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ORIGINAL ARTICLE

The impact of climate change on groundwater quantity and quality in a semi-arid environment: a case study of Ain Azel plain (Northeast Algeria)

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Abstract In the last decade, North Africa has witnessed significant population growth, particularly those bordering the Mediterranean Sea. This led to increased demand for groundwater, which is an essential source for various water uses such as drinking water supplies and irrigation. Generally, human activities play a crucial role in the different quantitative and qualitative changes in groundwater. Now, climate changes such as a decrease in precipitation have also led to a shortage of water resources and a decline in the groundwater table. This paper presents the impact of climate changes on groundwater resources in the Ain Azel region, Setif, northeastern Algeria. The analysis of long-term spatiotemporal variability in rainfall over 63 years (1958–2021) revealed a significant decline in groundwater recharge, especially after 2013. In contrast, the Pettitt and Mann–Kendall tests show increased temperatures with breaks between 1984 and 1986. A piezometric analysis of the alluvial aquifer demonstrated a significant decline in groundwater levels in the last 20 years. Hydrochemical analysis showed that groundwater in the region is dominated by Ca–Mg–Cl water type, which indicates the presence of water salinity phenomenon. Water Quality Index (WQI) analysis showed the deterioration of groundwater in the area, which may be caused by several factors: brine intrusion from the Salt Lake (Sebkha) in the north; the dissolution of evaporites (Triassic) and/or anthropogenic sources of agricultural and industrial origin. Our findings provide an overview summarizing the state of groundwater, which will help improve groundwater resource management in the region in the coming years.

Keywords Climate changes · Groundwater resources · Pettitt and Mann–Kendall tests · WQI · Salt Lake

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1 Introduction

Groundwater is the primary source of drinking water in the world, making it a valuable water supply. Especially in the current era, where climate changes affect all parts of the world, which has known large fluctuations in the atmospheric temperature; a decrease in rainfall through various periods (Abbass et al. 2022; Letcher 2021; Matyssek 2013; Pandey et al. 2021; Singh et al. 2021). These climatic changes greatly affect the quantity and quality of groundwater (Alamdari et al. 2020; Al-Maliki et al. 2022; Duran-Encalada et al. 2017; Margaryan 2017).

North African countries rely on groundwater for various purposes, including irrigation, drinking water, and domestic uses, but have recently experienced severe water scarcity and quality degradation (Atwoli et al. 2022; Downing et al. 1997; Leal Filho et al. 2017; Ouhamdouch et al. 2019;

Ouhamdouch and Bahir 2017; Steynor and Pasquini 2019). According to many studies (Barbieri et al. 2023; Costa et al. 2021; Marquina 2004; Palutikof and Holt 2004), climate change is the leading cause of groundwater deterioration, in addition to human activities. In northern Algeria, groundwater is essential for drinking and agriculture. The latter is one of the regions overlooking the Mediterranean Sea that has been considered one of the leading climate change hotspots, which suffers from water scarcity, over-exploitation, saline intrusion in coastal aquifers due to rising sea levels and resource reduction, especially in semi-arid areas (Bouderbala 2019; Meddi and Boucefiane 2013; Mohamed and AL-AMIN 2018; Rajosoa et al. 2022; Sharan et al. 2023a).

Setif area (NE Algeria) is one of the most significant regions that experienced an increase in population after independence in 1962 until the present, it has resulted in an increasing demand for water supply for drinking, agricultural irrigation, and industrial uses (Bouregaa 2018; Bouznad et al. 2020; Chenni Hadj et al. 2020; Rouabhi 2018). Therefore, groundwater in the area is a sensitive issue as it is the only water source available. According to Rouabhi (2018), this region has experienced persistent droughts, significant fluctuations in precipitation, rising temperatures, and increased evaporation over the last decade, especially during the period between 1981 and 2012.

Based on available historical temperature and precipitation data, piezometric measurements, geochemical analyses, and statistical tools, this paper attempts to assess the impact of climate change on groundwater resources in Ain Azel Plain, Setif, East Algerian. We will try through this study to provide a report on (1) The analysis of climatic changes in the region over 63 years (1958–2021); (2) The current state of groundwater resources in terms of quantity and quality, its suitability for drinking purposes and their spatiotemporal variability during the last twenty years. This work may provide an overview that will help to develop the best strategies for exploiting and protecting groundwater resources in the region.

2 Location and description of the study area

The Setifian high plains cover the central and southern parts of the province. They are located between the Mounts of Hodna in the south and the Mounts of Djemila in the north. The Ain Azel district, with an area of 1127 km^2, is located in the East of Algeria, 50 km south of Setif province (Fig. 1). It is characterized by a semi-arid climate with an average annual rainfall of 328 mm and an average atmospheric temperature of 14.6 °C (Demdoum 2009). Many mountains surround the region with altitudes ranging from 950 to 1200 m (Kada and Demdoum 2020; Mezerzi Aboutaleb 2015).

The geology of the Setif area is complex, with a long and dynamic history of sedimentation and tectonic activity. This area is characterized by sedimentary rocks from the Mesozoic and Cenozoic eras (Galcon 1967; Guiraud 1973; Savornin 1920; Vila 1980). The Mesozoic is represented by Triassic salt deposits (gypsum, anhydrite, and halite) (Mezerzi Aboutaleb 2015), while the Jurassic formations are dominated by limestone, dolomite, and marl (Fig. 2). Cretaceous formations (from Barremian to Cenomanian) are distinguished by an alternation of marl and limestone (Guiraud 1973). The Tertiary and Quaternary represent the Cenozoic. The Miocene formation is composed of limestone, sandstone, and clays. In contrast, the Quaternary is formed by alluvial deposits of sand, clay, and gravel (Boudoukha 1998; Boutaleb 2001).

Several geological and hydrogeological studies (Belkhiri et al. 2010, 2012a, b; Boudoukha 1998; Demdoum 2009; Kada et al. 2022; Kada 2022) have revealed the presence of two major aquifers in the region: The first is a deep aquifer, constituted by the carbonates and sandy formations of the Barremian. The latter is considered a carbonate aquifer recharged by vertically infiltrating meteoric water by fractures and fissures of Djebels Boutaleb, Djebel Hadjar Labiod, and Djebel Fourhal (Belkhiri et al. 2010, 2012a, b; Boudoukha 1998). The second is the Mio-Plio-Quaternary alluvial aquifer, composed of alluvial deposits including sand, gravel, and sandy clay (Belkhiri et al. 2012b; Boudoukha 1998; Kada et al. 2022). The general direction of groundwater flow is toward the alluvial plain, where the study area belongs, which is characterized by many wells with a depth of about 40 m (Belkhiri et al. 2010, 2012b). This alluvial aquifer plays a crucial role in supplying water for drinking and agricultural uses in the region.

3 Material and methods

3.1 Data collections and procedures

A variety of data sources were used in the present study, including meteorological, piezometric level measurements, and hydrochemical analyses. The annual precipitation and atmospheric temperature records from the meteorological station of the Setif Sefiha station (Fig. 1) over 63 years (1958–2021, the National Meteorological Office, ONM). Piezometric levels were measured in 2004 and 2008, 2015, and 2016 (Belkhiri et al. 2012a; Kada 2022; Lazhar et al. 2010).

Groundwater samples were collected four times in 2002, 2008, 2017, and 2018. All physicochemical data and analytical procedures are shown in Table 1 and the statistical summary of hydrochemical parameters is given in Table 2.

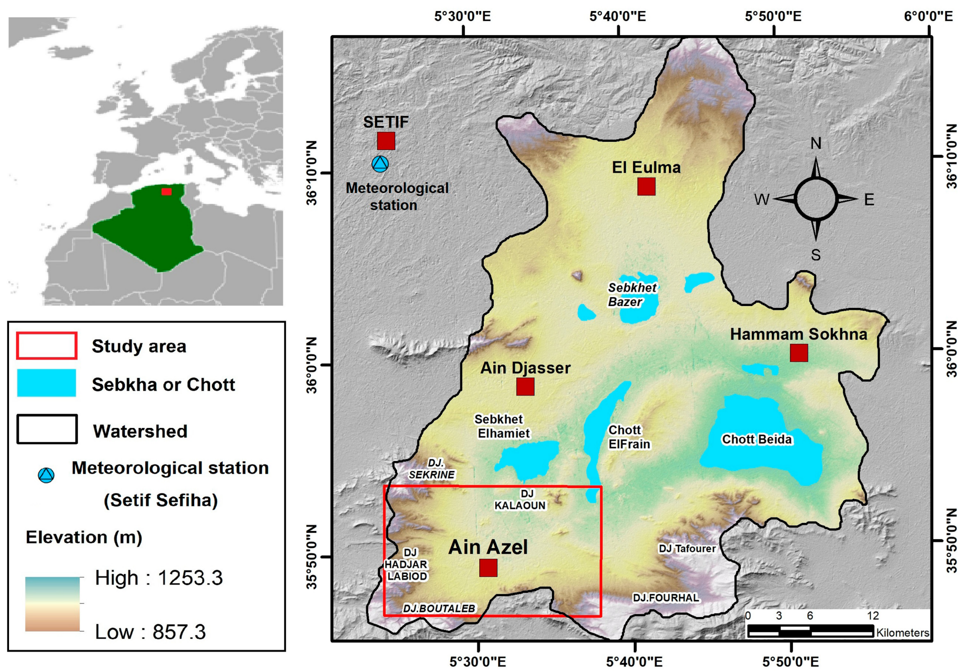

Fig. 1 Geographical location of the study area

3.2 Trend analysis

Statistical tests described by Pettitt (1979) and Mann–Kendall (Kendall 1975; Mann 1945) were applied to identify trends in a time series using non-parametric tests. In these tests, the null hypothesis H0 "No trend" is accepted if the P value is higher than the alpha significance level. The direction of the trend is defined by the Mann–Kendall statistical coefficient (Umk); if Umk is positive, the trend is upward; but if Umk is negative, the trend is downward.

Let the series Xi (× 1, × 2,…, *xn*); the Mann–Kendall test sets the standard Umk as follows:

$$\mathrm{Umk} = \frac{s}{\sqrt{\mathrm{Var}(s)}} \tag{1}$$

$$\mathrm{With} : \mathrm{S} = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(xj - xi) \tag{2}$$

$$\mathrm{Var}(s) = \frac{n(n-1)(2n-5)}{18} \tag{3}$$

n = the number of data in the series. All statistical analyses were performed using XLstat software (trial version).

3.3 Standardized precipitation index (SPI)

To estimate wet and dry periods, McKee et al. (1993) created the standardized precipitation index (SPI). SPI was adopted by World Meteorological Organization (WMO) in 2009, and it was used to evaluate drought in several studies where it is considered one of the most important indicators used for drought analysis (Azizi and Nejatian 2022; Fu et al. 2022; Huang et al. 2016; Moazzam et al. 2022; Vélez-Nicolás et al. 2022). The SPI is the result of dividing the difference from the mean of the precipitation over the specific period by the standard deviation. The classification of SPI values is shown in Table 3.

3.4 Water quality index (WQI)

Water Quality Index (WQI) is an efficient method for assessing the general quality of groundwater (Adimalla and Qian 2019; Atta et al. 2022; Bhavsar and Patel 2023; Bouderbala 2017; Kouadra and Demdoum 2020; Magesh et al. 2013; Ram et al. 2021; Talalaj 2014). Different weights (*wi*) have been assigned to each water quality parameter based on their relative importance in the overall water quality for drinking water. The maximum weight of "5" has been assigned for its significant importance in water quality assessment, and the minimum weight of "1" has been assigned for its minor significance (Table 4). The normalized weight of each parameter is obtained as follows:

$$Wi = \frac{wi}{\sum_{i=1}^{n} wi} \tag{4}$$

where, Wi is the relative weight, wi is the weight of each parameter, and n is the number of parameters.

To determine the quality rating scale (Qi) for each parameter, the concentration of each water sample was divided by its respective standard according to World Health Organization (2008):

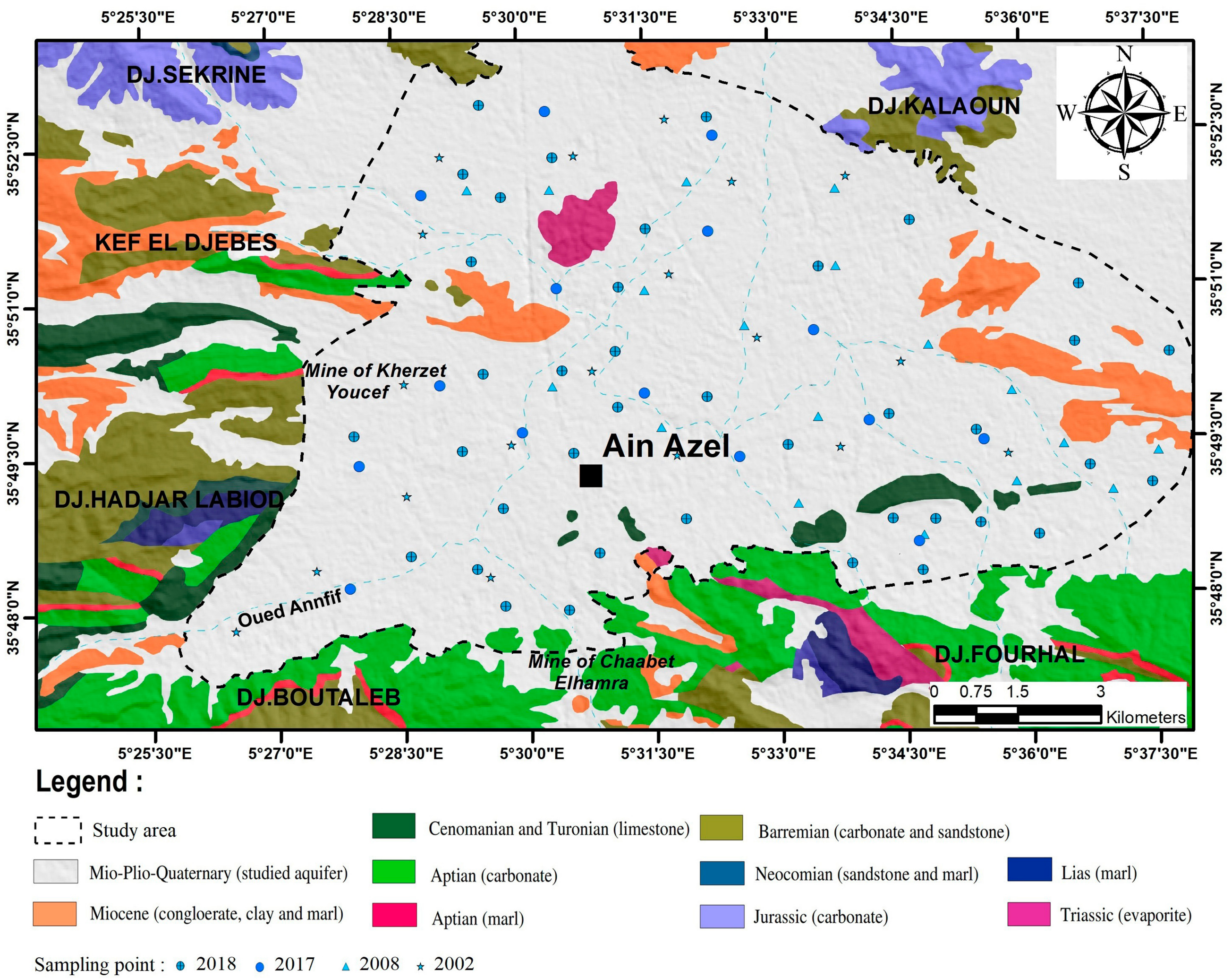

Fig. 2 Geological map of the study area

$$Qi = \frac{\mathrm{Ci} - \mathrm{Cip}}{\mathrm{Si} - \mathrm{Cip}} \times 100 \tag{5}$$

$$\mathrm{SI} = \mathrm{Wi} \times \mathrm{Qi} \tag{6}$$

where: Qi is the rating based on the concentration of the "ith" parameter. Ci: is the concentration of each chemical parameter in each water sample in mg/L. Si is the concentration acceptable for each chemical parameter according to the WHO guidelines (2008) in mg/L.

Cip: is the ideal value of the parameter in pure water (Consider Cip = 0 for all, except pH where pH Cip = 7). SI: is the sub-index of the "ith" parameter. The WQI is obtained from the following equation:

$$\mathrm{WQI} = \sum_{i=1}^{n} \mathrm{SI} \tag{7}$$

The WQI distribution maps were created using the inverse distance weighting (IDW) interpolation method (Arcgis 10.7 software) (Table 5).

4 Results and discussions

4.1 Climate perturbation

The long-term temporal changes in rainfall using the data from 63 years (1958–2021) show that the driest year was in 1983 when the minimum recorded rainfalls were 231.3 mm. The wettest year was in 1976 (620 mm), with an annual average of 444 mm (Fig. 3a). A significant annual reduction can be observed for the last decades that can be represented by the trend line (slope of regression line) which in this case is about − 0.47 mm/year. Based on the Mann–Kendall test (with a significance level of 5%,

Table 1 Physicochemical data and analytical procedures of groundwater samples from the study area

Year	Physicochemical data	Analytical procedures
2002; 2017	Physicochemical data of **20** and **15** groundwater samples (*Laboratory of Hydrogeology, Faculty of Earth Sciences, University of Constantine1, Algeria*)	**pH, EC** *in-situ* by a portable conductivity meter (HANNAHi-9813 Multiparameter) **Ca^{2+}, Mg^{2+}, HCO_3^-, Cl^-** by volumetric titrations SO_4^{2-} using a Jenway 6051 Colorimeter, **Na^+, K^+** by atomic absorption spectrometer
2008	Physicochemical data of **18** groundwater samples (Belkhiri et al. 2010)	**pH, EC** in the field using a multi-parameter WTW (P3 MultiLine pH/LF-SET) **Ca^{2+}, Mg^{2+}, HCO_3^-, Cl^-** by volumetric titrations **Na^+, K^+** using a flame photometer (Model: Systronics Flame Photometer 128) **SO_4^{2-}**by turbidimetric method
2018	Physicochemical data **39** groundwater samples were collected during **May 2018.** (*Algerian water laboratory (ADE) of Sétif, Algeria*)	**EC**, **pH** *in-situ* using portable measuring (HANNA HI 76/98195) **Ca^{2+}, Mg^{2+}, HCO_3^-, Cl^-** by volumetric titrations **SO_4^{2-}** by ion chromatography **Na^+, K^+** by flame spectrophotometer (Jenway Clinical PFP7)

Table 2 Statistical summary of hydrochemical parameters of the Ain Azel groundwater

	EC	pH	Ca	Mg	Na	K	HCO_3	SO_4	Cl
Campaign 2018 (n = 39)									
Min	580	6.8	18	16	14	1	73	64	25
Max	3700	9.6	375	104	309	10.3	671	750	705
Mean	1502.41	7.76	117.33	57.98	95.55	4.36	251.53	233.33	193.87
Campaign 2017 (n = 15)									
Min	850	7	74	31	19	1.1	152	72	50
Max	3500	8.1	162	73	176	7.9	323	272	350
Mean	1480.33	7.44	103.4	51	84.46	3.74	233.73	178	154.66
Campaign 2008 (n = 18)									
Min	830	6.9	80.16	26.88	37.95	2.13	164.7	180	42.6
Max	2730	7.9	184.36	143.38	155.25	10.03	427	660	337.25
Mean	1450.55	7.41	119.61	61.75	93.72	5.48	302.63	298.33	146.14
Campaign 2002 (n = 20)									
Min	660	6.9	74.15	20	17.4	0.7	52.8	38.4	38.99
Max	2730	8.4	428.8	150.7	161.5	6	347.7	1191	457.3
Mean	1444.6	7.5	145.02	74.25	74.61	2.17	186.14	287.56	167.88

Min minimum; *Max* maximum; *SD* Standard deviation

The ion concentrations are in (mg/L), EC (μS/cm)

Table 6), a significant change point has been detected after 2013 that reveals inhomogeneities in the weighted annual rainfall data (Fig. 3b). In contrast, as shown in Fig. 3c, the Pettitt test concludes that there are significant breaks in maximum, minimum, and annual temperatures over 1986, 1984, and 1986, respectively (Table 7). The Mann–Kendall test also confirms this result with an upward trend ($4.5 \leq Umk \leq 5.4$, Table 7). These rising air temperatures lead to increased evapotranspiration, which has a direct effect on groundwater recharge (Swain et al. 2022; Taylor et al. 2013).

Table 3 Standardized precipitation index (SPI) values and the associated drought categories (McKee et al. 1993)

SPI classes	Drought category
SPI > 2.0	Extremely wet
1.5 < SPI < 1.99	Very wet
1 < SPI < 1.49	Moderately wet
− 0.99 < SPI < 0.99	Near normal
− 1.0 < SPI < -1.49	Moderately dry
− 1.5 < SPI < -1.99	Very dry
SPI < -2.0	Extremely dry

Table 4 The weight (*wi*) and the relative weight (*Wi*) of each parameter

Parameters	WHO (2008)	Weight (*wi*)	Relative weight (*Wi*)
EC	1500	5	0.16
Cl	250	5	0.16
SO4	200	5	0.16
Na	150	5	0.16
Mg	75	4	0.12
pH	8.5	3	0.09
Ca	100	2	0.06
HCO3	300	2	0.06
K	12	$\sum wi = 32$	$\sum Wi = 1$

The standardized precipitation index (SPI) was calculated for 63 years (1958–2021), as shown in Fig. 3d, which illustrates the periods where drought and rainfall occur throughout the temporal period. According to the SPI Drought Index, it can be said that the Ain Azel region was subjected to drought near normal. Generally, 1976 was a very wet year, followed by 1983, considered the driest year in 63 years (1958–2021).

4.2 Groundwater level evolution

The piezometric maps drawn from the 2004, 2008, 2015, and 2016 data allowed us to characterize groundwater flow directions and spatial and temporal evolution of the aquifer piezometric surface. The piezometric maps of the alluvial aquifer of the Ain Azel plain (Fig. 4) show groundwater flow from the North-East the South-West, where the groundwater keeps the same flow direction with a progressive decrease in the piezometric level toward the plain.

A high hydraulic gradient was observed in the southern part, which can be explained by a high substratum slope, high flow, and/or low permeability. In contrast, the Center and North parts have low hydraulic gradients caused by low substratum slopes, low flow rates, and high permeabilities.

Figure 5 shows an evident overall decline in groundwater levels between 2008 and 2016 in the area. On the one hand, this can be explained by the overexploitation of groundwater, which is the only source of water supply in the region. A significant increase in drilling wells has resulted in continuous and intensive pumping for irrigation and industrial purposes. On the other hand, a significant reduction in the amount of rainfall is considered an important factor affecting groundwater levels in the study area.

4.3 Hydrogeochemical characteristics

Hydrogeochemical techniques are practical tools for describing groundwater chemistry (Ekbal and Khan 2022; Hennia et al. 2022; Nawrin et al. 2022; Shaikh et al. 2020; Singh et al. 2023). In addition to host rock properties and the hydrodynamics of groundwater flow, climate change, overexploitation conditions, and anthropogenic pollution can significantly affect groundwater geochemistry (Brindha et al. 2014; Dragon and Gorski 2015; Li et al. 2014; Mustafa et al. 2017).

A Piper diagram (1944) was created to define hydrochemical facies and identify the geochemical evolution of groundwater. The results of the chemical analysis of the study samples in different periods are plotted on the Piper

Table 5 Classes proposed for drinking water quality based on the Water Quality Index (WQI) (Magesh et al. 2013)

Class	The range of (WQI) for drinking purposes	Type of water quality
1	< 50	Excellent water
2	50–100	Good water
3	100–200	Poor water
4	200–300	Very poor water
5	> 300	Unfit for drinking

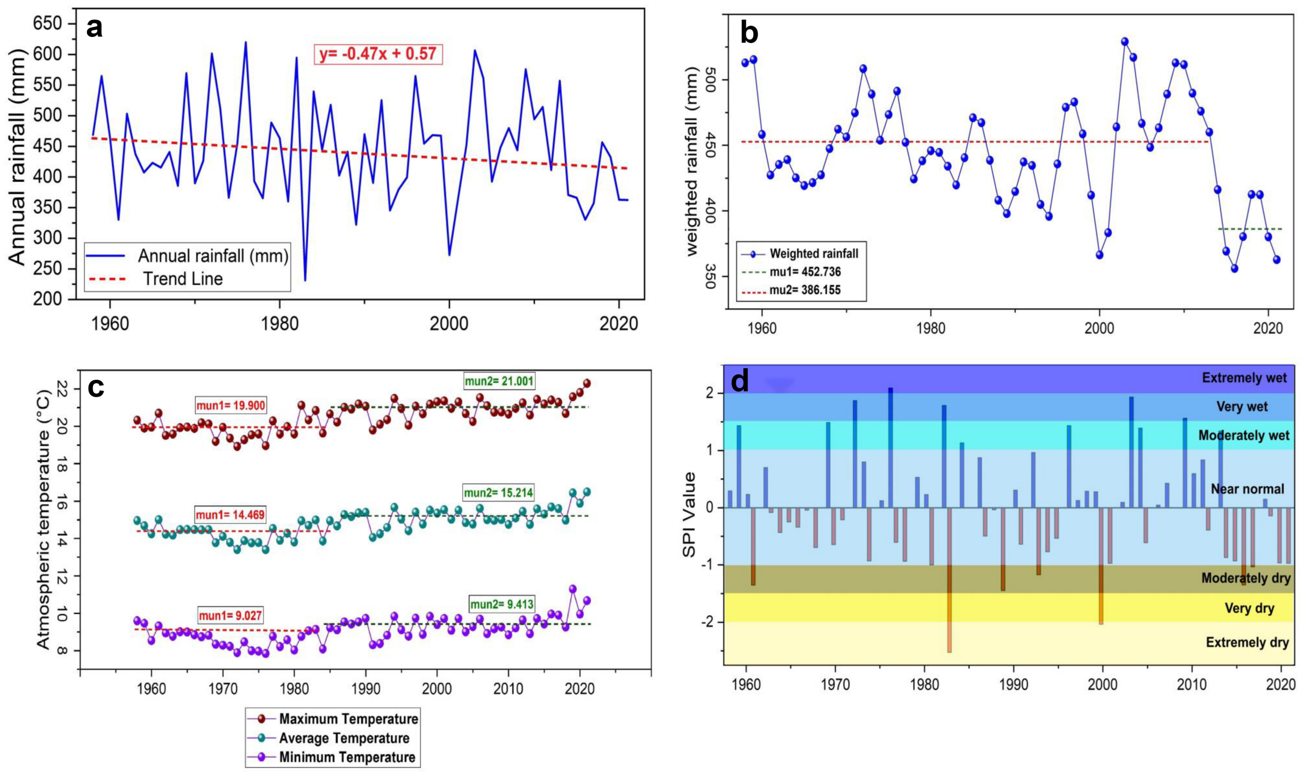

Fig. 3 **a** Annual rainfall variability in Setif Sfiha Station (1958–2021); **b** Pettitt test applied to the weighted rainfall series from the station of Sefiha for the period 1958–2021; **c** Pettitt test results on minimum, average, and maximum temperature (1958–2021); **d** Variation of the standardized precipitation index (SPI) for the Sefiha station (1958–2021)

Table 6 Mann–Kendall test results on rainfall in the study area (Sefiha station; 1958–2021)

Mann–Kendall test			
P value (%)	Alpha (%)	Umk	Trend sense
4.11	5	− 1.73	To the decline

diagram (Fig. 6a). As can be seen, the most dominant groundwater type in 2008 and 2018 was mixed CaMg-Cl, while those of 2002 and 2017 were Ca–Cl and Ca-HCO_3.

Ca, Mg, HCO_3, and Cl are the dominant ions in the study area (as shown in the Piper diagram) that are dominated by sedimentary rocks (limestone, marl, clay, and alluvial deposits). These latter could be the source of HCO_3 and Mg (limestone and dolomite), while calcium may be another evaporitic source (gypsum dissolution). Chloride can be derived from halite dissolution that dominates the Triassic salt formation and/or from anthropogenic activities (various sources of pollution).

The relationship between (Ca + Mg) and HCO_3 (Fig. 7a) shows that the majority of samples are above the 1: 1 line, indicating that alkaline earth has dominated bicarbonate by carbonate weathering, suggesting a carbonate origin for bicarbonates and an additional source for calcium, probably evaporitic origin (gypsum dissolution) and/or ion exchange (clay). Study samples were nearly 1:1 in the relationship between calcium and sulfate (Fig. 7c), suggesting gypsum dissolution in the groundwater. As seen in Fig. 7b, most groundwater samples fell along the 1:1 line, suggesting that the Ca, Mg, SO4, and HCO_3 are derived from the dissolution of carbonate minerals (calcite, dolomite) and sulfate minerals (gypsum).

The chloride concentrations of the study samples ranged from 25 to 705 mg/L with a mean of 193 mg/L (Table 2). These latter show a very strong correlation with sodium concentration ($R^2 = 0.8$, Fig. 7d), indicating that halite dissolution is the source of these ions in groundwater. In addition, most of the groundwater samples fell along the 1:1 line (halite dissolution). In contrast, few samples fell below the dissolution line (Fig. 7d), indicating another secondary source of chloride which is anthropogenic activities from various pollutants of industrial or agricultural origin.

In sedimentary basins, the presence of clay materials in the aquifer often causes an ion exchange phenomenon which is considered an important process affecting the chemical quality of groundwater (Carroll 1959). The plot (Ca + Mg-HCO_3 + SO_4) against (Na–Cl) (Fig. 7e)

Table 7 Pettitt, Mann–Kendall test results on the minimal, mean and maximal temperature in the study area (Sefiha station; 1958–2021)

Pettitt test (minimal temperature)			
P value (%)	Alpha %	Break date	Warming rate
0.01	5	1984	4
Pettitt test (mean temperature)			
P value (%)	Alpha (%)	Break date	Warming rate
0.01	5	1986	5.31
Pettitt test (maximal temperature)			
P value (%)	Alpha (%)	Break date	Warming rate
0.01	5	1984	5.01
Mann–Kendall test (minimal temperature)			
P value (%)	Alpha (%)	Umk	Trend sense
0.01	5	4.51	To the rise
Mann–Kendall test (mean temperature)			
P value (%)	Alpha (%)	Umk	Trend sense
0.01	5	5.45	To the rise
Mann–Kendall test (maximal temperature)			
P value (%)	Alpha (%)	Umk	Trend sense
0.01	5	5.44	To the rise

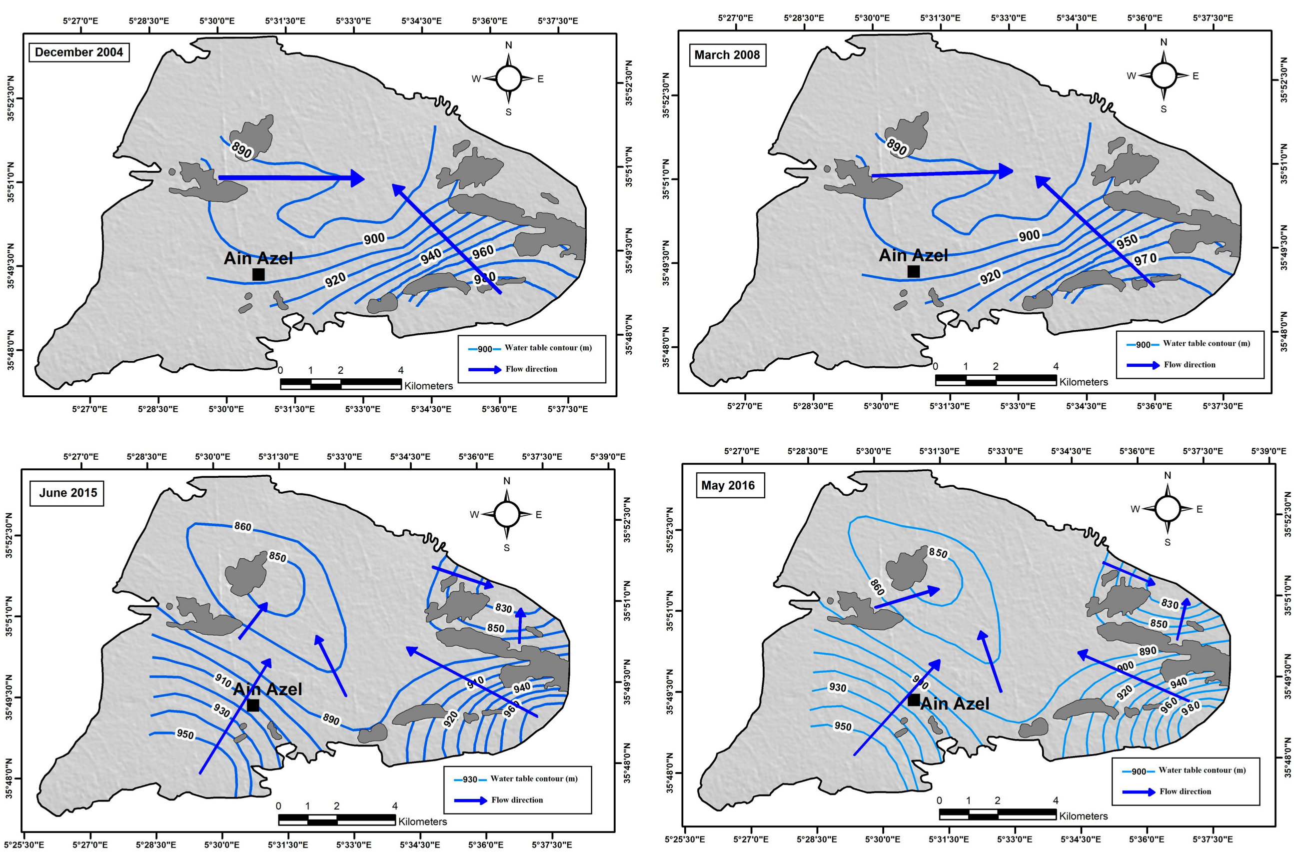

Fig. 4 Piezometric maps of the alluvial aquifer

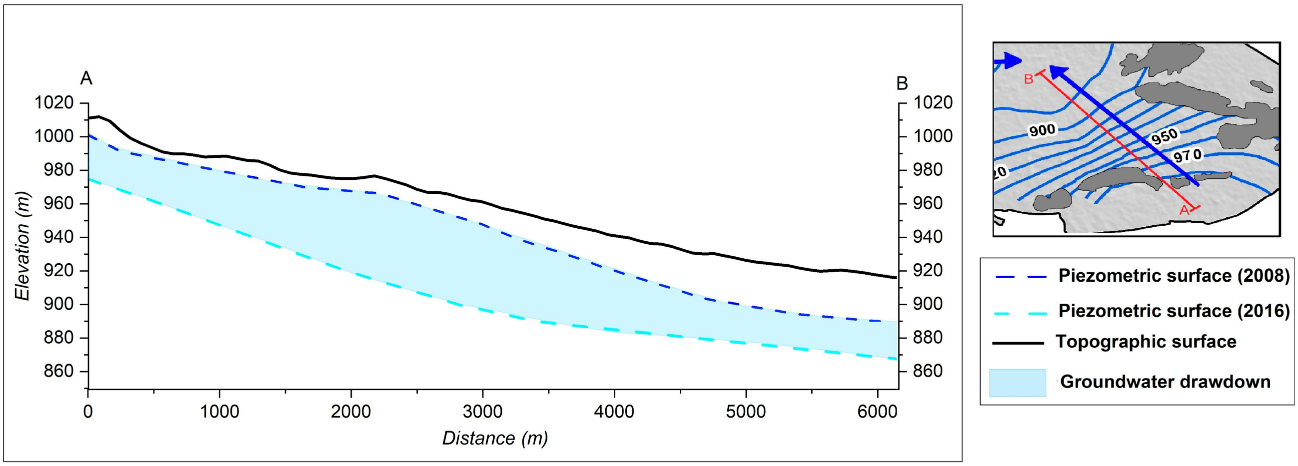

Fig. 5 profil across the alluvial formations

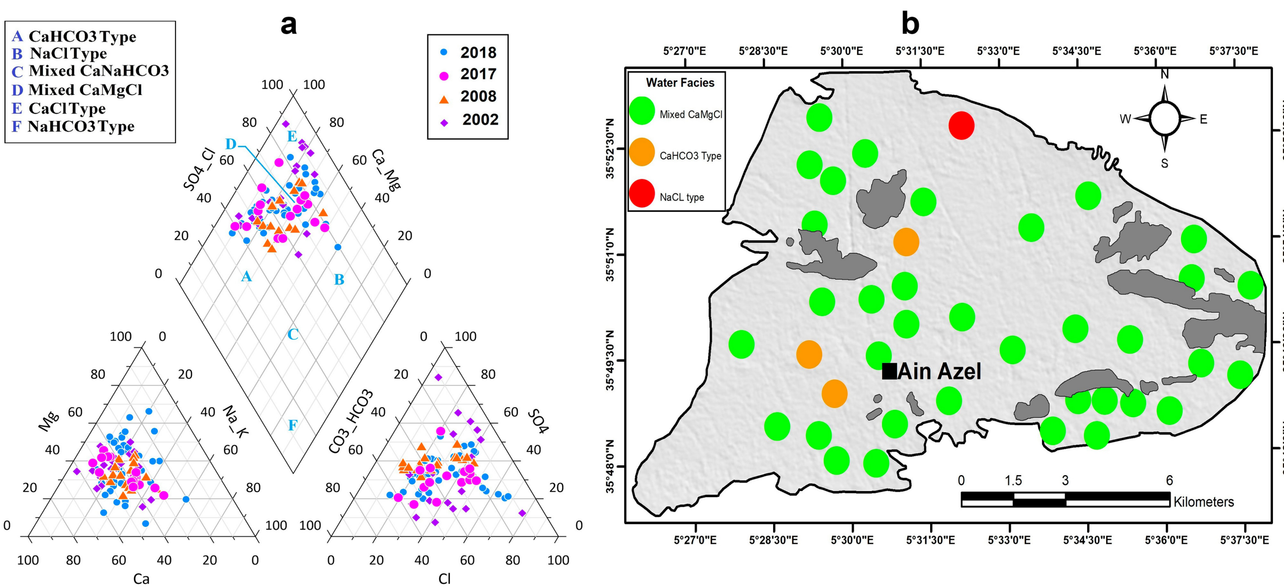

Fig. 6 **a** Piper trilinear diagram for groundwater samples. **b** Spatial distribution of hydrochemical facies of alluvial aquifer (2018)

demonstrates the ion exchange reaction, which is strongly correlated ($R^2 = 0.8$) with a negative slope of − 1 (Fisher and Mullican 1997; Singh et al. 2015). This ion exchange is a significant geochemical process for controlling groundwater composition, as it increases calcium and magnesium concentrations and decreases sodium concentrations (Appelo and Postma 2004; Hem 1992).

4.4 Water quality index

The water quality index was calculated to assess groundwater quality on the Ain Azel plain. The WQI values ranged from 34 to 210 (Fig. 8). Based on inverse distance weighting interpolation (IDW), the spatial distribution map of the WQI showed that the highest WQI values were found in the north of the plain (Fig. 8). It can be explained by the presence of Triassic salt deposits and/or evaporitic formations of Sebkha (salt lake) such as Sebkhet Elhamiet (Fig. 1), which can lead to a significant increase in salinity concentrations of groundwater.

While the deterioration of groundwater quality in the center and southeastern parts of the plain is probably caused by anthropogenic pollution from various pollutants of agricultural (plant waste, domestic wastes, etc.) and/or industrial origin (mine refuse) from various mines such as mine of Kherzet Youcef and mine of Chaabet Elhamrat (Fig. 2) (Panthi et al. 2022; Sharan et al. 2023b; Werner et al. 2013).

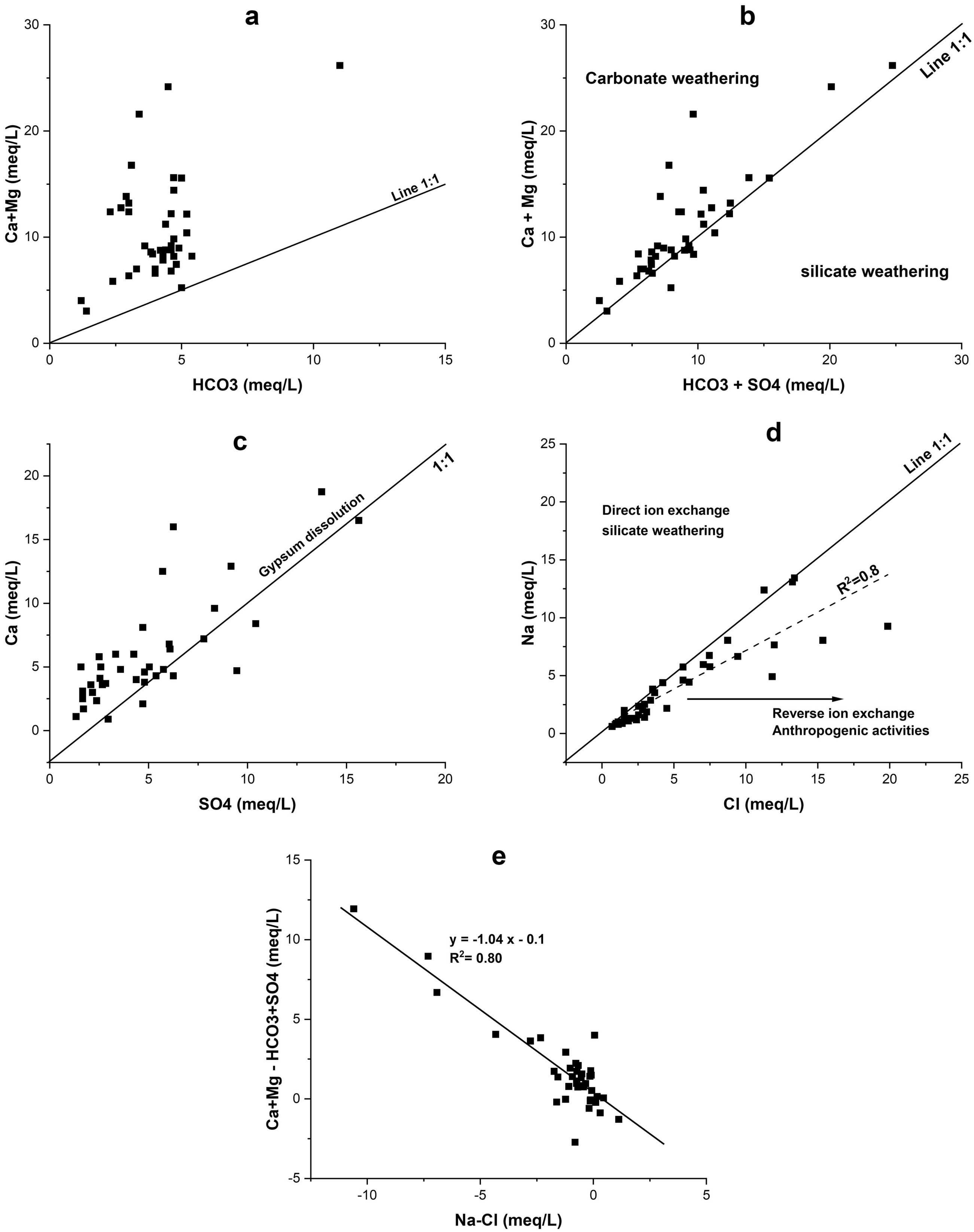

Fig. 7 Correlation relationship of major ions. **a** HCO_3 vs Ca + Mg; **b** HCO_3 + SO_4 vs Ca + Mg; **c** SO_4 vs Ca; **d** Cl vs Na; **e** (Ca + Mg)–(HCO_3+SO_4) vs Na–Cl

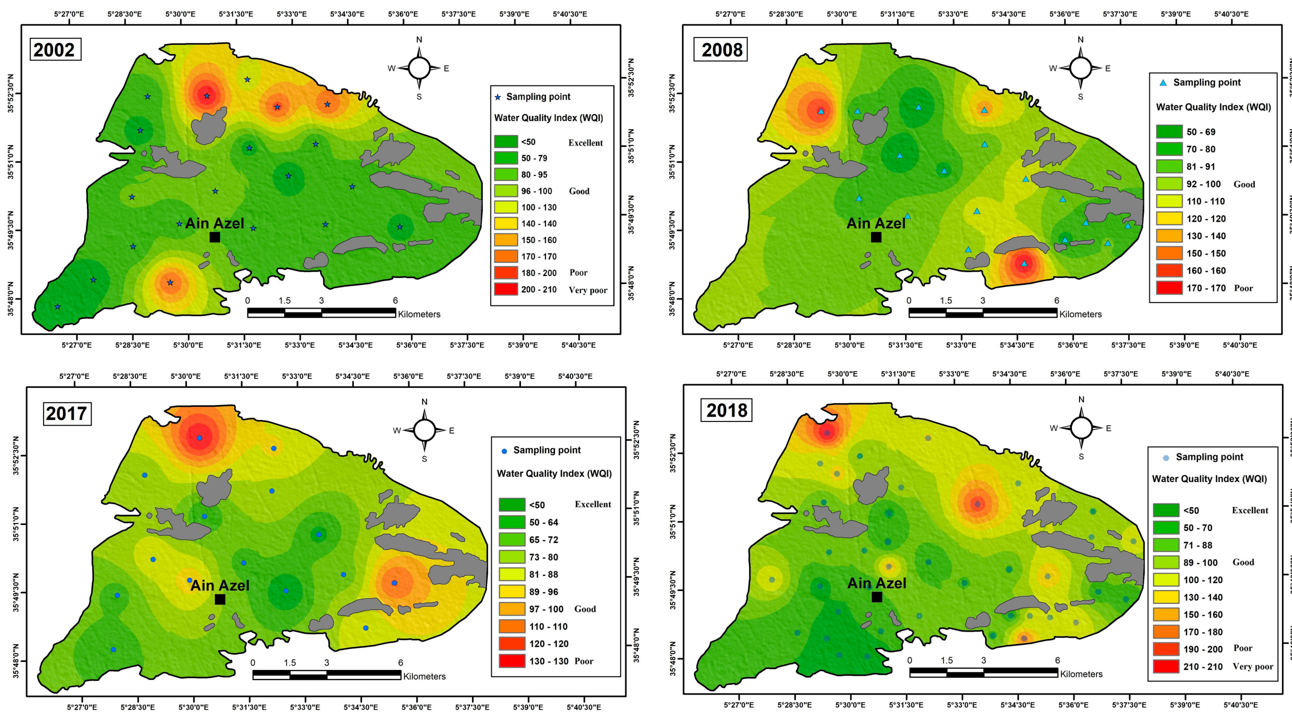

Fig. 8 Spatial distribution of Water Quality Index in the study area

5 Conclusions and recommendations

Groundwater resources have been a significant issue in recent years. Therefore, studying and evaluating its quality, quantity, and the main factors affecting it is extremely important since it is the source of drinking and irrigation purposes. Generally, climate change directly affects surface water resources like lakes and rivers through increasing temperatures and evapotranspiration rates. In contrast, it indirectly affects groundwater through the recharge process, such as a decrease in precipitation amounts and intensity rates. In addition to human activities (overexploitation and pollution) and seawater intrusion, which also significantly impact groundwater resources, we assessed the impact of climate changes on groundwater in the Ain Azel region in northeastern Algeria in this study, using different climate, piezometric, and hydrochemical data. The findings of this study reveal that:

The region has seen large-scale climatic fluctuations over the past 63 years (1958–2021), especially in recent years, with a gradual decrease in precipitation volume after 2013 which can particularly affect groundwater availability. Whereas the analysis of temperature data using statistical tests like the Pettitt and Mann–Kendall test showed a significant increase in the long-term temperature recorded (1958, 2021). The analysis of piezometric maps over the last 20 years shows groundwater generally flows toward the plain with a significant decrease in the groundwater level. Groundwater samples in the area were classified as fresh waters in the south (Ca-Mg-HCO_3 type, recharge zone) to highly saline waters Mg–Ca–Cl type in the center and north (transition and discharge zones). The predominance of chloride ions in the groundwater geochemistry is due to brine intrusion from the salt lake (Sebkha), Triassic salt dissolution, and anthropogenic activities from various pollutants of agricultural origin (such as plant waste, domestic wastes) and industrial origin such as mine refuse from various mines in the area.

To protect water resources and prevent deterioration of groundwater quality in the region, it is necessary to develop a comprehensive strategy and adopt integrated management to monitor the status and quantity of water through (Sharan et al. 2021): (1) trying to develop laws and regulations that prevent illegal drilling of wells that lead to further over-exploitation of groundwater resources; (2) Continuous monitoring of well conditions to maintain and protect them from drying, damage, or contamination; (3) Construction of water treatment stations that will improve drinking water quality, especially in places near the Sebkhet (salt lakes) and the mines; (4) Educate the public on sustainable groundwater management to better manage the overexploited groundwater and highlight the importance of groundwater, particularly in light of climate change.

In this study, we only referred to the effect of climatic changes on groundwater quantity and quality. We did not study it more deeply, and this is due to the lack of climatic data and the lack of recent studies in this field, especially around the study area.

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Declarations

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

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