Original article

Groundwater quality assessment of the coastal alluvial aquifer of Wadi Hachem, Tipaza, Algeria

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ABSTRACT

Groundwater quality in the alluvial aquifer of Wadi Hachem, Tipaza, was assessed for drinking and irrigation purposes. This alluvial plain covers an area of 13 km² and lies in a semiarid climate. Groundwater is the major source for domestic and agricultural water activities in this region, and it is facing natural conditions and anthropogenic activities. The groundwater quality was evaluated on the basis of its physicochemical parameters for the dry period of 2015. The results of these parameters were compared with WHO and Algerian standards recommended for drinking water. The water quality was found to be slightly alkaline, with moderate water quality for drinking based on Total Hardness (TH), Electrical Conductivity (EC) and Total Dissolved Solids (TDS), and all water samples were within the permissible limit for drinking and irrigation purposes. The samples also showed two water types, Ca- HCO₃ for the majority of samples, that characterize natural water quality controlled generally by the recharge area and by geological influences and Ca-Cl water type for one sample that is likely influenced mainly by anthropogenic activities, which was affirmed by the higher values of EC, TDS and of some ion concentrations. The analytical data plotted on Riverside and Wilcox diagrams illustrated high and very high salinity, and low sodium hazard rendering groundwater usable only on soils with good permeability.

KEY WORDS: groundwater quality, Wadi Hachem plain, alluvial aquifer, physicochemical parameters, drinking water

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1. Introduction

Water is the most vital element for human life, and for all living things on this Earth which need water for their life processes and for their sustainable development (NADAL ET AL., 2020). Unfortunately, during recent years, the continuous growth of urbanization and industrialization has decreased the availability of water resources, mainly in semi-arid climate areas, which have known periods of drought which continue to extend (JIANG ET AL., 2020). Groundwater constitutes an alternative source for drinking and industrial water supplies and for irrigation purposes; so, groundwater management needs to be given greater attention. Natural conditions and anthropogenic activities are the principal factors controlling the

quality of groundwater (BOUDERBALA, 2017a). It is very necessary to monitor groundwater quality for better water resources management, because once it is contaminated by any kind of pollution, its quality cannot be restored easily. Groundwater degradation can come from many sources, such as seawater intrusion in coastal aquifers, discharge of untreated wastewater in inhabited rural areas, discharge of uncontrolled industrial wastewater, use of intensive fertilizers in agriculture, evaporation and others (BOUDERBALA, 2019; BAHIR ET AL., 2020). Several studies have been done about the assessment of groundwater quality and hydrochemical characterization with the aim to better understand the origin of water, the chemical composition of groundwater and the interaction between water and aquifers (BOUDERBALA, 2016; AKSEVER, 2019).

The Algerian water policy over the last decades has promoted the adoption of strategies for water management for its sustainable use. These policies focus on the development of water resources, good management of available resources, increasing the efficiency of drinking and irrigation water networks, reducing the discharge of wastewater, monitoring of water quality by establishing surveillance networks, and protecting the environment and water resources against different kinds of pollution (BOUDERBLA ET AL., 2016). The importance of developing a strategy for the management of water resources is a consequence of the exacerbation of the problem of the scarcity of water resources due to droughts, which has become more frequent and of longer duration (ABBOD, 2018; GHOULI ET AL., 2018).

Algeria has significant groundwater resources for both renewable and non-renewable resources. But; these are overexploited and exposed to various forms of pollution. In coastal areas for example, several alluvial aquifers constitute the main resources which are used for irrigation, and for industrial and human needs. They are facing an excessive exploitation; actually these aquifers are affected by the phenomenon of marine intrusion and by a deterioration in the quality of groundwater (BOUDERBALA, 2015a and b).

The coastal alluvial aquifer of Wadi Hachem in Tipaza (Northern Algeria) has suffered serious deterioration in the last few years due to uncontrolled discharge of urban wastewaters, intensive use of chemical fertilizers in agriculture, as well as overexploitation of groundwater. These factors affect the chemistry of the groundwater, which makes it unsuitable for some uses. The aim of this study was to determine the water quality parameters of this aquifer, and to compare the results with the permissible limit for drinking water as provided by WHO (2017), and to try to understand the mineralization processes in the water of this coastal aquifer.

2. Study area

The study area is located approximately 70 km west of the capital Algiers, between 36°32' and 36°36' north and between 02°13' and 02°19' east, and covers an area of 13 km². The plain is located in the coastal sub-watershed of Cherchell, which belongs to the coastal Algiers Watershed. It lies between the Massif of Chenoua in the east, the dam of Boukourdane and the hill of Menaceur in the south, the Mediterranean Sea in the north and Djebel Chem in the west. The study area is

characterized by a Mediterranean semi-arid climate, with hot dry summers and cold rainy winters.

The climate diagram (Ombrothermic diagram) which summarizes the trends in temperature and precipitation for 28 years in this region (period 1988-2015). It determines the length of dry and wet periods (Fig. 1). It shows seven wet months (from October to April) and five dry months (from May to September). The annual average temperature for the period of 1988-2015 was 18°C and the precipitation average for the same period was about 555 mm. An estimation of the real annual evapotranspiration by the Thornthwaite method gave a value of 425 mm, while runoff estimated by the Tixeront-Berkaloff method gave a value of 80 mm; however, infiltration is about 50 mm (9 % of annual rainfall).

Fig. 1. Ombrothermic diagram

The study area is located in the West Algiers Coast. The watercourse of Wadi Hachem originates in the mountains of Djebel Boumaad in the south at an altitude of 1400 m. This Wadi crosses the plain and gives its name to it, and then flows into the sea. It is also noted that this temporary stream flows only during the rainy periods or in cases of water release from Boukourdane dam located upstream of this plain.

3. Geological and hydrogeological conditions

In this region (Fig. 2), the geological secondary formations are formed by: Trias, which is represented by dolomitic and gypsum breccia; with the passage of multi-coloured marls and fragments of eruptive rocks. Jurassic in this area is represented by massive dolomites and limestone of Lias, which is observed mainly in the Chenoua Massif. Cretaceous, is divided into Lower and Upper Cretaceous. Lower Cretaceous, begins with Neocomian, which is represented by very siliceous hard shales with a few banks of quartzite, up to 1000 m of thick. The Barremian is represented by schists and limestones with some blades of quartzite. The Aptian is represented with marl and limestone. The Albo-Aptian is represented by flysch series

that outcrops in anticlines under the Neogene layers and the layers are characterized by schists and quartzites, surmounted by limestone and black schist. The Upper Cretaceous is formed with Cenomanian, which is represented at the base by black schist and marls, and at the top by limestone, and has a thickness of about 100 m. The Senonian is represented by marls, yellow limestone and shale with a thickness of more than 1000 m.

Fig. 2. Geological map of the study area

The geological tertiary formations are formed by: Eocene, its layers are represented by nummulitic limestone of Lutetian age with only a small outcrop in this region. It is composed of red pudding and

brecciated limestone. Oligocene shows a low extension, it outcrops in the form of micaceous sandstones and thin layer of marls. Miocene is presented by the following succession from bottom to top: sandstone and red pudding of Burdigalian age, the marls and clay of Cartennian. Pliocene is formed of Lower and Upper Pliocene. Lower Pliocene, outcrops in the form of yellow marl or sandy marl. The Lower Pliocene is represented also by sands, sandstones, and clays. Upper Pliocene is formed by pebbles, gravel and rocks from the Villafranchian age.

Quaternary formations are represented by marine and alluvial deposited facies, where several terraces are observed. The marine terraces are formed by the current beaches and are made up of sands, dunes, silts, and gravels from the floods of the great coastal wadis such as Wadi Hachem. The alluvial terraces are represented: in the basic terrace from 10 to 20 m r.s.l, is generally formed of shell limestone. It is lower than 20 m to sea level and in some places has a thickness of 8 m. In the intermediate terrace from 30 to 60 m r.s.l, is composed of pudding and shellfish, with small outcrops along the coast. This terrace is particularly developed in the Menaceur basin and on the alluvial cones limiting it to the east. The higher terrace, from 90 to 100 m r.s.l, is constituted of pudding, well-rolled pebbles, and debris of shell limestone.

From a hydrogeological point of view, the Wadi Hachem valley is formed by alluvial deposits, which constitute the alluvial aquifer over an area of 13 km². This aquifer is unconfined in the south part of this valley, but is confined in the northern part. This aquifer is formed from the bottom to the top by: red clays, pebbles and gravels, with a thickness from 5 to 20 m which constitute the aquifer reservoir. While, the substratum is mainly formed by Cretaceous marls and Eocene limestone (Fig. 3). The transmissivity highlights a channel of good transmissivity with values from 10⁻² to 10⁻³ m² /s.

Fig. 3. Cross-section of the alluvial aquifer of Wadi Hachem

The sedimentary formations such as recent and old alluvium constitute the main alluvial aquifer of Wadi Hachem and provide a periodic water supply. The recharge of this aquifer comes mainly from effective rainfall, water irrigation excess and lateral recharge on certain sections of streams. The groundwater in this aquifer flows in a SE to NW direction, towards the Mediterranean Sea. The recharge of the alluvial aquifer by infiltration from the release of water from the Boukourdane dam is very low, because these water releases are carried out during the wet season (in winter and spring) when the groundwater reaches the highest piezometric levels of this aquifer.

4. Material and methods

4.1. Chemical analysis

Thirteen hand-dug wells were selected for sampling (Fig. 4A and 4B.). Water samples were collected in the dry period (September 2015). Groundwater samples from selected wells were carefully collected in clean prewashed polyethylene bottles and stored in lightproof insulated boxes containing ice-packs to ensure cooling before transport to the laboratory for analysis. Sampling site geo-positions were determined using a Garmin 12XL handheld GPS. The physicochemical parameters such as pH, temperature (T), electrical conductivity (EC), and total dissolved solids (TDS) were measured in situ using a Multi340i (WTW) handheld Multi-Parameter device after calibration.

The water levels of hand-dug wells and drilling wells in the study area in the dry period 2015 ranged between 0.4 to 15.6 m, while the depth of water samples were under the static levels at more than 0.5 m. However, the depths of these wells capturing this alluvial aquifer are between 15 to 45 m according to Watershed Agency (ABH, 2012).

Fig. 4. (A) Map of sampling wells, with (B) some photos of few hand-dug wells (ABH, 2012)

Water quality analysis was carried out in the chemical laboratory at the National Water Resources Agency, Algeria (ANRH). The chemical composition was determined using the standard analytical methods of the American Public Health Association (APHA, 2005) as shown the Table 1.

Table 1. Water quality parameters, analytical methods and references

Parameters	Method	References
Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Potassium (K^+), and Sodium (Na^+)	Atomic Absorption Spectrophotometry	ISO 6058
Bicarbonates (HCO_3^-)	Potentiometry	ISO 9963-1
Chlorides (Cl^-)	Mercuric Thiocyanate	NF T 90 - 014
Sulphates (SO_4^{2-})	Turbidimetric	ISO 22743
Nitrates (NO_3^-)	Colorimetry	ISO 5667

4.2. Irrigation water quality

The suitability of groundwater for agricultural uses has been determined in many studies including calculating various indices (SAR, %Na and RSC) (BRINDHA ET AL., 2016; EHYA & MOSLEH, 2018; PAPAZOTOS ET AL., 2019).

5. Results

The results have been analysed to evaluate the groundwater quality for drinking water purposes (Table 2), based on the standard values recommended by the World Health Organization (WHO, 2017). The calculated ion-balance errors are within the acceptable limit of $\pm 5\%$ for all samples, which indicates an acceptable chemical analysis for water samples.

5.1. Physical parameters

Groundwater temperature ($T^{\circ}\text{C}$). The temperature of the water samples fluctuated between 20°C and 24°C with an average of 21.5°C . A high water temperature has negative impacts on water quality by increasing the growth of micro-organisms which

may increase taste, odour, colour and corrosion problems (UNICEF, 2008).

pH. pH is the measure of hydrogen ion (H^+) concentration in water. High levels of carbonate and bicarbonate in groundwater conduct to high pH values. pH also provides information on numerous kinds of geochemical equilibrium or solubility estimations (KUMAR & KURIACHAN, 2020). The pH values of the groundwater samples varied from 7.7 to 8.3 with an average value of 8.04, clearly showing the alkaline nature of the groundwater in this alluvial aquifer.

Electrical conductivity (EC). Electrical conductivity is the capacity of water to convey an electrical current through it. The EC of the groundwater samples in the alluvial aquifer ranged from $1520\ \mu\text{S}/\text{cm}$ to $2500\ \mu\text{S}/\text{cm}$, with an average value of $1980.7\ \mu\text{S}/\text{cm}$, so all values for EC for the groundwater samples exceeded the standard range recommended by WHO for drinking water suitability (WHO, 2017), but they are in the permissible range for drinking purposes according to the Algerian standard (Table 3). The high values of EC have health effects including blood pressure variations, water balance disturbance in children, as well as being harmful to the heart and kidneys (KUMAR ET AL., 2013).

Table 2. Results of physicochemical groundwater of Wadi Hachemi aquifer (dry period 2015)

Wells	pH	EC $\mu\text{S}/\text{cm}$	TDS mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	Na^+ mg/l	K^+ mg/l	Cl^- mg/l	SO_4^{2-} mg/l	HCO_3^- mg/l	NO_3^- mg/l	TH mg/l
P1	8,3	1980	1274	147	75	122	5	195	233	549	20	68,0
P2	7,7	1680	1160	168	48	98	8	186	171	519	25	62,0
P4	7,7	2400	1970	170	75	154	9	277	140	549	53	75,0
P5	8,3	1520	975	109	65	98	6	178	139	397	42	54,3
P6	8,3	2100	1269	180	75	118	11	221	301	534	32	77,5
P7	7,9	1790	1062	133	41	96	9	127	177	442	36	50,3
P8	8	1800	1152	140	45	100	10	130	180	460	20	53,8
P9	8,1	1620	1068	162	48	74	6	103	164	503	33	60,5
P10	8,1	2500	1530	175	70	112	3	175	269	564	37	72,9
P12	8,2	1950	1248	180	75	95	4	180	275	550	45	76,3
P13	7,9	1750	1120	165	50	75	7	110	270	460	20	62,1
P14	8,3	2500	1517	169	61	178	8	330	268	427	26	67,7
F3	7,8	2100	1361	198	51	155	9	229	233	549	25	70,8
Min.	7,7	1520	975	109	41	74	3	103	139	397	20	50,3
Max.	8,3	2500	1970	198	75	178	11	330	301	564	53	77,5
Average	8,04	1980,7	1310,1	160,2	59,7	115,1	7,3	191,6	217,3	497,6	32,5	65,3
S.D.	0,23	329,1	265,2	23,5	13,2	31,6	2,4	65,6	57,0	56,1	10,5	9,1
Standard WHO, 2017	6.5 – 9.0	1500	1000	200	75	100	12	200	200	300	50	200
Standard Algerian OJPDRA, 2011	6.5 – 9.0	2800	1500	200	100	200	12	500	400	-	50	200

Table 3. Classification of water based on electrical conductivity (OJPDR, 2011)

Water class	EC range ($\mu\text{S}/\text{cm}$)	Classification	% for each class
I	< 1000	Desirable for drinking	0 %
II	1000 – 1500	Permissible quality	0 %
III	1500 – 2800	Moderate quality	100 %
IV	> 2800	Hazardous and Unfit for drinking and irrigation	0 %

Water quality is generally controlled by different hydrogeochemical processes such as rock weathering, dissolution, deposition, ion exchange etc. (KUMAR ET AL., 2009). In this alluvial aquifer, the EC values of the groundwater samples indicated moderate quality due to the interaction between water and rocks (in the aquifer) and the influence of anthropogenic activities in this plain mainly the impact of fertilizers, manures, and pesticides used in agricultural activities, and the domestic wastewater discharge.

Total dissolved solids (TDS). TDS refers to the total of inorganic salts and the amount of organic matter dissolved in the water in molecular, ionized or microgranular suspended form. In the study area, the values of TDS of the samples ranged between 975 and 1970 mg/l, with an average of 1310.1 mg/l. The permissible limit of TDS for drinking water is 1000 mg/l according to the WHO standard (WHO, 2017), and it is 1500 mg/l according to the Algerian standard (OJPDR, 2011). Ten of the groundwater samples had TDS values lower than 1500 mg/l, and these are permissible for drinking and irrigation purposes, while the other samples (three samples) had TDS values of more than 1500 mg/l, which indicates unsuitable

water quality for drinking from these wells, however, they can be used with care for irrigation purposes (Table 4).

The high TDS values of groundwater in this alluvial aquifer may be due to domestic untreated wastewater discharge and the use of pesticides and fertilizers in agriculture. These high values can cause acute, chronic, and carcinogenic effects in humans (KUMAR ET AL., 2013).

Total hardness (TH). Total hardness is defined as the sum of the calcium and magnesium ion concentration in water, and irreversible by boiling. The values of TH of the groundwater samples were ranged from 50.3 to 77.5 mg/l, with an average of 65.3 mg/l (Table 5), which indicate that all of the water samples had moderate soft water quality according to Gray classification (GRAY, 1994). Regular intake of a high concentration of TH in water may cause kidney stones and cardiovascular problems in humans. Exposure to higher concentrations of hardness will also exacerbate eczema. A high concentration of TH gives an alkali taste to drinking water and causes poor performance of soaps and detergent, as well as resulting in scale deposited on pipes and boilers (KUMAR ET AL., 2013).

Table 4. Classification of water based on TDS (Davis & De Wiest, 1966)

Water class	TDS range ($\mu\text{S}/\text{cm}$)	Classification	% for each class
I	< 500	Desirable for drinking	0 %
II	500 – 1500	Permissible for drinking	76.9 %
III	1500 – 3000	Not permissible for drinking, but useful for irrigation	23.1 %
IV	> 3000	Unfit for drinking and irrigation	0 %

Table 5. Water hardness classification (Gray, 1994)

Water class	TH range (mg/l)	Classification	% for each class
I	0 - 50	Soft	0 %
II	50 - 100	Moderate soft	7.7 %
III	100 - 150	Slightly hard	92.3 %
IV	150 - 250	Moderately hard	0 %
V	250 - 350	Hard	0 %
VI	> 350	Excessively hard	0 %

5.2. Chemical parameters

Chloride (Cl^-). The chloride contents recorded in the water samples from the Wadi Hachem aquifer varied from 103 mg/l to 330 mg/l (P14, which was located downstream of the plain) during the dry period 2015. These concentrations slightly exceed the standard recommended by WHO (WHO, 2017), but they were within the Algerian standard for drinking water (OJPDRA, 2011). The high Cl^- values are mainly explained by the impact of untreated wastewater discharges (the case of sample/well P4 which was 277 mg/l, located near the rural agglomeration of Bou Aroua), or they originated from the accumulation of this element (Cl^-) in the downstream area of this aquifer in the groundwater direction flow (the case of sample/well P14, which is located downstream of the plain). A high concentration of chloride in groundwater gives it a salty taste, which makes the water inappropriate for drinking. Intake of a high concentration of chlorides leads to hypertension, irritation of the eyes, renal stones, and asthma which increase the concentration of oxygen in the human body. Soils cannot absorb chloride, so a free movement of this ion is possible in the environment. It is easily dissolvable in water and forms hypochlorous acid and hypochlorite ions, both of which are unhealthy for humans (KUMAR ET AL., 2009; KUMAR ET AL., 2013).

Sulphates (SO_4^{2-}). Sulphate occurs naturally in numerous minerals and is considered to be one of the most significant anions after chloride and bicarbonate. The dissolution of minerals like barite, epsomite and gypsum are the main sources of sulphate, in drinking water (POROWSKI ET AL., 2019; SAHA & PAUL, 2019). The sulphate values of the samples varied between 139 mg/l (P5) and 301 mg/l (P6) during this dry water period. The concentrations of more than 50 % of the water samples exceed the WHO standard (< 200 mg/l); however, they were lower than the Algerian limit of 400 mg/l admissible for drinking water (OJPDRA, 2011). The high concentrations of sulphates are explained by the excessive use of sulphated fertilizers, insecticides, and fungicides in agriculture in the catchment, and possibly they may be due to the dissolution of gypsum or/and barite located in the Chenoua Massif. A high concentration of sulphate affects the taste of water and may have a laxative effect in humans (KUMAR ET AL., 2013).

Bicarbonate (HCO_3^-). Bicarbonate concentration in water is usually due to changes in carbonate equilibrium (SAHA & PAUL, 2019). The bicarbonate contents of groundwater samples in Wadi Hachem

aquifer varied between 397 mg/l (P5) and 564 mg/l (P10) during the sampling period (dry period 2015). The highest values were observed in the central part of the plain. All water samples exceeded the desirable limit of 300 mg/l. Health issues such as headaches, nausea and irritability can result from the intake of a high concentration of bicarbonate (KUMAR ET AL., 2009).

Nitrates (NO_3^-). Nitrogen is the most abundant element in the atmosphere and can be found in many forms. During rain, gaseous nitrogen interacts with water to increase the concentration of nitrate and ammonium ions. In natural conditions, the concentration of nitrate (NO_3^-) is less than 10 mg/l (ATOR & DENVER, 2012; WHO, 2017). The results showed that all water samples were within drinking water standards (< 50 mg/l), with the exception of well P4, where the nitrate content slightly exceeded the standard of drinking water. The contents varied from 20 mg/l (P1) to 53 mg/l (P4). High levels of nitrates in groundwater are generally due to the irrational use of fertilizers in agriculture. This ion is accumulated in the unsaturated zone, and then is leached by water towards shallow groundwater by infiltration. The uncontrolled rise of nitrate concentration in groundwater is a result of anthropogenic activities (BOUDERBALA, 2017b). Regular intake of water with high nitrate concentration causes health problems for humans, such as blue baby syndrome and methemoglobinemia. Several studies have shown that the chances of gastric cancer are higher in areas where there are high nitrate levels in groundwater (FORMAN ET AL., 1985).

Calcium (Ca^{2+}). Hardness in water is mainly due to a high concentration of calcium. The allowable limit of calcium for drinking water is 200 mg/l (OJPDRA, 2011; WHO, 2017). In this alluvial aquifer, the concentrations of Ca^{2+} ranged from 109 to 198 mg/l, with an average of 160.2 mg/l in this dry period. This indicated that all water samples were within the recommended standard limit for drinking purposes. The main source of calcium in groundwater in aquifers can be due to ion exchange of silicate minerals and/or dissolution of carbonate minerals. Calcium is an important element among nutrients that increase bone mass and reduce fracture risk in humans. Nevertheless, ingestion of calcium ions exceeding the maximum allowable limit may cause health problems such as kidney stones, hypercalcaemia, metabolic alkalosis as well as renal insufficiency in those who are prone to milk alkali syndrome (KUMAR ET AL., 2013).

Magnesium (Mg^{2+}). Magnesium is the key cause of permanent hardness in water. According to the WHO and the Algerian standard, the allowable

limits of Mg^{2+} for drinking water are 75 mg/l and 100 mg/l respectively (OJPDRA, 2011; WHO, 2017). The groundwater in this alluvial aquifer showed concentrations of Mg^{2+} which ranged from 41 to 75 mg/l, with an average of 59.7 mg/l in this dry period, so they were within standard limit recommended by WHO and by Algerian norm. These concentrations were lower than concentrations of Ca^{2+} , due to the low dissolution of magnesium minerals. High concentrations of Mg^{2+} ions in water may lead to nausea and diarrhoea, while low concentrations of Mg^{2+} create problems such as hypertension, coronary heart disease, Mellitus and metabolic syndrome (WHO, 2017).

Sodium (Na^+). Sodium is a common element in the natural environment. Its presence can result from road salt application, water treatment chemicals, and dissolution of salts in soil, silicate weathering, evaporation, anthropogenic activities, agricultural activities and poor drainage conditions which raise the concentration of sodium in groundwater (KUMAR ET AL., 2013). Sodium may affect the taste of drinking-water at levels more than 200 mg/l. In this alluvial aquifer, the concentrations of sodium ranged from 74 mg/l (P9) to 178 mg/l (P14), with an average of 115.1 mg/l, which indicate that all contents are within standard recommended by WHO and by Algerian norm (OJPDRA, 2011; WHO, 2017). The high concentrations of sodium in well P14 may be due to the accumulation of salts along the groundwater flow. The human body needs sodium in order to maintain blood pressure, control fluid levels and for normal nerve and muscle function. However, high values of Na^+ ions tend to destroy soil structure, thus making the water inappropriate for irrigation purposes (WHO, 2017).

Potassium (K^+). The concentration of potassium in groundwater is lower than other cations. The high concentration may be due to anthropogenic activities. The concentration of K^+ in this study area varied from 3 to 11 mg/l, with a mean value of 7.3 mg/l, indicating that all groundwater samples within the permissible limit for potassium in drinking water as recommended by WHO and Algerian norm of 12 mg/l (OJPDRA, 2011; WHO, 2017). High consumption of potassium leads to hyperkalaemia (KUMAR ET AL., 2013).

6. Discussion

6.1. Hydrochemical facies for groundwater

Determination of groundwater types provides vital information about the hydrochemical evolution

of groundwater, sources of ionic constituents and grouping of major ions (RAVIKUMAR & SOMASHEKAR, 2017). A Trilinear diagram (PIPER, 1944; Fig. 5) and Chadha's diagram (CHADHA, 1999; Fig. 6) were used to determine the various hydrogeochemical processes, and to classify the groundwater of the aquifer into different types.

The plot in the Piper diagram (Fig. 5) shows that there is no dominant cation or anion, and the plot of geochemical data on the central diamond-shaped field reveals a mixed type of water, except for one sample (P9) which indicates $Ca-HCO_3$ water type.

Fig. 5. Piper diagram of the 13 groundwater samples in the alluvial Wadi Hachem aquifer

The plot in Chadha's diagram shows that twelve groundwater samples have a $Ca - HCO_3$ water type showing the natural water quality, which was influenced by the recharge area and by geological influences (water infiltrates into the aquifer from the surface) and carries dissolved HCO_3^- and geochemically transportable/mobile Ca^{2+} . While one sample (P14) shows a $Cl-Ca$ water type, which belongs to the field 6, which indicates that the groundwater sample exhibits permanent hardness, or reverse ion exchange water, meaning that (Ca^{2+} and Mg^{2+}) are in higher abundance than (Na^+ and K^+) ions which may be caused by the release of Ca^{2+} and Mg^{2+} ions from weathering of the exposed aquifer rocks such as carbonate rocks or perhaps reverse base cation exchange processes of alkali earth metals into solution and consequent Na^+ adsorption onto the exposed rock's mineral surfaces (BOUDERBALA, 2017b).

Fig. 6. Chadha's plot showing hydrochemical processes involved in the groundwater samples

6.2. Hydrogeochemical processes

Binary diagrams. Dissolved species and their relationship with each other can reveal the origin of solutes and the processes that generated in the observed composition of the groundwater. Some binary diagrams were used to better identify the origin of salts dissolved in the groundwater (BOUDERBALA ET AL., 2016). The relationship between Na^+ and Cl^- showed a good correlation between sodium and chloride concentrations for most of the sample points ($R^2 = 0.87$), indicating their common origin, and confirms that the halite dissolution is the cause of the water salinity (Fig. 7).

The impact of seawater intrusion is confirmed by the ratio of $\text{Cl}^-/\text{HCO}_3^-$ against Cl^- . According to REVELLE (1941), the salinization of groundwater was grouped by use of the ionic ratio of $\text{Cl}^-/\text{HCO}_3^-$. Values from 0 to 0.5 indicate that groundwater samples are unaffected by seawater, values between 0.5 and 6.6 show that groundwater samples are slightly to moderately affected by seawater, and values > 6.6 suggest that groundwater samples are strongly affected (SUDARYANTO & NAILY, 2018; PAPAZOTOS ET AL., 2019). In the Wadi Hachem alluvial groundwater aquifer the ratio of $\text{Cl}^-/\text{HCO}_3^-$ ranges from 0.35 to 1.33 (Fig. 8), indicating that groundwater in this aquifer are unaffected by seawater intrusion.

The excess of $(\text{Ca}^{2+} + \text{Mg}^{2+})$ over $(\text{HCO}_3^- + \text{SO}_4^{2-})$ indicates the significant impact of carbonate mineral dissolution and/or reverse ion exchange on groundwater quality (PAPAZOTOS ET AL., 2019). Reverse ion exchange normally occurs in the presence of clays with exchangeable Ca^{2+} . As shown in Fig. 9, the scatter plot shows that some groundwater samples fall above the theoretical 1:1 line (silicate weathering), others fall below

the theoretical 1:1 line (reverse exchange) and others are at equilibrium.

Fig. 7. Scatter plot of Na^+ against Cl^- of 13 groundwater samples

Fig. 8. Scatter plot of $\text{Cl}^-/\text{HCO}_3^-$ against Cl^- of 13 groundwater samples

Fig. 9. Scatter plot of $(\text{Ca}^{2+} + \text{Mg}^{2+})$ against $(\text{HCO}_3^- + \text{SO}_4^{2-})$ of 13 groundwater samples

Chloro-alkaline index (CAI). The ion exchanges between the groundwater and its host environment during residence, or travel, are understood by studying the chloro-alkaline indices (CAI) ($CAI = [Cl^- - (Na^+ + K^+)] / Cl^-$ meq/l). The chloro-alkaline index (CAI) known as index of base exchange (IBE) is positive when there is an exchange of Na^+ and K^+ from the water with Mg^{2+} and Ca^{2+} of the rocks, and is negative when there is an exchange of Mg^{2+} and Ca^{2+} from the water

with Na^+ and K^+ of the rocks (NAGARAJU ET AL., 2016).

The IBE of groundwater in the alluvial aquifer of Wadi Hachem shows values ranging from - 0.26 to 0.17, which suggests that some of the samples in the study area fall into negative zones and some fall into positive zones (Fig. 10). It is imperative to understand the modifications in water chemistry during its movement and residency time within the aquifer.

Fig. 10. Indices of Base Exchange of groundwater samples in Wadi Hachem alluvial aquifer

6.3. Suitability of groundwater for agricultural purposes

The average, maximum, minimum and standard deviation of different water parameters have been described in Table 2. Three indices were used to determine the suitability of groundwater for irrigation activities: Sodium Adsorption Ratio (SAR), Sodium Percentage (Na %), and Residual Sodium Carbonate (RSC).

Sodium Adsorption Ratio (SAR). Classification of irrigation water with respect to SAR is based on the effect of exchangeable sodium on the physical condition of the soil. However, sodium-sensitive plants may suffer injury as a result of sodium accumulation in plant tissues when exchangeable sodium values are lower than those effective in causing deterioration of the physical condition of the soil (NAGARAJU ET AL., 2016). The SAR is defined as the square root of the ratio of the sodium (Na^+) to calcium + magnesium ($Ca^{2+} + Mg^{2+}$) (RICHARDS, 1954).

$$SAR = \frac{Na^+}{\sqrt{(Ca^{2+} + Mg^{2+})/2}}$$

All concentrations are expressed in meq/l

The Riverside diagram was used in many studies to classify groundwater quality for irrigation (PAPAZOTOS ET AL., 2019). According to this index, water can be classified into four different classes. The classes are 0–10 (S1), 10–18 (S2), 18–26 (S3) and > 26 (S4) which correspond to excellent, good, fair and unsuitable water for irrigation use, respectively (RICHARDS, 1954). The EC is classified into low (C1, EC = 0–250 $\mu S/cm$), medium (C2, EC = 250–750 $\mu S/cm$), high (C3, EC = 750–2250 $\mu S/cm$) and very high (C4, EC > 2250 $\mu S/cm$) salinity categories.

The SAR values of the groundwater samples in the study area were between 1.31 to 2.98 with an average value of 1.93. The SAR values of the groundwater samples in the study area are less than 10, which can be classified as excellent for irrigation. The plot of all water samples on the Riverside diagram shows two classes (C3S1 and C4S1) using the SAR and the EC values in the vertical and horizontal axes, respectively. C3S1 shows a high salinity hazard and low alkali hazard, and the C4S1 category indicates very high salinity and low alkalinity hazards (Fig. 11). This groundwater can be suitable for plants having good salt tolerance and it restricts the suitability for irrigation, especially in soils with restricted drainage (SINGH ET AL., 2015).

Percent Sodium (Na %). Sodium concentration is an important factor to classify the water for irrigation purposes because it can react with soil resulting in the clogging of particles, thereby, reducing the permeability of water and respiratory gases (NAGARAJU ET AL., 2016). The sodium hazard of irrigation water is expressed by using the formula:

$$SP = \frac{Na^+ + K^+}{(Ca^{2+} + Mg^{2+} + Na^+ + K^+)} \times 100$$

where, all the ionic concentrations are in meq/l.

The plots of groundwater samples on a Wilcox diagram (WILCOX, 1955) fall in the area of good irrigation water quality (61.5 %) and doubtful irrigation water quality (38.5 %) (Fig. 12).

Fig. 11. Classification of groundwater samples in the alluvial Wadi Hachem aquifer in terms of degree of suitability for irrigation using Riverside diagram 1954

Residual Sodium Carbonate (RSC). Residual Sodium Carbonate refers to residual alkalinity and is calculated for irrigation water by the following formula:

$$RSC = (CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+})$$

where, all ionic concentrations are in meq/l.

According to the U.S. Salinity Laboratory, an RSC value less than 1.25 meq/l is safe for irrigation; a value between 1.25 and 2.5 meq/l is marginal quality and a value greater than 2.5 meq/l is unsuitable for irrigation (EATON, 1950; NAGARAJU ET AL., 2016). The RSC values of the groundwater samples in the study area range from - 6.67 to - 2.78 meq/l. Therefore, the groundwater of the study area is safe for irrigation.

Fig. 12. Classification of groundwater samples in the alluvial Wadi Hachem aquifer in terms of degree of suitability for irrigation using the Wilcox diagram 1955

Fig. 13. Fluctuation of groundwater levels and electrical conductivity of the alluvial aquifer of Wadi Hachem (dry period 2015 and wet period 2016)

6.4. Impact of natural recharge on the water quality

According to the piezometric data recorded for the hydrologic year 2015/2016, and examination of Fig. 13, we note a rise of the piezometric level of groundwater in the Wadi Hachem aquifer, of about 1.85 m on average during the period September 2015 to April 2016, and this is likely due to the contribution of recharge from precipitation mainly during the rainy periods. This recharge by rainfall has contributed to the decrease of electrical conductivities of groundwater from the dilution effect as shown in the figure.

7. Conclusion

The groundwater quality of the alluvial aquifer of Wadi Hachem was evaluated, for the dry period of 2015, with the aim to determine its suitability for drinking water and for irrigation purposes. The water samples were found to be slightly alkaline in nature, and they had moderate soft water quality for drinking based on total hardness (TH), and the majority of samples had EC and TDS on the permissible limit recommended by the Algerian standard for drinking water. All cations and anions of the groundwater samples were within the permissible limit for drinking and irrigation purposes, and the plot of these samples on Chadha's diagram show two water types, Ca- HCO₃ for the majority of samples, which characterizes natural water quality controlled by a recharge area and by geological influences (which represent 92.3 %) and Ca-Cl water type for one sample, which is characterized by the influence of anthropogenic activities and hydrogeological conditions (which represent 7.7 %) in the catchment area.

Finally, we can say that based on the classification of irrigation water according to its SAR and Na% values, the majority of samples were suitable for irrigation purposes (more than 60%). However, the rest of the samples belonged to the doubtful to unsuitable category for irrigation use due to the presence of excess sodium salts that cause deflocculating and reduce the permeability of soil. We also notice that there was no marine intrusion into the plain due to the rise of the bedrock in the downstream part of this aquifer.

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