



Research Article

Evaluation of the quality of groundwater for its appropriateness for drinking purposes in the watershed of Naâma, SW of Algeria, by using water quality index (WQI)

Abdessamed Derdour¹  · Mahamat Mountassir Mahamat Ali² · Sidi Mohamed Chabane Sari²

Received: 4 July 2020 / Accepted: 27 October 2020 / Published online: 6 November 2020
© Springer Nature Switzerland AG 2020

Abstract

Naâma watershed is situated in the southwest of Algeria, where the climate is arid. It is highly dependent on groundwater resources, which are the only available resources for irrigation and domestic purposes. The study was carried out to assess groundwater appropriateness in the study area for drinking uses through a water quality index (WQI) and geographic information system (GIS). Fourteen (14) groundwater samples were collected, and several physicochemical parameters such as electrical conductivity (EC), potential for hydrogen (pH), total dissolved solids (TDS), cations (Ca, Mg, Na, K), and anions (SO₄, NO₂, HCO₃, Cl) were analyzed. The results report that the different water quality parameters were within the permissible limit given by the World Health Organization and Algerian Standards guidelines, except for some boreholes near the Sabkha of Naâma. Eleven (11) parameters were chosen to compile the water quality index. The results showed that 50% of groundwater sites sampled in the study area had excellent water quality, while 50% were suitable. By carefully examining the data, it was revealed that boreholes distant from Sabkha present an excellent groundwater quality, where the WQI ranges between 37 and 41.6 mg/L. On the other hand, the boreholes close to Sabkha are characterized by a high concentration of electrical conductivity, TDS, sodium, and sulfates, explained by the contamination of the surrounding area through the infiltration of salt elements from the Sabkha. This salt contamination of groundwater would be accentuated by the discharge of wastewater from Naâma town into the Sabkha, the irrational use of chemical fertilizers, pesticides, and intensive pumping. The spatial distribution of the physicochemical parameters and water quality index was generated using the inverse distance weighted interpolation method (IDW). This study demonstrates that the combination of WQI and GIS methods could be a helpful tool for water resources management and decision making.

Keywords Naâma · Groundwater · Quality · GIS · WQI · Sabkha

1 Introduction

Water is essential for life; without it, there would be no life possible on earth. All living things need water to exist. Water resources are becoming scarce due to the increasing needs of domestic, industrial, and agricultural demand and environmental degradation [1, 2]. Groundwater is the primary source of drinking water for most

of Algeria's population, especially in rural areas [3]. The amount of water extracted from groundwater is about 70% of the water used for Algeria's drinking and irrigation services [4]. Dependence on groundwater has increased due to changing lifestyles, urbanization, and population growth. These elements impact the quality and quantity of groundwater resources negatively. Water geochemistry specifies the appropriateness of groundwater for irrigation

✉ Abdessamed Derdour, samederdour@yahoo.fr | ¹Laboratory for the Sustainable Management of Natural Resources in Arid and Semi-arid Zones, University Center Salehi Ahmed of Naâma, 45000 Naâma, Algeria. ²Institute of Water and Energy Sciences (Incl. Climate Change), Pan African University, 13000 Tlemcen, Algeria.



and domestic uses [5]. However, in the arid and semiarid regions, groundwater quality is grossly affected by agricultural activities due to the use of chemical fertilizers [6]. The degradation of groundwater quality is generally caused by natural processes and human activities [7]. Therefore, in areas that are closed to the sea like Algiers and Annaba, it was observed that there is salt pollution in the groundwater due to the seawater intrusion. In the southwest of Algeria, the groundwater quality could be influenced by wastewater discharge [8]. Before the water is used in different sectors like domestic, agriculture, and industry, it is mandatory to evaluate its quality. Water quality is an expression used to interpret the physical, biological, and chemical characteristics of water, generally to its appropriateness for specific use [9, 10]. Water held underground has long been considered good quality water compared to surface water due to the soil column of purification [11]. The standards of water quality differ according to the countries. The concept of "potability" varies around the world. It is the result of a historical, scientific, and cultural context. It determines access to water since good quality water is essential for economic and human development. For example, the parameters frequently regulated are: Organoleptic quality (color, turbidity, odor, flavor), certain natural physicochemical parameters (temperature, pH, calcium, magnesium, chlorides, sulfates.); the presence of substances undesirable (nitrates, nitrites, pesticides, etc.); the presence of substances toxic (arsenic, cadmium, lead, hydrocarbons, etc.); specific microbiological parameters; the water must not contain organisms pathogenic, in particular fecal coliforms. Compliance with these parameters can be obtained by specific water treatment. If the physicochemical elements that characterize the water exceed national or international norms or standards, water is unfit for human consumption. This impure water is a real public health problem, especially in rural areas where water quality checks are less frequent. Several indicators have been developed by many researchers around the world to represent water quality data for groundwater and surface water resources [12–17]. Among these indices, the water quality index was defined by Horton [18] and posteriorly developed by Brown, McClelland [19]. The WQI (water quality index) is an essential parameter that can be applied to assess groundwater vulnerability because it reports groundwater in the region. Also, it's a powerful tool to evaluate the adequacy of surface water [20]. Besides, the WQI method is vastly applied in several countries and areas to assess groundwater quality around the world due to its outstanding capacity to assess and manage water quality parameters [21].

Some notable examples around the world are as follows: Varol and Davraz classified the quality of groundwater with WQI in the Tefenni plain in Turkey [22]. Bairu et al.

[23] used WQI and GIS to assess the quality of water in northern Ethiopia. Selvam et al. [24] applied the WQI to evaluate the groundwater quality in the south of India. In the Agro-Aversano area of southern Italy, Rufino et al. [25] used groundwater quality index (GQI) to evaluate the suitability of urban groundwater resources for drinking water and irrigation purposes. It was widely used in several regions in Iran to assess groundwater quality's appropriateness for drinking water and irrigation [26–31]. The most recent method for calculating a WQI is based upon integrating Fuzzy Logic with the GIS-based G.Q.I [32].

Some studies have also been accomplished in Algeria to evaluate the quality of water surface and groundwater of many aquifers for irrigation and drinking purposes using the water quality index [4, 33–37]. The region of Naâma is the chief town of the Naâma Wilaya, which is situated in the southwest of Algeria. It is highly dependent on groundwater resources for its development. The groundwater is the only water source for agricultural and domestic activities due to the massive evaporation of surface water resources. This research's main objective is to comprehend the status of the quality of the aquifer of Naâma watershed, using the WQI and GIS. We used several physicochemical parameters to estimate the appropriateness of groundwater for drinking uses such as electrical conductivity (EC), total dissolved solids (TDS), the potential for hydrogen (pH), major cations (Ca, Mg, Na, K), and major anions (SO₄, NO₂, HCO₃, Cl).

1.1 Study area

In 1984, the Naâma region was raised to the Wilaya rank within the Algerian Moroccan border and the Wilayas of Tlemcen, Sidi Bel abbes, El Bayadh, and Bechar. The Wilaya of Naâma comprises a vast rangeland zone to the north (75%), a median mountainous area, and a Saharian zone to the south. The Wilaya of Naâma consists of twelve (12) communes. It is located between the Tell Atlas and the Saharian Atlas and extends over 29,819 km² for a population estimated at 274,067 inhabitants, with a density of 9.19 inhabitants/km² [38]. The commune of Naâma is the capital of the Wilaya of Naâma; it has an area of 2 525,93 km². The geographic situation is between 3650000 to 3720000 m N and 720,000 to 780,000 m E (Fig. 1). The total population of the commune of Naâma is around 26156 inhabitants, and the density is estimated at 10.35 (Hab./km²). Groundwater is the leading resource on which most of the region's population depends on drinking and agriculture.

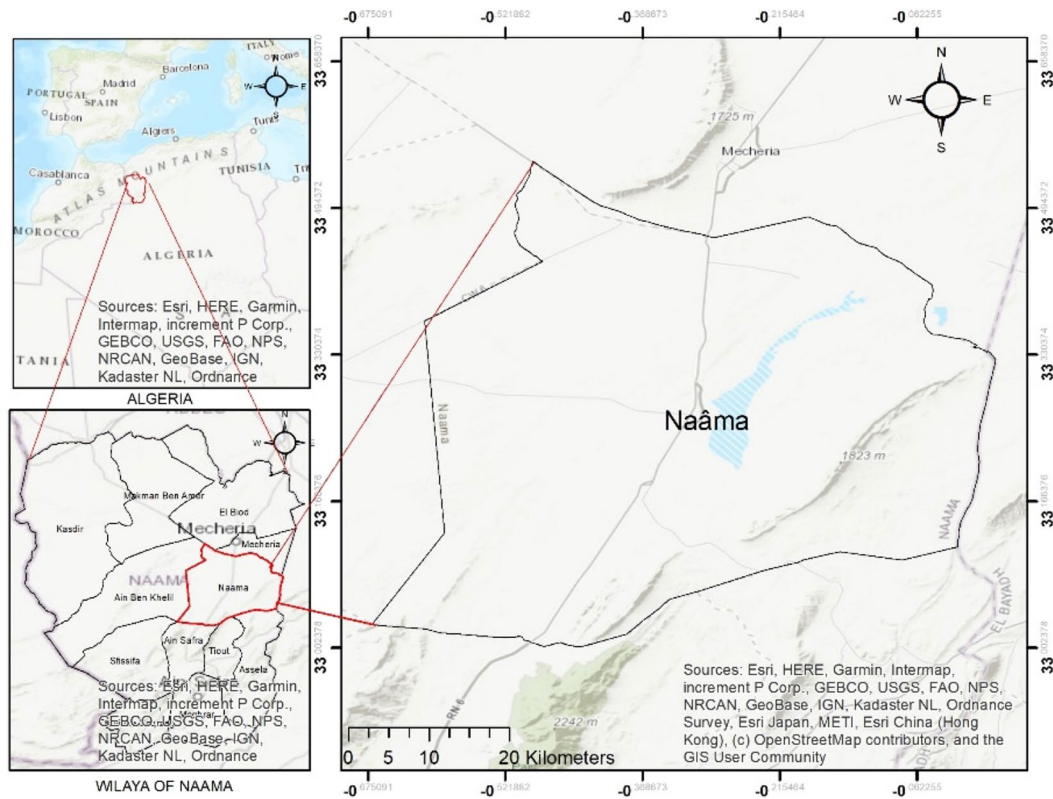


Fig. 1 Study area

1.2 The climate conditions

Meteorological data for 30 years (1995–2015) are collected from the weather station of Naâma town. Its UTM coordinates are 3683441.09 m N and 749904.50 m E, and its WMO code is 605570. After data, analysis, and interpretation, it has been concluded that the climate of Naâma is arid to semiarid, where the evaporation is very high, and rainfall is rare and very irregular but intense. The annual rainfall range is between 124 and 352 mm and the average rainfall is about 214.3 mm. July is the hottest and the driest month, with an average of 30 °C, and 6.3 mm of rain, while the most precipitation falls in October, with an average of 40.6 mm. The heat record is 41 °C recorded on Monday, July 16, 2012, and the cold record of –7 °C was recorded on Saturday, February 1, 2003.

1.3 Hydrology

The watershed's behavior results from different parameters, mainly geological, morphological, and meteorological factors. These regulate the temporal and spatial distribution of the surface flow [39]. Flows in the study area are infrequent, short-lived, and stormy. Its floods'

power is successive of having significant erosion and solid transport actions, which leads to aggressive flooding in this watershed. The only stream gauging station in the region is located far more than 100 km to the south, in the area of Ain Sefra [40]. A digital elevation model (D.E.M.) with 30 m resolution downloaded from USGS. "United States Geological Survey" website is used to delineate the Naâma watershed and define its physical characteristics. Naâma watershed is situated between 3600000 to 3710000 m N and 730,000 to 775,000 m E coordinates, and it has an area of 895 km² covering 35% of the area of the commune of Naâma (Fig. 2). The mountains surrounding the watershed are the starting areas of the streams that concentrate across the Sabkha, "a salt plain in North Africa occupied after the rain by a shallow lake." The Sabkha of Naama is formed by the leaching of the Triassic salt lands of Djebel El Mellah. It is characterized by altitudes ranging between 1140 and 1273 m above sea level, with a slope that is between complete flat to 7% [41]. A dendritic form characterizes the study area's hydrographic network, and it is moderately dense and ramified. The common direction of flow is across the northeast, and the longest drainage path measures approximately 59 km.

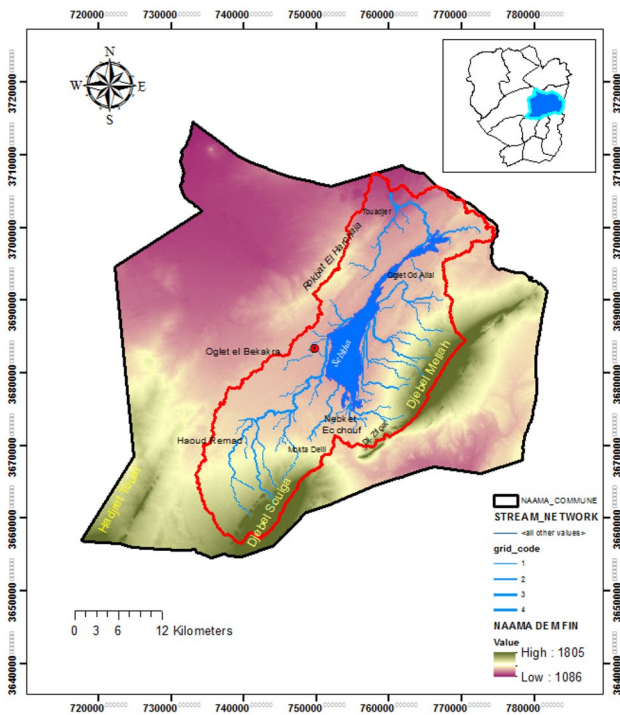


Fig. 2 Watershed of Naâma

1.4 Geology

Ksour mountains are part of the Saharian Atlas, of which they constitute the extreme western part, with altitudes reaching more than 2000 m [42]. They are subdivided into three zones: (1) The pre-Atlas area (Mechria and Naâma) with weak structure and low topographic relief, which is the subject of our study. (2) The location of the strongly folded atlas (Ain Sefra). The limit between the two zones is underlined by anticline ridges dominating the pre-Atlas corresponding to the North Atlas accident. (3) The pre-Saharan zone (Beni Ounif), constituting the southern-western end of the Ksour Mountain. Naâma watershed is part of the Ksour mountains (Fig. 3). Its geological setting is well known for photogeological studies [43]. Geological series spans from the Triassic to the recent Quaternary with a predominance of the Cenozoic Era [44]. Mio-Pliocene rocks wrap more than 76% of the area, and 12.37% represent the Jurassic Era. The other percentage (11.63%) filled with cretaceous and quaternary formations. Jurassic and Pliocene sandstones and limestones are the geological facies that widely dominate the region [45–48]. The underground of the Wilaya of Naâma contains great water potential, which is, however, very little exploited. Groundwater reserves are located throughout the Wilaya territory, in particular around Chott El-Gherbi, Chott Echergui, Naâma syncline, the aquifers of Ain Sefra, and Tiout valley. The most crucial groundwater aquifer in the study area is

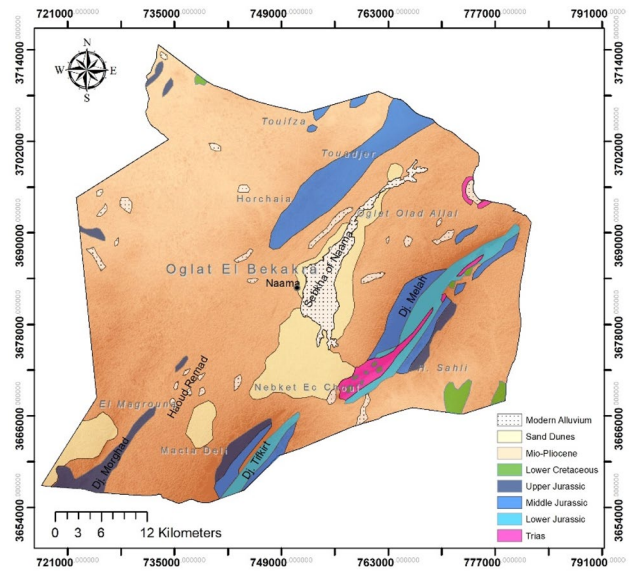


Fig. 3 Geological map

the Callovo-Oxfordian aquifer; it is formed of sandstones at the top then an alteration of sandstones and clays. It is a confined aquifer characterized by pores and cracks. Altitudes of the study region vary from 1086 to 1805 m, those located between 1200 and 1300 m represents 67% of the total area of the Naâma watershed. The slopes are medium to low. The altitude varies from 1086 m to 1805 m above the mean sea level. The most common heights are between 1200 and 1300 m, representing 67% of the total area of Naâma watershed. The relief is characterized by medium to low slopes.

2 Materials and methods

The acquisition of data in water resource knowledge programs sometimes leads to accumulating a large amount of information. It is not always easy to link this knowledge and the use we want to make of this water. To this end, the water quality index has been developed. WQI has a significant role in the evaluation of the quality of water. It has been used by numerous international organizations and researchers across the world. In this study, the weight arithmetic water quality index (WAWQI) method was selected; it has been widely applied in several countries and areas to calculate water quality [49–51]. 07 steps were followed to use the model in the study area:

2.1 Data collection

From the Naâma watershed, fourteen (14) groundwater samples were gathered from the boreholes (Fig. 4). The

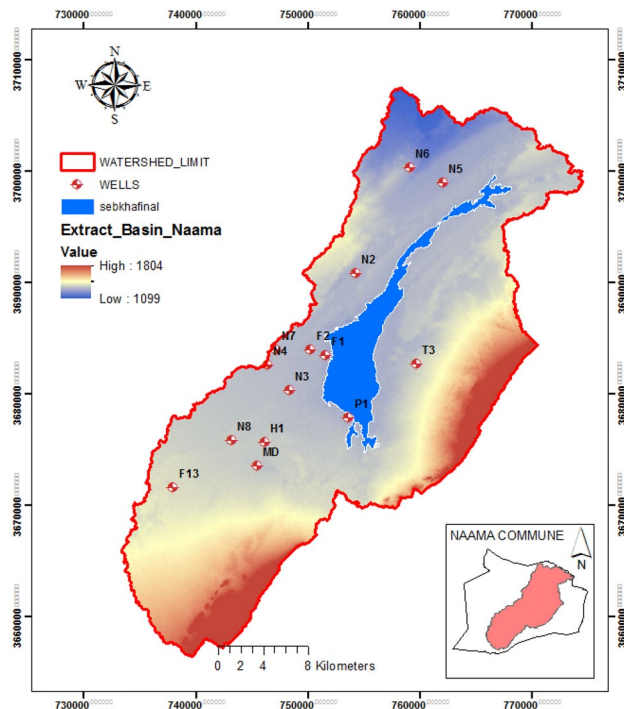


Fig. 4 Groundwater sampling wells map

samples are distributed uniformly to cover most of the study area. Before the sampling, the pumping of water for 10–15 min was necessary to obtain the composite sample. The samples were then collected in specific containers washed with the water of interest and distilled water and then immediately transferred to the Naâma laboratory for analysis. For every groundwater sample, geographic location and static water level were mentioned in a ticket, and various physicochemical analyses were performed. Electric Conductivity, Temperature, and potential hydrogen (pH) were measured in situ using HANNA waterproof portable multiparameter (HI98194). The method of complexometric titration was used to determine calcium (Ca), magnesium (mg), and total hardness (TH). Simultaneously, a flame photometer was utilized to analyze sodium (Na) and potassium (K). For anions: Mohr's method was applied to determine the concentrations of chlorides (Cl). And the spectrophotometer UV–VIS model was used to measure the concentrations of sulfates (SO₄), nitrate (NO₃). Evaporation of 1 filtered liter of the water sample at a high temperature (100 °C) was used to determine total dissolved solids (TDS). The residue was dried at 180 °C for 2 h. Finally, the analysis results were evaluated and compared with Algerian Standards' guidelines quality water [52] and the World Health Organization [53]. The analyses were carried out for internal precision through an ionic balance. The expression that was evaluated following Eq. 1:

$$E(\%) = \frac{\sum \text{cations} - \sum \text{anions}}{\sum \text{cations} + \sum \text{anions}} \times 100\%, \quad (1)$$

where $E(\%)$ is the charge-balance error, and $\sum \text{cations}$ and $\sum \text{anions}$ are the sums of cations and anions, respectively, expressed in equivalents per liter. The ionic balance is expressed in percentage. In this case, the interpretation of the results of the ionic balance was based on the following rating:

- Excellent analysis, when $E\%$ is ranging between -1 and $+1$.
- Acceptable analysis, when $E\%$ is ranging between -5 and $+5$.
- Poor analysis, when $E\%$ is ranging between -10 and $+10$.

After assessing the groundwater samples' chemical analysis, other technical water analysis techniques were applied since the results were judged reliable.

2.2 Assigning a weight (W_i)

At the next step, a weight (w_i) has been attributed to each of the study's 12 physicochemical parameters, according to its relative significance on the total quality of drinking water uses (Table 1). TDS and nitrates were given a maximum weight of 5, due to their high impact on groundwater quality, while magnesium was assigned the minimum value of 1, given to its low influence in the water quality of drinking. Weight between 1 and 5 was attributed to other physicochemical parameters [54].

2.3 Computing the proportional weight

In the following step, the proportional weight (W_i) is calculated using Eq. 2. [55–57]:

$$W_i = w_i / \sum_{i=1}^n w_i, \quad (2)$$

where W_i is the proportional weight, w_i is the weight of every parameter, and n is the number of parameters.

2.4 Assigning the quality rating scale

Then, the rating scale of quality (q_i) for every parameter was specified using Eq. 3:

$$q_i = (C_i/S_i) * 100, \quad (3)$$

Table 1 Weight and relative weight of each parameter for the study area

Parameter	WHO (2004)	Algerian Standards (2011)	Weight (w_i)	Relative weight (W_i)
pH	6.5 < pH < 8.5	6.9 < pH < 9.0	4	0.003968
Conductivity ($\mu\delta/cm$)	1500	2800	4	0.001984
TDS (mg/L)	500	No-Limit	5	0.001984
Calcium (mg/L)	75	200	3	0.002976
Magnesium (mg/L)	50	150	1	0.001984
Sodium (mg/L)	200	200	2	0.001984
Potassium (mg/L)	12	12	2	0.000992
Chloride (mg/L)	250	500	3	0.002976
Sulfates (mg/L)	250	400	4	0.001984
Nitrates (mg/L)	45	50	5	0.002976
Bicarbonates (mg/L)	120	No-Limit	3	0.001984
			36	1

where q_i is the quality rating scale, S_i is the drinking water standards for each chemical parameter (mg/L). And C_i is the concentration of every chemical parameter in mg/L.

2.5 Determining the sub-index value

In this step, the sub-index values SI_i are calculated for all chemical parameter, by the multiplication of the proportional weight and the quality rating, following Eq. 4:

$$SI_i = W_i * q_i. \quad (4)$$

2.6 Calculating the WQI

In the final step, WQI was computed by adding all the sub-index of all groundwater samples together, following Eq. 5:

$$WQI = \sum_{i=1}^n SI_i, \quad (5)$$

where SI_i is the sub-index of the i th parameter, and n is the number of parameters [27, 58].

The calculated water quality index (WQI) values are classified into 05 categories

- Excellent water, when WQI is less than 50.
- Good water, when WQI is ranging between 50 and 100.
- Poor water, WQI is ranging between 100 and 200.
- Very poor water, when WQI is ranging between 200 and 300.
- If WQI is more than 300, the water is unfit for drinking.

2.7 The spatial analysis

Analysis of the quality of groundwater is instrumental in the appropriateness evaluation of water for different

purposes. Generating spatial distribution maps of various quality of water parameters involves integrating the attribute and spatial data. Interpolation being a process of estimating unknown values that fall between known values could be the solution for this challenge [59]. Hence, the inverse distance weighted (IDW) interpolation techniques in ARC GIS have been used to prepare the spatial distribution maps for all physicochemical parameters. This interpolation method assumes that each point has a local influence that decreases with distance. Many researchers used (IDW) interpolation to create the water quality index maps [7, 23, 60–62]. The maps of the spatial distribution of the pH, EC, TDS, TH, anions and cations, and WQI for the study area have been created to help water resources management and decision making.

3 Results and discussion

3.1 Physicochemical assessment

The results of the physicochemical parameters of the groundwater quality of Naâma watershed are summarized in Table 2. The table also provides the average and standard deviation for each parameter. The last column of Table 2 shows the charge-balance error obtained with Eq. (1). We remark that All charge-balance errors are within an acceptable limit of 5%, except for the sample from well N1, which is just above the limit. Based on the results, we make the following observations:

The pH of the study area fell within 7.11 and 8.13 and had a mean of 7.71. All water samples analyzed fell within Algerian Standards' guidelines limit and the World Health Organization [52, 53]. With $pH > 7.0$, the groundwater of this study area is alkaline. Figure 5-a presents the spatial analysis of pH.

Table 2 Data of groundwater quality of Naama watershed

Boreholes	pH	TDS (mg/L)	EC ($\mu\text{S}/\text{cm}$)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	SO4 (mg/L)	NO3 (mg/L)	HCO3 (mg/L)	E (%)
N3	7.78	387	775	84	50.4	124	11.1	77.9	147	0.38	227	1.13
N1	7.9	496	993	104	62.4	806	7.3	92.2	141	20.7	214	5.84
N2	8.03	388	776	100	60	51	16.23	29	124	0.63	225	2.27
F13	7.89	224	551	72	43.2	57	4.04	38	84.6	20.8	266	0.62
N4	7.73	391	772	72	43.2	48	5.03	29	101	14.9	255	0.69
N6	7.72	231	560	64	50.4	55	6	34.2	95.2	12.3	190	1.56
N7	7.74	216	670	88	52.8	53	6	37.2	148	11.9	220	1.10
N5	7.71	318	675	88	52.8	51	4	52.4	113	28.6	272	0.39
N2	7.86	328	763	108	64.8	139	7	69.8	128	28.3	266	1.95
N8	7.65	535	1084	124	74.4	124	8.1	77.1	179	10.3	237	1.93
H1	7.64	900	999	73	57	124	7	177	210	25	237	-1.45
MD	7.11	560	622	74	37	21	3	25	154	25	242	-0.75
P	7.8	660	940	67	55	53	6	114	172	27	220	-1.53
T3	7.4	1660	700	72	79	304	12	562	213	7	227	-2.57
Min	7.11	216	551	64	37	21	3	25	84.6	0.38	190	-2.57
Max	8.03	1660	1084	124	79	806	16.23	562	213	28.6	272	5.84
Mean	7.71	521.00	777.14	85.00	55.89	143.57	7.34	101.06	143.56	16.63	235.57	0.89
SD	0.27	447.80	178.86	19.58	12.91	246.91	4.06	169.77	42.52	10.20	25.36	2.40

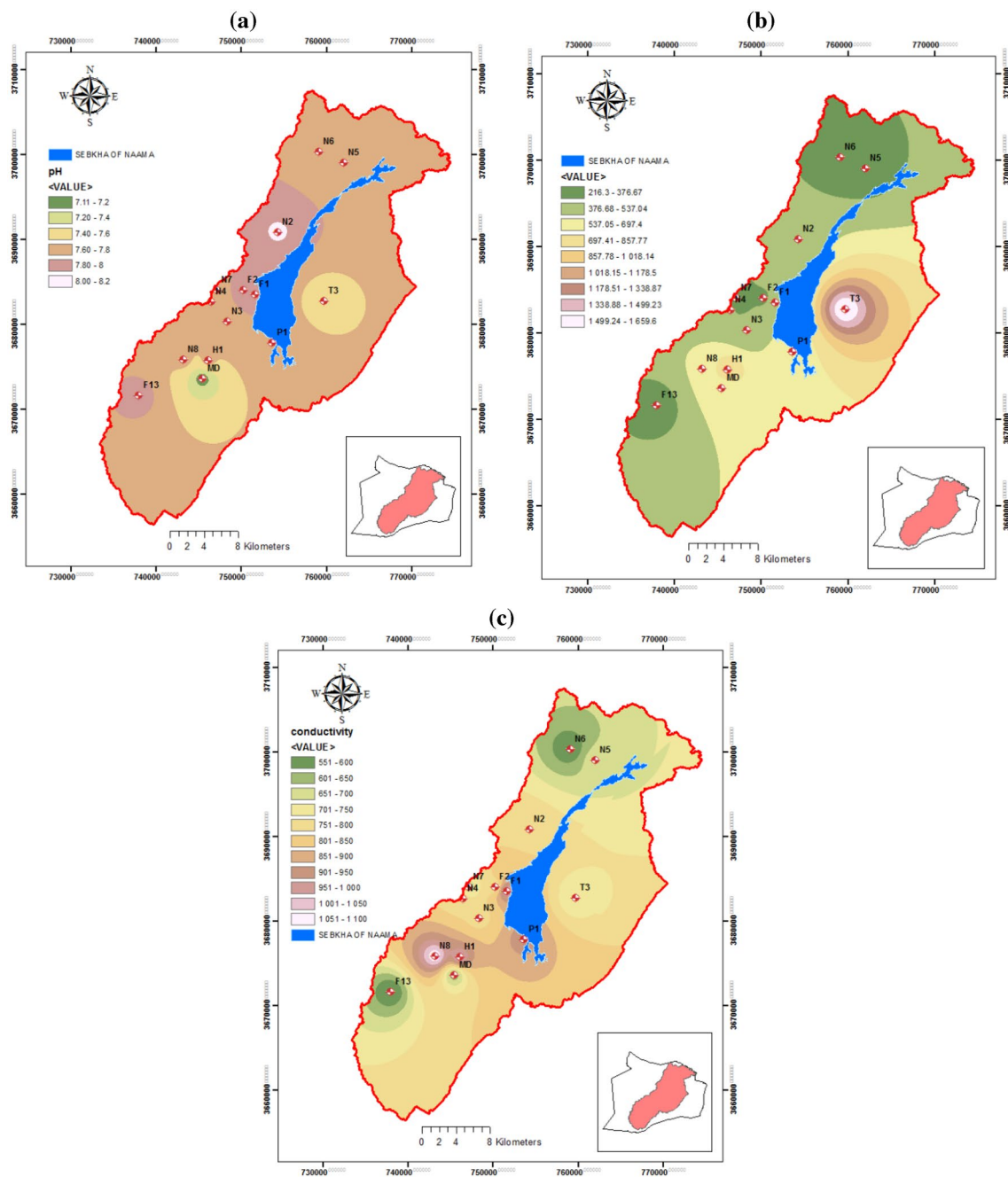


Fig. 5 Spatial distribution of in the Naâma watershed. **a** pH, **b** electrical conductivity, **c** total dissolved

The electrical conductivity in this study varied from 551 to 1084 $\mu\text{S}/\text{cm}$. It was noted that all measured values for EC were less than the indicative value for the water of 1500 $\mu\text{S}/\text{cm}$, prescribed by the World Health Organization, and they were also under the indicative value for the water of 2800 $\mu\text{S}/\text{cm}$, fixed by Algerian Standards [52, 53]. It was observed that at the location of borehole N8, the highest mean value of 1084 $\mu\text{S}/\text{cm}$ was recorded. High electrical conductivity values in certain parts of the study area

could be due to certain salts' infiltration from the Sabkha of Naâma toward the aquifer. Figure 5b shows the spatial distribution of EC in the Naâma watershed. It was found that the groundwater samples which are located far from Sabkha displayed a lower EC value (N6, N5, F13).

The values of TDS of Naâma aquifer range from 216 to 1660 mg/L in groundwater samples. It has been concluded that 93% of water samples are within the World Health Organization recommended limits of 1000 mg/L

[53]. It is noted that no limit is stipulated for the TDS by the Algerian Standards [52]. The spatial analysis for TDS of this study presented in Fig. 5c shows that the considerable concentrations of TDS located near Sabkha de Naâma (T3, P1, and F1). On the other hand, boreholes, located far from Sabkha, presented low concentration and varied from 216 to 376 mg/L (N6 and F13). TDS in the groundwater studied in this research was high due to the enrichment of salts in the water. It might also be because of the interaction of rock and water and agricultural activities.

The values of calcium in groundwater in the study area range from 64 to 124 mg/L. Figure 6a shows that all calcium concentrations are within the acceptable limits of the Algerian Standards of 200 mg/L, while 50% exceeds the consumption Standards stipulated by the World Health Organization of 75 mg/L [52, 53]. High amounts of calcium in tap water pose no health risk. However, they can affect the taste of the water. The content of magnesium in groundwater samples spread from 37 to 79 mg/L, and the average value is 55.88 mg/L. All magnesium values respect the Algerian Standards

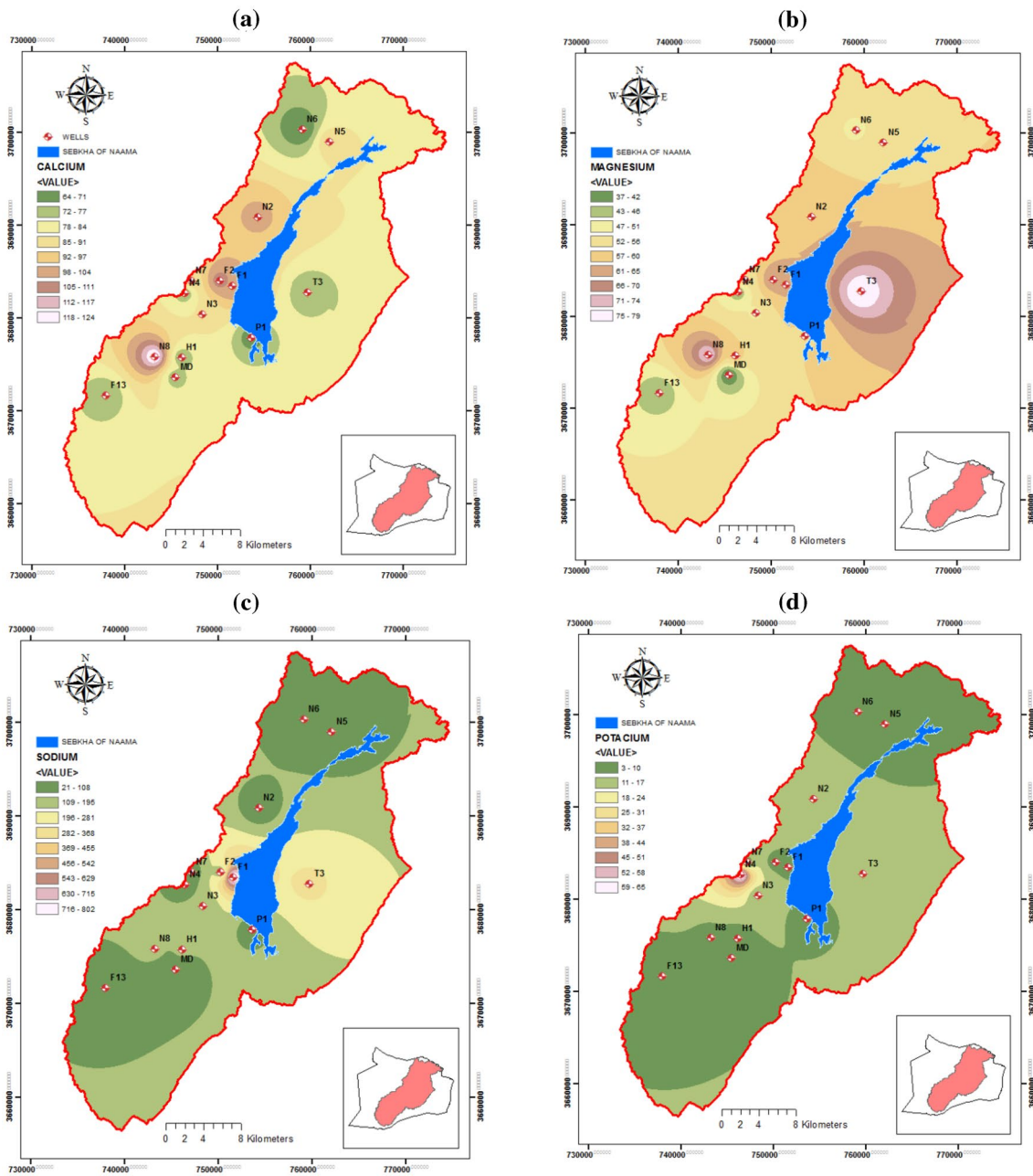


Fig. 6 Spatial distribution of major cations in the Naâma watershed. **a** Calcium, **b** magnesium, **c** sodium, **d** potassium

(150 mg/L), while 58% exceeds the drinking Standards stipulated by the World Health Organization of 50 mg/L [52, 53]. In the spatial distribution map of magnesium (Fig. 6b), it was shown that a high concentration of magnesium concentration is situated in the borehole T3, which is located near the Sabkha of Naâma. The content of magnesium is comparatively less than that of calcium. Together contributes to the hardness of the water.

The amount of sodium concentration in the present study was 21–806 mg/L. According to the World Health Organization and Algerian Standards [52, 53], the maximum concentration in drinking water may not exceed, respectively, 150 and 200 mg/L. The primary source of sodium ions in water comes from the liberation of soluble sodium products. Like other alkaline minerals, sodium is present in large quantities in natural waters. Figure 6c, which represents sodium's spatial distribution, shows that the highest sodium (806 mg/L) is found in the groundwater sample (F1) located near Sabkha of Naâma.

The mean concentration of potassium in our study area ranges from 3 mg/L in the borehole (MD) to 16.23 mg/L in the borehole (N2). The spatial analysis of potassium of groundwater samples shows that most of the samples had potassium concentration within the desirable limit of 12 mg/L, stipulated by the World Health Organization and Algerian Standards, except for the groundwater sample (N2) (Fig. 6d) [52, 53]. The general concentration in drinking water seldom can attain 20 mg/L [63].

Sulfates in our study area varied from 84.6 mg/L in the borehole (F13) to 213 mg/L in the borehole (T3), so whole samples respect the guideline value of 250 mg/L and 400 mg/L prescribed, respectively, by the World Health Organization and Algerian Standards [52, 53]. The spatial analysis of sulfates in the study area shows that the high values of sulfate of groundwater samples are presented in the nearest wells of the Sabkha (F1, P1, T3) (Fig. 7a). The high amount of sulfate could cause some adverse effects on humans like catharsis, dehydration, and gastrointestinal irritation due to the accumulation of large amounts of sulfates [64].

Chloride is a significant parameter used to estimate the water quality. The chloride concentration of water can be higher or lower depending on the soils' geology and their exposure to pollution by organic animal matter, massive fertilizer, and sewage [65]. The amount of chloride concentration in the present study ranged from 25 to 177 mg/L. The chloride concentration in all the boreholes sampled was within the guideline value prescribed by the World Health Organization and Algerian Standards [52, 53]. The spatial analysis of chloride shows that the borehole (N2) had a higher chloride concentration than the other boreholes (Fig. 7b). It was found that the groundwater

samples which are located far from Sabkha displayed a lower chloride.

The results showed that the study area's nitrate concentration was in the range of 0.38 mg/L at the sampling station (N3) to 28.6 mg/L at the sampling station (N5). They fell within the permissible limits by the World Health Organization and Algerian Standards of 45 and 50 mg/L, respectively [52, 53]. It was observed from the spatial distribution of nitrates (Fig. 7c) that the maximum value of nitrate concentration of 28.6 mg/L was found on the borehole N5. The nitrates have a toxic effect on some aquatic organisms when the concentration level is above 100 mg/L. Excessive application of fertilizer to agricultural soils creates the risk of too high a concentration of nitrate in the water.

Bicarbonate is one of many mineral substances found naturally in water. Water can contain varying amounts of bicarbonate depending on the types of soil it crosses (infiltration) or its flows (runoff). The biological process of plant roots, and the chemical reaction of oxidation of organic matter in the soil, are the leading causes of a high amount of bicarbonate in water [66]. Bicarbonate values vary from 190 to 272 mg/L. According to Heath's classification, the study area's groundwater samples are classifiers in a hard water category. The geological formation is a significant reason for the hardness of the water in the study area [67].

From the short review above, key findings emerge that the Sabkha salinity affects the groundwater indicated by the high level of electrical conductivity (EC), total dissolved solids (TDS), sodium (Na), and sulfates (So₄). With the increasing distance from the contamination source (Sabkha), the groundwater quality becomes better: N4, N6, and F13 present for all parameters values below the maximum allowable concentration. It should also be noted that the intensive pumping accelerates the migration of saltwater from the Sabkha to the groundwater.

3.2 WQI for drinking water assessment

The spatial distribution map of the water quality index (WQI) for the water samples was generated for the Naâma watershed by using the inverse distance weighted method IDW (Fig. 8). It has been concluded that the entire WQI of groundwater in Naâma was found to be either excellent or good. In some boreholes of the area like N2, N3, N5, N6, N7, F4, and F13, the water quality was excellent and convenient for drinking purposes. Meanwhile, the WQI in boreholes for the area like N1, N2, N8, H1, MD, P, and T3 was found suitable.

By carefully examining the data, it is found that boreholes distant from Sabkha present an excellent groundwater quality, where the WQI ranges between 37 and 41.6 mg/L. On the other hand, the boreholes close to

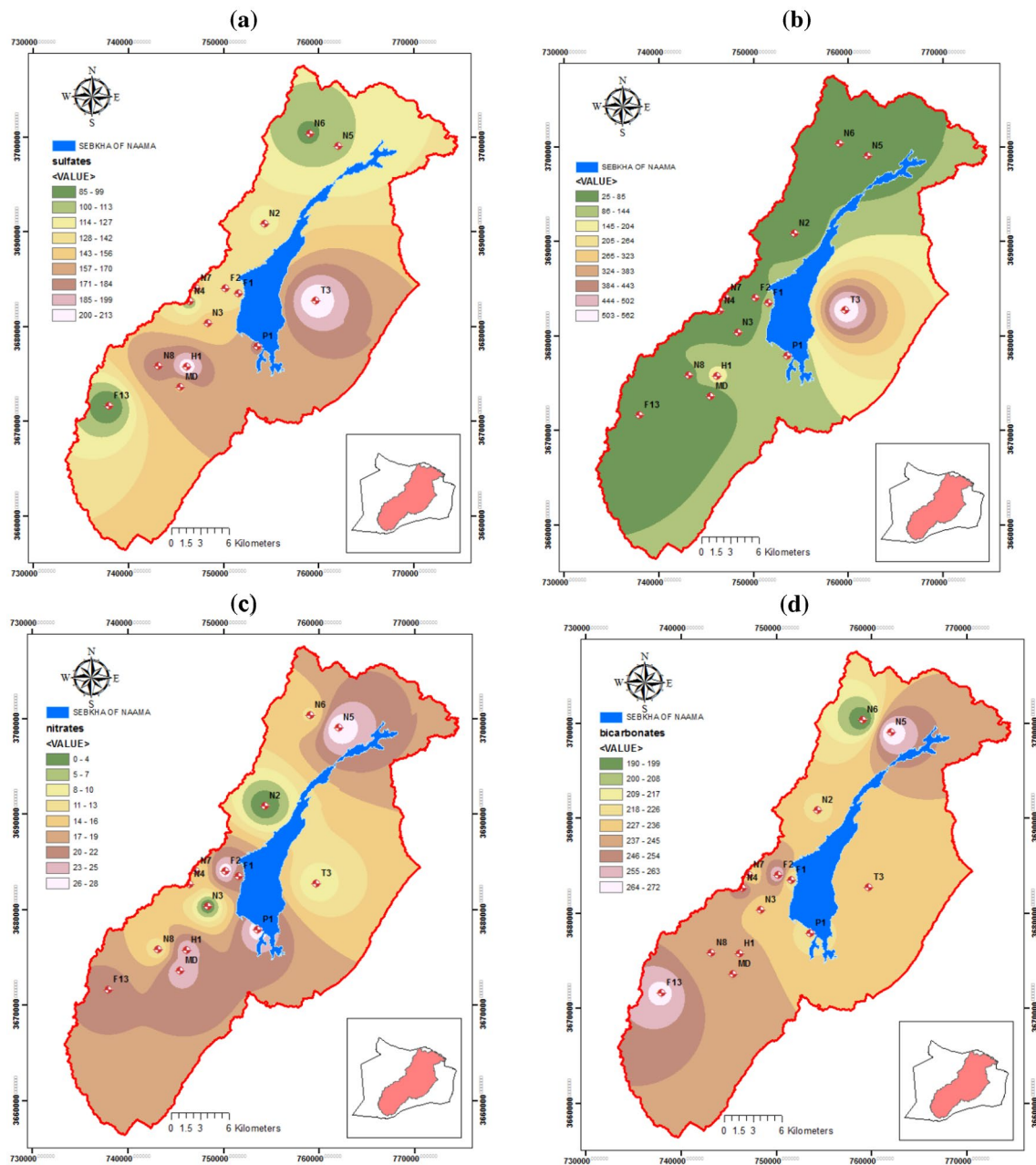


Fig. 7 Spatial distribution of major cations in the Naâma watershed. **a** Sulfates, **b** chlorides, **c** nitrates, **d** bicarbonates

Sabkha are classifiers in a hard water category due to the enrichment in silicate minerals, caused saltwater by intrusion from the Sabkha of Naâma. This salt contamination of groundwater would be accentuated by the discharge of wastewater from Naâma town into the Sabkha, the irrational use of chemical fertilizers, pesticides, and intensive pumping.

This study is a first contribution to the study of chemical quality in the Naâma watershed. Good agreement was found when comparing results from this work

against published studies in other regions in Algeria, such as Oran and Khenchela, in the north of the country [68, 69].

The map of WQI's spatial distribution could be a handy and useful tool for summarizing and reporting monitoring data to decision-makers to understand the state of groundwater quality in the region. The method presented in this work is sufficiently general to be applied to other areas.

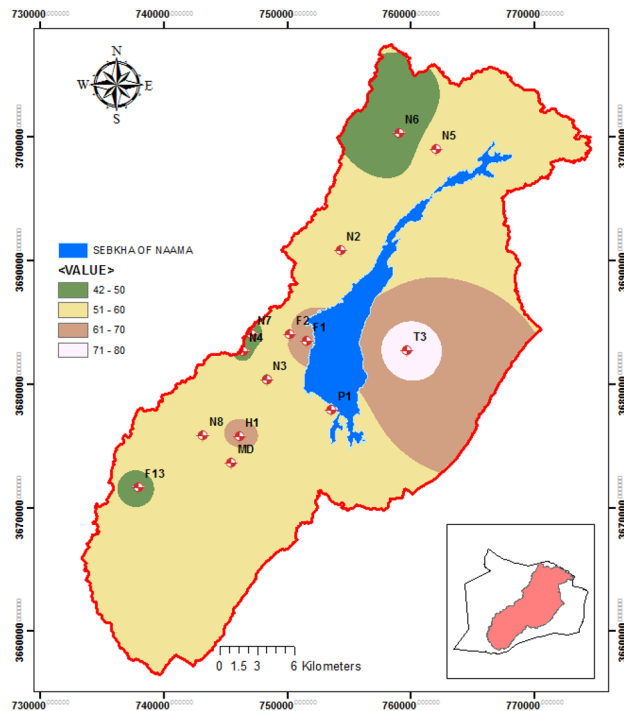


Fig. 8 Spatial distribution of WQI in the Naâma watershed

4 Conclusion

Naâma watershed situated in the southwest of Algeria, where the climate is arid and covers an area of 895 km²; it is highly dependent on groundwater resources, which are the only available resources that are used for irrigation and domestic purposes. In this study, fourteen (14) water samples of boreholes were collected and analyzed. The results report that the different water quality parameters such as conductivity EC, pH, TDS, major cations, and major anions were generally in the permissible limit given by World Health Organization guidelines Algerian Standards except some boreholes situated near the Sabkha of Naâma. Still, it does not have any impact on drinking water purposes.

The entire water quality index (WQI) calculated groundwater in the Naâma watershed was either excellent or good. In some boreholes of the area like N2, N3, N5, N6, N7, F4, and F13, the water quality index WQI calculated is less than 50. Meanwhile, WQI in boreholes for the area like N1, N2, N8, H1, MD, P, and T3 is between 50 and 100. It has been concluded that 50% of the groundwater samples were in excellent condition. The rest were in a good water category, and all the water samples are appropriate for drinking uses.

The spatial analysis of physicochemical parameters of the groundwater and IDW interpolation technique used to represent the distribution of major ions in the study area and to determine the water appropriateness for drinking

uses. After this study, we remark that salinity affects the groundwater in the nearest boreholes of the Sabkha's depression (N1, P1, T3) characterized by the high level of electrical conductivity, total dissolved solids, sodium, and sulfates explained by contamination by salt element through the infiltration of the surrounding area through infiltration. With the increasing distance from the contamination source (Sabkha), further wells' groundwater quality becomes excellent at N4, N6, and F13 boreholes, where the WQI ranges of between 37 and 41.6 mg/L. This salt contamination of groundwater would be accentuated by the discharge of wastewater from Naâma town into the Sabkha, the irrational use of chemical fertilizers, pesticides, and intensive pumping. It is recommended to avoid the sinking of boreholes in areas close to Sabkha of Naâma.

This study is a first contribution to the study of chemical quality in the Naâma watershed. It is a work whose results are a tool for orientation, decision support to local and regional authorities. The maps of spatial distribution created for several physicochemical parameters could help design a water program. Water engineering actors and decision-makers can use the combination of WQI and GIS to understand and evaluate groundwater quality in the study area. Further investigation of the microbiological parameter must be carried out to study the degree of pollution and anthropogenic effect on this area's groundwater.

Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

References

1. Azaza M, Dhraïef M, Kraïem M (2008) Effects of water temperature on growth and sex ratio of juvenile Nile tilapia *Oreochromis niloticus* (Linnaeus) reared in geothermal waters in southern Tunisia. *J Therm Biol* 33(2):98–105. <https://doi.org/10.1016/j.jtherbio.2007.05.007>
2. Pazand K, Hezarkhani A (2012) Investigation of hydrochemical characteristics of groundwater in the Bukan basin, Northwest of Iran. *J Appl Water Sci* 2(4):309–315. <https://doi.org/10.1007/s13201-012-0051-4>
3. Zafane D, Gharbi B, Douaoui A (2016) Mapping the index of the quality of groundwater (GWQI): Khemis Miliana Alluvial Plain, Algeria. https://doi.org/10.1007/978-3-319-70548-4_185
4. Bouderbala A (2017) Assessment of water quality index for the groundwater in the upper Cheliff plain, Algeria. *J Geol Soc India* 90(3):347–356. <https://doi.org/10.1007/s12594-017-0723-7>
5. Arumugam K, Rajesh Kumar A, Elangovan K (2014) Assessment of groundwater quality using water quality index in Avinashi–Tirupur–Palladam Region, Tamil Nadu, India. *Int J Appl Eng Res* 9(22):12177–12191. <https://doi.org/10.46488/nept.2020.v19i03.034>

6. Saidi S et al (2009) A GIS-based susceptibility indexing method for irrigation and drinking water management planning: application to Chebba–Mellouleche Aquifer, Tunisia. *J Agric Water Manag* 96(12):1683–1690. <https://doi.org/10.1016/j.agwat.2009.07.005>
7. Magesh N et al (2013) Groundwater quality assessment using WQI and GIS techniques, Dindigul district, Tamil Nadu, India. *Arab J Geosci* 6(11):4179–4189. <https://doi.org/10.1007/s12517-012-0673-8>
8. Hadidi A, et al. (2016) The oasis of Tiout in the southwest of Algeria: water resources and sustainable development. In: AIP conference proceedings, AIP Publishing LLC
9. Khan F, Husain T, Lumb A (2003) Water quality evaluation and trend analysis in selected watersheds of the Atlantic region of Canada. *Environ Monit Assess* 88(1–3):221–248. <https://doi.org/10.1023/a:1025573108513>
10. Sargaonkar A, Deshpande V (2003) Development of an overall index of pollution for surface water based on a general classification scheme in Indian context. *Environ Monit Assess* 89(1):43–67. <https://doi.org/10.1023/a:1025886025137>
11. Kannan N, Joseph S (2009) Quality of groundwater in the shallow aquifers of a paddy dominated agricultural river basin, Kerala, India. *Int J Agric Biosyst Eng* 3(4):223–241
12. Backman B et al (1998) Application of a groundwater contamination index in Finland and Slovakia. *Environ Geol* 36(1–2):55–64. <https://doi.org/10.1007/s002540050320>
13. Jinturkar A et al (2010) Determination of water quality index by fuzzy logic approach: a case of ground water in an Indian town. *Water Sci Technol* 61(8):1987–1994. <https://doi.org/10.2166/wst.2010.095>
14. Ketata M, Gueddari M, Bouhlila R (2012) Use of geographical information system and water quality index to assess groundwater quality in El Khairat deep aquifer (Enfidha, Central East Tunisia). *Arab J Geosci* 5(6):1379–1390. <https://doi.org/10.1007/s12517-011-0292-9>
15. Štambuk-Giljanović N (2003) Comparison of Dalmatian water evaluation indices. *Water Environ Res* 75(5):388–405. <https://doi.org/10.2175/106143003x141196>
16. Taherioun M, Karamouz M, Baghvand A (2010) Development of an entropy-based fuzzy eutrophication index for reservoir water quality evaluation. *Iran J Environ Health Sci Eng* 7(1):1–14
17. Tiwari T, Mishra M (1985) A preliminary assignment of water quality index of major Indian rivers. *Indian J Environ Prot* 5(4):276–279
18. Horton RK (1965) An index number system for rating water quality. *J Water Pollut Control Fed* 37(3):300–306. <https://doi.org/10.1007/s13201-018-0859-7>
19. Brown RM, McClelland NI, Deiningner RA, O'Connor MF (1972) A water quality index—crashing the psychological barrier. In: Thomas WA (eds) *Indicators of environmental quality*. Environmental science research, vol 1. Springer, Boston, MA. https://doi.org/10.1007/978-1-4684-2856-8_15
20. Oni O, Fasakin O (2016) The use of water quality index method to determine the potability of surface water and groundwater in the vicinity of a municipal solid waste dumpsite in Nigeria. *Am J Eng Res* 5(10):96–101
21. Sadat-Noori S, Ebrahimi K, Liaghat A (2014) Groundwater quality assessment using the Water Quality Index and GIS in Saveh–Nobaran aquifer, Iran. *Environ Earth Sci* 71(9):3827–3843. <https://doi.org/10.1007/s12665-013-2770-8>
22. Varol S, Davraz A (2015) Evaluation of the groundwater quality with WQI (Water Quality Index) and multivariate analysis: a case study of the Tefenni plain (Burdur/Turkey). *Environ Earth Sci* 73(4):1725–1744. <https://doi.org/10.1007/s12665-014-3531-z>
23. Bairu A, Tadesse N, Amare S (2013) Use of geographic information system and water quality index to assess suitability of groundwater quality for drinking purposes in Hewane areas, Tigray, Northern Ethiopia. *Ethiop J Environ Stud Manag* 6(2):110–123. <https://doi.org/10.4314/ejesm.v6i2.1>
24. Selvam S et al (2014) GIS-based evaluation of water quality index of groundwater resources around Tuticorin coastal city, South India. *Environ Earth Sci* 71(6):2847–2867. <https://doi.org/10.1007/s12665-013-2662-y>
25. Rufino F et al (2019) Evaluating the suitability of urban groundwater resources for drinking water and irrigation purposes: an integrated approach in the Agro-Aversano area of Southern Italy. *Environ Monit Assess* 191(12):768. <https://doi.org/10.1007/s10661-019-7978-y>
26. Abbasnia A et al (2018) Groundwater quality assessment for irrigation purposes based on irrigation water quality index and its zoning with GIS in the villages of Chabahar, Sistan and Baluchistan, Iran. *Data Brief* 19:623–631. <https://doi.org/10.1016/j.dib.2018.05.061>
27. Abbasnia A et al (2019) Evaluation of groundwater quality using water quality index and its suitability for assessing water for drinking and irrigation purposes: case study of Sistan and Baluchistan province (Iran). *Hum Ecol Risk Assess Int J* 25(4):988–1005. <https://doi.org/10.1080/10807039.2018.1458596>
28. Yousefi M, Ghoochani M, Mahvi AH (2018) Health risk assessment to fluoride in drinking water of rural residents living in the Poldasht city, Northwest of Iran. *Ecotoxicol Environ Saf* 148:426–430. <https://doi.org/10.1016/j.ecoenv.2017.10.057>
29. Yousefi M et al (2018) Data on corrosion and scaling potential of drinking water resources using stability indices in Jolfa, East Azerbaijan, Iran. *Data Brief* 16:724–731. <https://doi.org/10.1016/j.dib.2017.11.099>
30. Soleimani H et al (2018) Data on assessment of groundwater quality for drinking and irrigation in rural area Sarpol-e Zahab city, Kermanshah province, Iran. *Data Brief* 17:148–156. <https://doi.org/10.1016/j.dib.2017.12.061>
31. Sharifinia M, Adeli B, Nafarzadegan AR (2017) Evaluation of water quality trends in the Maroon River Basin, Iran, from 1990 to 2010 by WQI and multivariate analyses. *Environ Earth Sci* 76(22):781. <https://doi.org/10.1007/s12665-017-7132-5>
32. Jha MK, Shekhar A, Jenifer MA (2020) Assessing groundwater quality for drinking water supply using hybrid fuzzy–GIS-based water quality index. *Water Res*. <https://doi.org/10.1016/j.watres.2020.115867>
33. Benouara N, Laraba A, Hachemi Rachedi L (2016) Assessment of groundwater quality in the Seraidi region (north–east of Algeria) using NSF–WQI. *Water Sci Technol Water Supply* 16(4):1132–1137. <https://doi.org/10.2166/ws.2016.030>
34. Bouteraa O et al (2019) Groundwater quality assessment using multivariate analysis, geostatistical modeling, and water quality index (WQI): a case of study in the Boumerzoug–El Khroub valley of Northeast Algeria. *Acta Geochim* 38(6):796–814. <https://doi.org/10.1007/s11631-019-00329-x>
35. Guettaf M, Maoui A, Ihdene Z (2017) Assessment of water quality: a case study of the Seybouse River (North East of Algeria). *Appl Water Sci* 7(1):295–307. <https://doi.org/10.1007/s13201-014-0245-z>
36. Hamlat A, Guidoum A (2018) Assessment of groundwater quality in a semiarid region of Northwestern Algeria using water quality index (WQI). *Appl Water Sci* 8(8):220. <https://doi.org/10.1007/s13201-018-0863-y>
37. Rachedi LH, Amarchi H (2015) Assessment of the water quality of the Seybouse River (north–east Algeria) using the CCME WQI model. *Water Sci Technol Water Supply* 15(4):793–801. <https://doi.org/10.2166/ws.2015.033>
38. DPAT (2018) Direction de la Programation et du suivi Budgetaire de la Wilaya de Naama, Monographie de la Wilaya de Naama. p. 165

39. Bouanani A (2004) Hydrology, sediment transport and modeling, study of some basins in Tafna (NW-Algeria). PhD Thesis, University of Tlemcen, Algeria
40. Derdour A, Bouanani A, Babahamed K (2018) Modelling rainfall runoff relations using HEC-HMS in a semiarid region: case study in Ain Sefra watershed, Ksour Mountains (SW Algeria). *J Water Land Dev* 36(1):45–55. <https://doi.org/10.2478/jwld-2018-0005>
41. Guerine L, Belgourari M, Guerinik H (2020) Cartography and diachronic study of the naama sabkha (Southwestern Algeria) remotely sensed vegetation index and soil properties. *J Rangel Sci* 10:172
42. Derdour A, Bouanani A (2019) Coupling HEC-RAS and HEC-HMS in rainfall–runoff modeling and evaluating floodplain inundation maps in arid environments: case study of Ain Sefra city, Ksour Mountain, SW of Algeria. *Environ Earth Sci* 78(19):586. <https://doi.org/10.1007/s12665-019-8604-6>
43. Galmier D (1972) Photogéologie de la région d'Ain Sefra (Atlas Saharien, Algérie). Fasc. Sc. De Paris. p 320
44. Meddah A, Bertrand H, Elmi S (2007) La province magmatique de l'Atlantique central dans le bassin des Ksour (Atlas saharien, Algérie). *C R Géosci* 339(1):24–30. <https://doi.org/10.1016/j.crte.2006.10.006>
45. Bassoullet J-P (1973) Contribution à l'étude stratigraphique du Mésozoïque de l'Atlas saharien occidental, Algérie
46. Douhasni M (1976) Etude géologique de la région d'Ain Ouarka-Bousemghoun (partie centrale des Monts des Ksour). Stratigraphie et analyse structurale [Geological study of the region of Ain Ouarka-Bousemghoun (central part of Ksour Mountains). Stratigraphy and structural analysis]. Thèse 3ème cyc. Oran. University of Oran
47. Kacemi A, Talbi D, Ben Salah M (2011) Mise en évidence d'une déformation synsédimentaire transverse en compression au passage Lias-Dogger (Secteur de Zerga-Monts des Ksour-Atlas saharien-Algérie). *Geo-Eco-Trop* 35:81–90
48. Yelles-Chaouche A et al (2001) Chronologie de l'ouverture du bassin des Ksour (Atlas Saharien, Algérie) au début du Mésozoïque. *Bull Soc Géol de France* 172(3):285–293. <https://doi.org/10.2113/172.3.285>
49. Kumar B, Singh UK, Ojha SN (2019) Evaluation of geochemical data of Yamuna River using WQI and multivariate statistical analyses: a case study. *Int J River Basin Manag* 17(2):143–155. <https://doi.org/10.1080/15715124.2018.1437743>
50. Logeshkumaran A et al (2015) Hydro-geochemistry and application of water quality index (WQI) for groundwater quality assessment, Anna Nagar, part of Chennai City, Tamil Nadu, India. *Appl Water Sci* 5(4):335–343
51. Lumb A, Sharma TC, Bibeault J (2011) A review of genesis and evolution of water quality index (WQI) and some future directions. *Water Qual Expo Health* 3(1):11–24. <https://doi.org/10.1007/s12403-011-0040-0>
52. JORADP (2011) Executive Decree No. 11-125 of March 22, 2011 on the quality of water for human consumption in Algeria. *Off J Alger Repub* 18:6–9
53. WHO (2004) World Health Organization, Guidelines for drinking-water quality. World Health Organization, vol 1
54. Fathi E, Zamani-Ahmadmahmoodi R, Zare-Bidaki R (2018) Water quality evaluation using water quality index and multivariate methods, Beheshtabad River, Iran. *Appl Water Sci* 8(7):210
55. Sahu P, Sikdar P (2008) Hydrochemical framework of the aquifer in and around East Kolkata Wetlands, West Bengal, India. *Environ Geol* 55(4):823–835. <https://doi.org/10.1007/s00254-007-1034-x>
56. Tiwari AK, Singh PK, Mahato MK (2014) GIS-based evaluation of water quality index of ground water resources in West Bokaro Coalfield, India. *Curr World Environ* 9(3):843. <https://doi.org/10.12944/cwe.9.3.35>
57. Vasanthavigar M et al (2010) Application of water quality index for groundwater quality assessment: Thirumanimuttar sub-basin, Tamilnadu, India. *Environ Monit Assess* 171(1–4):595–609. <https://doi.org/10.1007/s10661-009-1302-1>
58. Yousefi M et al (2017) Data on water quality index for the groundwater in rural area Neyshabur County, Razavi province, Iran. *Data Brief* 15:901–907. <https://doi.org/10.1016/j.dib.2017.10.052>
59. ESRI, ArcGIS 10.5: Using ArcGIS Spatial Analyst. Software User Guide ESRI. 2015: USA
60. Nur A, Ishaku JM, Yusuf SN (2012) Groundwater flow patterns and hydrochemical facies distribution using geographical information system (GIS) in Damaturu Northeast Nigeria. *Int J Geosci*. <https://doi.org/10.4236/ijg.2012.35111>
61. Jayalakshmi S, Velappan E (2015) Assessment of water quality index in the St. Thomas Mount block using GIS and remote sensing. *Pol J Environ Stud*. <https://doi.org/10.15244/pjoes/39550>
62. Shil S, Singh UK, Mehta P (2019) Water quality assessment of a tropical river using water quality index (WQI), multivariate statistical techniques and GIS. *Appl Water Sci* 9(7):168. <https://doi.org/10.1007/s13201-019-1045-2>
63. Ambiga K (2016) Assessment of groundwater quality index using GIS at Tirupathi, India. *Int Res J Eng Technol* 3(02):552–564. <https://doi.org/10.22214/ijraset.2020.30882>
64. Sillin L et al (1978) Magnesium sulfate catharsis by cholecystokinin? *Gastroenterology* 74(5):1145. [https://doi.org/10.1016/0016-5085\(78\)93569-2](https://doi.org/10.1016/0016-5085(78)93569-2)
65. Kumar KS et al (2010) Ground Water quality assessment of Srikakulam district of Andhrapradesh, India, using GIS. *Int J Appl Environ Sci* 5(4):495–504
66. Raju NJ, Shukla U, Ram P (2011) Hydrogeochemistry for the assessment of groundwater quality in Varanasi: a fast-urbanizing center in Uttar Pradesh, India. *Environ Monit Assess* 173(1–4):279–300. <https://doi.org/10.1007/s10661-010-1387-6>
67. Heath RC (1998) Basic ground-water hydrology, vol 2220. US Department of the Interior, US Geological Survey
68. Sedrati A et al (2017) Determination of the contamination level in groundwater in the Sebkha of Elmahmel area north eastern of Algeria. *J Aerul si Apa Componente ale Mediului*. https://doi.org/10.24193/awc2017_47
69. Boualla N, Benziane A, Ait-Mokhtar A (2017) Assessing vulnerability of groundwater with GOD model: a case study in Oran Sebkha Basin, Algeria. *J New Technol Mater* 277(5619):1–9. <https://doi.org/10.12816/0044031>

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.