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Assessment of Iron Contamination in Groundwater of Catchment Area Water

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ABSTRACT

This study investigates the occurrence of iron (Fe) in the catchment area water in Derwiche from Hodh El Chargui in Mauritania. The study area was monitored during January and August. The occurrence of Fe in the groundwater showed significant spatial and temporal fluctuations. The relationship between Fe and some physicochemical parameters was also analyzed statistically using Pearson's correlation matrix. Firstly, the results suggested that the concentration of Fe was influenced by the dissolution of iron minerals. Secondly, the results show that the pH value was an important factor that influenced the Fe concentrations in the groundwater. The Water Quality Index (WQI) method was used to evaluate the suitability for human consumption. The results show that WQI is strongly influenced by Fe indicating that Fe removal would contribute to excellent well water. The Treatability Index (TI) is used to assess water quality. TI confirms the results obtained by the WQI. However, TI also shows that the pH is a parameter to be optimized for possible potabilization. These results show that there would be a close relationship between the recorded Fe levels and the pH. TI confirms the results obtained by Pearson's correlation matrix. Therefore, the presence of high Fe concentrations in groundwater in the study area could have a natural origin. The results recommended that different treatment techniques should be employed to purify groundwater before consumption. The primary focus should be cascaded toward Fe contamination.

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1. INTRODUCTION

Groundwater is a vital natural resource essential for drinking, irrigation, industry, and other economic sectors (Bodrud-Doza *et al.,* 2019). Because of being pathogen-free and available, groundwater is considered a prime source of potable water in most countries of the world (Rahman *et al.,* 2021).

About 80% of the diseases in developing countries are related to contaminated water and the resulting death toll is as much as 10 million per year. Among many contaminants, iron (Fe) is present in chemicals derived from both natural sources and human activities (Tekerlekopoulou *et al.*, 2013).

Fe is a fairly abundant element in rocks and is found in the form of silicates, oxides as well as hydroxides, carbonates, and sulfides. Fe exists in dissolved Fe^{2+} (ferrous ion) and suspended Fe^{3+} (ferric ion) forms (Zhang *et al.,* 2020). They can occur naturally as a result of water–sediment interaction which induces their dissolution. Dissolution processes are controlled by several environmental factors, primarily redox conditions (Weng *et al.,* 2007; McMahon & Chapelle, 2008; Palmucci *et al.*, 2016). Fe is one of the important elements, used by many technologies, including hydrogen energy generation (Nandiyanto *et al.*, 2023).

Although trace of Fe is indispensable to human survival, excessive exposure to them can damage human health. Excessive intake of Fe can lead to chronic intoxication (Zoni *et al.*, 2007). Drinking water containing Fe at concentrations 3 mg/L or higher for a long time causes hemochromatosis and other effects (Weng *et al.,* 2007). At the same time, the oxidation of Fe makes water turbid and odorous, and excessive Fe content in groundwater also causes pipeline rust and blockage of wells.

Much attention has been paid to this problem (Benrabah *et al.*, 2016; Ye *et al.*, 2020). The World Health Organization (WHO)'s maximum threshold for Fe^{2+} in drinking water is 0.3 mg/L. The objectives of this study are to (1) investigate the contamination levels of Fe in the groundwater in catchment area water in Derwiche from Hodh El Chargui in Mauritania and (2) examine the factors that influence the Fe concentrations in the groundwater. Through this work, we offer relevant recommendations that the government could consider in establishing a set of cost-effective measures for groundwater remedy and management.

2. METHODS

2.1. Presentation of the Study Area

The Hodh El Chargui, a region located in the southeast of Mauritania at 1000 km from the capital city of Nouakchott (**Figure 1**), is characterized by a hard and rural environment. The temperature rises during the summer to 50 °C and drops in winter to about 20°C. Farmers and agro-pastoralists are the main economic actors. The boreholes are located in the Nema watershed at the level of the pumping station (Dhar-service). These boreholes are located about 150 km from Nema, this aquifer has an area of about 30 thousand km². The alimentation of this aquifer is mainly done by the direct infiltration of rainwater. It is important to note that there is no industrial production or other pollution source in the study area. The selected boreholes were DL2 (N16°50'17.5' and W 06°11'24.2'), DL6 (N16°50'37.4' and W 06°11'07.0'**),** and DL9 (N 16°51'03.3' and W06°11'09.3'**).**

Figure 1. Hodh El Chargui localisation.

2.2. Sampling Procedures

Water samples were collected from three sampling sites (Boreholes) scattered along the catchment area water in Derwiche from Hodh El Chargui. The samples were collected two times: the first sampling was done in January and the last in August corresponding to the rainy period. The sampling for the analysis of physico-chemical parameters was carried out at the selected site, using a 1.5 L polyethylene bottle. The collected samples were stored at 4°C in insulated boxes and transported to the laboratory.

2.3. Determination of Physicochemical Parameters

Methods for measurement of physicochemical parameters such as Temperature (T), pH, Electrical Conductivity (EC), Total Dissolved Solid (TDS), nitrates (NO_3^-), chlorides (Cl^-), oxidizability (Organic Matter : (OM), and iron (Fe) are listed in **Table 1**. It is important to note that each sample was conducted in triplicate and the mean values are reported.

2.4. Calculation of Water Quality Index (WQI)

A WQI is considered a parameter that defined the composite effect attributed to diverse water quality parameters (Sahu & Sikdar, 2008) and was calculated using the Weighted Arithmetic Index method. The quality rating scale for each parameter q_i was calculated by using this expression:

$$q_i = \frac{C_i}{S_i} \times 100 \tag{1}$$

Table 1. Water quality parameters and measurement methods.

Parameters	Unit	Measuring equipment and method analysis
T	° C	pH meter HI 991001
pH		pH meter HI 991001
EC	µS/cm	Conductimeter HI98192
TDS	mg/L	Conductimeter HI98192
Cl^-	mg/L	Volumetric dosage with $AgNO_3$
NO_3^-	mg/L	Photometer Wagtech 7100
Fe	mg/L	Photometer Wagtech 7100
OM	mg/L	Hot oxidation by $KMnO_4$

A quality rating scale (q_i) for each parameter is assigned by dividing its concentration (C_i) in each water sample by its respective standard (Si) and the result is multiplied by 100. Relative weight (Wi) was calculated by a value inversely proportional to the recommended standard (Si) of the corresponding parameter:

$$W_i = \frac{1}{S_i} \tag{2}$$

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

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

Generally, WQI was discussed for a specific and intended use of water. In this study, the WQI for drinking purposes is considered and the permissible WQI for drinking water is taken as 100:

$$\text{Overall } WQI = \frac{\sum_{i=1}^{n} q_i w_i}{\sum_{i=1}^{n} w_i} \tag{4}$$

The determined WQI values are classified into five classes as mentioned in **Table 2** (Yidana & Yidana, 2010).

2.5. Treatability Index (TI) and Borehole Classification Model

The TI is an indicator that is often used to assess water quality (Enitan-Folami *et al.*, 2019; Masindi & Foteinis, 2021). Besides, the TI is defined as the ratio of the Measured Value (MV) of the contaminant understudy to its Maximum Allowed Limit (MAL) for drinking water, as shown in Equation (5):

$$TI = \frac{MV}{MAL} \tag{5}$$

When the TI is > 1, the water will require treatment to comply with the prescribed limits, since it is not suitable for human consumption. When the TI is < 1, the water will require zero treatment to comply with the required limit, and it is suitable for human consumption.

Equation (5) also implies that a wide range of physicochemical parameters such as pH, TDS, NO_3^-, Cl^-, OM, and Fe should be examined to assess water quality and its suitability for drinking purposes. The quality of the water will then be determined by the parameter that exhibits the highest TI value, i.e. if one parameter has a TI value higher than unity then water will be unsuitable for human consumption, regardless of the values of the other parameters. Therefore, treatment will be required to lower all TI values below unity before water consumption. When the TI value is higher than unity, the water boards should either treat the water or not used it at all.

Specifically, to classify water quality in Derwiche from Hodh El Chargui, a classification index was developed. In this study, the WHO (2011) in http://www.who.int/water_sanitation_health. Accessed 21 February 2014 for drinking water, was used to assess groundwater's quality. Finally, the water quality was divided into four different classes, as proposed elsewhere (Enitan-Folami *et al.*, 2019).

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

3. RESULTS AND DISCUSSION

3.1. Spatio-Temporal Variation of Fe

First, the physicochemical parameters such as Temperature, pH, EC, TDS, NO_3^-, Cl^- and OM studied in the catchment area water in Derwiche during January and August were represented in **Table 3**. The Temperature, pH, EC, TDS, NO_3^-, Cl^- and OM contents of water samples are within WHO for drinking water.

Concerning the spatio-temporal variation of Fe, Fe values range from 0.75 to 7 mg/L in January and 0.4 to 2.8 mg/L during August. The highest Fe values are recorded at sites DL2 and DL6, where they reached 4.8 and 7 mg/L in January, respectively. However, the lower Fe values are recorded at DL9 in January (0.4 mg/L).

The decrease in Fe in August is probably due to the dilution effect of rainwater. The concentrations of Fe obtained in this study are very lower than those obtained by Hossain et *al.,* **(2013)** (24.5 mg/L) and Rusydi *et al.,* **(2021)** (252 mg/L). The Fe concentration limit is set at 0.3 mg/L.

Table 3. Statistical summary of the physicochemical parameters of the catchment area water in Derwiche.

	DL2	**DL6**	**DL9**
T	25.80±1.48	25.55±0.80	25.45±0.38
pH	6.00±0.84	6.00±0.50	5.95±0.63
EC	68.15±3.51	59.10±30.77	63.65±11.68
TDS	25.5±10.97	29.76±15.07	31.4±6.05
Cl^-	21.30±3.89	21.40±3.94	21.42±3.94
NO_3^-	1.02±0.73	1.08±0.31	1.00±0.13
OM	1.09±0.68	1.21±0.75	1.25±0.31

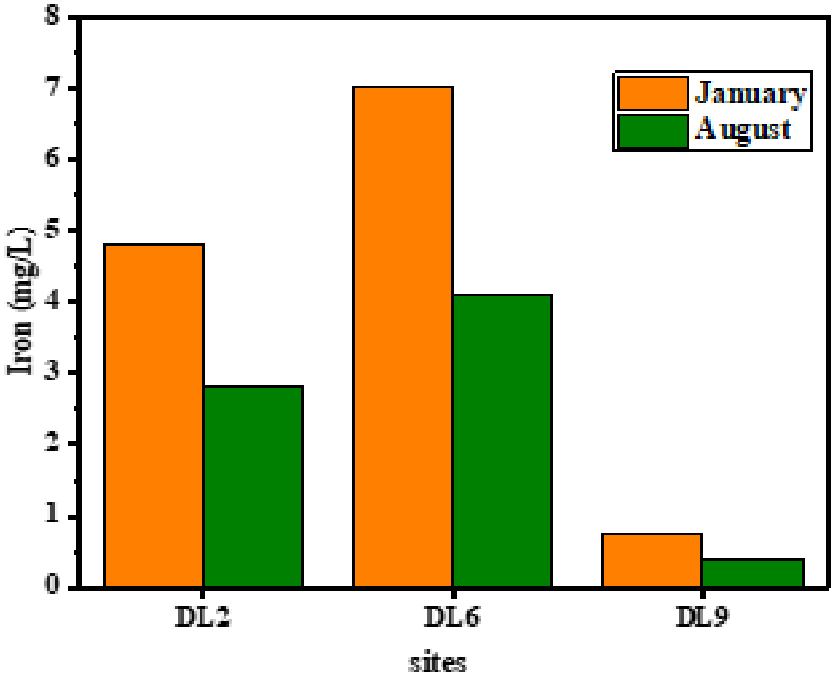

Figure 2. Spatio-temporal variation in Fe of Borehole waters from the catchment area water in Derwiche.

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3.2. Relationship Between Fe and Other Physicochemical Parameters

The degree estimated by Pearson's connection coefficients for the January and August catchment area water in Derwiche is exhibited in **Tables 4** and **5,** respectively. A strong and positive correlation was found between Fe and OM (r=0.986) while a strong and negative correlation was found between Fe and pH (r=-0.952) (**Table 5**) during January. This means that the higher Fe concentrations might have been the result of the interaction of underground oxidized iron minerals with OM present and can be due to the dissolution of Fe_2CO_3 present in rocks at a low pH. According to Harvey and Fuller (1998), a decrease in pH will accelerate the dissolution of carbonates and hydroxides. Fe bound to carbonates will be released into the water. The Fe–O bonds in the crystal lattices of Fe-bearing minerals will readily be destroyed in an acidic environment to release structural Fe or interlayer Fe and promote Fe dissolution. Similar observations are reported by (Applin & Zhao 1989; Mondal *et al*., 2010).

A strong and positive correlation was found between Fe–TDS (0.664) and Fe – EC (0.644) (**Tables 4-5**) during January, suggesting that the concentration of Fe in catchment area water in Derwiche well was influenced by dissolution minerals in groundwater. Similar observations are reported by Akbar *et al*., (2021).

A negative correlation was found between Fe^{2+} and NO_3^- during January (r=-0.267), probably because nitrate is the second preferential electron acceptor after oxygen. Nevertheless, the negative correlations noted between Fe^{2+} and NO_3^- imply a reduction process that encourages Fe dissolution (Robertson & Thamdrup 2017; Benkaddour *et al*., 2021).

3.3. Assessment of the Water Quality Using WQI

The parameters pH, TDS, Cl^-, NO_3^-, OM, and Fe, were taken into justification for the calculation of the WQI value for each sampling site in January and August. Furthermore, the WHO (limits were used to compute the WQI). Since the high values of borehole waters, the WQI values were categorized into two categories:

(i) Including Fe,
(ii) Without Fe

Table 4. Pearson correlation matrix of January.

Variables	Fe	pH	EC	TDS	Cl	NO_3^-	MO
Fe	**1**						
pH	-0,952	**1**					
EC	0,644	-0,848	**1**				
TDS	0,664	-0,862	1,000	**1**			
Cl	0,986	-0,990	0,763	0,781	**1**		
NO_3^-	-0,267	-0,042	0,565	0,543	-0,101	**1**	
MO	0,986	-0,990	0,763	0,781	1,000	-0,101	**1**

Table 5. Pearson correlation matrix of August.

Variables	Fe	pH	EC	TDS	Cl	NO_3^-	MO
Fe	**1**						
pH	1,000	**1**					
EC	-0,498	-0,481	**1**				
TDS	-0,572	-0,556	0,996	**1**			
Cl	-0,994	-0,996	0,399	0,478	**1**		
NO_3^-	0,884	0,893	-0,036	-0,123	-0,931	**1**	
MO	-0,963	-0,969	0,248	0,331	0,987	-0,977	**1**

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In the case of the Fe surveyed is included (**Table 6**) in the calculation of the WQI of the catchment area water in Derwiche, the results showed that the lowest WQI values were recorded at DL9 for all sampling months, indicating poor and very poor water quality. However, the highest WQI values were recorded at DL6 and DL2 indicating unsuitable for drinking water for all sampling months.

Without Fe (**Table 7**), it was observed that all WQI values are below 50, which means that the water is excellent for drinking in all boreholes from catchment area water in Derwiche for all sites and for all sampling months. These results obtained by WQI indicate that Fe removal would contribute to excellent quality water.

3.4. Assessment of the Water Quality Using TI

The parameters pH, TDS, Cl^-, NO_3^-, OM, and Fe, were taken into justification for the calculation of the TI value for each sampling site in January and August. Since the high values of borehole waters Fe, the TI values were categorized into three categories:

(i) Including Fe,
(ii) Without Fe
(iii) Without Fe and pH

In the case of the Fe surveyed is included (**Table 8**) in the calculation of the TI of the catchment area water in Derwiche, the results showed that if the Fe has a TI value higher than unity then water will be unsuitable for human consumption for all sampling sites and months. However once without Fe (**Table 9**), it was observed that pH has a TI value between 0.75 and 1, indicating water will be acceptable quality for human consumption for all sampling sites and months.

Without Fe and pH (**Table 10**), the results showed that all studied parameters have a TI value higher than unity then water will be of excellent quality for human consumption for all sampling sites and months.

The TI confirms the results obtained by the WQI. However, TI also shows that the pH is an important factor that influenced the Fe concentrations in the groundwater. So, the TI confirms the results obtained by the correlation matrix.

Table 6. WQI values of different sampling sites from catchment area water in Derwiche including Fe.

	January		August	
Boreholes	**WQI**	**Water type**	**WQI**	**Water type**
DL2	1449.3	Unsuitable for drinking	846.4	Unsuitable for drinking
DL6	2111.8	Unsuitable for drinking	1237.7	Unsuitable for drinking
DL9	229.9	Very poor water	124.7	Poor water

Table 7. WQI values of different sampling sites from catchment area water in Derwiche without Fe.

	January		August	
Boreholes	**WQI**	**Water type**	**WQI**	**Water type**
DL2	4.53	Excellent water	37.49	Excellent water
DL6	4.86	Excellent water	37.10	Excellent water
DL9	4.20	Excellent water	44.02	Excellent water

Table 8. TI values of different sampling sites from catchment area water in Derwiche including Fe.

	Sites	pH	TDS	Cl^-	NO_3^-	OM	Fe	Class
January	DL2	0.87	0.071	0.051	0.014	0.26	16	4
	DL6	0.86	0.087	0.060	0.017	0.32	23.33	4
	DL9	0.87	0.074	0.057	0.018	0.19	2.5	4
August	DL2	0.73	0.031	0.071	0.027	0.178	9.33	4
	DL6	0.74	0.032	0.071	0.026	0.164	23.67	4
	DL9	0.72	0.052	0.071	0.018	0.32	1.33	4

Table 9. TI values of different sampling sites from catchment area water in Derwiche without Fe.

	Sites	pH	TDS	Cl^-	NO_3^-	OM	Class
January	DL2	0.87	0.071	0.051	0.014	0.26	3
	DL6	0.86	0.087	0.060	0.017	0.32	3
	DL9	0.87	0.074	0.057	0.018	0.19	3
August	DL2	0.73	0.031	0.071	0.027	0.178	3
	DL6	0.74	0.032	0.071	0.026	0.164	3
	DL9	0.72	0.052	0.071	0.018	0.32	3

Table 10. TI values of different sampling sites from catchment area water in Derwiche without Fe and pH.

	Sites	TDS	Cl^-	NO_3^-	OM	Class
January	DL2	0.071	0.051	0.014	0.26	1
	DL6	0.087	0.060	0.017	0.32	1
	DL9	0.074	0.057	0.018	0.19	1
August	DL2	0.031	0.071	0.027	0.178	1
	DL6	0.032	0.071	0.026	0.164	1
	DL9	0.052	0.071	0.018	0.32	1

4. CONCLUSION

This study investigates the occurrence of Fe in the catchment area water in Derwiche from Hodh El Chargui in Mauritania. The occurrence of Fe in the groundwater showed significant spatial and temporal fluctuations and was possibly affected by the change in environmental conditions within the aquifer. The relationship between Fe and some physicochemical parameters was also analyzed statistically using Pearson's correlation matrix. Firstly, the results suggested that the concentration of Fe was influenced by the dissolution of iron minerals. Secondly, the results show that the pH value was an important factor that influenced the Fe concentrations in the groundwater. The WQI is used to identify the influence of Fe contamination. These results indicate that Fe removal would contribute to excellent well water. The TI confirms the results obtained by the WQI. However, TI also shows that the pH is a parameter to be optimized for possible potabilization.

These results show that there would be a close relationship between the recorded Fe levels and the pH. Therefor, the TI confirms the results obtained by Pearson's correlation matrix. Therefore, the presence of high Fe concentrations in groundwater in the study area could have a natural origin. From the result of the present study, it is highly recommended that different treatment techniques should be employed to purify groundwater before consumption. Adsorption is one of the most widely applied techniques for Fe and other pollutants removal.

5. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. The authors confirmed that the paper was free of plagiarism.

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