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The quality of surface water and groundwater in the eastern Haouz and Tassaout area, Morocco

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Abstract The eastern Haouz and Tassaout area of Morocco is an intra-mountain plain characterized by a semi-arid climate, where there is an increasing demand for agricultural productivity. To meet this need, local irrigation is dependent on the supply of water from surface and aquifer sources. Piezometric mapping shows that groundwater recharge is driven by anastomosis in contact with limestones outcropping in the High Atlas Mountains, and by re-infiltration of irrigation water along the upper Tassaout River. Another recharge area is located further downstream in the plain bordering the Jebilet Mountains. The hydrodynamic behaviour of the groundwater in the eastern Haouz and the Tassaout area is controlled by a divide, as evidenced by gravity anomalies. Electrical conductivity measurements and geochemical analysis have been used as a basis for mapping groundwater quality. The salinization problem is mainly caused by the presence of shales and salt Triassic deposits, whereas alternative pollution is primarily due to water contamination by nitrate leaching.

Key words Haouz plain; Tassaout area, Morocco; irrigation; geophysics; piezometric; salinity; nitrate pollution

INTRODUCTION

The Eastern Haouz basin and Tassaout area of Morocco represent a wide depression characterized by an irrigated perimeter of approx. 52 000 hectares. Both surface and groundwater are subject to intense exploitation to meet the supply requirements of increased tourism, irrigation and the industrial treatment of olive oil, reflecting the hundreds of hectares of olive trees exploited commercially. As a result of the semi-arid climate and additional stress caused by a succession of drought years over recent decades, local farmers have been forced to over-exploit groundwater supplies using pre-existing and new deeper wells. In addition to reduced groundwater supplies, other issues involve the quality of the groundwater due to salinity problems and increasing nitrate concentrations.

These problems have been reported by other authors working on plains with a semi-arid climate across Morocco, including the Kert plain (Elgettafi, 2011), the Bou-Areg plain (El Yaouti, 2009), the Haouzia Sahel (Mdiker, 2008), the Saidia plain on the eastern Mediterranean coast (El Mandour, 2008), the Triffa plain (El Mandour, 1998), the Chaouia coastal plain (Marjoua, 1995), the Souss Massa plain (Krimissa, 2004), the Tadla plain (Bouchaou, 2009) and the Bahira plain (El Mokthar, 2012). For all of these cases, the integration of geological, geophysical and hydro-geological data is essential for underpinning improved management of both surface and ground-water supplies. Against this context, this paper presents the interpretation of a range of datasets available for characterizing the principal aquifer of the Eastern Haouz and Tassaout study area.

THE GEOLOGICAL AND GEOPHYSICAL CONTEXT

The Eastern Haouz and Tassaout area is located about 60 km east of Marrakech city (Fig. 1). It is part of the Western Moroccan Meseta, and extends in an east–west direction, between the mountain ranges of the High Atlas in the south, the Hercynian Jebilet Mountains in the north, Ghdat River in the west and Lakhdar River in the east.

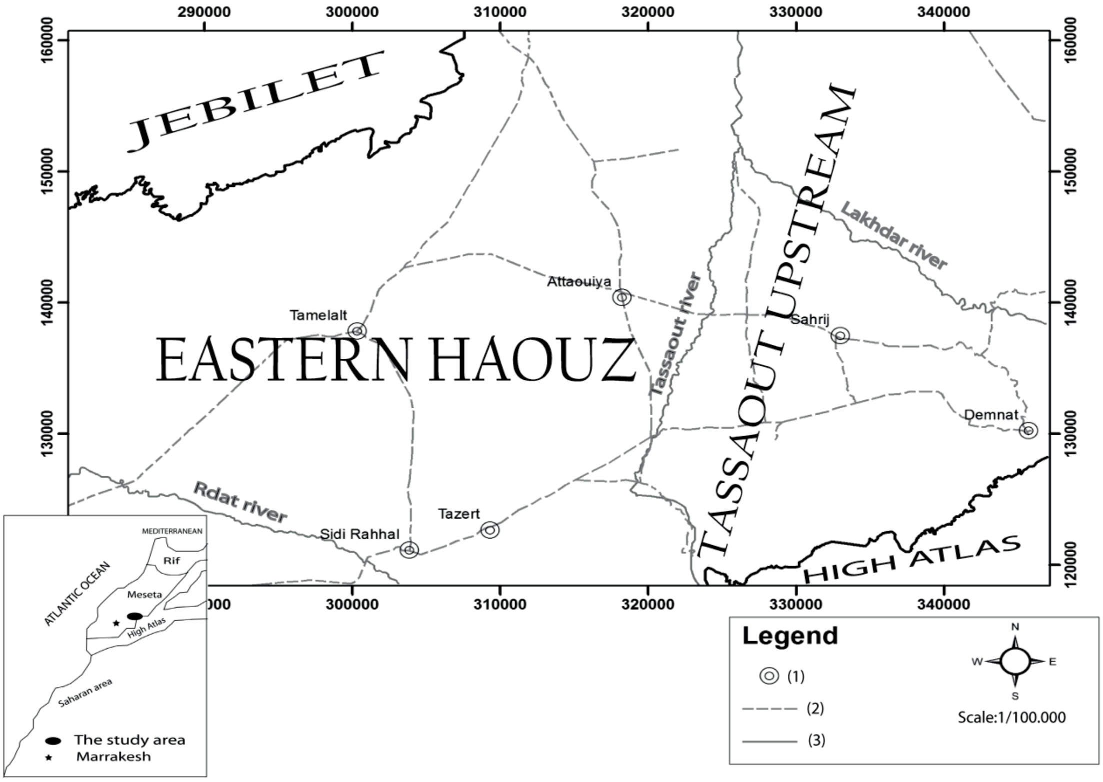

Fig. 1 Overview of the study area (legend: 1 - villages; 2 - roads; 3 - rivers).

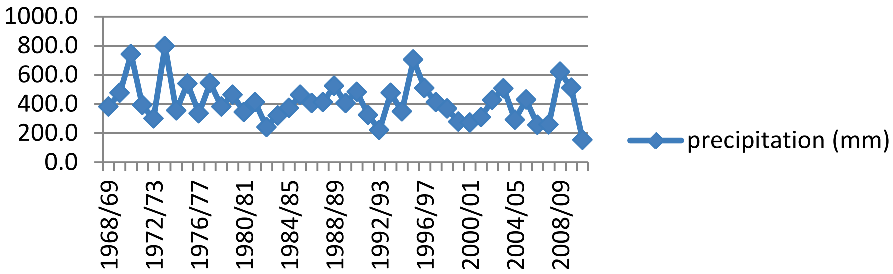

Fig. 2 Precipitation (1968–2011) recorded at Ait Aadel tipping bucket rain automatic gauge station.

The Haouz plain is characterized by a continental semi-arid climate with an average annual precipitation of about 300 mm (Fig. 2), high evaporation and high average temperatures (up to 39°C), but with significant monthly and daily variations. The area is drained by the Tassaout and Lakhdar rivers fed by the High Atlas Mountains.

Analysis of the geological map (Fig. 3) and interpretation of 100 boreholes, suggest that the study area consists of five principal geological formations from bottom to top, viz.:

– *Basement formation:* the nature of the basement of the Haouz basin is relatively well known thanks to many studies (Felenc, 1985; Bamoumen, 1988; Leblanc, 1993; Hibti, 2001; El Harti, 2004). It comprises a very thick series of micaceous schist, with quartzitic sandstone, and black shale with graptolites.
– *Triassic formation:* formed by lagoonal clastic continental deposits of clay, sandstone and evaporate layers with basalt and dolerite (Razoki, 2001).
– *Jurassic and Cretaceous formation:* formed of transgressive marine deposits (limestone), outcrops only in the southern part of the plain but has been picked up by some deep boreholes in the centre of the plain.

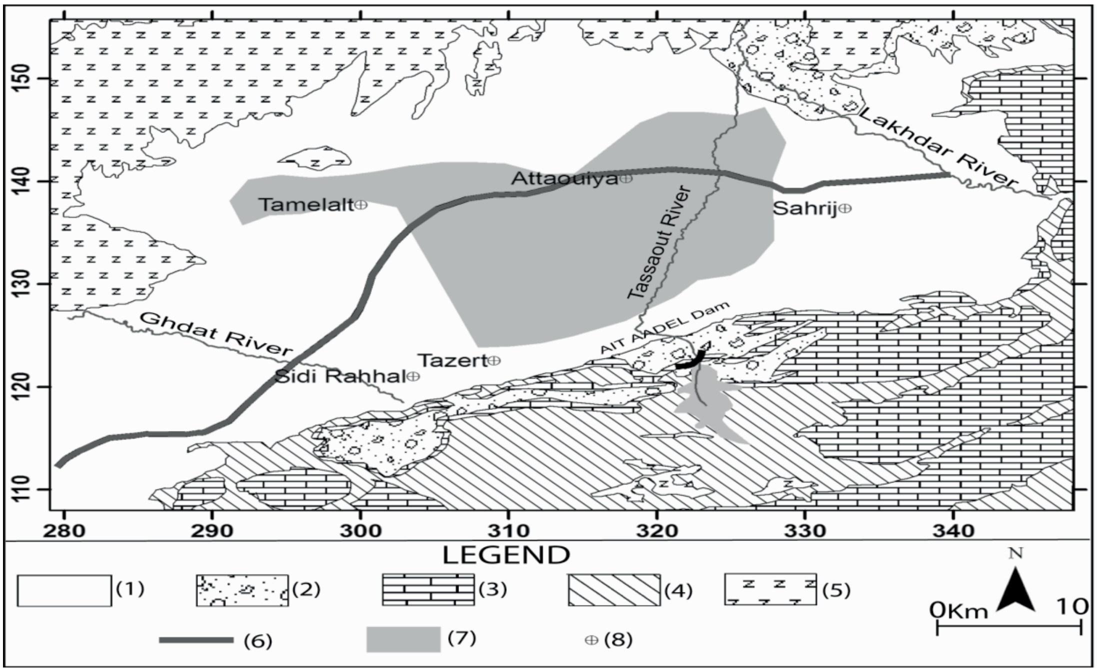

Fig. 3 Geology of the study area (according to the 1:50 000 geological map of Morocco) and location of the irrigated perimeter of Tassaout. 1. Quaternary: alluvium, silt and encrusted deposits; 2. Mio-Pliocene: conglomerates, limestones and marls; 3. Jurassic and Cretaceous: limestones, marls and sandstones; 4. Triassic: Dolerites, clays and conglomerates with deposition of evaporites; 5. Palaeozoic: schist, sandstones and quartzite; 6. Rocade channel; 7. Irrigated perimeter; 8. Villages.

– *Mio-Pliocene formation:* formed by limestones or dolomites, alternating with sandstone layers.
– *Quaternary formation:* formed by alluvial facies comprising sandstones, silt, gravel, cobbles and polymictic conglomerates.

Gravity data used by this study cover the period since the 1960s (El Goumi, 2010). The gravity measurements were conducted by the African Geophysical Company (GAC) at stations spaced 500 m apart, and placed along roads and tracks in a network that provides a good spatial coverage of the Haouz plain. Close examination of the gravity map of the Bouguer anomaly reveals the existence of a regional trend. This trend was determined and subtracted from the original data, which, in turn, yielded a residual map (Fig. 4), which highlights local anomalies more clearly. The detailed analysis of this map clearly suggests that the gravity signature of the study area is dominated by a large positive anomaly with an amplitude of the order of 50 miligals (0.0005 m/s^2). This anomaly can be explained by the outcrop of the Hercynian basement of the Haouz basin.

HYDROLOGY AND HYDROGEOLOGY

Water requirements in the Haouz area are of two principal types: agricultural irrigation and drinking water for the growing local population, economy and tourism sector. To meet these demands, people are forced to use both surface water and groundwater supplies intensively. The irrigated perimeter of Tassaout (Fig. 3) with an area of ~52 000 ha, is irrigated by surface water from the Ait Aadel dam (see Fig. 5 for the relative contributions from this source) and groundwater from the eastern Haouz aquifer.

In 2002, the contribution from the Ait Aadel dam to water supplies for irrigation was 70 Mm^3, while the total water requirement for the same year was ~260 Mm^3. This means that 30% of the irrigated perimeter of Tassaout in 2002 was irrigated by the Ait Aadel dam and the remaining 70% was irrigated from groundwater supplies.

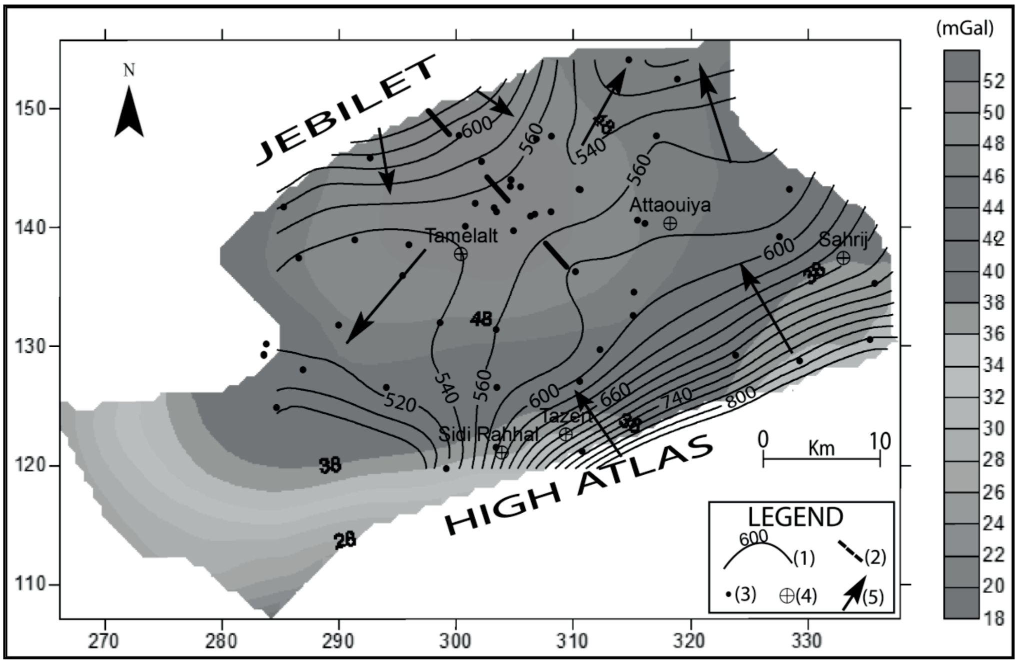

Fig. 4 Bouguer gravity map and piezometric surface of the eastern Haouz and Tassaout area. 1. Piezometric line; 2. Groundwater division line; 3. Measuring point; 4.Villages; 5. Axis and direction of groundwater flow.

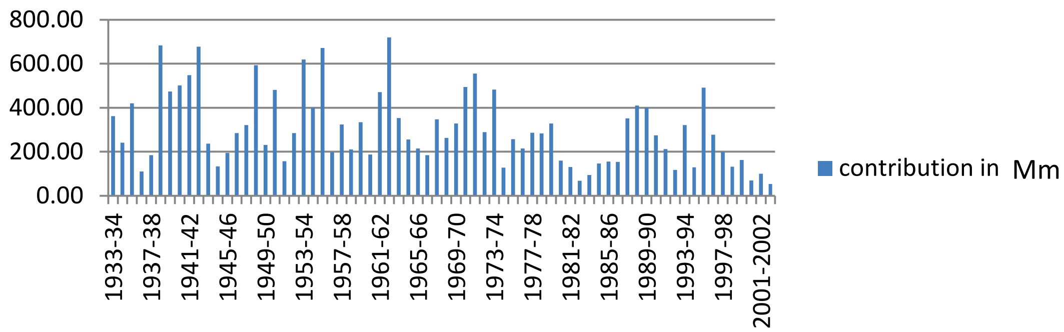

Fig. 5 Historical contributions of the AitAadel dam during the period 1933–2003.

Hydrogeologically, the study area is formed by an unconfined Quaternary and Mio-Pliocene aquifer and a deep confined Jurassic aquifer. The bedrock is formed of the red clays of the Triassic and shales of the Paleozoic basement. The piezometric map of the unconfined aquifer established in April 2011 (Fig. 4) shows that groundwater recharge occurs in two main areas. In the southern portion of the study area, the recharge takes place by anastomosis in contact with limestone outcrops of the Jurassic and Plio-Quaternary formations of the High Atlas Mountains. In the northern portion of the study area, water is recharged from Paleozoic formations neighbouring the Jebilet Mountains. Within the plain itself, the recharge is also driven by the infiltration of flood waters from the rivers cutting crossing the plain, namely the Lakhdar, Tassaout and Ghdat rivers, and also by the return of irrigation water at the perimeter of the Tassaout River. The groundwater flow is controlled by a watershed oriented NW–SE, which results in two main directions of flow, namely N–S and NE–SW. Figure 4 shows that the hydraulic gradient is lowest at the centre of the map and higher at the two recharge areas in the northwest and south of the study area.

Superimposition of the gravimetric and piezometric maps clearly shows that the groundwater hydrodynamics are controlled by the "paleotopography" of the top of the Hercynian basement, which is impervious bedrock. This superimposition highlights the coincidence of the line of the watershed and the outcrop of the basement, underlined by the gravity anomaly (Fig. 3).

GROUNDWATER QUALITY

Hydrochemical analysis was performed on 40 water samples collected from wells identified as being representative of the main aquifer of eastern Haouz. The groundwater of the aquifer has electrical conductivity ranging from 761 to 7680 µS/cm. Table 1 shows a comparison of five agricultural plains in Morocco described by El Mandour (1998), Krimissa (2004), El Yaouti (2009) and Elgettafi (2011). We observe that the electrical conductivity at the Eastern Haouz is less than other plains.

Table 1 Hydrochemical data of groundwater at five plains in Morocco.

	Eastern Haouz			Triffa			Bou Areg			Kert			Chtouka-Massa		
	Min.	Max	Moy.	Min.	Max	Moy.	Min.	Max	Moy.	Min.	Max	Moy.	Min.	Max	Moy.
C.E. (mS/cm)	0.761	7.680	2.351	1	13.39	4.1	2.55	21	6.79	1.08	12.3	5.15	0.52	13.610	3.968
pH	5.7	7.7	6.5	7.05	8.5	7.3	7.3	8.5	7.8	6.23	7.7	7.15	6	8.1	7.2
Cl^- (mg/L)	53.4	2176.08	477.34	97	4180	984	448	7797	1828	109	3389	1037	71	4276	1029
SO_4^{2-}(mg/L)	18.58	852.51	190.58	57.3	756	336	76	1473	795	69	2029	894	15	320	131.3
Na^+(mg/L)	17.93	1159.29	253.97	144	1334	420	400	3000	1237	40	2500	651	45	1600	422.5
NO^{3-}(mg/L)	2.4	150	38.7	4	151	65	0.4	95	34	1	145	17	1	301	48

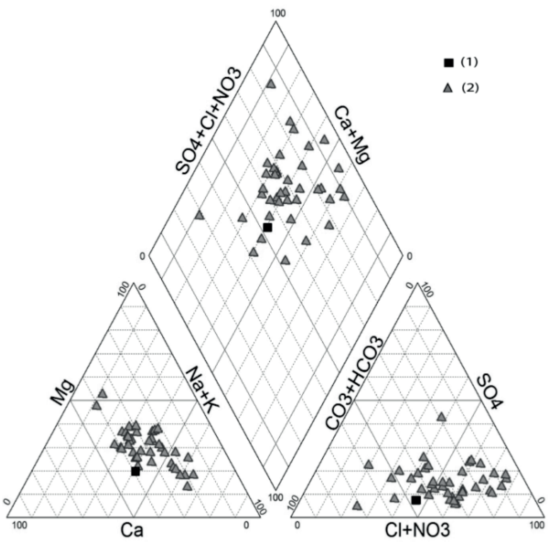

Fig. 6 Water quality of the well samples collected as being representative of Haouz water. 1. Surface water samples, 2. Groundwater samples.

The concentration data for the major elements (Fig. 6) suggest that there are three broad chemical groups; 65% of the sampled wells have a water quality signature dominated by chlorinated calcium, sulfate and magnesium, 25% of the sampled wells have a water quality signature dominated by chlorinated sodium sulfate and 10% have a signature principally comprising calcium bicarbonate and magnesium.

To better understand and visualize the impact of local agricultural activity on groundwater quality and the spatial distribution of groundwater mineralization in the Eastern Haouz and Tassaout area, contour maps of electrical conductivity and nitrate content were constructed.

Examination of the electrical conductivity map (Fig. 7) distinguished three zones (NW, SE and SSW) where high values in the order of 6000 to 7680 µS/cm are prevalent. In contrast, in the central portion of the plain, the mineralization is less than 1800 µS/cm. The spatial distribution of nitrate content in the groundwater (Fig. 8) also shows high concentrations (150 mg/L) in the NE and NW, and lower concentrations (20 mg/L) in the central portion of the plain.

Table 1 shows that nitrate concentration is almost equal in the four plains, except for the Chtouka-Massa plain, where the concentrations are very high, reaching 300 mg/L.

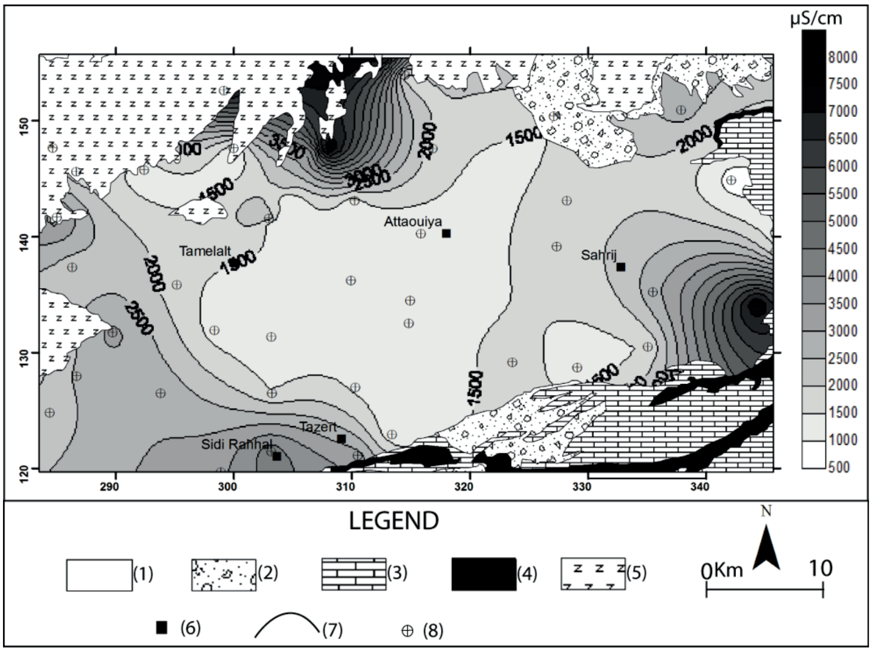

Fig. 7 Conductivity map for the Eastern Haouz and Tassaout area. 1. Quaternary: alluvium, silt and encrusted deposits; 2. Mio-Pliocene: conglomerate, limestone and marl; 3. Jurassic and Cretaceous: limestone, marl and sandstone; 4. Triassic: dolerite, clay and conglomerate with deposition of evaporites; 5. Paleozoic: schist, sandstone and quartzite 6. Villages; 7. Contour line; 8. Measuring point.

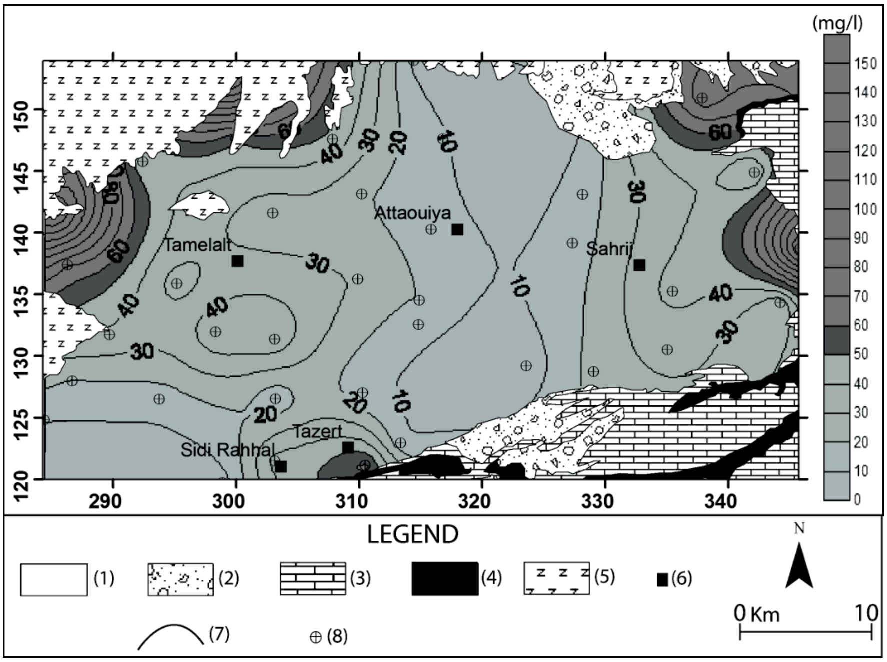

Fig. 8 The spatial distribution of nitrate content in groundwater of the Eastern Haouz and Tassaout area. 1. Quaternary: alluvium, silt and encrusted deposits; 2. Mio-Pliocene: conglomerate, limestone and marl; 3. Jurassic and Cretaceous: limestone, marl and sandstone; 4. Triassic: Dolerite, clay and conglomerate with evaporites; 5. Paleozoic: schist, sandstone and quartzite; 6. Villages; 7; Curve of equal value; 8. Sampling point.

The observed high salinities correspond with the outcrops of Triassic salt formations on the SE and SSW parts of the plain, and the outcrop of Paleozoic shale in the NW of the plain (Rochdane, 2012). Lower mineralization rates characterizing the central part of the plain, reflect the contribution of less mineralized waters from the High Atlas Mountains, water infiltration from the Lakhdar and Ghdat rivers and infilration of dam-derived water used for the irrigation of the Tassaout area. In the central part of the plain, nitrate inputs to groundwater from agricultural activities are diluted by the infiltration of water from the Tassaout and Ghdat rivers.

CONCLUSION

The combination of geological mapping and borehole data provided a basis for defining the geometry and principal features of the main aquifer in the Eastern Haouz and Tassaout area of Morocco. The aquifer is a synclinal depression formed by alluvial deposits of Plio-Quaternary age, limited by a Paleozoic and Triassic basement. On the southern edge of the plain, the aquifer is formed by Jurassic limestone. The geophysical and hydrogeological data suggest a groundwater watershed oriented NW–SE. Two directions of groundwater flow have been identified. The first is northerly, parallel to the surface flow (Tassaout River), whereas the second is oriented W–SW towards the Central Haouz. Groundwater recharge is driven partly by the contact with the High Atlas Mountains, formed of limestone, in the south and by contact with the Paleozoic shales in the NW, as well as along the Tassaout and Ghdat rivers.

Groundwater flow directions play an important role in groundwater mineralization and dilution of nitrate concentrations. In the central part of the plain there are very low groundwater mineralization rates, but groundwater salinity mineralisation occurs when the water reaches the salt Triassic and schist Primary formations. The improved rational use of water from the Ait Aadel dam and the installation of drip irrigation in the agricultural plantation are suggested as potential solutions for remedying the local water stress caused by successive years of severe drought.

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