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Evaluation of the quality of boreholes water using indicators like Water Quality Index (WQI), and the Comprehensive Pollution Index (CPI).

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Abstract: Mauritania is a country with a water deficit. The majority of these regions are supplied by groundwater through boreholes. Among these regions there is the Wilaya of Akjoujt. Water for domestic use from two boreholes in Benichab in the Wilaya of Inchiri was analyzed and assessed for quality in February, July and November 2023, using standard laboratory sampling and analysis methods. Parameters examined included temperature, pH, electrical conductivity (EC), Total dissolved solids (TDS), turbidity, chlorides (Cl^-), nitrates (NO_3^-), sulfates (SO_4^{2-}), calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), potassium (K^+) and fluoride (F^-). The results of the physico-chemical analysis demonstrated that the borehole water met World Health Organization (WHO) standards for human consumption. Water quality index (WQI) and Comprehensive Pollution Index (CPI) methods were used. The WQI confirmed that water from the Benichab boreholes, with a score below 50, was excellent for consumption. CPI values ranged from 0.22 to 0.27, suggesting slightly impaired borehole water at Benichab. However, without considering F^- and pH, CPI ranged from 0.14 to 0.20, indicating satisfactory borehole water quality in the Benichab region. These results underline the importance of F^- and pH in borehole water quality in Benichab. A statistical analysis of the correlation between F^- and certain physical parameters using Pearson's correlation matrix revealed that F^- concentrations could be influenced by pH in Benichab boreholes. The affirmative solution will be a continuous water quality monitoring program particularly F^- and pH and a detailed hydrogeochemical investigation is suggested for sustainable utilization of water resources.

Keywords: domestic water, Water Quality Index, Comprehensive Pollution Index, Mauritania.

Introduction

Water, essential for life and civilization, faces escalating threats from climate change, pollution, resource scarcity, and global conflicts. Its protection and sustainable management are crucial for preserving ecosystems, ensuring human survival, and maintaining economic stability (1, 2). Global water data reveal that only 2.5% of water is fresh, while 97.5% is saline, with groundwater accounting for around 30.1% of available freshwater resources. (3)

Groundwater is a precious natural gift that stimulates the growth and development of a country's industrialization, urbanization, agriculture, and overall economy (4, 5). Further groundwater is one of the most important sources of fresh water and it is essential for humans and all living organisms (6, 7). The health of organisms is closely linked to the quantity and quality of groundwater. The chemical properties of groundwater depend on various factors, such as the geological characteristics of the region, human activities, evaporation, and hydrogeological conditions. This is why groundwater contains a variety of chemical substances. Nevertheless, most of these compounds are naturally present in water sources. Their concentration has often increased as a result of human activity, leading to numerous adverse effects on human health (8). Several studies are documented and discussed groundwater quality for drinking and irrigation around the world (9-13).

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However, many studies have indicated that the quality of groundwater has been deteriorating over time due to various factors such as rapid industrialization, population growth, anthropogenic and geogenic activities, excessive exploitation, the intensive use of fertilizers and pesticides in agriculture, and the discharge of untreated municipal and industrial effluents into water sources (14- 16).

Thus, a better understanding of groundwater quality is essential in determining its suitability for different purposes (17). The study aimed to assess the water quality of boreholes located in the locality of Benichab in the Wilaya of Inchiri. The indicators used included the Water Quality Index (WQI), and the Comprehensive Pollution Index (CPI).

Materials and Methods

Description of the study area

Mauritania is divided into 15 regions, with the capital Nouakchott being divided between north, east and south and constituting 3 regions in all. Among these regions the Wilaya of Inchiri.

The wilaya of Inchiri, covering an area of 47,000 km², is made up of two districts: Akjoujt and Benichab (Figure 1). It is located some 200 km from the Atlantic, at coordinates 19°45' North and 14°35' West. Its economy is based mainly on gold and copper mining. Due to the aridity of the region, with an average annual rainfall of 60 mm, the agropastoral sector is experiencing limited growth.

The Benichab aquifer is part of the Senegalese-Mauritanian coastal basin. The static level is between 13 and 16 m below sea level. The fresh water layer is in contact with a brackish water layer to the west and ends to the east with a dry wedge. The groundwater has a mineralization of around 0.2 g L^{-1}. Benichab city is supplied by both boreholes (F_1 and F_2) managed by the National Water Company called SNDE.

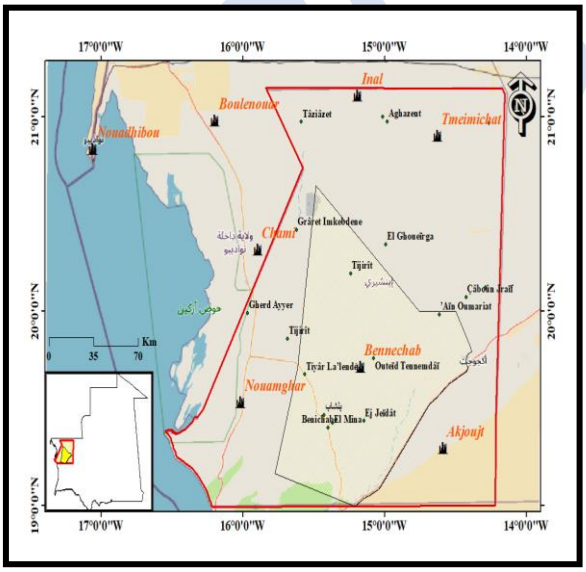

Figure (1): Wilaya of Inchiri localisation

Sampling procedures

The sampling process was carried out at the chosen site, using a polyethylene bottle (1.5 L). The collected water samples were stored in an ice box, and delivered to the laboratory on same day. The collected samples were analyzed in the laboratory for various physico-chemical parameters. During sample collection, handling, preservation and analysis, standard procedures recommended by the Quality Assurance. Each of the samples was taken three times: a first sampling campaign in February, a second sampling campaign in July and a third sampling campaign in November of the year 2023. All mathematical calculations like means were calculated for physico-chemical parameters using Excel 2007 (Microsoft Office).

Equipment and apparatus

Equipment used for measurement of physicochemical parameters such as temperature, pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), turbidity, Chlorides (Cl^-), Nitrates (NO_3^-), Sulfates (SO_4^{2-}), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), sodium (Na^+), potassium (K^+), and Fluoride (F^-) are listed in Table 1.

Table 1: Water quality parameters and measurement methods

Parameters	Unit	Measuring equipment and method analysis
Temperature	° C	pH meter HI 991001
pH		pH meter HI 991001
EC	µS/cm	Conductimeter HI98192
TDS	mg/L	Conductimeter HI98192
Turbidity	NTU	Turbidimeter
Ca^{2+}	mg/L	Titrimetry, complexometry with EDTA
Mg^{2+}	mg/L	Titrimetry, complexometry with EDTA
Na^+	mg/L	Flamme emission photometer
K^+	mg/L	Flamme emission photometer
Cl^-	mg/L	Volumetric dosage with Silver nitrate
NO_3^-	mg/L	Photometer Wagtech 7100
SO_4^{2-}	mg/L	Photometer Wagtech 7100
F^-	mg/L	Photometer Wagtech 7100

Calculation of Water Quality Index

WQI is a parameter that defines the composite effect of various water quality parameters (18). The WQI was calculated using the weighted Arithmetic Index method. This expression was used to calculate the quality rating scale for each parameter (q_i):

$$q_i = \frac{C_i}{S_i} \times 100 \qquad (1)$$

A quality rating scale (q_i) for each parameter is calculated by dividing its concentration (C_i) in each water sample by its respective standard (S_i) and multiplying by 100. The relative weight (W_i) was calculated using a value inversely proportional to the recommended standard (S_i) of the corresponding parameter:

$$W_i = \frac{1}{S_i} \qquad (2)$$

The overall WQI was calculated by aggregating the quality rating (q_i) with unit weight (W_i) linearly:

$$WQI = \sum_{i=1}^{n} (W_i \times q_i) \qquad (3)$$

Overall, WQI were considered for a specific and intended use of water. In this study, the WQI for drinking purposes is evaluated, and the allowable WQI for drinking water is set at 100.

$$WQI = \frac{\sum_{i=1}^{n} q_i w_i}{\sum_{i=1}^{n} w_i} \qquad (4)$$

The determined WQI values are classified into five classes as mentioned in Table 2 (19).

Table 2 : WQI categories

Range	Quality
<50	Excellent water
50-100	Good water
100-200	Poor water
200-300	Very poor water
>300	Unsuitable for drinking

Comprehensive Pollution Index

The CPI is used to determine the degree of pollution in a certain watershed by analysing monitoring data (20). The formula for calculating CPI is shown below:

$$CPI = \frac{1}{n}\sum_{i=1}^{n} PI_i \qquad (5)$$

where CPI stands for Comprehensive Polluted Index, n is the number of monitoring parameters, and PIi is the pollution index number i. PIi is determined using the following equation (20):

$$PI_i = \frac{C_i}{S_i} \qquad (6)$$

Where C_i = measured concentration of parameter number in water; S_i= permitted limitation of parameter number according to environmental standard. CPI is classified into five categories as mentioned in Table 3 (20).

Table 3: The CPI categories

Catégory	CPI	Classification
1	0-0.20	clean
2	0.21-0.40	Sub clean
3	0.41-1	Slightly polluted
4	1.01-2	Medium polluted
5	≥ 2.01	Heavily polluted

Results and Discussion

Spatio-Temporal Variation of physicochemical parameters

The physicochemical parameter of water samples from two boreholes from locality of Benichab in Wilaya of Inchiri during the months of February, July and November were represented in Table 4.

Table 4 Statistical summary of the physicochemical parameters of the boreholes from Benichab

	F1	F2	
	Mean	Mean	WHO (2011)
T(° C)	22.3±2.42	22.3±2.62	30
pH	8.37±0.06	8.1±0.08	8.5
EC (µS /cm)	263.3±32.1	261.3±40.4	1500
TDS (mg/L)	132±15.7	130.7±20.2	500
Turbidity(NTU)	0.28±0.02	0.26±0.017	5
Ca^{2+} (mg/L)	23.04±4.93	21.13±6.47	75
Mg^{2+} (mg/L)	8.87±0.40	8.78±0.82	50
Na^{+} (mg/L)	25.7±1.53	23.7±2.31	200
K^{+} (mg/L)	3.3±0.58	2.3±0.58	12
Cl^{-} (mg/L)	43.4±4.27	41.9±2.12	200
NO_3^{-}(mg/L)	0.67±0.21	0.23±0.21	50
SO_4^{2-}(mg/L)	6.3±0.58	6.3±2.89	250
F^{-} (mg/L)	0.78±0.16	0.55±0.17	1.5

Temperature values ranged from 25.1°C to 25.3°C in February, 20.8°C to 20.9°C in July and from 20.7°C to 20.9°C in November (Figure 2). Temperature in this study was found within permissible limit of WHO (2011) (30 °C) (21).

The water pH is considered to be of practical great importance, influencing most of the chemical and biochemical reactions (22). The values of pH in February, in July, and November are in the range of 8.16- 8.3, 8.1- 8.4 and 8- 8.4, respectively (Figure 3). The values indicate that water samples of these boreholes have alkaline properties. The values obtained indicate that pH of water samples from the boreholes were within WHO for drinking water (21).

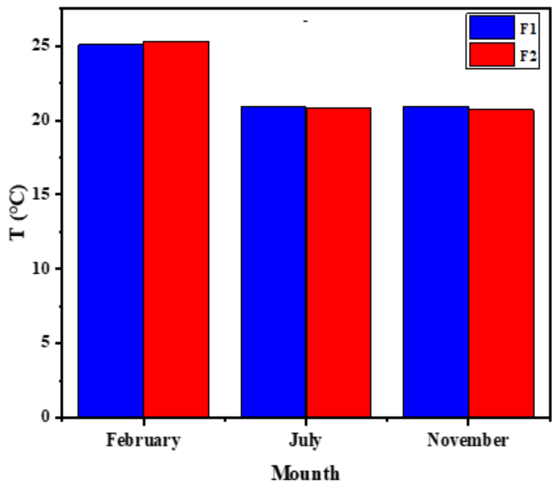

Figure (2): Spatial and temporal variation in Temperature of boreholes from Benichab

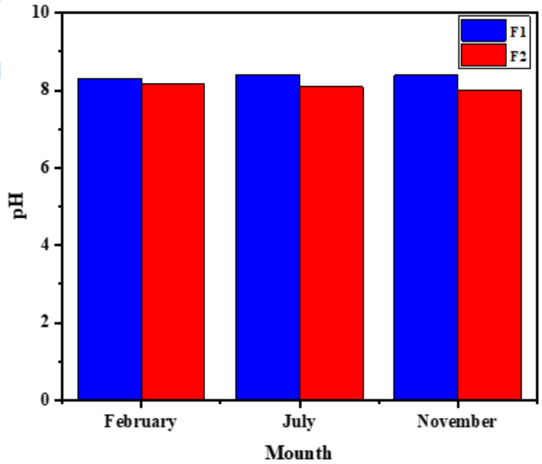

Figure (3): Spatio-temporal variation in pH of boreholes from Benichab

Electrical conductivity (EC) measures the ionic process of a solution that enables it to transmit current. It is important to note that the water has the ability to dissolve a wide range of inorganic and some organic minerals or salts such as potassium, calcium, sodium, bicarbonates, chlorides, magnesium, sulfates etc.

Generally, the amount of dissolved solids in water determines the electrical conductivity. The water with high TDS value indicates that water is highly mineralized. Increase in ions concentration enhances the EC of water (23). EC measures the presence of ions in water. EC values vary within a range of 240-298 µS/cm in February, 218-300 µS/cm in July and 250-268 µS/cm in November (Figure 4). TDS is a measure of inorganic salts. The TDS values vary within a range of 121-149 mg/L in February, 109-150 mg/L in July, and 125-134 mg/L in November (Figure 5). The values obtained indicate that EC, and TDS of water samples from the boreholes were within WHO for drinking water (21).

Chloride is a naturally occurring ion that can be found in a variety of rocks and soils. The concentrations of chlorides in February, July, and November are in the range of 42.6–46.2 mg/L, 38.5–39.6 mg/L, and 43.7–45.6 mg/L, respectively (Figure 6). The values obtained indicate that chlorides of water samples from the boreholes were within WHO for drinking water (21).

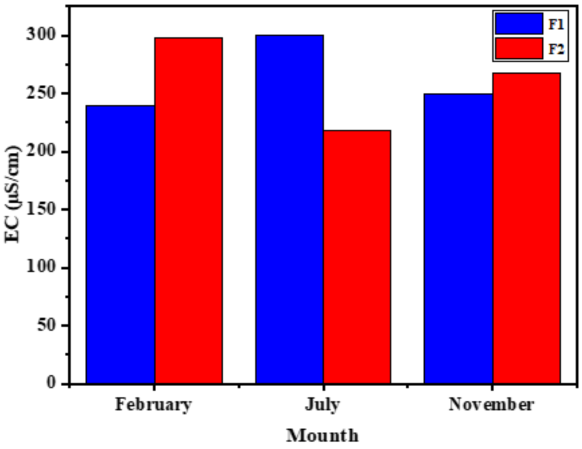

Figure (4): Spatial and temporal variation in EC of boreholes from Benichab

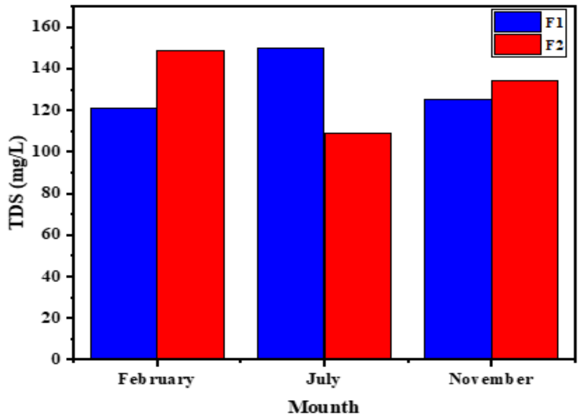

Figure (5): Spatial and temporal variation in TDS of boreholes from Benichab

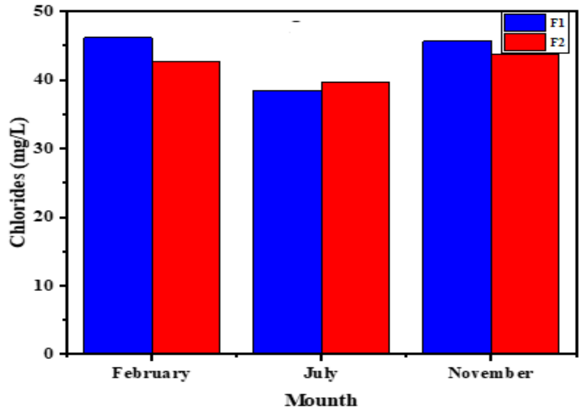

Figure (6): Spatial and temporal variation in Cl^- of boreholes from Benichab

Turbidity is a basic and easily determinable indicator that has been used to estimate the degree of light scattering or absorption caused by suspended material in water, including silt, organic and inorganic matter. The values of turbidity in February, July, and November are in the range of: 0.25–0.31 NTU, 0.27–0.38 NTU, and 0.25–0.27 NTU, respectively **(**Figure 7**).** The turbidity values recorded in the present study are lower than the admissible value limit (5 NTU) authorized by (21).

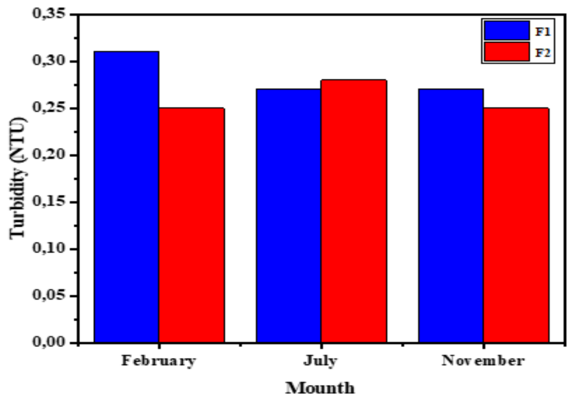

Figure (7.): Spatial and temporal variation in turbidity of Borehole water from Benichab

Sulfate mainly is derived from the dissolution of salts of sulfuric acid. Sulfate concentration in natural water ranges from a few to a several 100 mg/L, but no major negative impact of sulfate on human health is reported (23). In this study, the concentrations of Sulfates in February, July, and November are in the range of: 7–8 mg/L, 6–8 mg/L, and 3–6 mg/L, respectively (Figure 8). Sulfates concentrations were below the WHO recommended values of 250 mg. L^{-1} for drinking purposes (21).

Nitrate one of the most important diseases causing parameters of water quality particularly blue baby syndrome in infants. The sources of nitrate are nitrogen cycle, industrial waste, nitrogenous fertilizers etc (23). The concentrations of nitrates in February, July, and November are in the range of 0.5–0.9 mg/L, 0.1–0.5 mg/L, and 0.1–0.6 mg/L, respectively (Figure 9). Nitrate concentrations were below the WHO recommended values of 50 mg/L for drinking purposes, respectively (21).

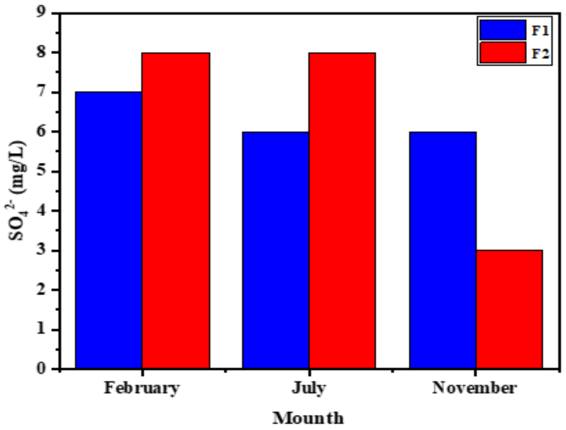

Figure (8): Spatial and temporal variation in SO_4^{2-} of boreholes from Benichab

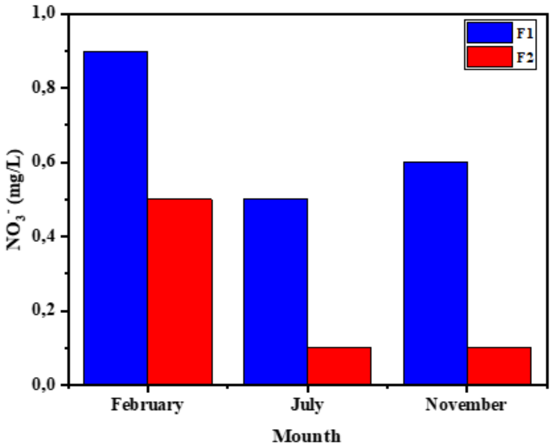

Figure (9): Spatial and temporal variation in NO_3^- of boreholes from Benichab

Calcium is 5th most abundant element on the earth crust and is very important for human cell physiology and bones. The high deficiency of calcium in humans may caused rickets, poor blood clotting, bones fracture etc. and the exceeding limit of calcium produced cardiovascular diseases. Magnesium is the 8th most abundant element on earth crust and natural constituent of water. It is an essential for proper functioning of living organisms and found in minerals like dolomite, magnetite etc. (23). Calcium is obtained by dissolving carbonate minerals. Similarly, magnesium, which is always found in low concentrations in all types of water, comes from Mg-bearing minerals and magnesium sulphate minerals (24). Calcium concentrations in February, July, and November are in the range of 27.1- 28.1 mg/L, 20.1–24.5 mg/L, and 15.2–17.6 mg/L (Figure 10). The concentrations of magnesium in February, July, and November are in the range of 9.3- 9.7 mg/L, 8.2–8.6 mg/L, and 8.3–8.4 mg/L (Figure 11). Both calcium and magnesium concentrations were below the WHO recommended values of 75 mg/L and 50 mg/L for drinking purposes, respectively (21).

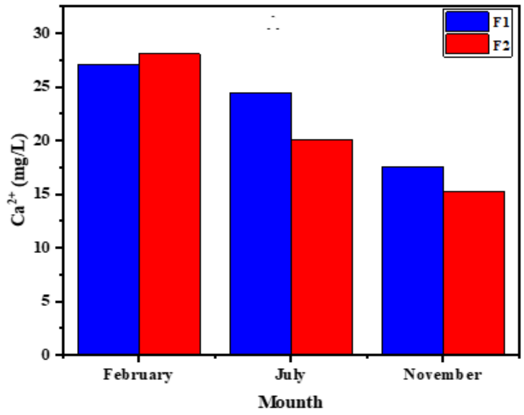

Figure (10): Spatial and temporal variation in Ca^{2+} of boreholes from Benichab

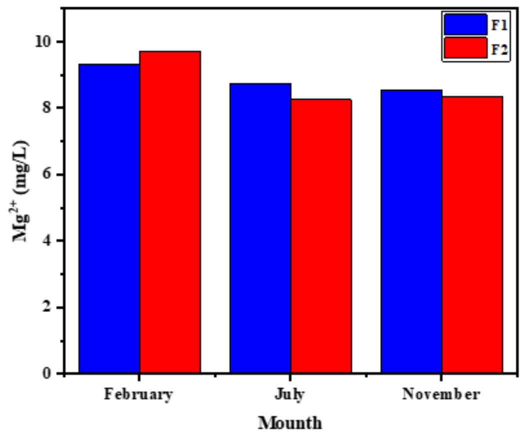

Figure (11): Spatial and temporal variation in Mg^{2+} of boreholes from Benichab

In water, sodium can occur naturally in rocks and soil. Our body needs it to maintain normal blood pressure levels, normal nerve, and muscle functions (24). Proper quantity of sodium in human body prevents many fatal diseases like kidney damages, hypertension, headache etc (23). According to WHO standards, concentration of sodium in drinking water is 200 mg/L (2011) (21). In the study areas, the finding shows that the concentrations of sodium in February, July, and November are in the range of 24–25 mg/L, 21–26 mg/L, and 25–27 mg/L, respectively (Figure 12).

Potassium is silver white alkali which is highly reactive with water. Potassium is necessary for living organism functioning hence found in all human and animal tissues particularly in plants cells. It is vital for human body functions like heart protection, regulation of blood pressure, protein dissolution, muscle contraction, nerve stimulus etc. Potassium is deficient in rare but may led to depression, muscle weakness, heart rhythm disorder etc (23). According to WHO standards (2011) the permissible limit of potassium is 12 mg/L (21). Results show that the the concentrations of potassium in February, and November are in the range of 2–3, and 2–4 mg/L, respectively (Figure 13). However, in July, the potassium content is constant (Figure 13).

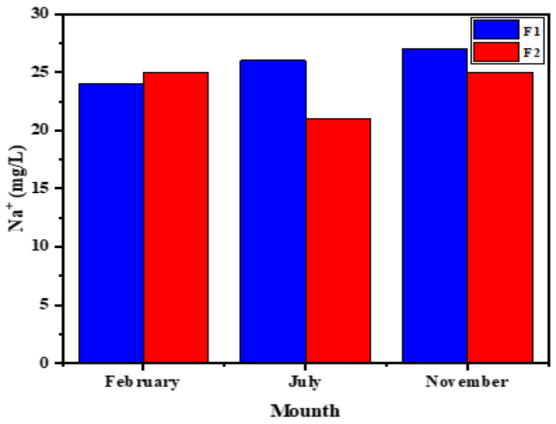

Figure (12): Spatial and temporal variation in Na^+,of boreholes from Benichab,

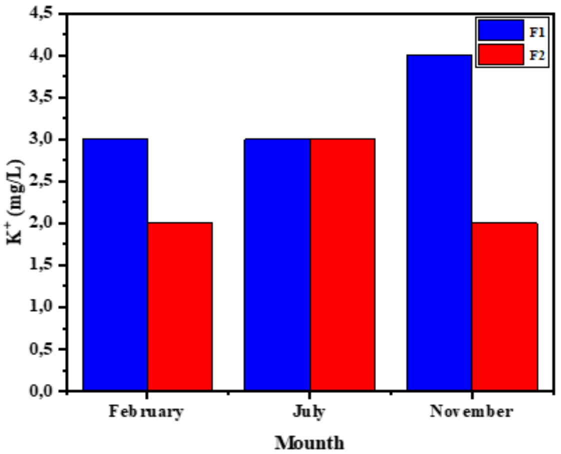

Figure (13): Spatial and temporal variation in K^+ of the boreholes from Benichab

The content of F^- in water supplies is of the greatest important (25); low concentrations of F^- (≤ 0.5 mg/L) lead to dental decay (27), but teethes are protected against decay at lower concentrations (0.5– 1.5 mg/L) (26). Besides, dental and skeletal fluorosis can be caused at higher concentrations of F^- (> 4 mg. L) (27). F^- values range from 0.64 to 0.7 mg/L in February, 0.36 to 0.75 mg/L in July and 0.59 to 0.96 mg/L (Figure 14) during November.

The highest F^- values are recorded at F_1 in November (0.96 mg/L). However, the lowest F^- values are recorded at sites F_2, where they reached 0.37 and 0.36 mg/L in July, respectively. The values of the concentration of F^- obtained in the present study can be compared with the concentrations of F^- reported by Aldrees & Al-Manea (28) in drinking water of Saudi Arabia (0.5–0.83 mg/L).

However, the values of the concentration of F^- obtained in the present study is lower than reported in drinking water by Mirzabeygi et al. (29) (range: 0.9–6 mg/L). The values obtained indicate that F^- of water samples from the boreholes were within WHO for drinking water (1.5 mg/L) (21).

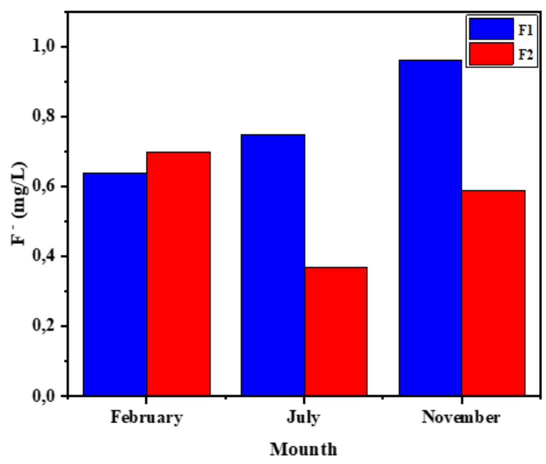

Figure (14): Spatial and temporal variation in F^- of Borehole water from Benichab

Water Quality Index

To assess water quality of the boreholes from Benichab, the WQI method was used. The parameters pH, EC, TDS, turbidity, Cl^-, NO_3^-, SO_4^{2-}, Ca^{2+}, Mg^{2+}, Na^+, K^+, and F^- were taken into justification for calculation of the WQI value for each borehole in February, July and November. Furthermore, the World Health Organization WHO (2011) (21) limits were used to compute the WQI. To calculate the WQI values for each borehole, the weight values of each physicochemical water quality parameter were defined according to their relative effect on the overall water quality (Table 5).

Table 5: Calculation of WQI of the boreholes from Benichab

Parameters	WHO standards (2011) (Si)	w_i
pH	8,5	0.11764706
EC (µS/cm)	1500	0.00066667
TDS (mg/L)	500	0.002
Turbidity (NTU)	5	0.2
Cl^- (mg/L)	250	0.004
SO_4^{2-} (mg/L)	250	0.004
NO_3^- (mg/L)	50	0.02
Ca^{2+} (mg/L)	75	0.01333333
Mg^{2+} (mg/L)	50	0.02
Na^+ (mg/L)	200	0.005
K^+ (mg/L)	12	0.08333333
F^- (mg/L)	1.5	0.66666667

The WQI data for the physicochemical parameters studied are summarized in Table 6. The results show that the WQI values in February, July, and November are all below 50 for both boreholes, confirming that the water is of excellent quality for consumption.

However, a WQI value of 51.94 was recorded for borehole F1 in November, suggesting that the water remains acceptable for consumption. It is important to note that borehole F1 has high levels of F^- measured at 0.96 mg/L. These results underline the significant role of F^- in determining water quality in boreholes in the locality of Benichab.

Table 6: Variation of WQI of boreholes water of Benichab

	F1	**F2**
February	39.02	40.36
Quality	Excellent water	Excellent water
July	43.23	27.37
Quality	Excellent water	Excellent water
November	51.94	36.53
Quality	Good water	Excellent water

Comprehensive Pollution Index

To evaluate the CPI values and classify the water quality of the Benichab boreholes, we analyzed the results of parameters such as pH, EC, TDS, turbidity, Cl^-, SO_4^{2-}, NO_3^-, Ca^{2+}, Mg^{2+}, Na^+, K^+, and F^- obtained during February, July, and November. The CPI values were categorized in three classes:

-With including F^-,

-Without F^-,

-Without F^- and pH,

When F- studied is included in the CPI calculation for water from boreholes in the locality of Benichab (Table 7), the results reveal CPI values between 0.22 and 0.27. This indicates that, according to the classification presented in Table 3, water from boreholes in the locality of Benichab is Sub clean.

Table 7: CPI values of borehole water in Benichab area

		F1	F2
February	CPI	0.25	0.25
	Classification	Sub clean	Sub clean
July	CPI	0.26	0.22
	Classification	Sub clean	Sub clean
November	CPI	0.27	0.22
	Classification	Sub clran	Sub clean

Without including F^- (Table 8), the results showed that the values of CPI are between 0.21 and 0.23 which means that the boreholes water of Benichab area is Sub clean according to the classification in Table 3.

Table 8: CPI values of borehole water in Benichab area without including F^-

		F1	F2
February	CPI	0.24	0.23
	Classification	Sub clean	Sub clean
July	CPI	0.21	0.21
	Classification	Sub clean	Sub clean
November	CPI	0.23	0.21
	Classification	Sub clran	Sub clean

However, without including F^- and pH (Table 9), the results showed that the values of CPI are between 0.14 and 0.20. This indicates that, according to the classification presented in Table 3, water from boreholes in the Benichab locality is clean. These results show that the pH is an important parameter which influences the quality of boreholes water from Benichab locality.

Table 9: CPI values of borehole water in Benichab area without including F^- and pH

		F1	F2
February	CPI	0.16	0.16
	Claddification	clean	clean
July	CPI	0.20	0.14
	Claddification	clean	clean
November	CPI	0.20	0.18
	Claddification	clran	clean

Correlation matrix analysis

The relationship between F^- and some physical parameters was also analyzed statistically using Pearson's correlation matrix and shown in Table 10.

A positive correlation was found between F^-–TDS (0.444) and F^- – EC (0.442). The strong and positive correlation was found between F^- and pH (r = 0.721).

The results obtained by Pearson's correlation matrix confirm those obtained by the CPI that the F^- concentrations of water from Benichab boreholes could be influenced by the pH. Some researchers have reported that the alkaline pH is more favorable for F^- dissolution and promotes the desorption of F^- in groundwater (30-33).

Table 10: Pearson correlation matrix between F^- and physical parameter

Variables	F^-	pH	EC	TDS
F^-	1			
pH	0,721	1		
EC	0,442	0,174	1	
TDS	0,444	0,181	1,000	1

This preliminary study must be conducted by regularly monitoring the physicochemical parameters, particularly F- and pH. It is important to note that the high F concentrations are associated with a variety of health conditions in humans and animals, including anemia, low birth weight newborns, nervous system problems, abortion, hypertension, and so on (34, 35). It is also responsible for lowering children's intelligence quotient (36).Therefore, this preliminary study could be supplemented by a continuous water quality monitoring program and a hydro geochemical studies.

Conclusion

This preliminary study revealed that water from two boreholes at Benichab meets WHO drinking water standards for temperature, pH, EC, TDS, turbidity, as well as concentrations of Cl^-, NO_3^-, SO_4^{2-}, Ca^{2+}, Mg^{2+}, Na^+, K^+, and F^-. The WQI indicates that water from the Benichab boreholes, with a value below 50, is excellent for consumption. However, the results obtained by the CPI highlight the influence of F^- and pH in water quality in the locality of Benichab, although the F- and pH concentrations are not exceeding the recommended limits. A correlation between F^- and some physical parameters suggests that F^- concentrations in Benichab wells may be influenced by pH. The results obtained by Pearson's correlation matrix confirm those obtained by the CPI. In addition, it is reported that the alkaline pH is more favorable for F^- dissolution and promotes the desorption of F^- in groundwater. Moreover, additional measures must be taken by the government and stake holders to improve the water quality of the town of Benichab:

- Water quality monitoring program,

- Control periodically the F^- and pH contents in the water from the Benichab boreholes.

- Hydrogeochemical investigation for to understand the interactions between F^- and pH.

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and materials

The raw data required to reproduce these findings are available in the body and illustrations of this manuscript.

Author's contribution

The authors confirm their contribution to the paper as follows: study conception and design: S.D.S, A.D.N, O.E.M.A, B.K.M,; data analysis and validation A.D.N, B.K.M, M.E.K.C.A., B.H & M.K; draft manuscript preparation: A.D.N, Y.A.E.H.A,. Editing and writing: S.J.

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Conflicts of interest
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