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Quality of Hamadian groundwater table of the continental tertiary of Wadi Mehiya in Tindouf province (South-West of Algeria)

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Abstract

The Hamadian groundwater table ensures water supply for the agricultural perimeter of Wadi Mehiya region in the North-East of Tindouf city. In order to determine the behaviour of this groundwater table, a piezometric map have been realized, followed by physicochemical analyses to assess the chemical facies, the suitability of this water for irrigation and drinking purposes, as well as its vulnerability to different pollutants. This groundwater table is essentially composed of fine to coarse and clayey sands, surmounted by a silicified limestone slab. It is a free groundwater table with a thickness of 18 to 99 m. The sampling has been done in June 2010. Then, the physicochemical analyses have been performed on 7 samples taken from 7 boreholes. The piezometric study proved that the flow of groundwater table follows a North-East to South-West direction, towards the Sebkhah of Tindouf. The graphic representation of chemical facies, using Piper and Schoeller–Berkaloff diagrams, reveals that the water of Wadi Mehiya contains mainly magnesium sulphate. The graphical representation of irrigation water quality, using Wilcox diagram, revealed an acceptable quality with a high salinity. Moreover, this water is potable with hard-mineralized character. Nitrates contamination has been also noted, which is a logical result of the excessive use of chemical fertilizers.

Key words: *Hamadi groundwater table, irrigation, quality, salinity, vulnerability, Wadi Mehiya*

INTRODUCTION

This study aims to present the main hydrogeological and hydrochemical characteristics of the Hamadian groundwater table, feeding the agricultural perimeter of Wadi Mehiya, situated in North of Tindouf city [HAISSOUNE 1998]. The chemical analysis of water is an important complement for the hydrogeological study of the groundwater table, consequently for water resources management. It provides a database on the aquifer environment, the host nature, the supplying and circulation zones in the groundwater table, and the concentration of water pollutants [BENKHLIFA, BELABBES 2017].

The groundwater table of Wadi Mehiya, located in the Hamada zone, in the North of Tindouf city belongs to the continental tertiary. It deposits in horizontal layers, the Hamada is essentially composed of fine yellow sandstone

with marly cement. This groundwater table covers all the northern region of the province. The reservoir is formed mainly by fine to coarse sand and clay sand, with thickness of about 10 m near the Sebkhah of “Abdallah”, reaching a hundred meters in the basin centre, next to the zone of “Hassi el naga” [HAISSOUNE 1998].

The groundwater table is currently solicited by dozens of boreholes. It is known in the regions of “Hassi Ammar” (low flow), “Wadi Zez” (low flow), “Wadi Mehiya”, “Graret el Harth”, “Hassi el Naga” (low flow), “Oum el-Assel” (low flow), and the West of the sub-basin of “Hassi Khebbi” (flow 2–10 dm³·s⁻¹). The Hamadian formation has no Hydrogeological interest on the axis linking the region of “Fort Lotfi” to “Hassi Khebbi”. The water mineralization varies between 0.9 and 3 g·dm⁻³ [KASBAOUI, ALLAOUI 2017].

MATERIAL AND METHODS

PHYSICAL FRAME OF THE STUDIED AREA

Tindouf province is located in the South-West of Algeria near the Algerian-Moroccan borders, 1900 km from Algiers and between 26–28° N and 6–9° W (Fig. 1). The Hamada of Tindouf has local names such as Hamada of “Arouieda” and Hamada of “Ed Douakel”. It is limited in the North by the Atlas piedmont, in the East and West by the outcrops of old formations, and in the South by a cliff rising on Paleozoic formations. The surface of the Hamadian is tabular with small undulations; the shores range from 420 m to 480 m. Many Sebkhha are settled in the depressions, but the main one is the Sebkhha of Tindouf. It extends along a West–East line of more than 100 km long and 20 km wide [ZANAGUI 2016].

The studied area is located in the North-East of Tindouf city, bordered to the North by “Garret el Harth”, to the West by Hamada of “Merkala”, to the South by “Wadi Nebka”, and to the East by “Wadi el Maa” (Fig. 1). The geographical coordinates of the region of Wadi Mehiya are 27°47’39” N and 8°4’53” W.

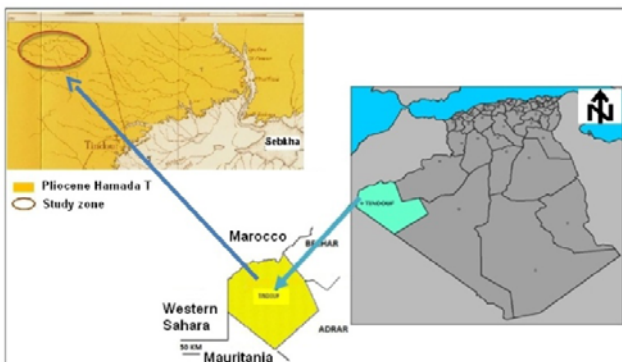


Fig. 1. Localization of the study area; source: own elaboration

The studied region is characterized by a dry and arid climate with average interannual (average of 9 years, 2007–2016) rainfall of 25.9 mm and high evapotranspiration rates (Fig. 2) [RAGGADI, BOUNAIM 2015].

On the geological plan, the basin of Tindouf is a vast syncline, East-West oriented [HANI *et al.* 2003] and a surface of 180.000 km² [ANRH 2010].

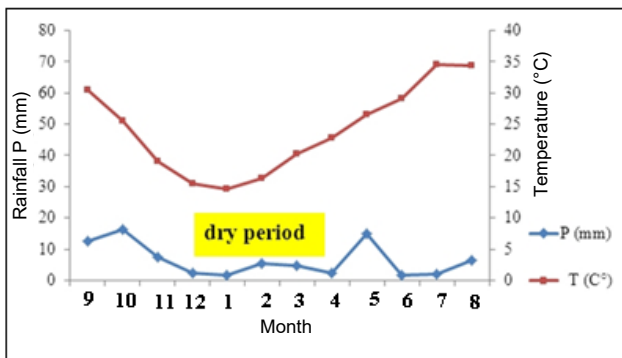


Fig. 2. Ombrothermic diagram of Gaussen of the Tindouf province (2007–2016); source: own elaboration

The centre of the syncline is occupied by Mio-Pliocene deposits (Hamada) reposed on Paleozoic formations (Carboniferous, Devonian, Gothlandian, Ordovician and Cambrian), in the South and South-East, the territory consists of volcanic and metamorphic of Yetti-Eglab massif rocks.

According to the geological data of the water drillings (OM2, OM3, OM5) the Hamadian groundwater table consists mainly of fine to coarse sands and clay sands, the whole is surmounted by a slab of silicified limestone, also is a free tablecloth their thickness from 18 to 99 m (Fig. 3).

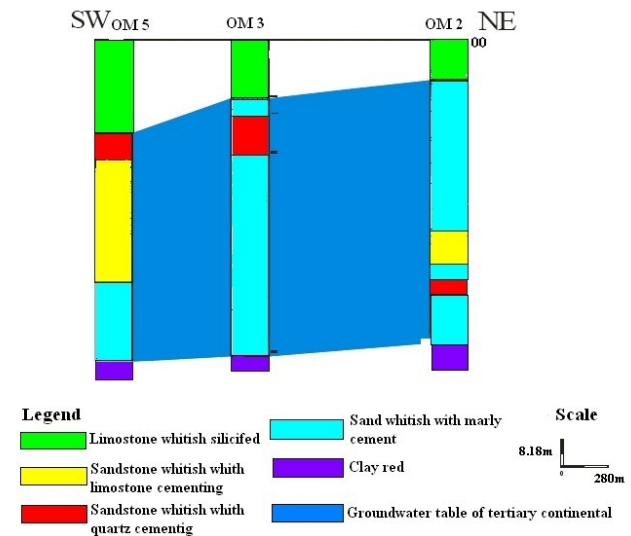


Fig. 3. Correlation of boreholes located in the groundwater table of Wadi Mehiya; source: own elaboration

On the hydrogeological plan, the piezometric map (Fig. 4) reveals that groundwater flow follows a NW–SE direction with a cone of depressions on the water drillings (OM5, OM3) proving an overexploitation of the groundwater table.

The isotopic study allowed to define three groups of water, according to the tritium content: old water (before 1952) (from 0 to 8.3 UT), relatively recent water (from 8.3 to 16.6 UT), and recent water (more than 16.6 UT). The combination of these groups of water permits to identify six families of water according to the water salinity and tritium content [HANI *et al.* 2003; MELLOUL 1995].

The Hamadian groundwater table is marked by the presence of all water families, which indicates the influence of evaporation and local supply on the water chemistry.

The supply axis is characterized by a transition zone between the Hamada of Tindouf, supplying the Hamadian groundwater table by precipitation. The Sebkhha of Tindouf represents the main outlet of the groundwater table [HANI *et al.* 2003]. We notice a hydraulic continuity between the Hamadian formations and the underlying layers of Viséan limestones. The supply of the latter is governed by the precipitations on the Hamadian formations, which can be in hydraulic continuity with the limestones over a broad band West-East oriented [HANI *et al.* 2003]. It comes also from the inputs of outcrop zones of the Atlas aquifers [Progress Sarl Annaba 1999].

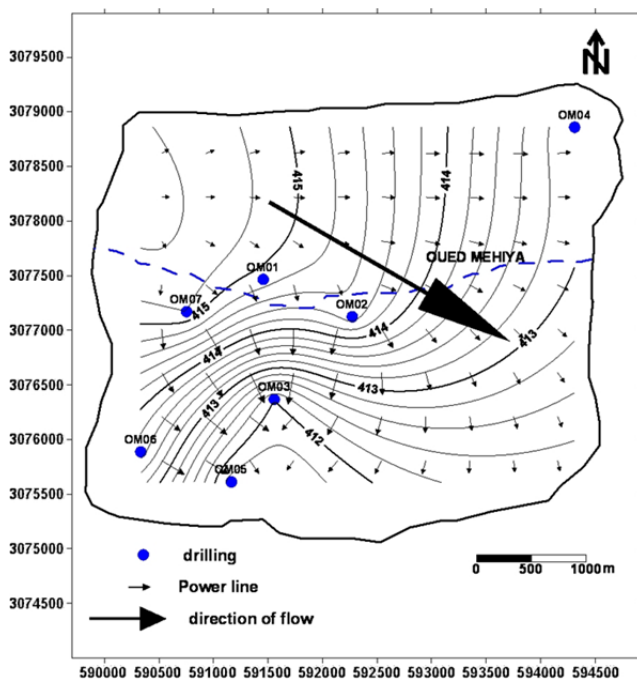


Fig. 4. Piezometric map of Wadi Mehiya basin (June, 2010); source: own study

SAMPLING AND ANALYSIS

The sampling has been done in June 2010 and the physicochemical analyses have been performed on 7 samples taken from 7 boreholes (Fig. 5), on the laboratory of physico chemical analysis of the National Water Resources Agency (Fr. Agence Nationale des Ressources Hydrauliques – ANRH) in Adrar city, following the French Standardization Association standards (Fr. Association Française de Normalisation – AFNOR) [AFNOR 1997].

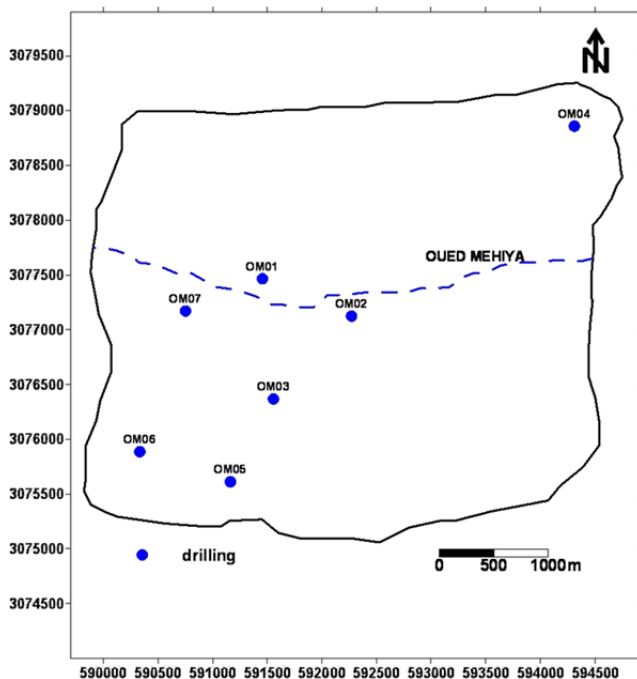


Fig. 5. Inventory map of sampling points; OM1–OM7 as in Fig. 4; source: own elaboration

The assay has focused on the following major elements: cations: Ca^{2+} , Mg^{2+} , Na^+ and K^+ anions: Cl^- , SO_4^{2-} and HCO_3^- ; physicochemical parameters: pH, electrical conductivity (*EC*), dry residue (*DR*) and temperature; total mineralization: SiO_2^- , total hardness (*TH*), total alkalinity (*TAC*) and alkalinity (*TA*); pollution elements: NH_4^+ , NO_2^- , NO_3^- , and PO_4^{3-} . The material and methods used in the study are presented in (Tab. 1).

Table 1. Equipment and methods for water analysis

Parameter	Measurement by electrochemical portable probe	Photometry (spectrometry)	Titration or colorimetry
pH	X		
Conductivity	X		
Chlorides			X
Alkalinity			X
Organic. phosphates		X	
Ammonium		X	
Sulphates		X	
Nitrates / nitrites		X	
Calcium			X
Magnesium		X	
Sodium			
Potassium		X	
Hardness			X
Silica		X	

Source: own elaboration.

RESULTS AND DISCUSSION

PARAMETERS FOR IRRIGATION

The results of physico-chemical analysis of the Hamadian groundwater table revealed the parameters used to estimate the quality of irrigation water (Tab. 2). Among these parameters, we note the salinity expressed by the electrical conductivity (*EC*), the residual sodium carbonate (*RSC*), the percentage of Na, the *SAR* (sodium absorption ratio), and the chlorides toxicity [GOUAIDIA *et al.* 2013].

The *EC* values reached $2470 \mu S \cdot cm^{-1}$, which corresponds to an average salinity due to the arid climate producing a high evaporation, increasing then the concentration of the soil solution [CHEVERRY, ROBERT 1998]. The average conductivity is $2180 \mu S \cdot cm^{-1}$ (Tab. 2) which proves the acceptable quality of the groundwater table of Wadi Mehiya. However, the average *SAR* is $3.03 meq \cdot dm^{-3}$, referring to low to medium sodization risk. The chlorides come probably from the percolation through the salty ground none of the analysed samples has reached the concentration $10 meq \cdot dm^{-3}$, which is the maximal concentration admissible for the plants.

Table 2. Statistical parameters of some groundwater variables of the Hamadian groundwater table of Wadi Mehiya (2010)

Specification	<i>EC</i> $\mu S \cdot cm^{-1}$	<i>SAR</i>	Cl	
			$meq \cdot dm^{-3}$	
Min	2 040	2.38	6.72	29.45
Max	2 470	3.86	9.03	41.60
Average	2 180	3.03	7.51	35.70

Source: own study.

CHEMICAL FACIES

According to Piper diagram (Fig. 6), there is only one chemical facies which is the sulfated magnesian except for the sample No. OM2, where the facies is sulfated sodic. The origin of sulphates is the gypseous formation of the Sebkhia of Tindouf due to the leaching of this formation by the water supplying the Hamadian groundwater table, from cracked limestones (roof of the water table) enriching the later with sulphates; while, the magnesium originates from the sandstone reservoir of the Hamadian water table [HAISSOUNE 1998].

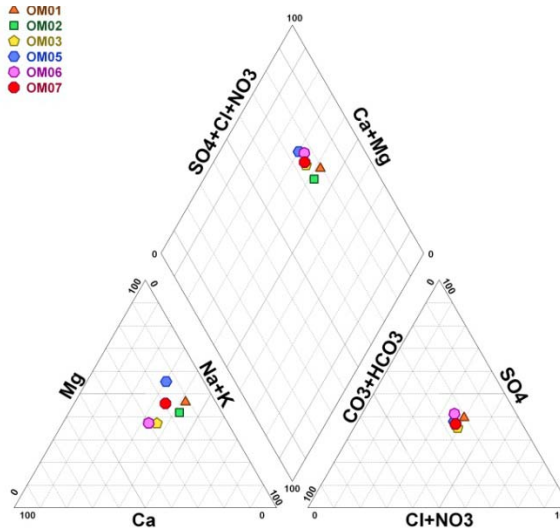


Fig. 6. Graphical representation of chemical facies (Piper diagram, June 2010); OM1–OM7 as in Fig. 4; source: own study

WATER QUALITY FOR IRRIGATION

Irrigation plays a dominant role in agriculture because of degrading water resources and variant distribution of the rainfalls. Farmers need to save water and make judicious use of it, especially during the dry season [HALIMI *et al.* 2017; ZARE *et al.* 2014]. When the concentration of soluble Na^+ ions in the soil is high, these ions replace the Ca^{2+} cations (basic exchanges) in the absorbing complex; this can be induced by salt-loaded water; this risk is determined by the measurement of sodium absorption ratio (*SAR*) [GOUAIDIA *et al.* 2013].

$$SAR = (\text{Na} + \text{K}) / \sqrt{(\text{Ca} + \text{Mg})/2} \quad (1)$$

For the same conductivity, the risk is even greater when the coefficient is higher.

After plotting all the water points on the Wilcox diagram (Fig. 7) and according to the electrical conductivity and the *SAR*, the water classes found are:

- C3S1 class designates water admissible in the irrigation of salt-tolerant crops, on well-drained soils, with good permeability, where the salinity should be controlled; the C3S1 class characterizes all boreholes except OM1;
- C4S1 class indicates mediocre highly mineralized water; suitable for the irrigation of certain crops with high salt tolerance on well-drained soils; the C4S1 class characterizes the OM boreholes.

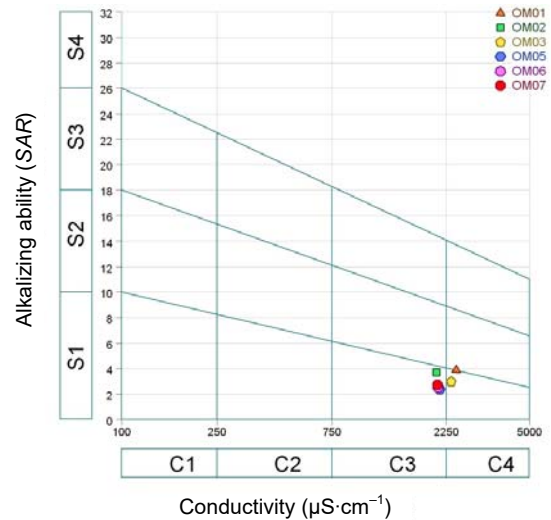


Fig. 7. Water quality according to Wilcox diagram (June, 2010); source: own study

It is noted that when the chemical facies of agricultural water is chlorinated, the *SAR* often minimizes the risk of water sodization and alkalisation. Therefore, the residual sodium carbonate (*RSC*) has been used as another parameter to evaluate the quality of irrigation water in this study.

The determination of *RSC* is performed according to the following equation:

$$RSC = (\text{CO}_3^- + \text{HCO}_3^-) - (\text{Ca}^{2+} + \text{Mg}^{2+}) \quad (2)$$

Following the *RSC*, the water is divided into two classes:

- type 01 ($RSC > 0$), presenting a risk of degradation of the soils physical properties, by sodization;
- type 02 ($RSC < 0$), with a low risk of degradation compared to the previous type [GOUAIDIA *et al.* 2013; MARLET, JOB 2006; SUMNER 1993].

The results obtained proved that the water of the Hamadian groundwater table of Wadi Mehiya belongs to the type 02 (Tab. 3).

Table 3. Water types according to residual sodium carbonate (*RSC*)

Specification	<i>RSC</i>	Type
Min	-10.36	2
Max	-7.66	2
Average	-9.02	2
%		100

Source: own study.

WATER POTABILITY AND VULNERABILITY OF THE WATER TABLE

Concentration in physical parameters

• pH

The water acidity itself does not pose any problem for consumer health. However, acidic water distributed through pipeline system may present an indirect risk to the health of misinformed or careless consumer.

Acidic water is aggressive (corrosive) and can release the constitutive metals of the pipes i.e. iron, copper, lead, nickel, chromium and zinc [HANON, ROUELLE 2011; KAHOUL, TOUHAMI 2014].

The local and international standards for drinking water quality recommend a pH between 6.5 and 8.5 [Journal... 1993; WHO 1994]. Regarding these standards, the analysed water has a normal pH, ranging from 6.15 to 7.51 study (Tab. 4).

• Conductivity

The conductivity measurement permits to determine the degree of water mineralization, since most of the water dissolved materials are present as electrically charged ions. According to the conductivity, the water classification is done as follows: conductivity equal to $0.05 \mu\text{S}\cdot\text{cm}^{-1}$: demineralized water; conductivity from 10 to $80 \mu\text{S}\cdot\text{cm}^{-1}$: rainwater; conductivity of $80\text{--}100 \mu\text{S}\cdot\text{cm}^{-1}$: water with little mineralization; conductivity from 300 to $500 \mu\text{S}\cdot\text{cm}^{-1}$: moderately mineralized water; conductivity from 1000 to $3000 \mu\text{S}\cdot\text{cm}^{-1}$: saline water; conductivity more than $3000 \mu\text{S}\cdot\text{cm}^{-1}$: seawater [RODIER *et al.* 2009]. The conductivity of Wadi Mehiya groundwater table ranges from 2040 to $2470 \mu\text{S}\cdot\text{cm}^{-1}$ (Tab. 4); thus, it belongs to saline water. It is also mineralized with mineralization degree ranging between 1300 and $1600 \text{mg}\cdot\text{dm}^{-3}$; (Tab. 4) but without exceeding the local norms ($2000 \text{mg}\cdot\text{dm}^{-3}$). The origin of this salinity and mineralization is the leaching of the crossed carbonated and gypseous formations in addition to the impact of evaporitic gypsiferous formations the Sebkhah of Tindouf.

Table 4. Statistical parameters of some physical variables of the groundwater of Hamadian groundwater table (2010)

Specification	pH	EC $\mu\text{S}\cdot\text{cm}^{-1}$	Dry residues at 100°C $\text{mg}\cdot\text{dm}^{-3}$
Min	6.15	2 040	1 300
Max	7.51	2 470	1 600
Average	6.92	2 180	1 415

Source: own study.

Concentration of chemical parameters

• Calcium

Calcium is generally the dominant element in drinking water where its content varies mainly according to the nature of the crossed ground (limestone or gypsum) [RODIER *et al.* 2009]. The undesirable organoleptic and aesthetic characteristics of the drinking water, following the presence of calcium, come from its contribution to the hardness [AWWA 1990]. The calcium content of the water analysed (Tab. 5) is lower than the maximum permissible concentration ($200 \text{mg}\cdot\text{dm}^{-3}$), established by local standards [KAHOUL, TOUHAMI 2014; NA 1992] for drinking water.

• Chlorides

Chloride is very common element in nature where its content in water is highly variable and mainly related to the nature of the crossed ground. According to the local standards for drinking water quality, chlorides must have a concentration of less than $500 \text{mg}\cdot\text{dm}^{-3}$ in drinking water [KAHOUL, TOUHAMI 2014; NA 1992].

The analysis revealed normal quantities of chlorides in Wadi Mehiya groundwater table, ranging from 250 to $320 \text{mg}\cdot\text{dm}^{-3}$ (Tab. 5); similar results were noted in many previous studies. The chlorides have no adverse effect on the consumer health, even with a high concentration in drinking water. This is because the chloride concentration in the body is regulated by a complex system involving both the nervous and the hormonal systems. Even after the absorption of high quantities of chlorides, the chloride balance is maintained, especially by the excretion of the excess in the urine.

• Hardness

The results of water hardness measurements of the Wadi Mehiya groundwater table (Tab. 5) revealed values exceeding the local standards that require a maximum permissible concentration of $500 \text{mg}\cdot\text{dm}^{-3}$; this high degree of hardness have no impact on consumer health, since a number of epidemiological studies performed in Canada, England, Australia and the United States respectively proved an inverse statistical correlation between the hardness of drinking water and certain types of cardiovascular diseases.

Table 5. Statistical parameters of some chemical variables of the groundwater of Hamadian groundwater table (2010).

Specification	Ca ²⁺	Mg ²⁺	Na ⁺ +K ⁺	Cl ⁻	SO ₄ ²⁻	HCO ₃ ⁻	SiO ₂ ⁻	TH	TAC
	mg·dm ⁻³								
Min	66	96	161	250	365	290	17	650	240
Max	124	154	246	320	482	360	30	780	300
Average	89	121	192	266	405	329	23	700	270

Explanations: TH = alkalinity, TAC = total alkalinity.

Source: own study.

Concentration in pollution parameters

• Nitrate

Nitrates (NO₃⁻) are common natural ions resulting mainly from the nitrogen oxidation by microorganisms in plants, soil and water. The sources of nitrates in water (particularly groundwater) are generally decomposed of animal and plant matter, agricultural fertilizers, manure, domestic sewage, and geological formations containing soluble nitrogenous compounds. According to the Algerian [Décret exécutif... 2011] and European standards [Council Directive... 1998], the nitrates concentration does not $50 \text{mg}\cdot\text{dm}^{-3}$ in drinking water.

The analysed water has nitrates concentration varying between 3.20 and $70 \text{mg}\cdot\text{dm}^{-3}$ (Tab. 6), which refers to a contamination of the groundwater table, due to the excessive use of agricultural chemical fertilizers. Such a water has no impact on the health of infants under 6 months, but once reduced to nitrites, it can cause methemoglobinemia [L'HIRONDEL 1993].

Apart from nitrates, the groundwater table of Wadi Mehiya remains protected against pollution; due to its remoteness from the urban perimeter and industrial discharges.

According to concentration in the NH₄⁺, NO₂⁻ and PO₄³⁻ the groundwater table of Wadi Mehiya does not present a pollution (except at OM2 a small pollution with NO₂⁻).

Table 6. Statistical parameters of some pollution variables of the groundwater of Hamadian groundwater table (2010)

Specification	NH ₄ ⁺	NO ₂ ⁻	NO ₃ ⁻	PO ₄ ³⁻
	mg·dm ⁻³			
Min	0	0	3.20	0.03
Max	0.03	0.21	70	0.40
Average	0.016	0.08	58.3	0.14

Source: own study.

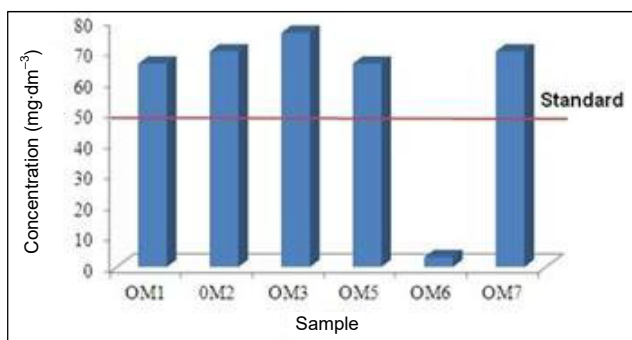


Fig. 8. Nitrate concentration in the Wadi Mehiya groundwater table; OM1–OM7 as in Fig. 4; source: own study

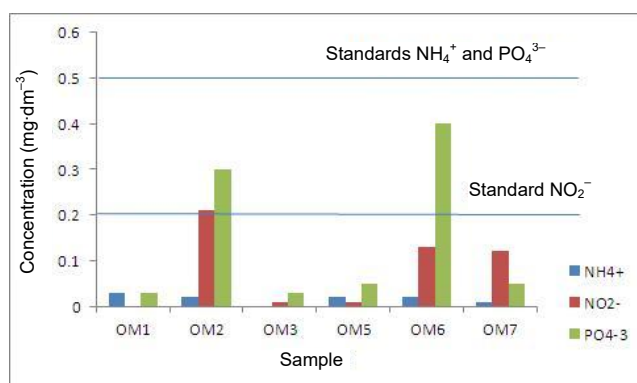


Fig. 9. NH₄⁺, NO₂⁻ and PO₄³⁻ concentration in the Wadi Mehiya groundwater table; OM1–OM7 as in Fig. 4; source: own study

GENERALE CONCLUSION

The evaluation of the quality of groundwater used for irrigation in the agricultural zone of Wadi Mehiya has a high necessity, due to many environmental troubles in this region such as drought and the unavailability of surface water, added the high water demand for the agricultural activities. The analysis of the salinity parameters has allowed the evaluation of the quality of these waters. Using conventional methods, this assessment revealed the presence of water with medium salinity and acceptable quality for irrigation. The water salinity is the result of many factors, namely:

- aquifer material, with an heterogeneous lithology, composed essentially of clays, limestone, sandstone, and gypsiferous and evaporitic formations of the Sebkhia of Tindouf rich in Cl⁻, Na⁺, SO₄²⁻, and Ca²⁺;
- climatic conditions, characterized by an arid and dry climate, during the whole, inducing an important evapotranspiration;

- the studied groundwater presents a low risk of alkalization and can be used for irrigation due to its average SAR value (5 meq·dm⁻³).

In term of water quality for human consumption, almost all the parameters analysed meet both national and international standards, regarding the drinking water quality. The excessive mineralization and the hardness are due to the lithological nature of the reservoir and the impact of the Sebkhia. In the face of the problem of excessive nitrates, known by their adverse effects on health, it is strongly recommended to minimize the use of agricultural chemical fertilizers. According to concentration in the ammonium, nitrite and phosphate, the groundwater table of Wadi Mehiya does not present pollution.

To sum up, the water of the Hamadian groundwater table of Wadi Mehiya can be considered potable only after treatment, while it is admissible for irrigation. However, the low water flow does not cover the demands of the agricultural perimeter, requiring then other researches to quantify the reserve and a good exploitation management.

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Jakość wód gruntowych poziomu Hamadi w utworach kontynentalnego trzeciorzędu w zasięgu rzeki Mehiya, prowincja Tindouf w południowo-zachodniej Algierii

STRESZCZENIE

Poziom wodonośny Hamadi zapewnia dostawy wody dla rolniczych terenów regionu Wadi Mehiya na północny wschód od miasta Tindouf. W celu określenia właściwości poziomu wodonośnego wykonano mapę piezometryczną, a następnie przeprowadzono analizy fizyczne i chemiczne do oceny składu wody, jej przydatności do nawodnień i zaopatrzenia ludności w wodę pitną, jak również podatności zasobów na różne zanieczyszczenia. Poziom wodonośny znajduje się w warstwie gliniastego piasku o zmiennym uziarnieniu podścielonego warstwą krzemionkowo-wapienną. Jest to poziom o swobodnym zwierciadle wody o miąższości od 18 do 99 m. Próbkę wody pobrano w czerwcu 2010 r. Analizy fizyczne i chemiczne wykonano w 7 próbkach pobranych z 7 odwiertów. Badania piezometryczne wykazały, że woda gruntowa płynie z północnego wschodu na południowy zachód w kierunku Sebkhia k. Tindouf. Graficzna prezentacja wyników z wykorzystaniem diagramów Piper'a i Shoellera–Berkaloffa dowodzi, że w składzie chemicznym wody Wadi Mehiya dominuje siarczany magnezu. Graficzne przedstawienie jakości wody do nawodnień wg diagramu Wilcoxa wykazało akceptowalną jakość z dużym zasoleniem. Ta wysoce zmineralizowana woda nadaje się do celów spożywczych. Zanotowano także zanieczyszczenie azotanami, co jest skutkiem nadmiernego stosowania nawozów mineralnych.

Słowa kluczowe: *jakość, nawodnienia, podatność, poziom wodonośny Hamadi, Wadi Mehiya, zasolenie*