Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 5 (4): 678-685, 2005
ISSN 1812-5654

The Hydrodynamism of the Coastal Aquifer System Belonging to the Southern Border of the Rharb Basin (Morocco)

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Abstract: The present study examines the hydrodynamism of the southern border of the Rharb basin. The groundwater system is characterized by two piezometric families marked by stable and unstable groundwater behaviours. The analysis and the interpretation of the piezometric levels are concentrated on the most informative piezometers. Between 1988 and 1998, the study reveals a variability in the piezometric levels according to different sectors of the coastal zone. The piezometric levels vary globally from +1.6 to +5.88 m in the northern sector (Ns), +0.5 to +4.5 m in the central sector (Cs) and +1.9 to +25.73 m in the southern sectors (Ss). The lateral repartition of the transmissivity values is materialized by a heterogeneous distribution ($1,5.10^{-1}$ to $2,8.10^{-3}$ m^2s^{-1} in the coastal part with an average is about 5.10^{-2} to $4,9.10^{-3}$ m^2s^{-1}). The causes of piezometric level variations are related firstly to the combination of deductions and pumping effects to supply in drinking water, towns and the industrial sector. They are also related to the geometry of the aquifer, that displays an important role in the knowledge of these variations and the aquifer functioning.

Key words: Groundwater behaviour, piezometric levels, transmissivity, water balance, hercynian reactivation

INTRODUCTION

The Rharb-Mamora basin represents the southernmost border of the Rifean Mountains. It is limited by two structural domains: the Mesetian zone affected by the Hercynian orogeny (Fig. 1a) and Rif Cordillera characterized by the complex structures resulting from the Alpine orogeny. The Rharb basin has been the subject of numerous sedimentological, paleontological and geodynamic studies[1-3]. Its petrochemical and hydraulics potentialities are considered as the most important economical area of Morocco.

The southern part of the Rharb is represented by the Mamora basin which feeds industrial and urban cities: Rabat the capital, Kenitra, Casablanca, El Jadida and the Rharb basin (Fig. 1b)[4]. From Kenitra to El Jadida towns extends a littoral urban network passing by Rabat. This conurbation includes 6 million of residents, 20% of the Moroccan people and 70% of industrial jobs of the country. In 1952, the Casablanca agglomeration has used 54 millions m^3 drawn in the Mamora groundwater[5]. The adductions realized between 1976 and 1983 from Bouregreg river increase to 410 millions of m^3an^{-1}. So, the Mamora groundwater represents a vital hydraulic system in the Atlantic margin.

The Mamora groundwater knows since forty years, an important economic boom with a great agricultural and industrial activity development associated with a strong demographic expansion.

Consequently, the important groundwater deduction causes piezometric fluctuations. Local authorities, agencies of Water (like the National Office of Drinking Water in Rabat City) or the Hydraulics Directorate are closely interested by problems involving the planning and the development of this sector.

The present study proposes to examine different factors controlling the variations of the piezometric levels. Hydrodynamical parameters and the structural approach have been taken into account.

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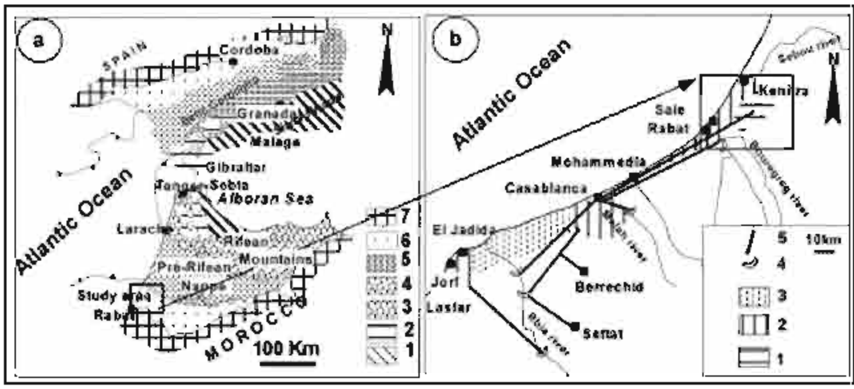

Fig. 1 (a, b): Tectonic map of the Gibraltar Arc and Supply water network (After[4], modified). a: 1. Internal domain, 2. Flysch units, 3. South-Iberian domain, 4. Maghrebian domain, 5. Accretionary wedge, 6. Foredeep, 7. Foreland, 8. Front of nappe. b: 1. Mamora groundwater, 2. Main urbanised zone, 3. Current and future urbanised zone, 4. Dam, 5. Supply water conduits

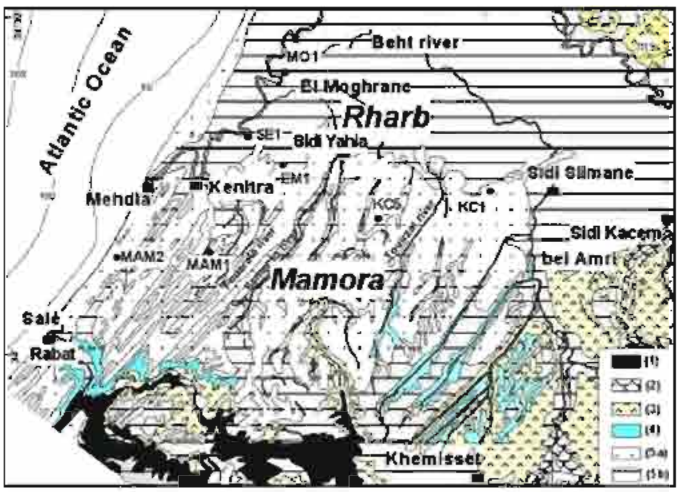

Fig. 2: Location and geology of the Rharb-Mamora basin[1]. Paleozoic, 2. Mesozoic (Middle and Upper Liassic, Middle Jurassic), 3. Miocene (Tortonian), 4. Pliocene, 5. Quaternary: 5a. Marine and beach formations (Middle to Upper Quaternary), 5b. Continental formations (Moghrebian, Villafranchian, Lower to Upper Quaterna ry), KC5. Oil wells (After[4], modified)

Geological characteristics of aquifer: The Mamora aquifer is composed by Plio-Quaternary deposits. It fundamentally consists of sandstone, limestones, sands, conglomerates and clays. Its impermeable is represented by the Mio-Pliocene blue marls[4] which outcrop in the vicinity of the Tiflete town and Bouregreg valleys (Fig. 2).

The geological level map (Fig. 3) realized from the interpretation of 230 hydrogeological drillings consist to determinate the formations at the fixed deep (+20, 0, -20, -40 m) The analysis of various deposits covering the aquifer basement reveals a heterogeneous distribution of the permeable deposits and a conglomeratic concentration in the eastern part.

Analysis and interpretation of the geological levels map reveal a deepening of the Mio-Pliocene aquifer basement and the thickening of the Plio-Quaternary deposits towards Atlantic Ocean and towards the Rharb basin. In order to understand this disposition, correlations between hydrogeological wells have been realized (Fig. 4). They reveal several informations: I) the first one is marked by the multilayered character of the aquifer, previously homogenous and monolayered[6-8]; ii) the Mio-Pliocene basement is surmounted by deposits thickens towards the north. The thickness of limestone formations varies from 20 to 40 m (drillings F13-1 and F13-5); iii) some hydrogeological units (sandy clays) present a lenticular

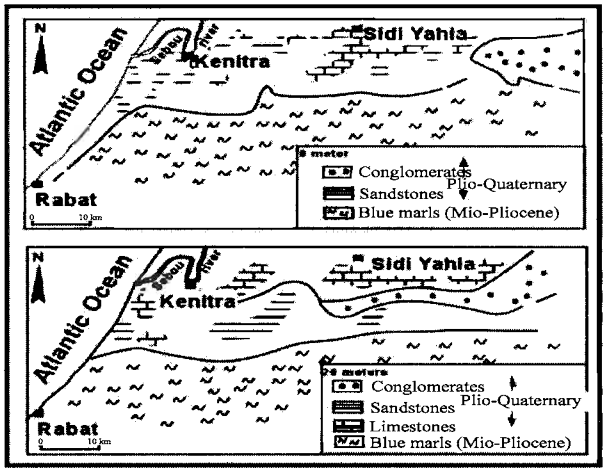

Fig. 3: Lateral repartition of the different deposits overlying the blue marls

character; iv) the deepening of the impermeable and the thickening of the permeable deposits are controlled by the fault network.

Piezometric levels: This work is based on piezometers which covering the coastal area (Fig. 5) and provide maximal informations. It is characterized by the continuity of measures and by their location. Three major zones have been distinguished:

The coastal Mamora groundwater is subdivided into three piezometric sectors:

i) northern sector, Ns: piezometers 1516, 1029;
ii) central sector, Cs: piezometers 1270, 1269, 1016, 1113;
iii) southernmost sector, Ss: piezometers 1292, 1117;

Northern sector Ns: It is located at the North-East of the Kenitra town. The piezometric analysis records since 1991 a fall of the PL. At the 1516, from 1991 to November 1995, the PL fell of 3.01 meters. The combination of the piezometry and the height of rainfall, reveals that this fall is related to the pluviometric deficit (Fig. 6a).

The Kenitra town is a center of industrial activities. The water deduction for supply this sector and the alimentation of drinky water can be considered as another argument causing this piezometric fall. From 1991 to 1997, the 1516 record levels oscillating between +1.6 and +5.88 m, while for 1029 it varies from -1,16 to +1,85 m. The both piezometers have the same behaviour, although with different levels. The extreme amplitude recorded in 1996 in the Eastern Mamora is about 3.3 m.

Central sector Sc: The piezometric analysis of this area (Fig. 6b) shows that the variation of the piezometric levels oscillate between +0,5 and +4,5 m. In 1988, for example, were recorded: +0,68; +0,65; +3,92 and +2,91 m, respectively for the piezometers 1270, 1269, 1016 and 1113. The groundwater behaviour led to the individualization of two piezometrics families: I) the first one present the variations of PL with the strong amplitude (1113 and 1016); ii) the second family is characterized by the weak amplitudes (1269 and 1270).

The preceding studies[9] showed that the piezometry of 1016 downward trend from 1979 to 1995. This fall reached 2.77 m in 16 years, that is to say about 17 cm an^{-1}. The Piezometric Plotting up to 1998, revealed an increase of the PL as from 3 January 1996. The water balance realized[9] underlined a very significant excess (Table 1) in Kenitra station, in particular 811.92 mm in 1996. The principal water deficit year was 1992. The strong fall, that we have just mentioned and the amplitude variations of LP could be caused by the combination of a pluviometric deficit and deduction series carried out by the ONEP (the National Office of Drinking Water) to feed the Kenitra town, its neighbourhoods and its industrial sector (Fig. 7).

Infiltration values are characterized by a heterogeneous spatial and temporal distribution. In 1989, the Kenitra station recorded 406.77 mm of infiltration against 308.58 mm in Rabat and 203.92 mm in Sidi Slimane. In the three stations, the infiltration values fall up to 1992 (deficit year), moreover, the second pick again is characterized by the increasing of infiltrations, globally light and which the strong value has been recorded in the Kenitra station (about 207.02 mm)

Coastal southern sector Ss: This area is characterized by the stable groundwater behaviour, except some piezometric fluctuations: a decrease observed as from February 1993 for the 1292 and an increase since 1997 for the piezometer 1117. Variations of the PL observable between these two piezometers varied from +1.9 m (for 1292) to 25.73 m (for 1117) (Fig. 8). Between 1988 and 1998, the piezometric levels oscillate from +23 to +25.73 m at the piezometer 1117 and +1.9 to +5.26 meters at 1292.

Table 1: Daily water balance of the Kenitra station (1988-1997)

Years	P (mm)	ETR (mm)	RFUi-RFUf (mm)	EXCTot (mm)
1988	410.50	249.99	25.00	160.51
1989	705.80	282.08	3.99	423.72
1990	485.10	233.78	5.22	251.32
1991	471.90	241.76	25.00	230.14
1992	295.70	247.45	15.90	48.25
1993	537.50	321.85	15.84	215.65
1994	378.90	244.17	25.00	134.73
1995	426.80	270.55	1.77	156.25
1996	1132.00	320.08	0.00	811.92
1997	757.40	271.57	0.00	485.83
Total	5601.60	2683.29		2918.31

This heterogeneity is one of the characteristics of Mamora groundwater. Globally, in zone A, it is of the +1.9 to +25.73 m in the South (Ss), +0.18 to +4.55 m in the center (Sc) and -1.27 to +5.88 m in North (Sn).

DISCUSSION

The spatial and temporal study of the piezometric levels in the Mamora aquifer showed that according to the sector, the groundwater behaviour results from heterogeneities in piezometric levels. Two families can be distinguished:

i) the first family shows an unstable character marking by various groundwater behaviours. It affects the northern part Sn and central Sc of coastal zone area where the amplitudes can respectively reach 5.88 and 4.5 m. A fall of the water level was underlined in these two sectors, until 1995. The piezometers recorded in these sectors an increasing groundwater since 1995.
ii) the second family in almost stable character was identified in the southern part and in the centre of the coastal zone. In order to understand the variation of the piezometric amplitudes in the various zones of the field study, pumping test interpretations highlight to establish a distribution of the transmissivity values. Their spatial repartition is generally heterogeneous (Fig. 9):

- In the Western part, the transmissivity values varied between $2,8.10^{-3}$ to $1,5.10^{-1}$ m^2s^{-1}. The transmissivity average (Table 2) in this zone was evaluated between 49.10^{-3} to 5.10^{-2} $m^2 s^{-1}$;
- Between the Fouarate and Semento rivers the pumpings test made it possible to determine a transmissivity varying from 5.10^{-4} to $1,5.10^{-2}$ m^2s^{-1} and an average of $7,75.10^{-3}$ m^2s^{-1};

The interpretation of the transmissivity values shows a heterogeneous lateral repartition. The various lithofacies and thickening of the permeables bodies[10] can explain this distribution which influences the amplitude repartition of the piezometric levels.

The causes of the piezometric levels variation are not only related to the pumping test and water deductions intended to supply towns, agricol and industrial sectors. The geometrical configuration of the aquifer could also play a significant role in the understanding of these variations. The structural work realized in the Rharb-Mamora basin[4,10,11] show that the aquifer system is subdivided into several blocks (horst and graben).

Table 2: Repartition of the average transmissivity (m^2 s^{-1}) in the different sectors of the mamora aquifer

Sectors	Zones	Average (m^2 s^{-1})
Ss	Coastal	5.10^{-02}
Sc		6.10^{-02}
Sm		$4,8.10^{-03}$

The geological sections (Fig. 10b) have been established following N030 (section 1 based on the hydrogeological drillings) and N140 (section 2, based on the hydrogeological and oil wells). Two major Hercynian faults are identified: Kenitra-Sidi-Slimane Faulted Zone (K2SFZ, Fig. 10a) and Rabat-Kenitra Faulted zone (RKFZ). The K2SFZ, is attached to the Hercynian fault Rabat-Tiflete[12] and RKFZ is parallel at the coast line, is related to the regional accident Rabat- Agadir[13]. The Rharb-Mamora is separated by a replique of the K2SFZ (Fig. 10c), individualizing two sectors: I) southern part with geometrical configuration in horst and graben, ii) northern part characterized by a thickening of the Plio-Quaternary deposits. The correlation between the structuration of the aquifer (in horsts and grabens) and the variation of the piezometric levels is strongly probable. The Hercynian reactivation (Fig. 11) highlights a faulting play involving a display in the Plio-Quaternary aquifer and in its basement (The Mio-Pliocene blue marls). This device controls the aquifer partition in horst and grabens and the distribution of the piezometric levels.

The piezometry of the aquifer system (Fig. 12) provides qualitative informations on the direction of groundwater flow and the various structural directions in conformity with the geological investigations in the area. The piezometric levels varied between 0 and 90 m. The altitude of the groundwater top is maximum in the South-East of Mamora. On the other hand, minimal altitude is in the North-West. In the coastal area, the piezometric map highlights a parallel anomaly on the coast. It is characterized tight of the isopiezes, in particular between the Sidi Bouqnadel and Kenitra towns (zone affected by the Hercynian fault RKFZ). The groundwater level falls there brutally from 65 to 5 m. We distinguish two dividing limits and one drainage axis: a) two dividing limits identified in this zone and representing a groundwater flow toward northern Kenitra city and toward the west; b) the presence of the drainage axis allows groundwater draining toward the Atlantic Ocean

The analysis and the interpretation of the piezometric levels realized in the southern part of the Rharb basin show several behaviours of the groundwater. According to the piezometry analysis, the study area is subdivided into three coastal sectors : northern, central and southern zones. The behaviour is stable to unstable in the coastal zone. The piezometric levels varied in the western area

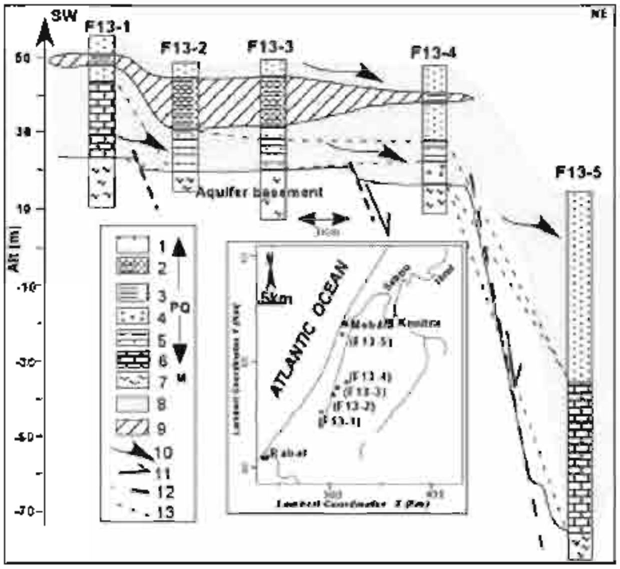

Fig. 4: Geometrical characteristic of the aquifer and hydrogeological units. 1. Sands, 2. Sandy clays, 3. Clays, 4. Gravels, 5. Sandstones, 6. Limestones, 7. Blue marls, 8. Aquifer zone, 9. Lenticular form, 10. Groundwater flow, 11. Displacement sense, 12. Faults, PQ. Plio-Quaternary, M. Mio-Pliocene, 13. Correlations

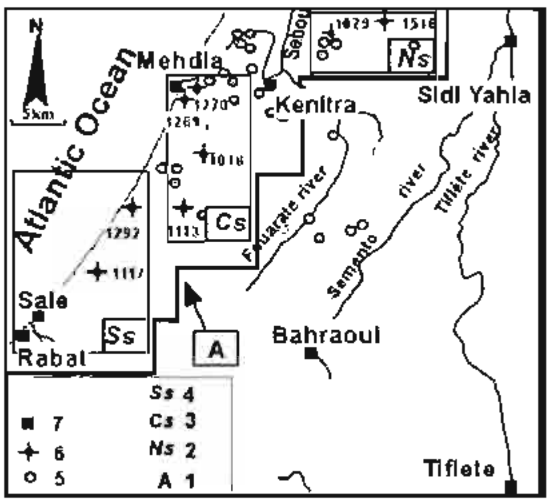

Fig. 5: Piezometric subdivisions of the Mamora (1. piezometric area, 2: northern sector, 3: central sector, 4: southern sector, 5: water deductions, 6: piezometrs, towns)

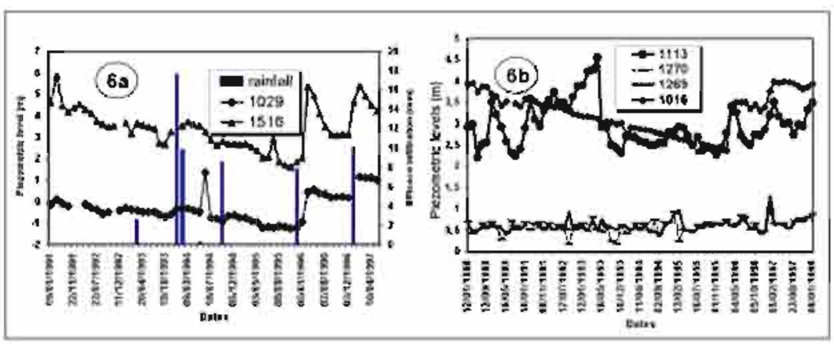

Fig. 6: Groundwater behaviour in the northern (Ns) and central (Cs) sectors of the coastal zone

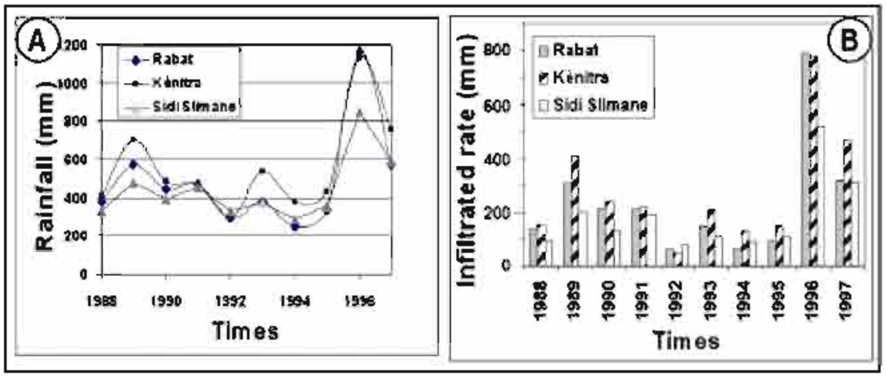

Fig. 7: Rainfall distribution in the Mamora basin

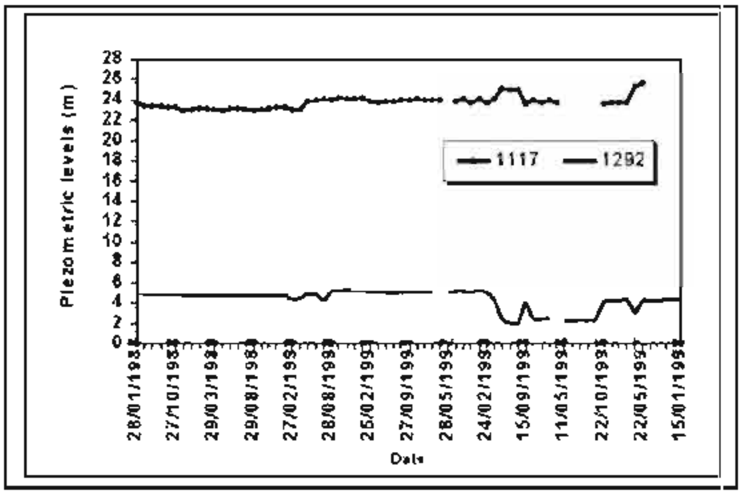

Fig. 8: Piezometric levels partition in the southern part (Ss)

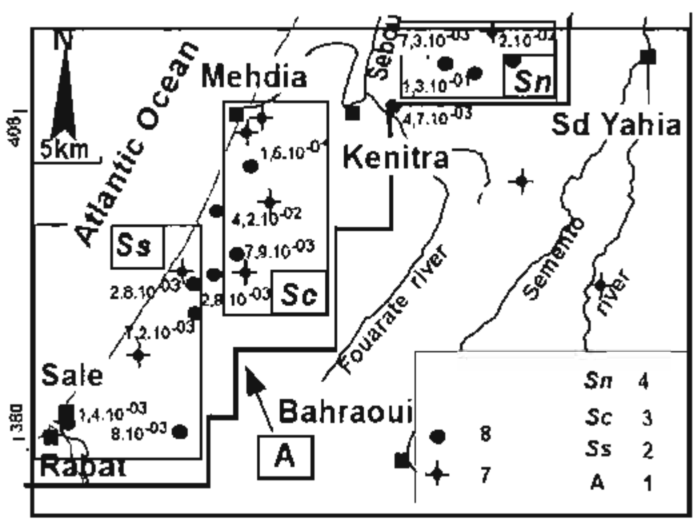

Fig. 9: Spatial distribution of the transmissivity values

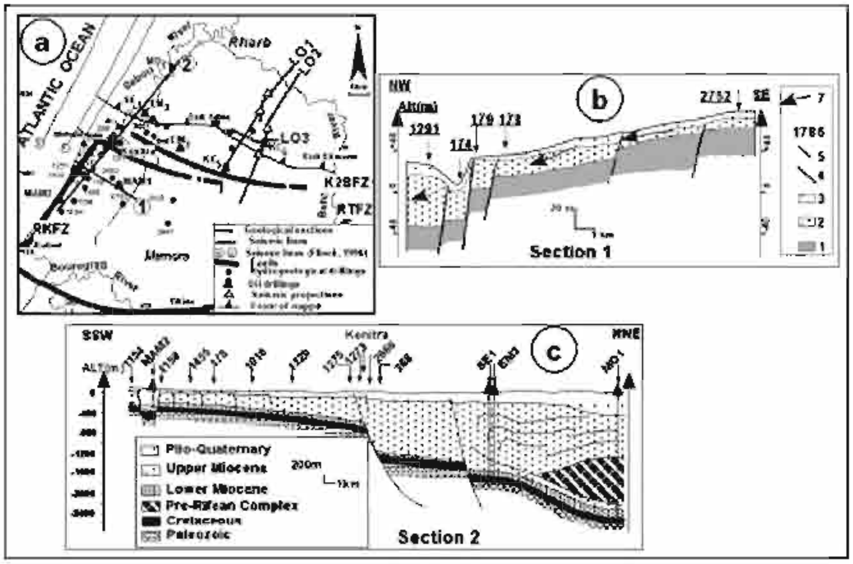

Fig. 10: A: Location of the geological and seismic sections[4], B: horsts and grabens devices of the Mamora aquifer, C: geometrical configuration of the Rharb-Mamora with the Hercynian faults. [B: 1. Mio-Pliocene, 2. Pliocene, 3. Quaternary, 4. Faults, 5. Probable fault, 6. Drilling, 7. Groundwater flow] (after[10,11], modified)

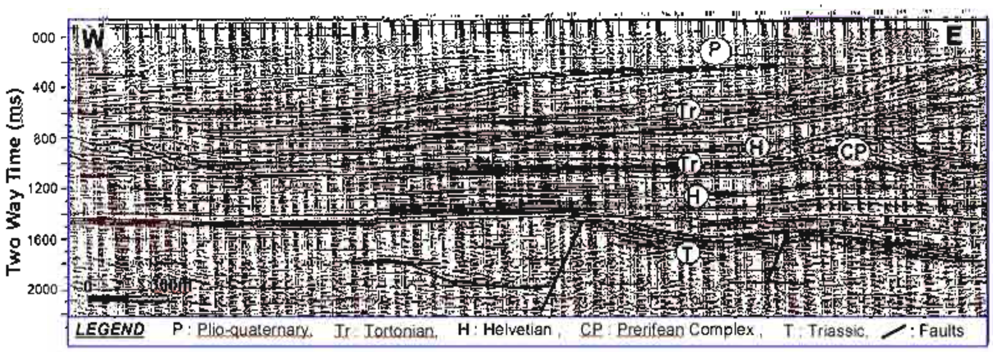

Fig. 11: Hercynian activity and structural influence on the underlain formations (After[11], modified)

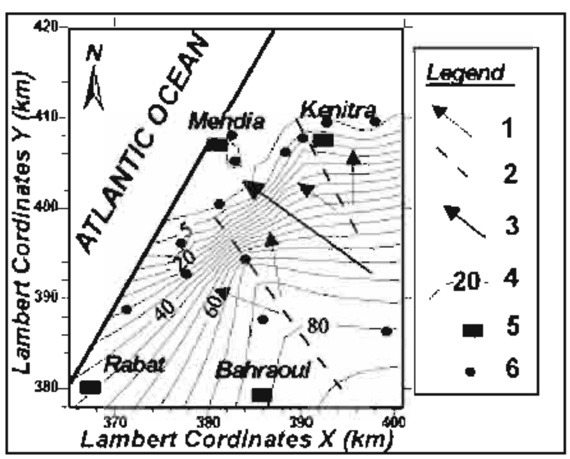

Fig. 12: Piezometric map of the Western Mamora groundwater (1995) [1. Groundwater flow, 2. Groundwater dividing, 3. Drainage axis, 4. Isopiez (in metres), 5. Cities, 6. Piezometers. After [4], modified]

from +1.6 to +5.88 m in the northern sector (Ns), +0.5 to +4.5 m in the central sector (Cc) and +1.9 to +25.73 m in the southern sectors (Ss). The relation between the transmissivity variation and the lateral variation of deposits, in the other hand, the structural control can explain distribution of the piezometric levels in the Mamora basin.

ACKNOWLEDGMENTS

The authors are grateful to the Editor, I PASHA, Managing Editor, MM BENBIBA, ZEROUALI (Hydraulics Directorate, Rabat) and the ONAREP (Rabat) for their helpful comments and suggestions on earlier drafts of this work.

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