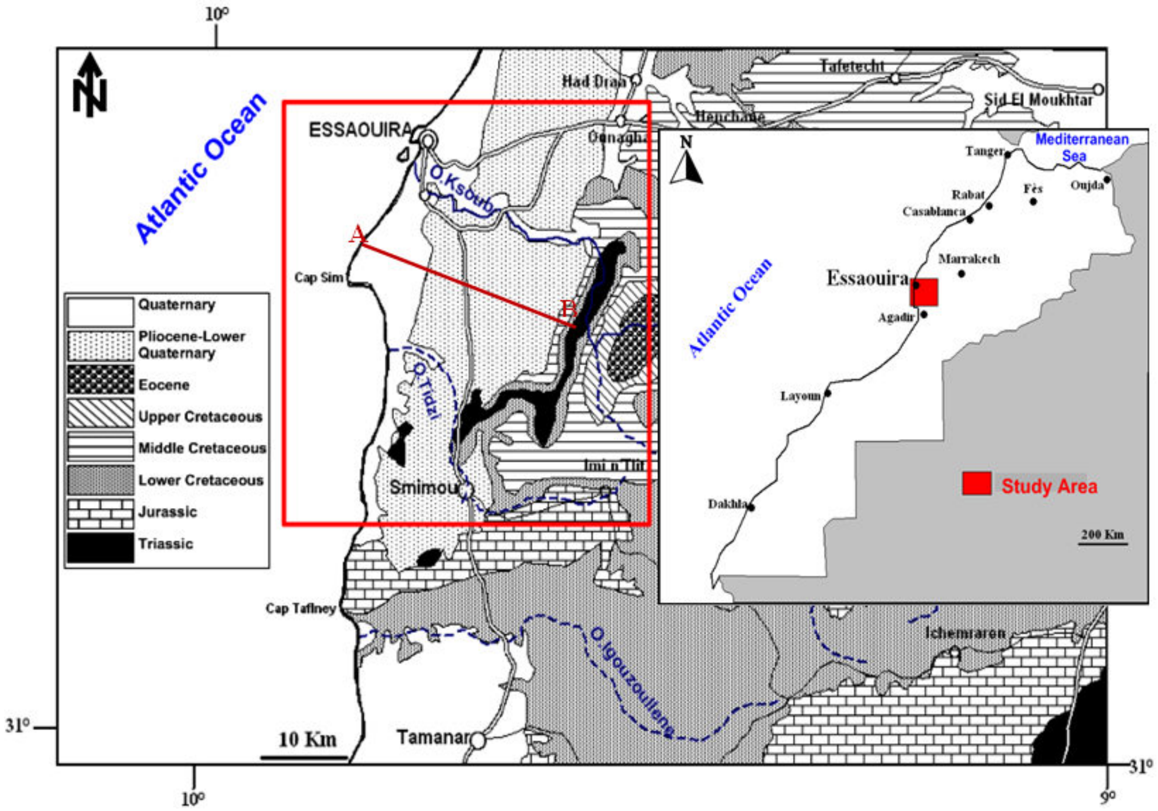

Figure 1. Geological map (adapted from geological map of Morocco 1 / 1000000. 1985). A–B represents the cross-section location of Fig. 4.

In geological terms, the Essaouira synclinal zone is less rugged, with a lower relief (Fig. 3), 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 irrigate farmland (Bahir et al. 2000). The Turonian, contains a layer quickly captivated by the Senonian marls in the synclinal structure and probably in direct contact with the Pliocene-Quaternary on the edges of this structure to the north to Ksob Wadi, the West's approach of Essaouira diapir hidden in the east and south near the Tidzi diapir. The aquifer is made of dolomitic limestone affected by a Fracturing N 110 °, the same direction as the fault detected by geophysics along the Ksob Wadi (Fekri, 1993). The wall of this layer is constituted by the Cenomanian marls are representative of the study area.

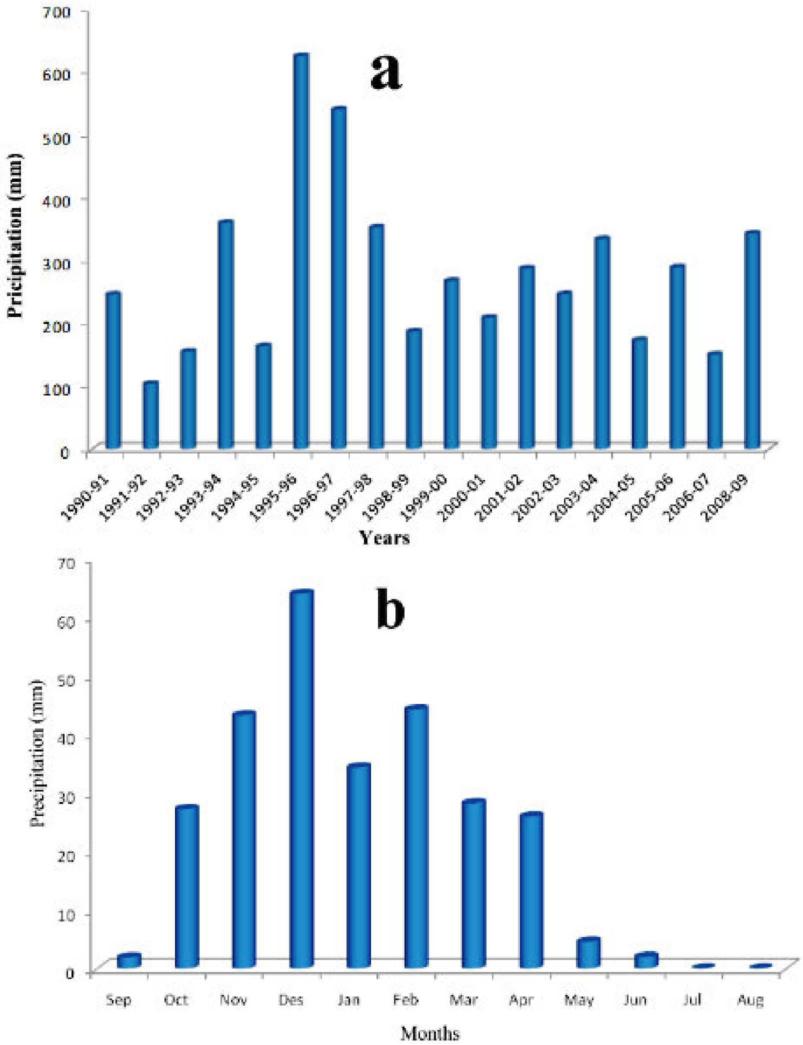

Figure 2. Precipitation (a) annual values and (b) monthly mean values at Essaouira Station (1990-91 to 2008-09).

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.

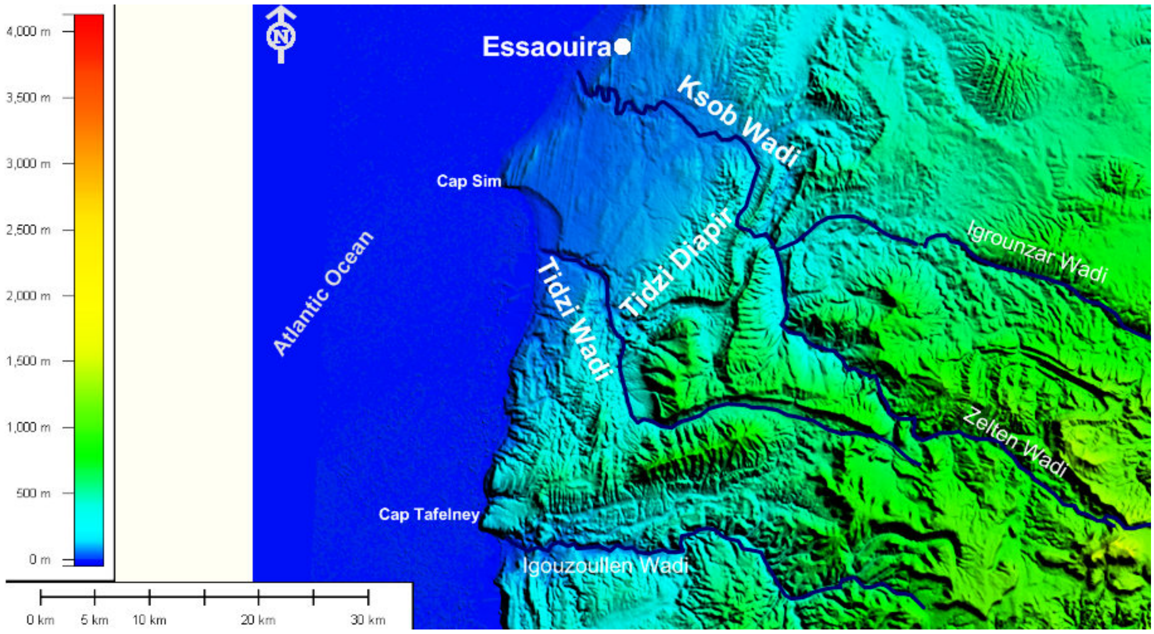

Figure 3. MNT map of the study area.

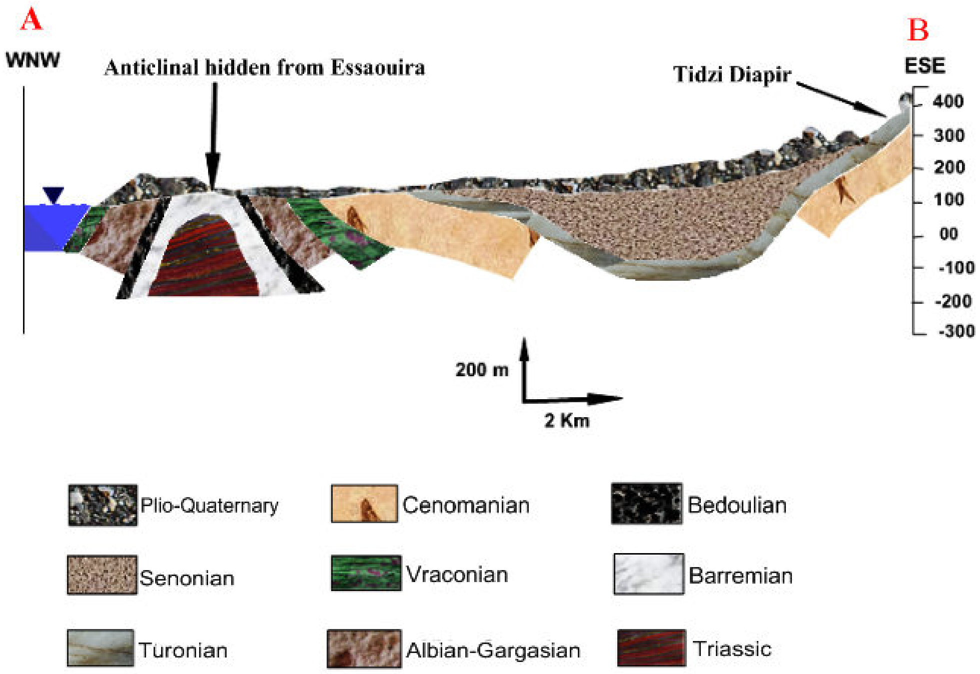

Figure 4. Geological section of the syncline of Essaouira (after Fekri 1993, modified). For location, see Fig. 1, section AB.

The present position of the study area leads to a deterioration of water quality caused by the rise in salinity and the danger of seawater intrusion due to over-exploitation of groundwater. It is a region that is expected to experience a significant development given position as a crossroads area. The development is not without problems related to the quality of groundwater resources. Although the situation is not yet alarming, the fact remains that the quality of the groundwater resource is constantly put to the test because of the growth sources as diffuse pollution that point. To prevent pollution of groundwater, one approach is the knowledge of especially vulnerable areas. Vulnerability maps produced and indicate the most vulnerable to contamination. Our study aims, to make a map of intrinsic aquifer vulnerability in order to make a regional mapping of vulnerable areas to prevent the risk of pollution in the region, and to assist public authorities in the development, management, protection of groundwater for raising public awareness of environmental things. To achieve our objective, the methodology used to realize our vulnerability map is the DRASTIC method.

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).
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.

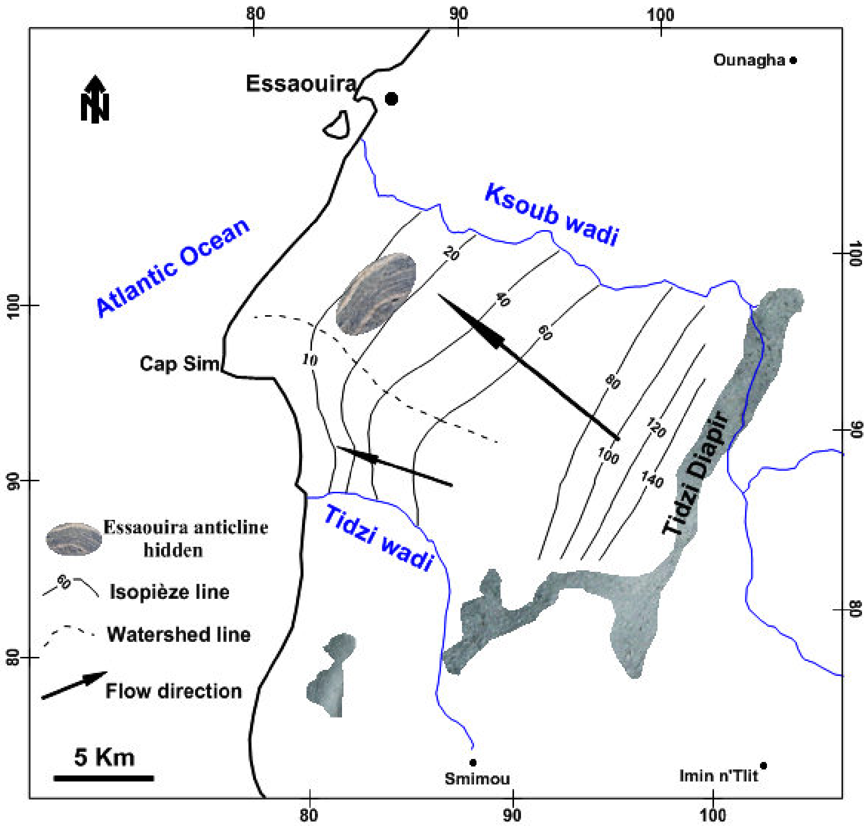

Figure 5. Essaouira basin piezometric map in October 2009.

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.

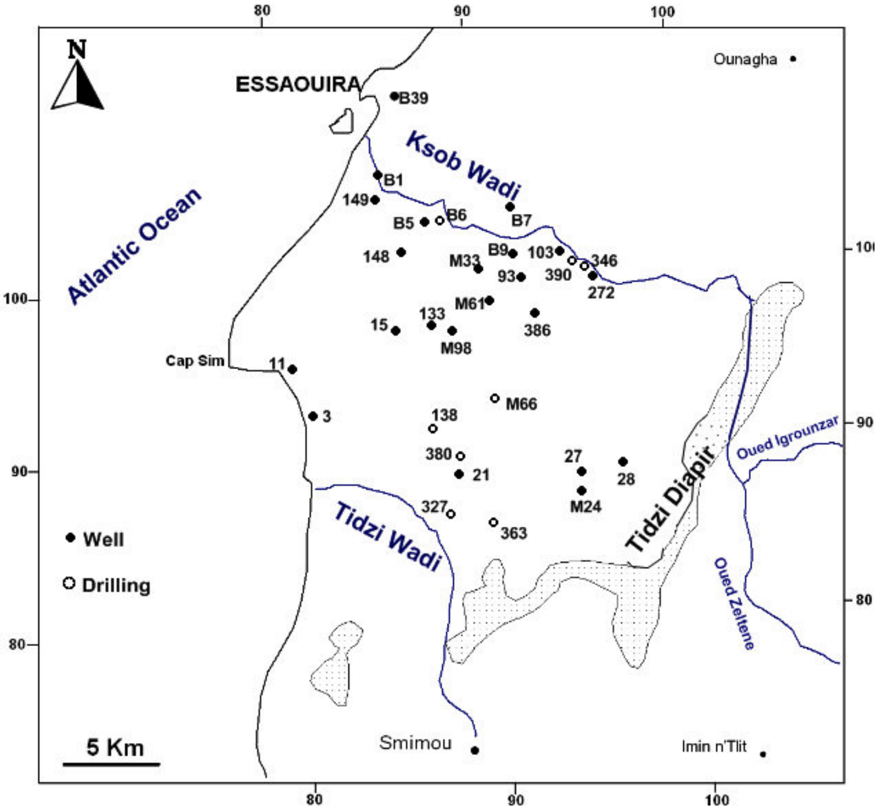

Figure 6. Distribution of sampled water points in the study area.

- 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.

Table 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	PlioQuat
B3=138-51	87,85	92,83	109	5	104	26	3520	21	7,31	PlioQuat
B4=M33	91,15	102,3	78	29	49		2040	20	7,41	PlioQuat
B5	90,29	102,26	102	48	54	56	2249	19	7,4	PlioQuat
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	PlioQuat
B8=93-51	92,37	101,9	98	44	54	28,7		21		PlioQuat
B9	93,41	102,68	114	47	67	50	1763	19	7,41	PlioQuat
B10=M61	91,2	100,75	90	34	56	40	1720	23	7,5	PlioQuat
B11=103-51	94,82	102,17	99	22,5	76,5	26,5	1671	21	7,3	PlioQuat
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	PlioQuat
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	PlioQuat
B17=15-51	86	97,97	70	7	63	8,8	3070	15,5	7,1	PlioQuat
B18=3-51	81,4	93,4	18	4	14	11	2130	19	7,44	PlioQuat
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	PlioQuat
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	PlioQuat
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	PlioQuat

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.

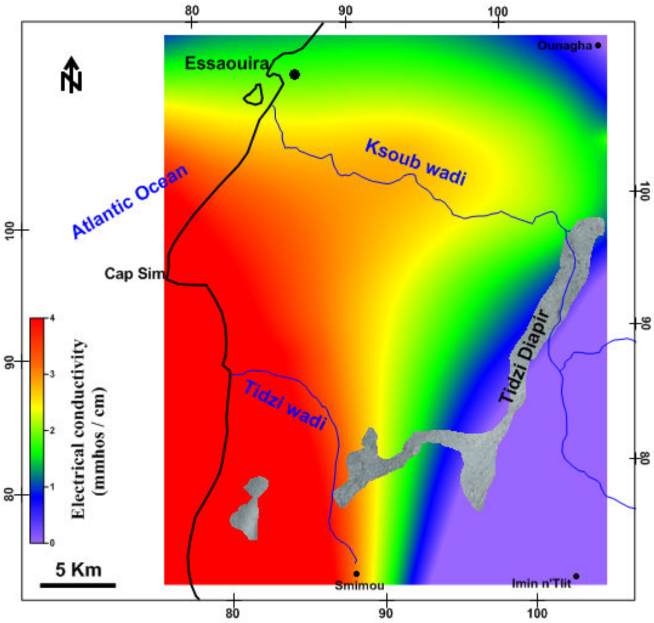

Figure 7. Spatial distribution of electrical conductivity in the Essaouira basin.

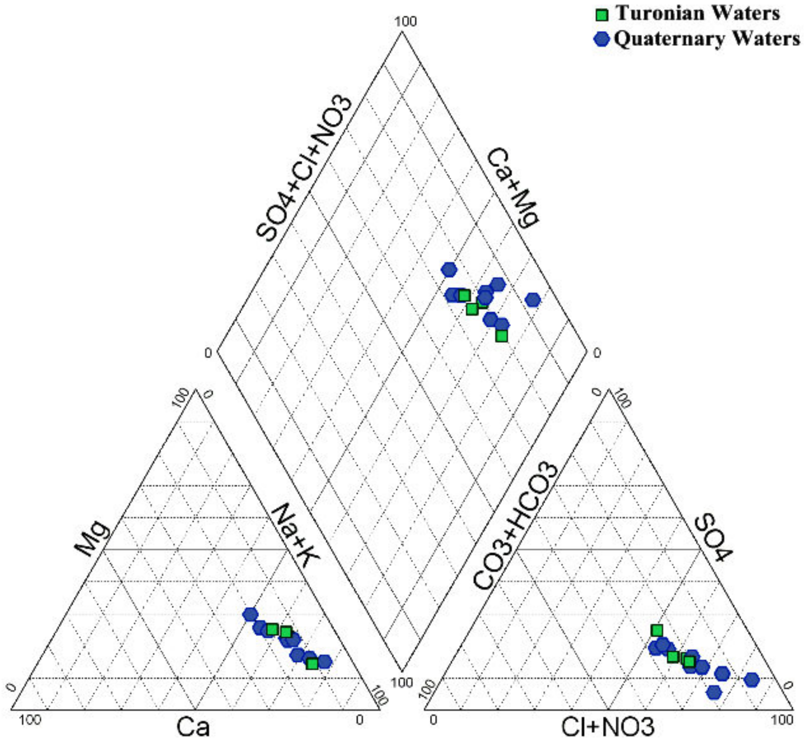

Figure 8. Piper diagram of Plio-Quaternary water and Turonian water.

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).

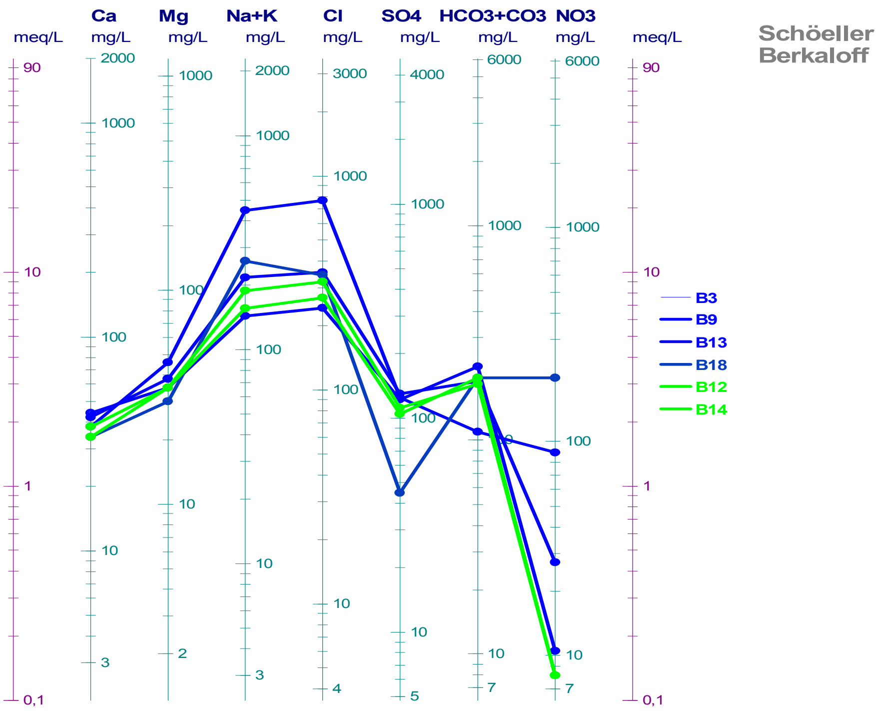

Figure 9. Facies chemical wastewater Plio-Quaternary (B3, B9, B18 B13et) and Turonian (B12 and B14).

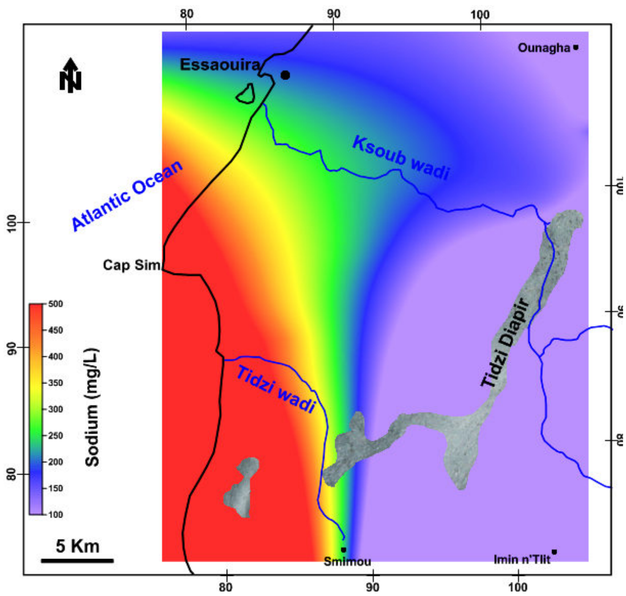

Figure 10. Spatial distribution of sodium in the Essaouira Basin Syncline.

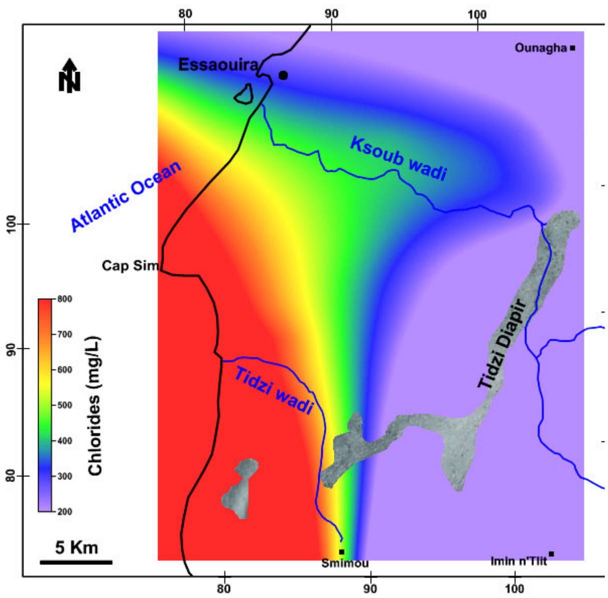

Figure 11. Spatial distribution of chlorides in the Essaouira Basin Syncline.

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.

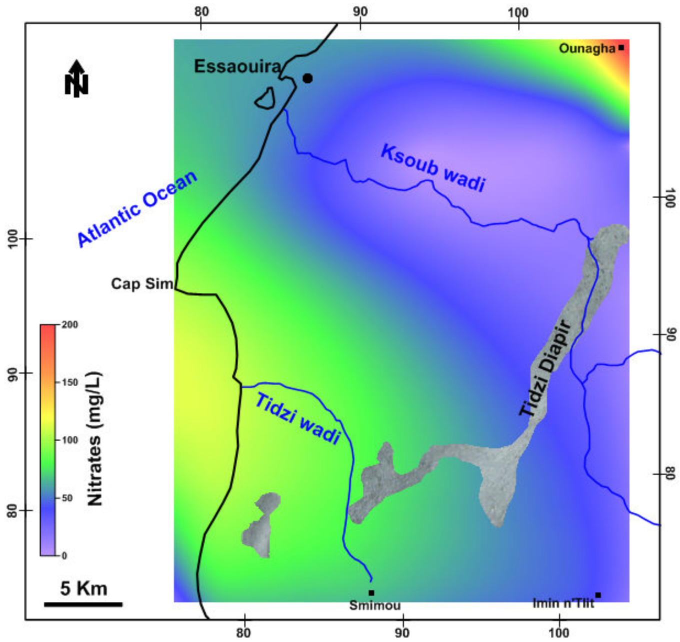

Figure 12. Spatial distribution of nitrates in the Essaouira Basin Syncline.

- 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.

Table 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).

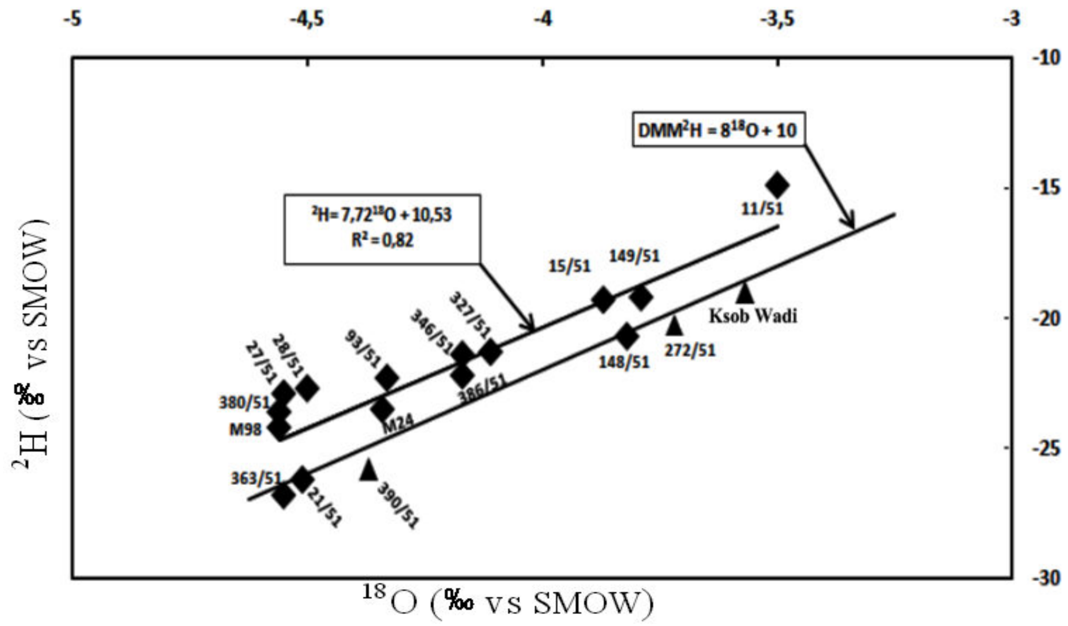

Figure 13. Relationship ^{18}O – deuterium the groundwater in the area of Essaouira synclinal.

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.

Table 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.Establishment of the Vulnerability Map

In the case of the vulnerability map of the coastal groundwater basin Essaouira we present (Figure 14), the criteria considered are shown in Table 4. Card overall vulnerability of the syncline Essaouira basin has four classes of vulnerability. Two major areas are distinguished: the coastal area downstream of the basin where Class 4 very high vulnerability (> 200) dominate this area is particularly noteworthy because it is very high permeability, high density of lineaments strong and effective charging very low runoff. The inner area where the high vulnerability class 3 (142-200) dominates. Classes 2 and 1 medium vulnerability (140-101) to low (<101) are poorly represented and located only a lover of the basin. Thus, the coastal edge that provides the most important hydraulic potential, where groundwater is the most exploited and concentrates most of the agricultural activities is the most vulnerable urban aquifer system, without neglecting the effect of sea spray and aerosols washed out by rain seeping into the aquifer.

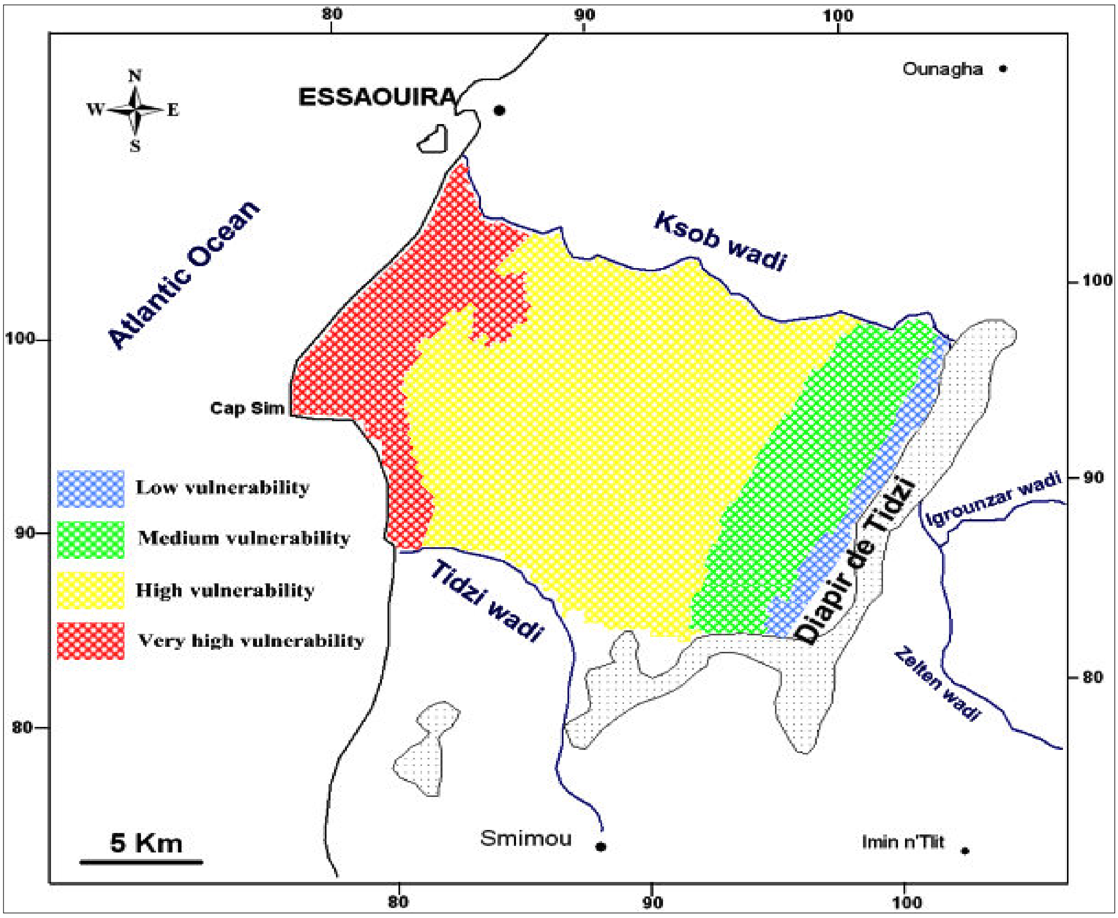

Figure 14. Map of vulnerability of the coastal aquifer Essaouira.

The difficulty in achieving a vulnerability map using the DRASTIC method is related to the number of hydrogeological factors (7) taken into account. The values of some factors, such as charging, was determined by extrapolating a lot of data such as flow stream values. To this we must add a limitation to the accuracy of the measurement of the depth of the water. This accuracy is a function of the interval between contours of the groundwater. More intervals are wider and less precise is the estimate of the depth of the water and that the problem of data continuity. The hydraulic conductivity values depend on the method used for making the estimate. Being in the middle of base, the permeability values found are they those of regolith aquifers or cracks? This map depicts the relative vulnerability of aquifers based on data available at different levels of accuracy and resolution. The resolution itself depending on the number and proximity of measurement points. Several maps of different resolutions were combined and this may pose problems of scale for example. However, the combination of resolution is acceptable to assess the relative vulnerability of aquifers but not adequate to determine the specific vulnerability of a given (Osborn et al., 1998) site.

Table 4. Criteria considered for the acquisition of vulnerability assessment criteria in the study area

Criterion	Notation	Criteria retained
(D) Depth of water	We will consider six or seven classes thickness. For example, the note will go from 10 to zero thickness of 1 to a thickness greater than 10 m	6 classes Weight parameters is 5
(R) Value charging	The note may be from 10 to interannual average rainfall exceeds 500 mm to 1 for 100 mm	1 class. 4 is the weight parameter
(A) Lithology of the aquifer	The notes can vary between 10for karst limestone to 1 for clay fine sand	1 class Weight parameter is 3
(S) Soil (Soil Science)	The rating will depend on the type of soil	2 classes 1 is the weight parameter
(T) topography (slope value)	The score of 10 is attributed to low slopes (plain) and up to 1 for the steeper slopes (rugged mountains)	3 classes 1 is the weight parameter
(I) Nature of the training of the unsaturated zone.	The rating will depend on the nature of the surface formations: from 10 to 1 for coarse alluvial clays	1 class Weight parameter is 5
(C) permeability of the aquifer	The notes can vary between 10 for 10-3 permeability to 1 for 10-8permeability	1 class Weight parameter is 3

This is a map designed on a scale of 1/100 000 for a regional study and should not be used at larger scales because it would create the analysis because many details are lost during its development errors. Despite various limitations arising from this kind of card, there remains the intrinsic vulnerability map using the DRASTIC method is reliable and gives an idea of the sensitive areas that will have to take into account during the development of the basin.

6.Conclusion

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 application of the DRASTIC method possible to achieve map intrinsic aquifer vulnerability of coastal Essaouira basin. The analysis of the latter shows four classes of vulnerability uneven spatial distribution:

A class of very low vulnerability covering 20% of the department and mainly located in the western part, in direct contact with the Atlantic Ocean;

A class of high vulnerability, by far the largest, covering 61% of the basin area and identify the center;

A class medium vulnerability covering 15% of the basin identified in the eastern part;

Finally a low vulnerability class covering 4% of the department identified in the East zone right touch with the diapir Tidzi.

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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