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Hydrgeochemical Assessment of the Nubian Sandstone Aquifer of the Northern Part of El Kharga Oasis, Western Desert, Egypt

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Abstract

The primary issue with the groundwater aquifer's concept of sustainability in the survey area is overexploitation. In addition to measuring the water depth in 65 groundwater wells for the purpose, standard analytical techniques were used to analyse 12 physiochemical properties. The investigation wells were built in order to provide groundwater management with preliminary data on water quality. Diagrammatical analyses, including hydrographs and Schoeller's semi-logarithmic diagrams, were used to manipulate water quality informations of the groundwater resources in the investigated region. The findings revealed that $NaHCO_3$ is the most prevalent type of water, followed by Na_2SO_4 and NaCl. The abnormally high content of the Fe element ranged between 2 and 10 mg/l, revealed rust-colored deposits on well screens, and sanitary fittings. As a result, the current flood irrigation system should be changed with more advanced drip and sprinkle agricultural technologies.

Keywords: El-Kharga Oasis, Environmental impacts, Groundwater aquifer, Water quality

Introduction

Egypt's consumption of water has risen significantly over the past few years as a result of population expansion. According to **Dawoud *et al*. (2005)**, the only important source of water to meet this growing demands in some dry regions of Egypt, particularly in the Nubian Sandstone Aquifer (NSSA). As a result, groundwater is crucial to the Egyptian economy and helps the nation's manufacturing and agricultural growth. As stated by **Gheith and Sultan (2002)**, Egypt's population growth has become a significant issue because of the country's rising groundwater consumption and the requirement for additional desert reclaimed land. The research area determined the most encouraging sites for new community development and land reclamation projects, particularly outside of Egypt's Nile Valley and Delta. **El Bastawesy *et al.* (2013)** demonstrated that the only significant water source for this innovation would be suitable for irrigation from the NSSA.

However, this aquifer already faces issues as a result of exaggerated abstract concept, and it is anticipated that increased groundwater use in the area will result in further decrease in groundwater heads and increases in salinity **(Aeschbach-Hertig and Gleeson 2012)**. When groundwater exploitation exceeds the average rate of aquifer resupply, the term "over-exploitation" is used to describe the circumstance **(Foster, 2006).** A number of irreparable and hydrogeological issues, including lowering groundwater heads, altered recharge/discharge conditions, and reduced single well production, can be brought on by over-exploitation of groundwater. These issues have a significant negative impact on the execution of the regional economy's sustainable development approach. Additionally, excessive pumping may significantly increase the mixing zone's thickness, which could be detrimental for the aquifer. Any area's ability to develop is constrained by the ensuing environmental issues. Water supplies in the NSSA have been negatively impacted over the past ten years by both the ongoing development of human society and the unintended consequences of land reclamation initiatives. Such detrimental effects are clearly visible in the ongoing contamination of the water supply and the decline of groundwater. The El-Kharga region is situated in the western desert's southern region.

The Pre-Cambrian basement rocks serve as an underpinning for the depositional succession, which spans the Cretaceous, Tertiary, and Quaternary **(CONOCO, 1987)**. Due to the influence of structural components, it rests unevenly on the Precambrian at greater depths. In some locations, the surface-exposed Abu Bayan uplifts have an impact on the distribution of sedimentary sequence in terms of the thickness and facies **(Heinl and Thorweihe, 1993)**. The objectives of this study are to: (i) define different types of groundwater;

(ii) explore hydroulic characteristics, piezometric heads, and groundwater movement directions; and (iii) evaluate the quality of the groundwater and its regulating variables.

Materials and Methods

Study area

El-Kharga Oasis's northernmost region is represented by the area being examined. It is located between the longitudes of 30° 00' and 31° 00' east and the latitudes of 25° 00' and 26° 00' north **Fig. 1.** The research area is approximately 33,000 km^2. The depression's floor is elevated between close to 0 m and 120 m. Surface elevations in the Kharga plain, increases gradually from the depression to over 400 m.

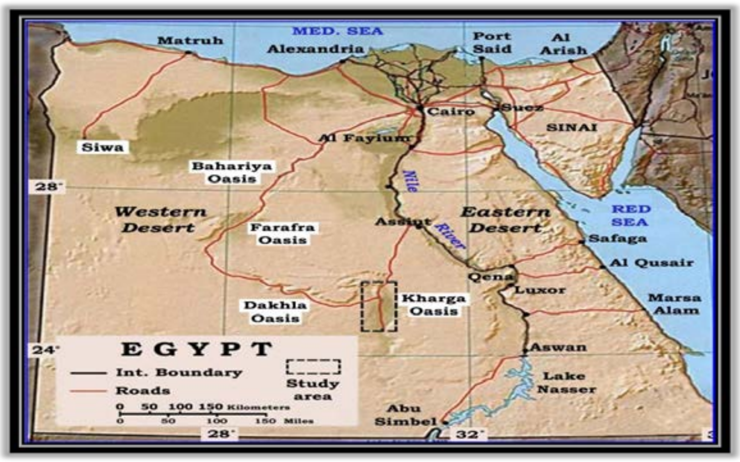

Fig. 1. Study area location map

Sampling and analyses

Physical and chemical properties of 65 groundwater samples were performed in accordance with **ASTM standards (2002)**. Temperature (T ^{o}C), TDS, pH, EC, concentrations of ions, and trace element (Fe, Mn) were measured according to standard analytical methods. In order to determine Fe and Mn using a HACH (DR/2040) metre and examine Ca^{2+}, Mg^{2+}, Cl^{-}, and HCO_3^{2-} using argentometric and titration techniques (ASTM 2002), respectively. While Na^{+} and K^{+} were determined using flame photometer instrument (ELEX 6361, Hamburg, Germany).

Results and discussion

Hydraulic parameters

Aquifer potential was determined by identifying the primary hydraulic characteristics. The transmissivity (T) ranged from 85.2 to 226.35 m^2/day and and hydraulic conductivity (K) varied between 0.47 and 1.1 m/day. The findings revealed that formation loss ranged from moderate to high ($2.75x10^{-3}$ - $2.2x10^{-2}$ day/m^{-2}). The well loss ranged between 8.21x10-8 and 3.13x10-6 day2/m-5. The well loss values for the majority of the wells were very close to zero, implying flow pattern via the system and excellent well construction. When the groundwater aquifer was covered by substantial thick layers of clay, groundwater could only exit under constrained circumstances. The current observation wells were used to detect depth to water, and groundwater flow map was created **Fig. 2**.

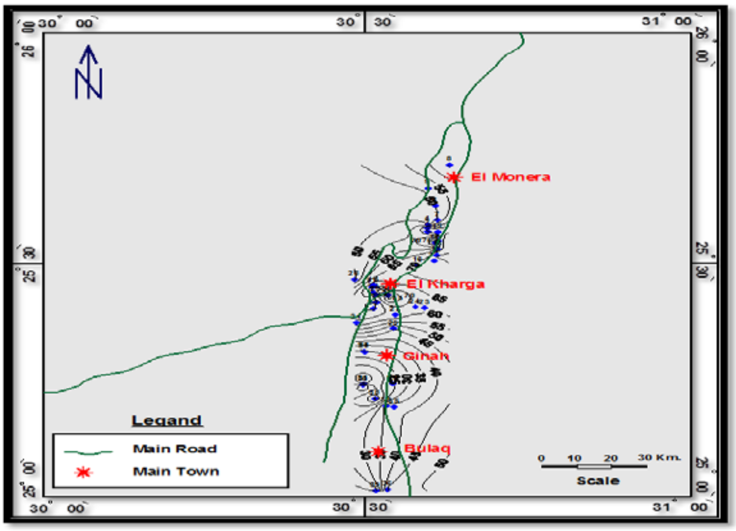

Fig. 2. Directions of groundwater flow in the study area

Environmental impacts

Water supplies in the NSSA in the El El-Kharga area have suffered as a result of the ongoing development of human society and the unintended consequences of land reclamation projects over the past ten years. Overexploitation caused peizometric heads to rapidly decline and to experience significant drawdowns. To show how the groundwater head in the study area decreased over time, two hydrographs were created **Figs. 3 and 4**. Plots like these demonstrated the notable and quick decline in groundwater levels that started happening in El Kharga City and its surroundings after 1975, with an

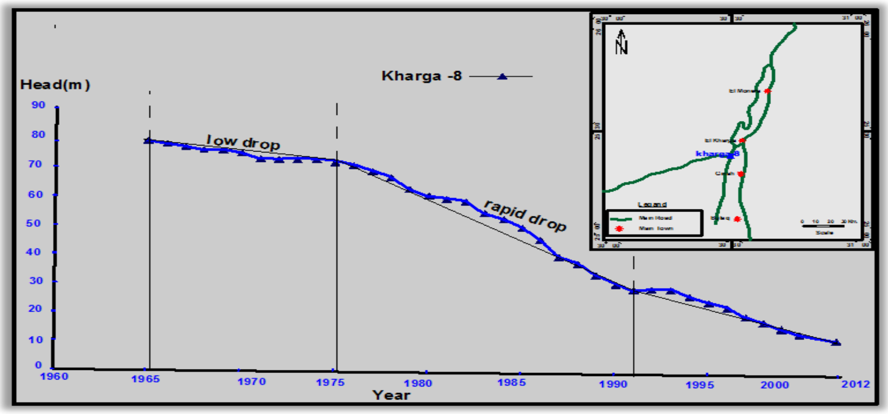

Fig. 3. The decreasing in water table in El kharga-8 well

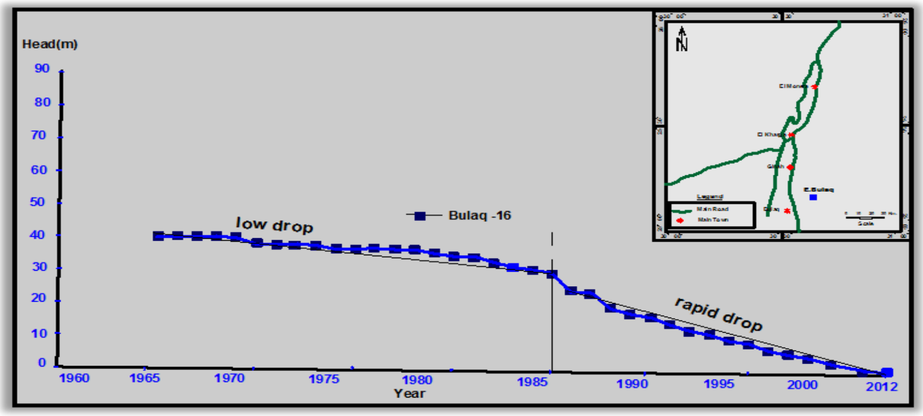

Fig. 4. The decreasing in water table in Bulaq-16 well

annual rate that varied from 2.2 to 1.2 m/year. After the years 1985 and 1990, it starts in the Bulaq region and its surroundings. The Malab El Kheil well, which is situated in the far western part of the investigated region, revealed a slow decline in groundwater heads over time (about 0.48 m/year) on the hydrograph that shows head-time relationships.

According to the previously stated discussion of the groundwater aquifer's depletion rates and fluctuating peizometric heads under the investigated area, the aquifer was deteriorating. More specifically, the area under investigation was divided into three categories: strongly hazard area, moderately risk area, and slightly unsafe area **Fig. 5**. Finally, the current groundwater extraction in these areas has shown that there are insufficient

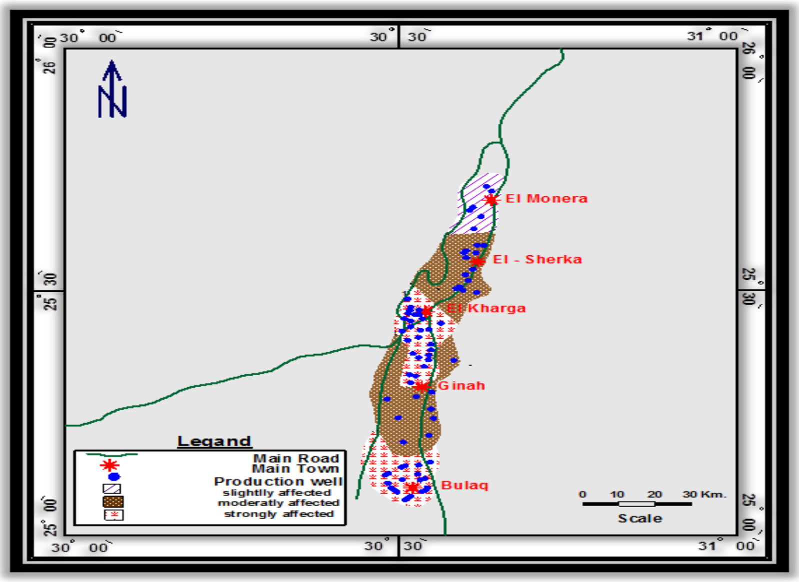

Fig. 5. Hazardous zones map in the study

groundwater resources and that the study area's groundwater aquifer is deteriorating.

Hydrogeochemistry

Salinity contents

The examined area's groundwater is of the fresh water category, with salinity levels varied from 200 to 400 mg/l **Fig. 6**. Salinity levels in some samples range from 400 to 600 mg/l. Aquifer materials containing intercalated shale were leached and dissolved, which resulted in relatively high salinity.

In water samples, Na^{+} was the most prevalent cation, followed by Ca^{2+} and Mg^{2+} ions **Fig. 7**. The range of Na^{+} concentrations was varied from 30 to 145 mg/l, while the ranges of Ca^{2+} and Mg^{2+} concentrations were varied from 7 to 23 mg/l and from 7 to 31 mg/l, respectively. HCO_3^{-} was the most common anion, followed by SO_4^{2-} and Cl^{-} ions, which were present in concentrations of 20 to 380, 6 to 164, and 15 to 115 mg/l, respectively. The different physicochemical properties for the obtained samples had suitable values that did not have an impact on the quality of the groundwater. The values of Fe contents ranged from 2 mg/l to 10 mg/l and were distinguished by

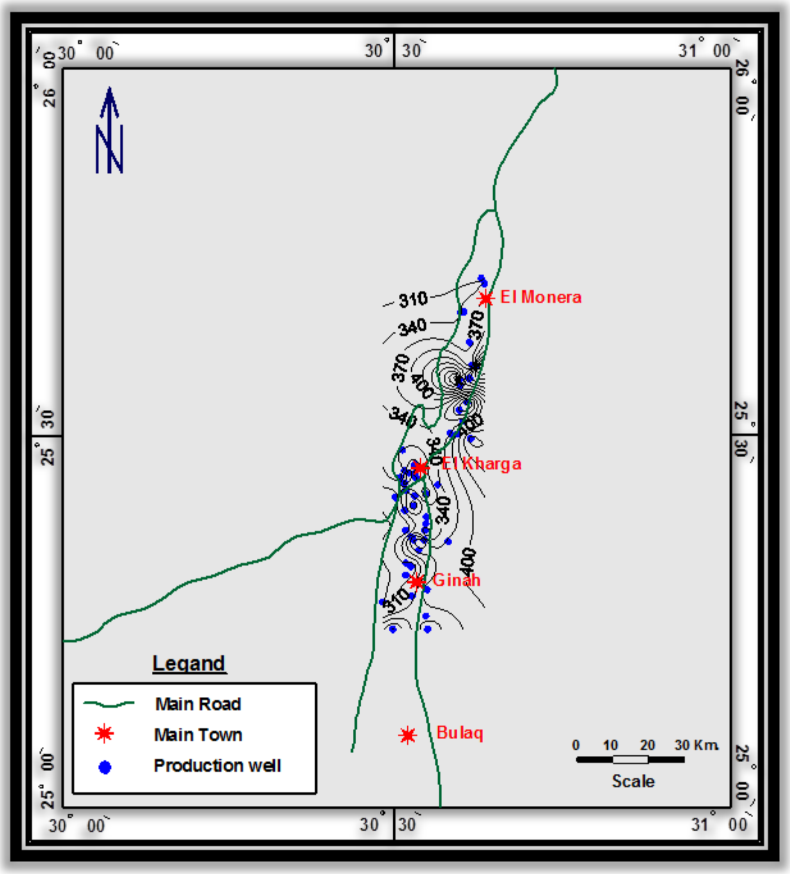

Fig. 6. Spatial distribution map of salinity contents.

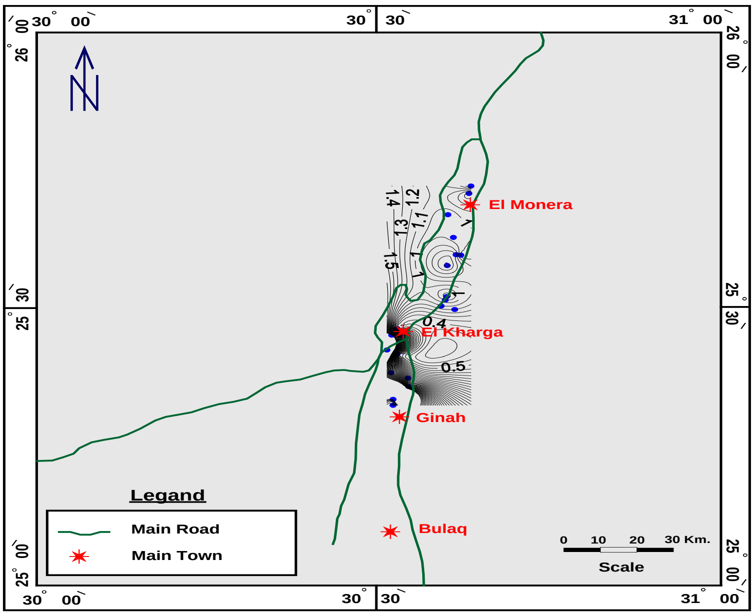

Fig. 7. Spatial distribution map of Fe in the study area.

abnormally high concentrations. The distribution of Fe concentration increased gradually toward the southwest of the investigated region **Fig. 7**.

Groundwater samples' ion sequences and semilogarithmic graphs created by Schoeller **(Schoeller, 1962)** and presented in **Table 1, and Figs. 8, 9 and 10**. The majority of the groundwater wells have ion sequence (Na^+ > Ca^{2+} > Mg^{2+})/(HCO_3^- > Cl^- > SO_4^{2-}), (Na^+ > Mg^{2+} > Ca^{2+})/(Cl^- > HCO_3^- > SO_4^{2-}), and (Na^+ > Mg^{2+} > Ca^{2+})/(SO_4^{2-} > Cl^- > HCO_3^-). In the majority of samples, Na^+ was the dominant cation, followed by Ca^{2+} and Mg^{2+} as cations and HCO_3^- over SO_4^{2-} and Cl^- as anions. This was indicative of the predominance of $NaHCO_3$, Na_2SO_4, and NaCl water types. These findings showed that minerals bearing in aquifer materials, such as CO_3^{2-}, SO_4^{2-}, and Cl^-, were actively leaching and dissolving.

Table 1. Ionic sequences of the NSSA in the investigated region.

Wells No.	Ion sequence	Chemical type	Percentage %
1-2-3-5-6-8-9-10-11-12-13-14-15-16-17-25-43-44-45-46-47-48-49-50-51-52-53-54-56-58-59-61-64	Na^+ > Mg^{2+} > Ca^{2+} HCO_3^- > Cl^- > SO_4^{2-}	Na^+ - HCO_3^-	54.01 %
1-4-7-18-19-23-24	Na^+ > Ca^{2+} > Mg^{2+} HCO_3^- > Cl^- > SO_4^{2-}	Na^+ - HCO_3^-	11.47 %
21-26-27-28-29-30-31-32-33-34-38-39-41-42	Na^+ > Mg^{2+} > Ca^{2+} > SO_4^{2-} > Cl^- > HCO_3^-	Na^+ - SO_4^{--}	23 %
20-55-57-22-35-37-40	Na^+ > Mg^{2+} > Ca^{2+} Cl^- > HCO_3^- > SO_4^{2-}	Na^+ - Cl^-	11.5 %

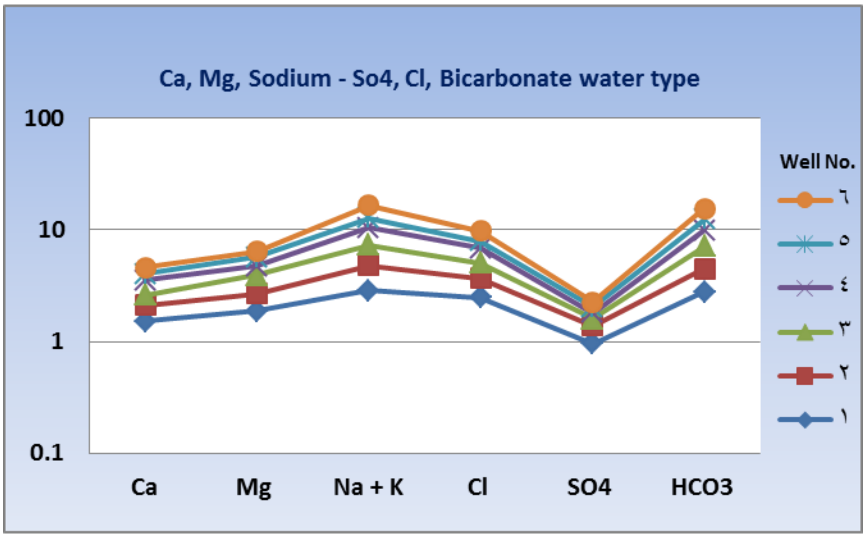

Fig. 8. $NaHCO_3$ facies.

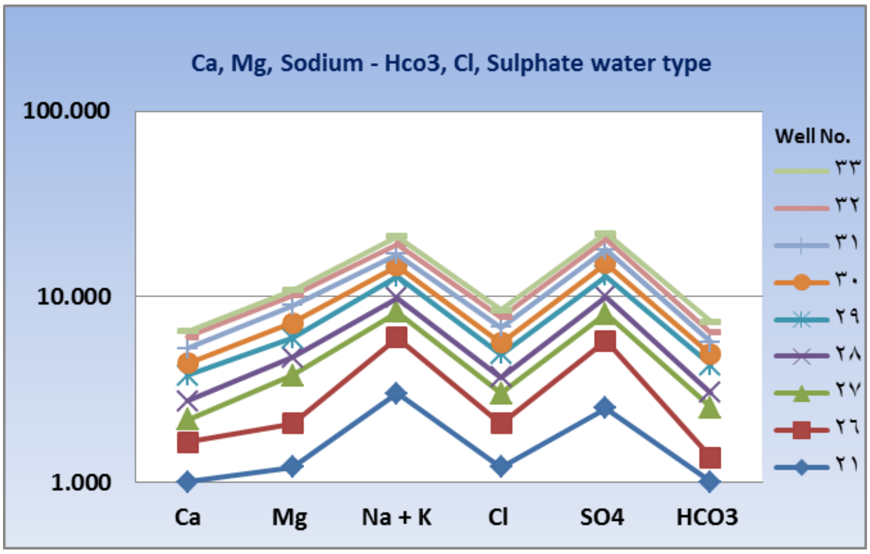

Fig. 9. $NaSO_4$ facies.

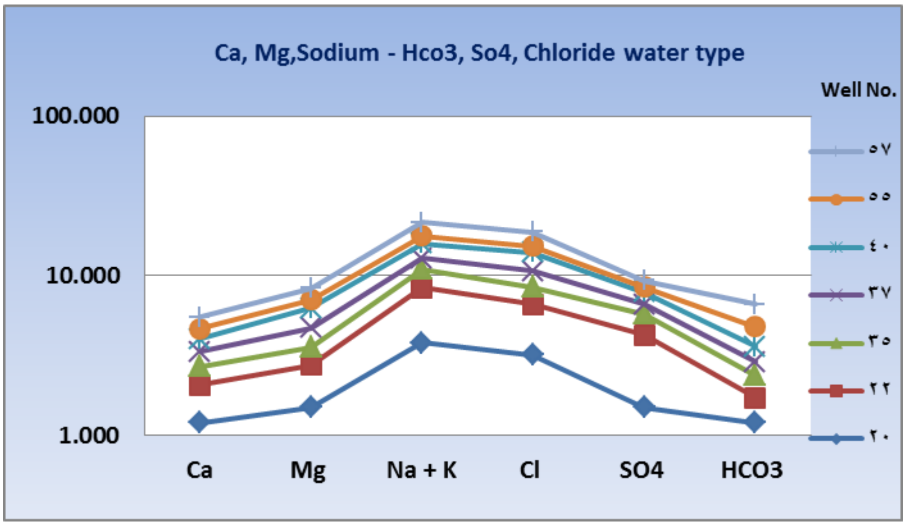

Fig. 10. NaCl facies.

Because it can affect iron's solubility and biological availability, the pH level of water is crucial. It was created a relationship between pH and iron values **Fig. 11**. As a result, the PH values decreased while the iron concentration gradually increased. Low PH values lead to the retention of iron deposits in solutions and frequently result in corrosion issues. Typically, standardisation and encrustation happen when the pH is higher than 8.5. When wells or water systems were being drilled, repaired, or serviced, the pH values were in the range of 6.5 to 7.54, which allowed iron bacteria to grow and was very difficult to treat **(Rummel 1970; Judd 1980; Johnson and Wichern 1992; Berry 1995).**

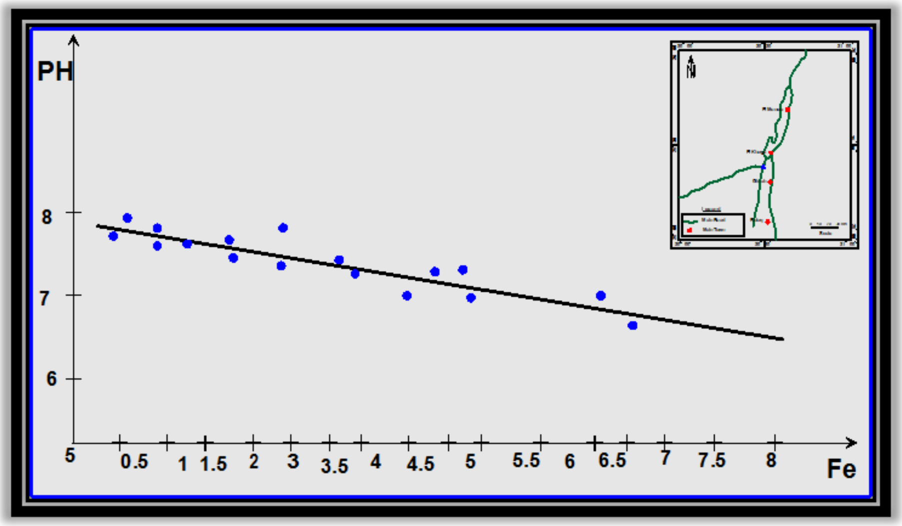

Fig. 11. The Relationship between pH and Fe.

Bacteria convert soluble iron(II) to insoluble iron(III), which is thought to be the primary cause of well and screen blocking up, coloured formation, and bacterial slime buildup that can clog sprinkler emitters, lateral movement, and intake screens. Most of the world's environments naturally contain iron bacteria. Metal deposits are created when these microorganisms combine oxygen and dissolved iron or manganese. This process resulted in the bacteria producing a brown slime that collects on plumbing fixtures, pipes, and well screens. The following equation predicts that iron bacteria will consume the dissolved oxygen and change the soluble ferrous iron back into an insoluble reddish precipitate of ferric iron.

$2Fe(OH)_2 + O_2 \rightarrow H_2O + Fe_2O_3$

(Iron [II] hydroxide) + (oxygen) → (water) + (Iron [III] oxide)

Iron bacteria had significant impacts on groundwater, leaving brown slimy masses on lakeshores and stream bottoms, as well as an oily sheen on the water. Bacterial overgrowth in well systems caused more serious issues. Wells with iron bacteria cause health issues and lower well produces by blocking up screens and pipework **Fig. 12**.

Fig. 12. Filters and pipes at the El-qulaa water station are clogged.

Conclusion

The water supply in the NSSA are necessary for the community development in the Western Desert. Groundwater should be exploited for the construction of the new regions. The dominant cation in water samples was Na^+ followed by Ca^{2+} and Mg^{2+} ions. The most of collected samples revealed ion sequences as the following: ($Na^+ > Ca^{2+} > Mg^{2+}$)/($HCO_3^- > Cl^- > SO_4^{2-}$), ($Na^+ > Mg^{2+} > Ca^{2+}$)/($Cl^- > HCO_3^- > SO_4^{2-}$), and ($Na^+ > Mg^{2+} > Ca^{2+}$)/($SO_4^{2-} > Cl^- > HCO_3^-$). When wells or water systems were being drilled, repaired, or maintained, the pH levels were in the range of 6.5 to 7.54, which were valiable for growing iron bacteria. Bacterial overgrowth in well systems caused more serious issues. Wells with iron bacteria cause health issues and lower well yields by clogging screens and pipes. Therefore, it is advisable to recommend less water-intensive crops and replace the current flood irrigation system with more advanced drip and sprinkle irrigation techniques.

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