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Impact of Climate Change and Human Activities on Groundwater Resources in the Alluvial Aquifer of Upper Cheliff, Algeria

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Abstract: In the agricultural plain of Upper Cheliff, the human activities increased water demand. The objective of this study is to identify the impact of the anthropogenic activities on groundwater resources of the alluvial aquifer in the Upper Cheliff (Algeria) due to intense agricultural activity. The groundwater recharge reduced by 30% in the 50 years from 1970 to 2020 in this alluvial aquifer due to the mean yearly growth rate of the population of 20 ‰ and associated with the water use rate increasing from 25 % to 50%. In addition to that, the water seepage in the network of drinking water coming from groundwater pumping is up to 10%. The use of water for irrigation agriculture is increased 30 % over the period of 50 years due to the development of agricultural programs, which have significant effects on the status of the water resources in the aquifer. As a result, groundwater levels dropped by 2-15 meters in most areas, except in some irrigation areas in this plain. We also observed a decrease in water discharge from wells by 30-60% of the alluvial aquifer, and an expansion of the area of polluted groundwater with high concentrations of certain chemical parameters.

Keywords: Anthropogenic activities, Alluvial aquifer, Upper Cheliff, Agricultural activity, Groundwater depletion

Groundwater resources in alluvial aquifers are crucial for human activities such as agriculture, industry, and domestic use. Alluvial aquifers are found in the permeable layers of sand, gravel, probes making them a significant source of fresh water, and can be recharged by infiltration of water from the surface, from rivers, or from effective precipitation, and they can be a reliable source of water in areas with limited surface water resources. However, groundwater resources in alluvial aquifers face a number of challenges, including overexploitation, contamination, and declining water levels. Human activities such as land use change, urbanization, and groundwater pumping can lead to depletion of groundwater resources (Wang et al 2022). Contamination from agricultural chemicals, industrial pollutants, and waste disposal can also negatively impact the quality of groundwater. Climate change, with its impacts on precipitation patterns and temperature, can further exacerbate these challenges (Swain et al 2022, El-Rawy et al 2023). To ensure the long-term sustainability of groundwater resources in these aquifers, it is necessary to implement better management practices and address the challenges they face (Bouderbala 2014, Mersha et al 2018). Compared to other countries with a humid climate, countries with semi-arid and arid climates have unstable water reserves and they are extremely vulnerable to the climatic conditions. The decrease in precipitation and the increase in temperature observed in the last four decades had directly affected surface water resources and made them limited, for this reason, the recourse for the use of groundwater is an inevitable solution to guarantee sustainable satisfaction in water needs. Indeed, groundwater is widely used for irrigation, domestic and industrial purposes in regions with a semi-arid and arid climate, which is the cases of the Sidi Bouzid aquifer in Tunisia, Tadla and Haouz aquifer in Morocco, Mitidja and Haut Chéliff aquifer in Algeria (Bouderbala et al 2021).

Population growth, industrial development, and the launch of the agricultural program in 2004 by the Algerian government, as well as the incentives for agricultural investors, are factors that have favoured the exploitation increase of groundwater in this alluvial aquifer through intensive pumping, while during the last years this region has experienced remarkable drought, resulting from low recharge rates of the aquifer (Chaudhari and Pathak 2022). The decrease in the flow rates of certain wells, the drying up of shallow boreholes (< 50m), and the deterioration of the quality of groundwater by the increase of some chemical concentrations, are harmful to humans and crops, and they are really felt by farmers and citizens in this region (Hennia et al 2022, Guenfoud et al 2021). In addition to that, this plain knew a decrease of rainfall between 10 and 20% and an increase of temperatures between 0.5 and 1.0°C, and it will augment from 2 to 4°C over the next 100 years based on some researchers, which has a direct consequence on the global weather by rising evaporation and an indirect impact on groundwater resources. Algeria has a semi-arid climate for the most part in the north of the country. It will suffer droughts, desertification, soil salinization and water supply under the pressure of population growth and continued needs (Bouderbala 2019, Bouderbala 2020). This survey highlights the impact of anthropogenic activities and climate change on groundwater resources in the alluvial aquifer of the Upper Cheliff. Using an analysis of the annual rainfall data recorded at a pluviometric station located in the plain, and the analysis of the temporal evolution of piezometric levels in some wells, as well as, the analysis of groundwater quality can identify the influence of the natural and human activities on the groundwater resources in this agricultural plain.

MATERIAL AND METHODS

Study area: The Upper Cheliff plain is located approximately 120 km south-west of the capital Algiers, between 36°10' and 36°20' north latitude and 02°00' and 02°25' east longitude and covers an area of 370 km². The plain lies between the massif of Zaccar in the North (1580m.s.l) and the Ouarsenis chain in the South (1985 m.s.l). The width is between 5 to 12 Km and length is approximately 55 Km. The Wadi Chéliff watercourse crosses the plain from east to west, and divides it into two large irrigated perimeters, one on the left bank and the other on the right bank. The most significant tributaries which discharge into the main watercourses are: Deurdeur, Harreza, Boutane, Erraihane, Telbanet, and Massine wadis. The plain that contains this aquifer is an agricultural area with wheat, tomatoes, potatoes, and fruits as the main crops, and it requires vast amounts of irrigation water. The irrigation is ensured by private drillings and by a pressure network supplied from three dams located near the plain. The study area is characterized by a Mediterranean semi-arid climate, with hot dry summer and cold rainy winter. The annual average temperature for the period of 1971-2021 is 17°C, and the rainfall average for the same period is about 430 mm, concentrated between December and April. The average annual evapotranspiration according to Thornthwaite method is about 350 mm/year, and an infiltration rate is of 9 % of rainfall.

Geologic and hydrogeology context: The plain of Upper Cheliff is a large depression with a syncline axis orientation from East to West, where Mio-Plio-Quaternary deposits have been accumulated (Fig. 1). The stratigraphy of the formations from bottom to top is as follows.

The primary formations are observed in Zaccar and Doui massifs, and are formed of black schist, clays and quartzite. The Triassic is characterized by massive gypsum, dolomitic limestone and dolomite formations. The Jurassic in Zaccar massif is mainly underlain by sedimentary rocks of fractured and karstified limestone, dolomite and other carbonate rocks, with a thickness can reach 1000 m. The Cretaceous outcrops are observed on the lateral borders of the plain, and they are represented by a highly thick series of Neocomian schists (about 1000 m), a grey schist alternating with benches quartzite of Albian-Aptian (near to 1000 m). The Miocene formation is about 300 m thick. The lower Miocene is essentially represented by blue marls. It is surmounted by Burdigalian (middle Miocene) with sandstone, conglomerates and marls. The outcrop of coarse sandstones interbedded with conglomerates and clays appear in the Gantas hills where completes the Miocene cycle (Upper Miocene) with thickness of about 100 m. The Mio-Pliocene consists of pebbles, conglomerates, detrital sandstones and clays, and travertine deposited at the Zaccar sources.

In terms of hydrogeological context, the analysis of lithostratigraphic layers in this plain highlighted the existence of two principal aquifers (Fig. 2). The unconfined Quaternary aquifer consists of alluvial and terrace deposits of silt, clay, sand, gravel and pebbles of Quaternary age. It has a heterogeneous layer's system, and the recharge to the alluvial and terrace deposits is mostly from precipitation, and from the Wadi Cheliff in certain sections of the wadi, and the excess of irrigation water can contribute also to the recharge of the Quaternary aquifer. This aquifer is the most exploited in this region, where the wells and boreholes of 40 to 150m are used commonly for drinking supply and irrigation of agricultural lands. The Quaternary aquifer is covered by silt and clay on the surface, from 5 to 20 m of thickness in the centre of the plain (Bouderbala and Gharbi 2017). The

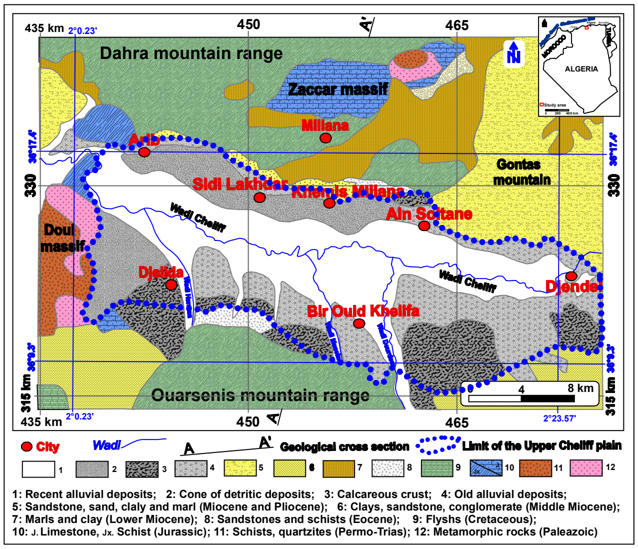

Fig. 1. Geological map of the Upper Cheliff plain

confined Mio-plioce aquifer is the deeper one, it is collected by deep well drilling exceeding 200m, and groundwater of this has a good quality. It is mainly formed by sands and sandstones with clayey and marly intercalations. The sandstone and sands of Miocene appear mainly in the north-east of the plain in Gontas Mountain, and in the southeast of the city Djendel (Bouderbala 2017). The system aquifer in this area can be considered as multi-layered aquifer systems. The hydraulic continuity between the alluvial aquifer and Mio-Pliocene aquifer exists only in the borders of the plain where there is a contact between the two aquifers without impermeable layer between them; however, in the centre of the plain there is thick clay layer between the two aquifers (Bouderbala and Gharbi 2017). We note here that we are only interested in the quaternary alluvial aquifer in this study.

The piezometric map dressed from data of groundwater in metres above sea levels are important to characterize the aquifer behaviour (spatial distribution of hydraulic loads and potentials of groundwater, the hydrodynamic boundary conditions of aquifer, the directions of groundwater flow path, the recharge areas, the outlet of the water table, relationship watercourse and groundwater.

The piezometric map established for the dry water period 2018 (Fig. 3) shows an alluvial aquifer flows toward the centre of the plain where the main drainage axis is located, which coincides with wadi Cheliff, with a main flow is from east to west. The aquifer's flows are conditioned by the geological structure of the basin, the hydrodynamic parameters, as well as, the supply and exploitation conditions of this aquifer. The depth of groundwater levels varies from 5 m in the west part of the plain (near to Djelida and Arib cities) to 40 m in the east of the plain (near to Djendel city), while in the central part of the plain the depth of the groundwater levels is about 25 m. This indicates that the eastern part of the aquifer is more vulnerable to anthropogenic pollution, and as results a probable degradation of groundwater quality, particularly when the unsaturated area is composed with a permeable soil.

The hydraulic gradient in the eastern part of the plain is

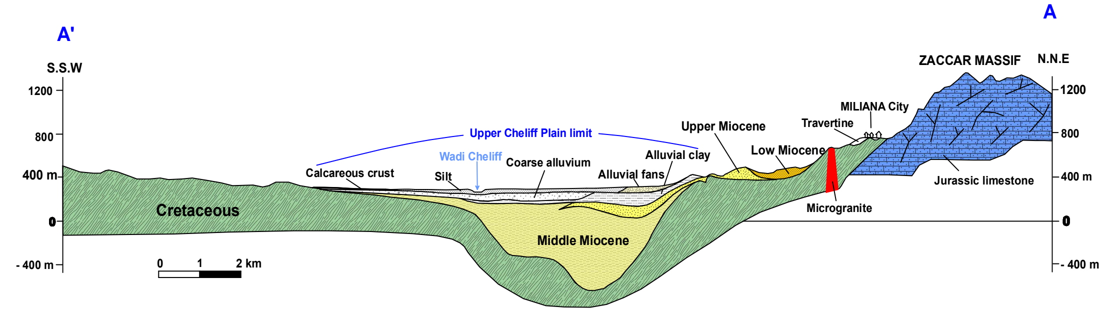

Fig. 2. Geological cross section A–A' in the Upper Cheliff plain

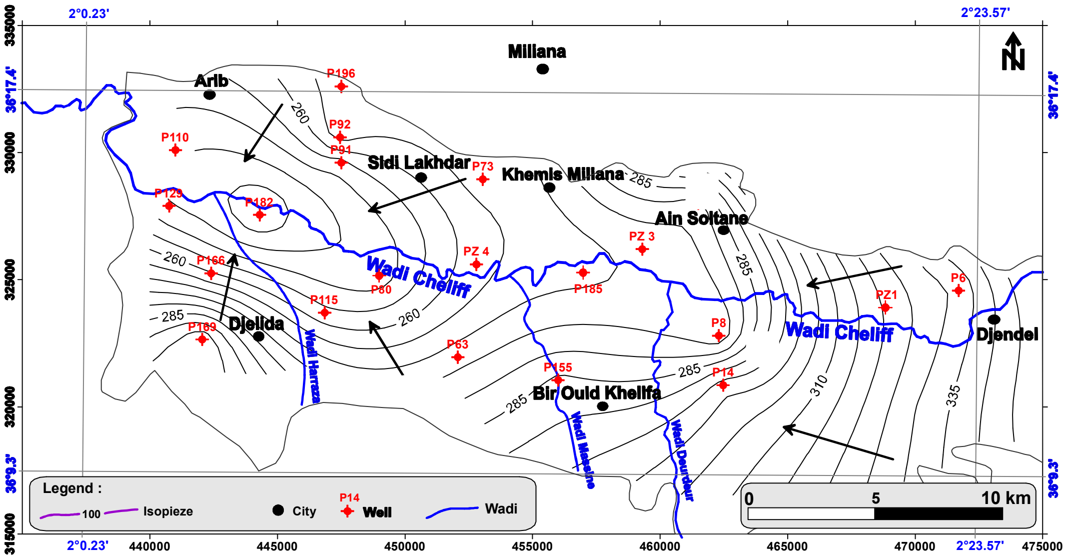

Fig. 3. Groundwater level contour map of the Upper Cheliff plain, dry period 2018

quite high, oscillates from 10^{-2} and 3. 10^{-2} and in the south-western zone near to Djelida city the hydraulic gradient oscillates from 10^{-2} to 2.5 10^{-2}. This is due to the rising of the aquifer substratum (sloping situation) and the low thickness of the aquifer. While, in the central part the plain, the hydraulic gradients are between 0.9 10^{-3} to 9 10^{-3}; which is explained by the high thickness of the aquifer; the high permeability and the low slope of the substratum. We also note that relationship between watercourse of Cheliff and aquifer is not very clear due to the low density of the monitoring wells network near this watercourse of Wadi Cheliff.

Caractérisation of the climate régime: Analyze the impact of climate change on ground water ressources in the alluvial aquifer, including changes in précipitation patterns, and temperature, base on the data acquisition and analysing. The data of precipitation used in this study belong to one long observation rainfall station located in the center of the alluvial plain. In this work, piezometric water levels recorded in years 1975, 1991 and 2014 were used to see the spatio-temporal evolution of groundwater in this alluvial aquifer, by using geographical information system (GIS). Data were collected from technical service in charge of water resources mobilisation (ANRH and DRE). The data were used to calculate the balance between water need and groundwater resource available.

The trends and breaks through the analysis of rainfall variability were examined, mainly by analysing the main trends of the annual rainfall during the time of the series (observation period), and the determination of the breaks of each rainfall station. This rupture of chronological series marks the modification of hydrological regime. The detection of one or more breaks provides information on the rainfall trend in a given region.

The Standardized Precipitation Index (SPI) is a widely used index to characterize meteorological drought associated with climate change on a range of timescales. The SPI is closely related to soil moisture and can be related to groundwater and reservoir storage. It quantifies observed precipitation as a standardized departure from a selected probability distribution function that models the raw precipitation data (Karavitis et al 2011). The SPI is done by the formula:

$SPI = (Pi - Pm)/\sigma$ Where:

Pi: rainfall for the year I (in mm); Pm: Average of rainfall (in mm); σ: standard deviation (in mm).

The SPI values for any area are classified into seven different precipitation regimes, from dry to wet (Table 2).

The Standardized Precipitation Index (SPI) is used to analyse the various aspects of drought based on time-scale. The SPI range is divided into near normal conditions ($-1<SPI\leq1$), moderately dry ($-1.5<SPI\leq-1$), severely dry ($-2<SPI\leq -1.5$) and extremely dry ($SPI\leq-2.0$). A drought event starts when SPI value reaches −1.0 and ends when SPI becomes positive or close to positive again.

Quantitatif and qualitatif of groundwater resources reserves : The quantity of groundwater reserves is derived from natural recharge of the aquifer, which occurs when a portion of rainfall infiltrates into the soil and reaches the water table. Natural recharge is closely linked to the climate regime; during rainy periods, high recharge of the aquifer can be observed, and vice versa. Determining natural recharge is one of the most challenging hydrogeological parameters, and estimates obtained using different methods tend to approximate the true value. In this study, we use the simple and traditional WTF method, which is applied to unconfined aquifers. This method takes into account fluctuations in groundwater levels and is used when the groundwater storage is unknown (Maréchal et al 2006, Khatri and Tyagi 2015). The recharge is estimated by the following equation (Addisie 2022):

$$R = S_y . \frac{\Delta h}{\Delta t}$$

where Sy is the specific yield or drainable porosity of the unconfined aquifer, h is the water table height, and t is time. Δh is the difference between the peak of the rise and the low point of the extrapolated antecedent recession curve at the time of the peak.

RESULTS AND DISCUSSION

Trend of the interannual rainfall: The analysis of annual rainfall data of the ITGC station, located in Khemis Miliana city, recorded during the period from 1971 to 2021, highlighted that the Haut Cheliff plain is characterized by a great irregularity of rainfall regime, with an annual average of 430 mm, a maximum value of 720 mm recorded in 1972, and a minimum value of 147 mm recorded in 1994. Rainfall data also show a rainy season from November to April and a dry season with very low rainfall during months between June to August.

The trend analysis performed on annual rainfall values recorded over 50 years (period from 1971 to 2021) by using the three (3) years moving average filter highlight the rainy years and the less one. Three distinct periods are observed: a moderately rainy period extending from 1971 to 1982 (517 mm), a second period of decline rainfall ranging from 1983 to 2007 (380 mm), with values below the average of annual period and a third one is slightly rainy period extending from 2008 to 2021 (454 mm). The rainfall station from the 82 until 2007 show a deficit period in term of intensity and duration, which had a direct impact of groundwater resources in term of quantity and quality (Fig. 4).

In order to characterize the drought in the Upper Cheliff plain, the SPI index was calculated for a time scale of one year. The examination of the chronological variations of the SPI index shows that the 'extreme drought' character is not dominant in the plain, except for the year 1994 where an extreme drought was recorded, corresponding to the value of -2. We also note that the SPI values show dry conditions (negative values) for the period from 1982 to 2007 with an extended drought event. This indicates that the drought conditions in the Upper Cheliff plain have been persistent for a long period of time, which can have severe impacts on the water resources in the region (Fig. 5).

Drought can have a significant impact on the groundwater resources in the Upper Cheliff plain, as it reduces the recharge rate of the aquifer and increases the demand for water. This can lead to groundwater depletion and a decline in the water table. It can also affect the quality of groundwater, as it can lead to a higher concentration of dissolved ions and pollutants. Additionally, drought conditions can have a significant impact on the agricultural sector in the Upper Cheliff plain. Reduced water availability can lead to a decline in crop yields and a loss of productivity.

Trend of temperature: Algeria over the last fourteen years, the annual average temperatures have increased by 0.5°C, which has an effect on quantity and quality of groundwater reserve. The analysis of the variations in the annual average temperatures recorded at the Herreza climatic station located in the Upper Cheliff plain shows an average annual temperature of approximately 18.5°C, with a high value of 20.3°C recorded in 2010 and a low of 16.0°C recorded in 1993. The increase in temperatures over the past few decades, has a direct impact on the evaporation of water reserves in the soil and aquifer. The warmer temperatures lead to a higher rate of evaporation and transpiration of water from the soil and aquifer, which can cause a decline in the water table and water availability. This can have a significant impact on the groundwater resources in the Upper Cheliff plain, particularly for the irrigation and domestic water supply. As a result of the increased temperatures, the water demand in the agricultural sector increases, and it may lead to over-exploitation of the groundwater resources, which can cause groundwater depletion and reduction of the water table (Fig. 6).

Natural recharge of groundwater: Evaluation of natural

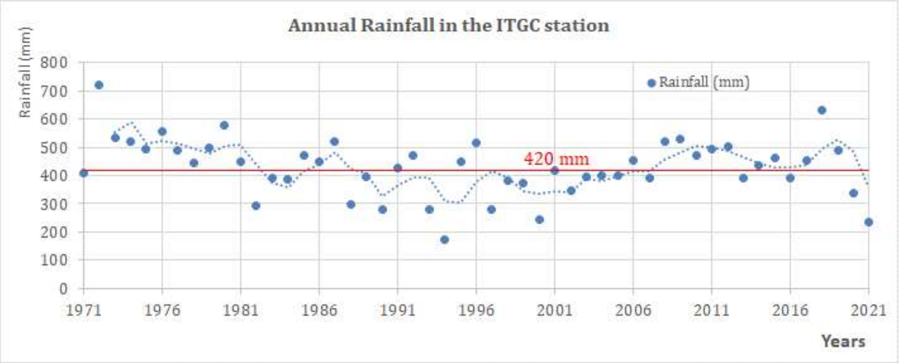

Fig. 4. Evolution of annual rainfall including the three years moving filter

Fig. 5. Standardized Precipitation Index (SPI) for the rainfall data

recharge in an alluvial aquifer typically involves measuring the amount of water entering the aquifer and comparing it to the amount of water being withdrawn through pumping or other means. This can be done using groundwater level monitoring by measuring the water level in wells over the aquifer. The first sector represents the recharge area of the alluvial aquifer on the eastern part of the plain, where significant drawdown of the water table is observed, with fluctuations exceeding 15m, and where the hydraulic gradient is greater than 10^{-2}. The central zone of the plain is characterized by a hydraulic gradients between 10^{-2} and 10^{-3}, with drawdowns between 4 and 10 m. The downstream zone, where hydraulic gradient is less than 10^{-3}, which showed weak fluctuations between the two periods, less than 4m. The analysis of piezometric variations between high and low water periods for the periods 1971-1981, 1982-2007, and 2008-2021 showed average fluctuations of the piezometric levels of: 7m, 15m and 10m for the first zone across the three periods, respectively; 4 m, 9 m and 6.5 m for the second sector across the three periods respectively; and 0.8 m, 3.5 m and 1.2 m for the third sector across the three periods, respectively. The storage coefficient of an aquifer is equal to effective porosity can vary widely depending on the specific characteristics of the aquifer material and the conditions of the site. Generally, they range from 0.2 to 0.4 for coarse-grained aquifers on grain size range from fine-sand to coarse-gravel, and from 0.01 to 0.2 for fine-grained aquifers on grain size range from fine sand to Coarse-silt. The estimation of the approximative groundwater reserve in the alluvial aquifer of the Upper Cheliff showed a decrease when we compare volume of the decade 1971-1981 (195.8 H.m^3) with that of the next two decades 1982-2007 (102 H.m^3), which was contacted to rate of the natural recharge. In the last decade 2008-2021 we assist to a small increase of volume of groundwater in the alluvial aquifer to 135 H.m^3 (Table 1).

Evolution of groundwater levels: The analysis revealed a strong correlation between rainfall levels and groundwater levels during the wet period. However, during dry periods, our analysis also revealed that the pumping of water for various uses has a significant impact on the aquifer. This is confirmed by the observed decrease in water levels during these periods. The overexploitation of the aquifer to ensure different uses supplies, such as irrigation, industrial and domestic use, leads to an imbalance in the water resources management, which could have severe consequences on the long term.

Overall, our study provides important insights into the relationship between hydroclimatic conditions and the groundwater resources of the Upper Cheliff alluvial aquifer. It highlights the need for proper management of water resources, especially during dry periods, to ensure the sustainable use and preservation of this important resource. Regarding low water levels, the series of consecutive deficit years observed in the study region has resulted in a decrease of groundwater levels, particularly during the period of low precipitation from 1985 to the early 2000s. The evolution of the average piezometric levels in the Upper Cheliff alluvial aquifer from 1970 to 2020 during dry periods indicates a drop in the water table by about 8.0 meters over the entire period. Afterward, there is a gradual increase starting in the 2000s, with the aquifer level rising by over 6.0 meters (Fig. 7, 8 and 9).

Groundwater quality: The analysis of groundwater samples

Table 2. SPI classification scheme used by European Drought Observatory (EDO)

Anomaly	Range of SPI values	Precipitation regime
Positive	2.0 ≤ SPI ≤ Max.	Extremely wet
	1.5 ≤ SPI ≤ 2.0	Very wet
	1.0 ≤ SPI ≤ 1.5	Moderately wet
None	-1.0 ≤ SPI ≤ 1.0	Normal precipitation
Negative	-1.5 ≤ SPI ≤ -1.0	Moderately dry
	-2.0 ≤ SPI ≤ -1.5	Very dry
	Min. ≤ SPI ≤ -2.0	Extremely dry

Table 1. Average water table drawdown and groundwater volume reserve

Sector	Surface (Km²)	Aquifer materials	Sy	Q (l/s)	Water table drawdown 1971-1981 (m)	Water table drawdown 1982-2007 (m)	Water table drawdown 2008-2021 (m)
1	15	Fine-grained	0.05	4-8	7	4.5	6
	25	Medium-grained	0.15	10-15	6	4	5.5
	30	Coarse-grained	0.25	20-35	5	3.5	5
2	100	Coarse-grained	0.25	10-40	3	1.5	2
3	90	Coarse-grained	0.30	20-70	2	0.7	0.8
	30	Fine-grained	0.05	1-5	1	0.6	0.7
Volume (H.m^3)					195.8	102	135

for the dry season of 2021 in the Upper Cheliff plain showed slightly alkaline water with a pH range of 7.1 to 8.3. Electrical conductivity (EC) was used to assess the ionic content of the groundwater. The groundwater in this alluvial aquifer is moderately mineralized (EC range of 1300 to 5000 µS/cm; TDS range from 650 to 2950 mg/l, TH range from 35 to 150 °F) and is not suitable for drinking or irrigation in some parts of the agricultural plain. This is due to hydrogeological conditions and anthropogenic pollution, specifically from fertilizers such as ammonium sulphate $(NH_4)_2SO_4$ and superphosphate Ca $(H_2PO_4)_2$, as well as untreated wastewater (Fig. 10).

The untreated wastewater flowing in Wadi Cheliff, where it was analyzed at different points during the dry period of 2021, showed very high values on average: (pH = 5, EC = 4500 µS/cm, Cl^- = 1000 mg/l, SO_4^{2-} = 75 mg/l, Na^+ = 600 mg/l, Ca^{2+} = 2400 mg/l, Total Nitrogen = 300 mg/l, Phosphorus = 10 mg/l, Ammonium = 400 mg/l). This confirms that one of the major sources of groundwater pollution is the untreated wastewater flowing in Wadi Cheliff. In terms of ion concentration, calcium and sodium were the most dominant cations, while chloride and bicarbonate were the most dominant anions, making up 75% and 15% of the anions and cations respectively. This resulted in the dominant chemical facies of the groundwater being calcium-chloride (> 50%) and sodium chloride (> 25%). Calcium was the dominant cation, followed by sodium and magnesium (Fig. 11). The high concentration of calcium ions is likely due to the dissolution of limestone crusts, while the high sodium levels may be due to the leaching of sodium fertilizers used in agricultural activities, as well as organic pollution from untreated wastewater discharge and cation exchange processes in the aquifer. The high levels of chloride in the groundwater may be due to the dissolution of NaCl salts, seepage of wastewater, and the flow direction and residence time of the groundwater in the aquifer. The high levels of sulfate may be due to the use of fertilizers in agriculture, evaporation, wastewater discharge, and the dissolution of gypsum minerals. The nitrate levels in the study area range from 2 to 160 mg/l, with more than 30% of wells exceeding the

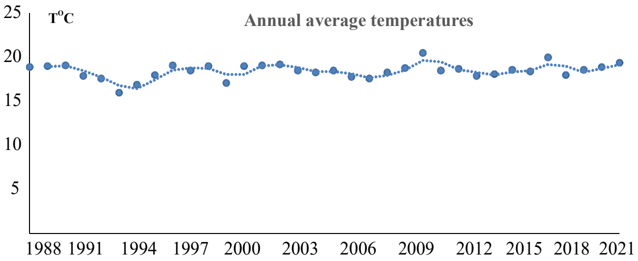

Fig. 6. Evolution of annual average temperature for the period 1988-2021

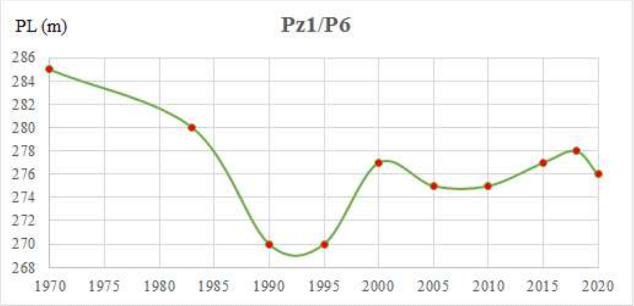

Fig. 7. Evolution of piezometric levels in the upstream of the Upper Cheliff Aquifer

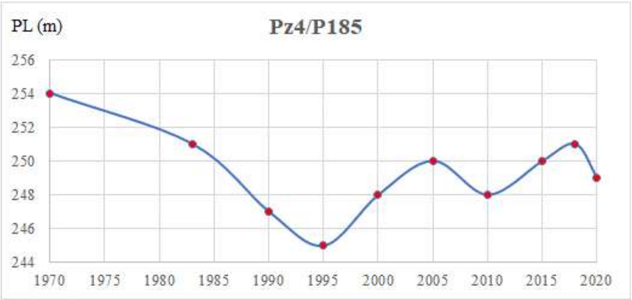

Fig. 8. Evolution of piezometric levels in centre of the Upper Cheliff Aquifer

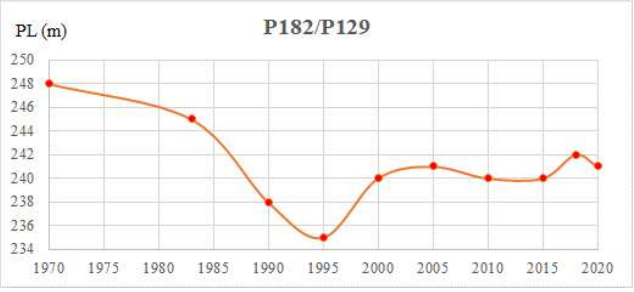

Fig. 9. Evolution of piezometric levels in the downstream of the Upper Cheliff Aquifer

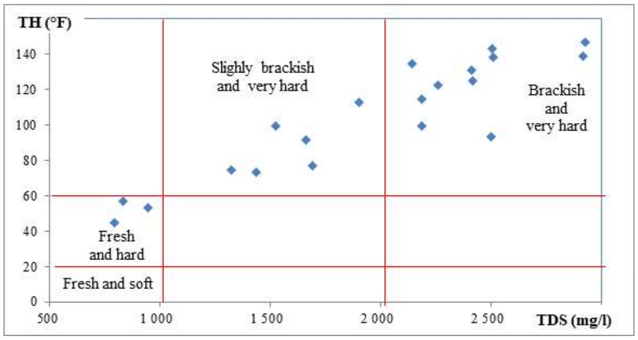

Fig. 10. TH (°F) Vs TDS (mg/l) for the dry period 2021 in the alluvial aquifer

limit of 50 mg/l set by the World Health Organization (WHO). This may be related to the use of nitrogen-based fertilizers in the agricultural area, which is characterized by high permeability in the old quaternary formations (conglomerate, pebble, calcareous crust and alluvial fans), and may also be related to waste discharge from animals, manure, and soils containing nitrogen compounds.

The groundwater in this alluvial aquifer is not suitable for drinking or irrigation in some parts of the agricultural plain due to the high levels of ions, specifically calcium and sodium, as well as the high levels of chloride and sulfate. These high ion levels are a result of both natural processes, such as the dissolution of limestone crusts, and anthropogenic pollution from fertilizers and untreated wastewater. It is important to note that these high ion levels can have negative effects on both the environment and human health. High levels of calcium and sodium can affect the taste and quality of the water, and can also lead to scaling and corrosion in pipes and other equipment. High levels of chloride and sulfate can be toxic to certain plants and animals, and can also affect the taste and quality of the water. Additionally, the high nitrate levels present in the study area can pose a risk to human health, particularly for infants and pregnant women. It is important for local authorities and water management agencies to take action to address the issues of groundwater pollution in this agricultural plain. This could include stricter regulations on the use of fertilizers and the disposal of wastewater, as well as implementing water treatment and conservation measures to ensure that the groundwater is safe for drinking and irrigation. Additionally, more frequent monitoring and testing of the groundwater should be carried out to keep track of any changes in water quality and to identify potential sources of pollution.

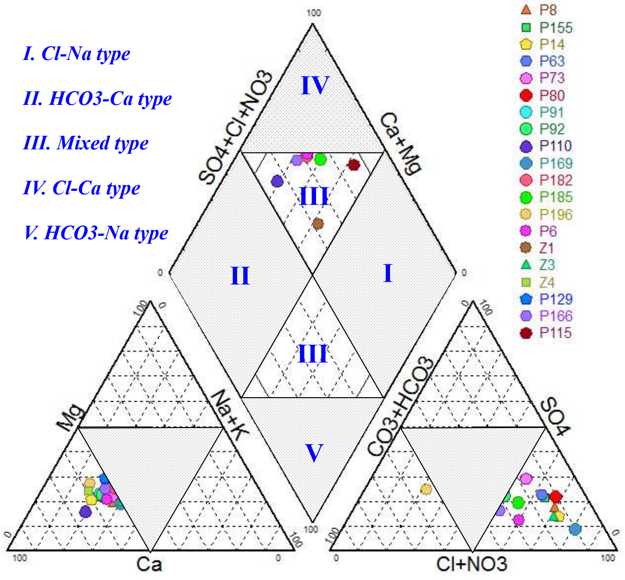

Fig. 11. Piper's diagram for dry period 2021 in the alluvial aquifer of Upper Cheliff

CONCLUSIONS

The study focuses on the Upper Cheliff alluvial aquifer in Algeria and its groundwater resources, and it reveals some concerning findings about the current state of the aquifer. The data collected over 50 years shows irregular rainfall, with a rainy season from November to April and a dry season from June to August. The decline in rainfall from 1983 to 2007 has affected the quantity and quality of groundwater resources in the area. Additionally, over the last 14 years, the annual average temperatures in Algeria have increased by 0.5°C, which has further impacted the groundwater reserves. The evaluation of natural recharge in the alluvial aquifer involves measuring the water entering and leaving the aquifer, which can be done through groundwater level monitoring. The analysis of piezometric maps for this aquifer reveals three sectors with different fluctuations in water levels. The eastern sector has the greatest drawdown and hydraulic gradient, the central sector has moderate drawdown and gradient, and the downstream sector has the least drawdown and gradient. The study finds that there is a correlation between rainfall and groundwater levels during wet periods. However, during dry periods, pumping has a significant impact on the aquifer, leading to an imbalance in water resources management. Overexploitation of the aquifer for various uses has further worsened the situation. The analysis of groundwater in the Upper Cheliff plain during the dry season of 2021 found slightly alkaline water with moderate mineralization. This water is not suitable for drinking or irrigation in some parts of the agricultural plain due to hydrogeological conditions and anthropogenic pollution, specifically from fertilizers and untreated wastewater. The untreated wastewater in Wadi Cheliff during the dry season of 2021 showed high levels of ions and pollutants, confirming it as a major source of pollution. The groundwater has high levels of calcium, sodium, chloride, and sulfate, which can affect taste, quality, and be harmful to plants and animals, and human health. The study highlights the need for proper management of water resources to ensure sustainable use and preservation of this important resource. Local authorities need to take action to address the issues of groundwater pollution in this agricultural plain through regulations, treatment, and monitoring.

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