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Evaluating the Groundwater Quality from a Well in Assiut Province, Egypt, and Its Suitability for Human uses and Aquaculture

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Abstract

In Egypt, groundwater is considered the second most important water source after the River Nile water, particularly for supporting progress and sustainable development. However, it becomes the primary solution and alternative during water shortage periods. The present study aimed to investigate groundwater quality in wells, focusing on its suitability for human safe consumption and future development for applications as aquaculture. Twelve water samples were taken between 2021 and 2022 (one sample per month) from a well in Habaisha area, Sahel Sleem City, Assiut Governorate, Egypt, to evaluate its quality including physicochemical, and bacteriological characteristics of the well's groundwater. The results showed that the most important physicochemical features of water quality for the investigated well were a low percentage of turbidity, Mn ranged from 0.01 to 0.03mg/ L, and an annual average of Fe ranging from 0.01 to 0.03mg/ L. The bacteriological investigations indicated that there are no coliform bacteria observed in the water samples. From the present results, it was concluded that this well represents a good groundwater source in this area for various purposes. This work, therefore, recommends the usage of this groundwater and expanding quality assessments to other wells in nearby areas. Further, a nationwide investigation of groundwater wells should be conducted to create a detailed map of groundwater resources to support the sustainable development and water management in Egypt.

INTRODUCTION

Aquifers are subsurface reservoirs of groundwater. In parts of Egypt where surface water is scarce or nonexistent, these aquifers have become important water storage areas. For instance, groundwater is vital for agricultural purposes in the Sinai Peninsula and the Western Desert, both of which experience severe water scarcity. Despite a high demand for water due to population growth, agricultural expansion, urbanization, and improved living standards, Egypt's fresh water supplies are limited due to the country's location in the desert zone of North Africa. Worldwide, people rely on groundwater for both drinking and watering plants **(Quang *et al.*, 2022)**. **Liesch and Wunsch (2019)** state that groundwater is a significant component of the climate system. It is worth noting that due to the influence of dissolved ions, groundwater exhibits higher hydrochemical variability than surface water **(Ayyadurai *et al.*, 2022)**.

For domestic use, about two-thirds of the global population uses groundwater. There is a huge strain on the already-scarce supply of groundwater, with over 65% used by humans, 20% for irrigation, and 15% for industrial need **(Li *et al*., 2018; Ismail *et al*., 2020)**. Groundwater is extensively used due to its exceptional physical and chemical characteristics. The viability of groundwater for human and agricultural uses has been the subject of research on a global scale. Moreover, the importance of groundwater research in semi-arid regions for the sustainable management and development of water resources has grown in recent years **(Li *et al*., 2018; Ismail *et al*., 2020)**.

Kumar *et al.* (2019) found that sedimentary deposits in aquifers play a major role in determining groundwater quality. Groundwater becomes unsuitable for human consumption because its physicochemical properties are altered as it flows from recharge to discharge zones.

There are countless natural and anthropogenic factors that affect groundwater quality. These include, but are not limited to, topography, structures, rates of evaporation or precipitation, interactions between water and rock, weathering, and many more. Additionally, there are other factors affecting groundwater quality including human overexploitation of resources, pesticides contamination, overuse of fertilizers, and improper disposal of industrial waste. By evaluating these factors, the suitability of groundwater for irrigation, industry or human consumption can be determined. Therefore, assessing the quality of groundwater to determine its suitability for various purposes is considered an urgent necessity **(Sheikh *et al*., 2017; Adimalla *et al*., 2018)**.

The maximum acceptable quantities of various ions in drinking water are summarized by World Health Organization (WHO) and the Permissible Egyptian Limits (PEL). When these ions exceed the permissible limits, groundwater becomes unsuitable for human consumption and irrigation. On the other hand, determining the usefulness of groundwater resources for different purposes and performing quality evaluations are two of the biggest challenges faced by groundwater specialists **(WHO, 2017; Adimalla *et al*., 2018)**.

Globally, due to rapid industrialization and population growth, the demand for freshwater has increased dramatically in recent years. This has led numerous researchers to investigate the status of groundwater in various regions **(Narsimha *et al*., 2017; Li *et al*., 2018)**. Recently, concerns about water availability and economic development have increasingly focused on the groundwater resources in the Mediterranean region. Major and trace elements contamination of groundwater resources occur in Mediterranean countries because of agricultural practices and related human activities. Recently in Egypt and similar to what's happening on the global scale, rising populations and agricultural output have contributed to an unprecedented demand for freshwater. This has led the country to rely on its abundant groundwater supply to support multiple sectors, including agricultural, household, and industrial activities **(Alexakis *et al*., 2021)**.

This necessitates both sufficient availability and high-quality groundwater reserves. The deterioration of groundwater quality is directly tied to human health and exacerbates global groundwater depletion **(CEU, 1998)**. Moreover, a lot of groundwater resources are currently underutilized or mismanaged, which may lead to environmental concerns. However, with sustainable management these resources could be transformed into naturally renewable storage systems **(Jamshidzadeh & Mirbagheri, 2011; Chen *et al*., 2014)**.

The total current volume of water resources is 59.8x10^9 m^3/year including 55.5 x10^9 m^3 from the Nile River (i.e. Aswan High Dam is required to release a minimum amount of water of 75 million m^3/h, with a portion allocated for drinking water supply), 1.6 x10^9 m^3 from the coastal scattered winter rainfall and flashfloods, and 2.4 x10^9 m^3 from the non-renewable deep groundwater from the Western Desert and Sinai, in addition to 0.3 x10^9 m^3 from the desalination of seawater and brackish water. Unfortunately, the total water needs in Egypt of the various sectors exceeds this amount **(Omar & Moussa, 2016)**. Currently, the national efforts are focusing on water treatment and sustainable exploitation of all water resources. About 80% of the Nile system in Egypt is operationally effective **(Diawara, 2008)** due to the expansion of urbanization, development, agricultural areas and population growth across the country. The other sources of water such as groundwater and wells need to be evaluated continually for further utilization as alternative and supportive water resources in each region or province.

The objective of the current study was to evaluate the quality of the groundwater of a well at Habaisha area, in Sahel Sleem City, Assiut Province, Egypt to determine its suitability for current and future human consumption and industrial applications such as aquaculture.

MATERIALS AND METHODS

Study sites and sampling

The selected well, representing the local groundwater resource, is located in the Habaisha area, Sahel Sleem City, Assiut Governorate, Egypt. It is located between 27º 02′ 20″ N and 31º 25 ′ 46″ E (Fig. 1). This area is characterized by a large population density, schools and agricultural lands. The well under study is the primary source of water in the area and functions as the emergency supply for drinking and household uses. Monthly water samples were taken during the year 2021-2022 from this well. The samples were collected in polyethylene bottles (1 liter capacity), which had been thoroughly washed with distilled water.

Physicochemical measurements

Water temperature was measured immediately after sample collection using an ordinary thermometer. The pH was measured using a pH meter (HANNA, HI 9125). The main physical measurement of water quality was turbidity, which is defined as the cloudiness or haziness of a fluid caused by large numbers of particles that are generally invisible to the naked eye. It was measured using a portable turbidity meter (Model: LaMotte, 2020), while the total hardness was evaluated by burette titration **(Ferreira *et al*., 2019)**. Conductivity and total dissolved salts were measured using a calibrated Conductivity Meter (HANNA, Conductivity meter). Total alkalinity, chloride, nitrate-N, sulfate, and major cations were determined according to the Water and Wastewater Examination Manual **(Adams, 1991)**. Iron and manganese concentrations were determined in triplicate according to the method described by **Majestic *et al*. (2007)**.

Fig. 1. Geographic location of the studied well in Sahel Sleem, Assiut Governorate, Egypt

Bacteriological investigation

For bacteriological investigation, the ten-tube procedure using lactose broth (DIFCO) was used for estimating the Most Probable Number (MPN) of coliform organisms. Tubes were incubated at 37°C for 48h and the MPN was obtained according to the Standard Methods for the Examination of Water and Wastewater **(Rice, 2012)**. The confirmed coliform test was done by culturing positive tubes into brilliant green bile broth (DIFCO) and incubating them at 37°C for 48h.

Groundwater quality characterization

1) Sodium ratio (SR)

Previously, the quality of irrigation water was evaluated using sodium ratio (SR), calculated as the ratio of sodium ions (Na^+) to the sum of calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions in the water. This parameter is also defined as Kelly's ratio (KR) **(Fallatah & Khattab, 2023)** and can be calculated by the following equation:

$$SR = (Na^+) / (Ca^{2+}+Mg^{2+})$$

All the ions concentrations are expressed in meq L^{-1}. In good water quality, this ratio should not exceed 1.0. If its value is greater than 1.0, this indicates that there is an excessive sodium amount in water samples.

2) Sodium adsorption ratio (SAR)

Several methods were used to predict the expected risks related to the presence of excess sodium in irrigation water, particularly its impact on soil permeability. Residual Sodium Carbonate (RSC) was the most prevalent evaluation method. Subsequently, **USSL (1954)** introduced the concept of Sodium Adsorption Ratio (SAR) to assess the potential risks of sodium concentrations in irrigation water on soil permeability. Since then, it remained the most widely used evaluation method. The sodium hazards of irrigation water, expressed through SAR, do not account for the effects of anionic composition. Instead, SAR is used to estimate the sodium cation adsorbed onto soil particles due to sodium prevalence in irrigation water. It is calculated by the following formula. All the ions are expressed in meq L^{-1}

$$SAR = \frac{(Na^{+})}{\sqrt{\frac{(Ca^{2+} + Mg^{2+})}{2}}}$$

3) Magnesium hazard (MH)

Ca^{2+} and Mg^{2+} are typically balanced in nature. The equilibrium can occasionally be thrown off by a high Mg^{2+} concentration, and an excess of Mg might stunt plant growth by making the water more alkaline. The magnesium hazard (MH) value was measured according to the formula given by **Abdulhussein (2018)**.

$$MH = \frac{Mg^{2+}}{(Ca^{2+} + Mg^{2+})} * 100$$

4) Permeability index (PI)

The use of mineral-rich water for an extended period reduces soil permeability, which indirectly affects crop output. The formula used to calculate the Permeability Index (PI) in accordance with the normative requirements was given by **Falowo *et al*. (2017).**

$$PI = \frac{\left(Na^{+} + \sqrt{HCO_3^{-}}\right)}{(Ca^{2+} + Mg^{2+} + Na^{+})} * 100$$

Statistical analysis

Statistical analysis was performed using an IBM compatible 486 computer. The means obtained for the various measured water quality parameters were subjected and compared to the drinking water standards and guidelines **(SASO, 2000; USEPA, 2009; WHO, 2011)** for human uses, while compared also with those of **WHO (2003)**, **Carballo *et al*. (2008)**, **Ezeanya *et al*. (2015)**, **FAO (2016)** and **Osman *et al*. (2021)** for other applications as aquaculture.

RESULTS AND DISCUSSION

The current investigation evaluated the quality of the selected well for current and future utilization for different purposes. The assessment included the physical, chemical and microbiological measurements.

Physical investigations

The main physical investigations are listed in Table (1) and represented graphically in Figs. (2-5) as follows:

Temperature (°C)

In the study area, the thermal variations were small. The temperature recorded ranged between 15 and 26°C in December and May. These results showed no significant monthly variations (Fig. 2). During the study period, the temperature values obtained in almost all the sampled water points were lower than the Maximum Allowable Value MAV (25°C) of the Moroccan standard related to the quality of drinking water. These results agree with earlier studies by **Ibeda *et al*. (2013)**, **Kherrati *et al.* (2015)** and **Akkaoui *et al.* (2017**).

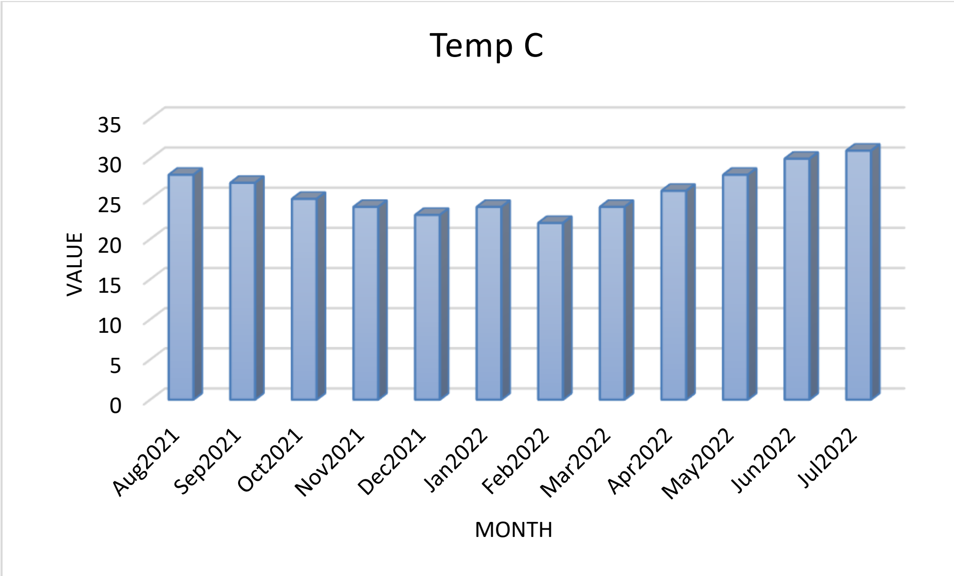

Fig. 2. Variations in the temperature (°C) of Habaisha well groundwater during the study period (2021-2022)

Hydrogen ion concentration (pH)

In the current study, the pH values of the groundwater varied from 7.5 to 7.7 during August 2021 and June 2022, respectively. The results were within the acceptable levels according to WHO and the Egyptian standard criteria for drinking water (Fig. 3). The results of pH measurements obtained during different months of the current study did not exceed the Moroccan standards for water intended for human consumption, which is 8.5 **(El Ouedghiri *et al.* 2014)**. The present findings corroborate those of other researchers **(Nechad *et al.*, 2014; Al-Qawati *et al*., 2015)**.

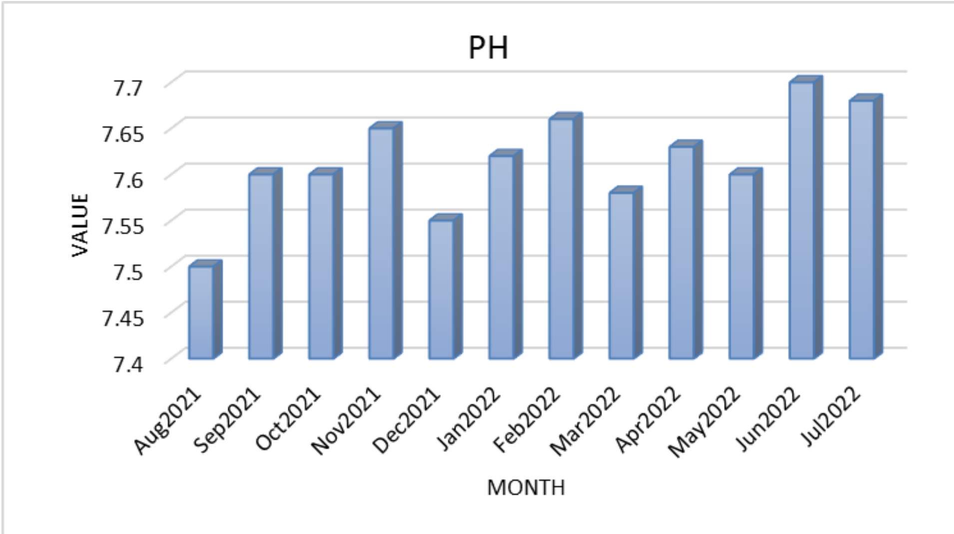

Fig. 3. Variation in pH of Habaisha well groundwater during the study period (2021-2022)

Turbidity (NTU)

In the current study, turbidity values varied from 0.17 to 0.28 (NTU) during March 2022 and July 2022, respectively. These results showed that the turbidity values during the inspection months were lower than the permissible limits according to MAV of the Moroccan standards (Fig. 4). During the study period, the results of turbidity obtained during different months did not exceed MAV of the Moroccan standards, which is 1, recommended for water intended for human consumption **(El Ouedghiri *et al.*, 2014)**. Further, all results were within the safe limits according to both the WHO and Egyptian drinking water standards **(Nechad *et al.*, 2014; Al-Qawati *et al.*, 2015)**.

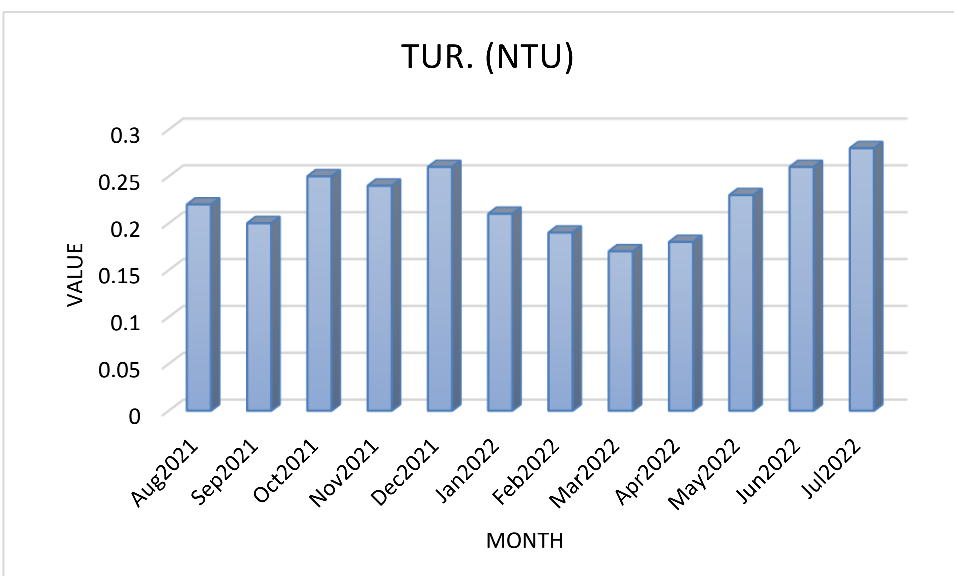

Fig. 4. Variation in turbidity (NTU) of the studied well during the study period (2021-2022)

Conductivity

The electrical conductivity is influenced by the water pH and temperature. Its value increase with the increase of temperature. During the current study, the electrical conductivity values of the groundwater ranged between 877 and 950µS/ cm. These results showed small but notable monthly variations. Compared to Moroccan (2700µS/ cm) and WHO (2500µS/ cm) standard values for drinking water, the electrical conductivity in the current study was in the acceptable levels.

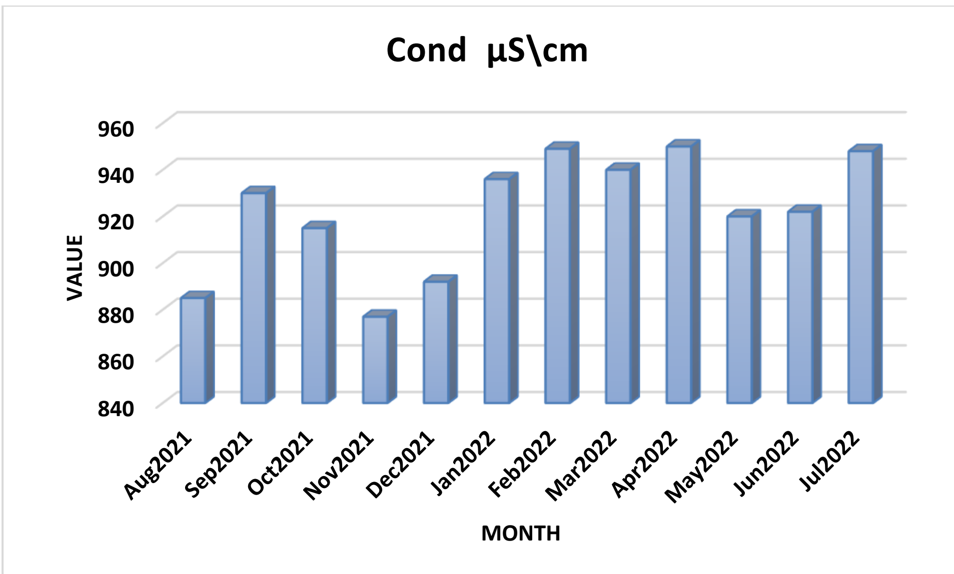

Fig. 5. Variation in the conductivity of Habaisha well groundwater during the study period (2021-2022)

Total dissolved salts (TDS)

In the current study, total dissolve salts (TDS) values varied from 585 to 635mg/ L in November 2021 and April 2022, respectively. These results showed no significant variations between different months during the study period (Table 1 & Fig. 6). Further, the results of TDS obtained during different months did not exceed the MAV of the Moroccan standards **(El Ouedghiri *et al.*, 2014)** or those recommended by the WHO (1000mg/ L) for water intended for human consumption. Moreover, the current results did not exceed the Egyptian standard specifications for drinking water. These findings are consistent with earlier research by several authors **(Nechad *et al.*, 2014; Al-Qawati *et al.*, 2015)**.

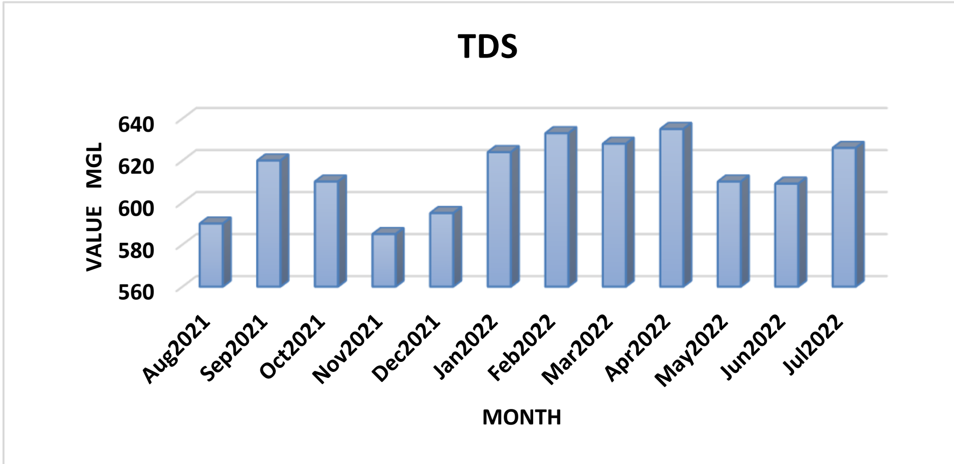

Fig. 6. Variation of total dissolved salts (TDS, mg/L) in Habaisha well groundwater during the study period (2021-2022)

Table 1. Physical properties of groundwater samples collected from Habaisha well groundwater during the study period (2021-2022)

Date	Temp C	PH	Turbidity(ntu)	TDS (mg/l)	Conductivity
8\2021	28±1	7.5±0.01	0.22±0.03	590±6	885±8
9\2021	27±1	7.6±0.02	0.2 ±0.02	620±5	930±6
10\2021	25±2	7.6±0.02	0.25±0.04	610±5	915±6
11\2021	24±2	7.65±0.01	0.24±0.02	585±4	877±8
12\2021	23±1	7.55±0.03	0.26±0.04	595±6	892±6
1\2022	24±2	7.62±0.03	0.21±0.02	624±7	936±5
2\2022	22±2	7.66±0.02	0.19±0.04	633±6	949±4
3\2022	24±1	7.58±0.02	0.17±0.02	628±6	940±4
4\2022	26±2	7.63±0.03	0.18±0.04	635±6	950±4
5\2022	28±2	7.6±0.02	0.23±0.02	610±8	920±6
6\2022	30±2	7.7±0.02	0.26±0.02	609±8	922±6
7\2022	31±1	7.68±0.02	0.28±0.02	626±6	948±6

Chemical investigations:

The evaluation of some chemical properties of water samples in the studied well was conducted and the results are listed in Table (2) and represented graphically in Figs. (6-12) as follows:

Chlorides (Cl^-)

The concentrations of chlorides in the current study ranged from 222 to 232mg/ L. The minimum value was recorded in February and March 2022, while the maximum value was recorded in December 2021 (Fig. 7). All the chloride results in the current study did not exceed the levels of Moroccan (750mg/ L) or Egyptian (250mg/ L) standards for human consumption **(El Haissoufi *et al*., 2011)**, which classified these waters as acceptable for human use.

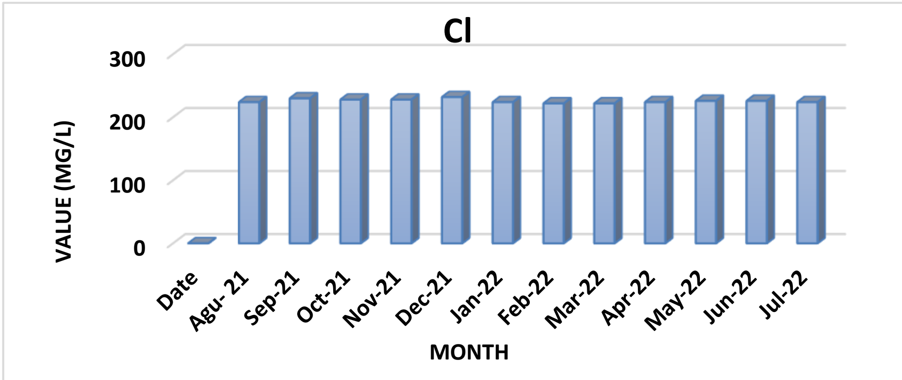

Fig. 7. Variation of chloride concentrations (mg/L) in Habaisha well groundwater during the study period (2021-2022)

Bicarbonate

The concentrations of bicarbonate in the current study ranged from 280 to 310mg/ L. the minimum value was recorded in August 2021 and September 2021, while the maximum value was recorded in February 2022 (Fig. 8). All bicarbonate results in the current study did not exceed the levels of Moroccan (750mg/ L) or Egyptian (250mg/ L) standards for human consumption **(El Haissoufi *et al*., 2011)**. This classifies these waters as acceptable for human use.

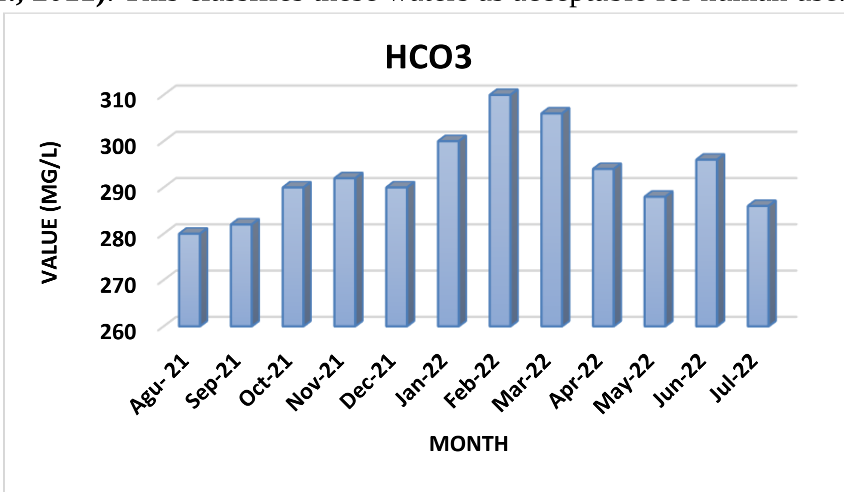

Fig. 8. Variation of bicarbonate concentrations in Habaisha well groundwater during the study period (2021-2022)

Total alkalinity

During different months, the total alkalinity values had insignificant monthly variations. The minimum value (280mg/ L) was recorded in August 2021, while the maximum value (310mg/ L) was recorded in February 2022 (Fig. 9). The total alkalinity levels did not exceed the Moroccan and Egyptian standard levels (500mg/ L).

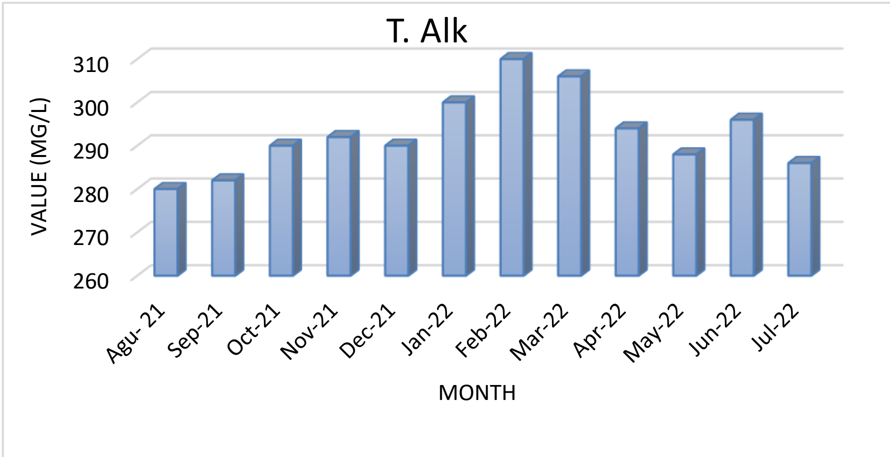

Fig. 9. Variations of total alkalinity (mg/L) in Habaisha well groundwater during the study period (2021-2022)

Calcium hardness (Ca^{2+})

Calcium concentrations in the groundwater of the studied well ranged from 168mg/ L in January 2022 to 174mg/ L in June and July 2022 (Fig. 10). The values recorded in all the collected samples are lower than those of the WHO standard (350mg/ L) **(Derwich *et al*., 2013)**.

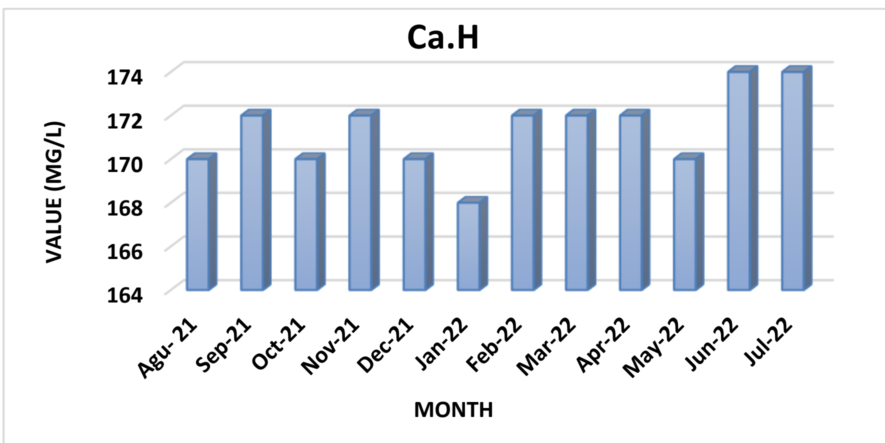

Fig. 10. Variations of calcium concentrations (mg/L) in Habaisha well groundwater during the study period (2021-2022)

Magnesium (Mg^{2+})

The recorded values of magnesium hardness (Mg^{2+}) in the groundwater of Habaisha well ranged from 96mg/ L (March 2022) to 104mg/ L (November and December 2021). These results were not of notable monthly variations (Fig. 11). During the study period, almost all water samples exhibited magnesium hardness values below the maximum admissible value of 30mg/ L of the Moroccan drinking water standards **(Lupton *et al*., 2008)**. These findings indicated that the groundwater in the research region has an adequate chemical quality.

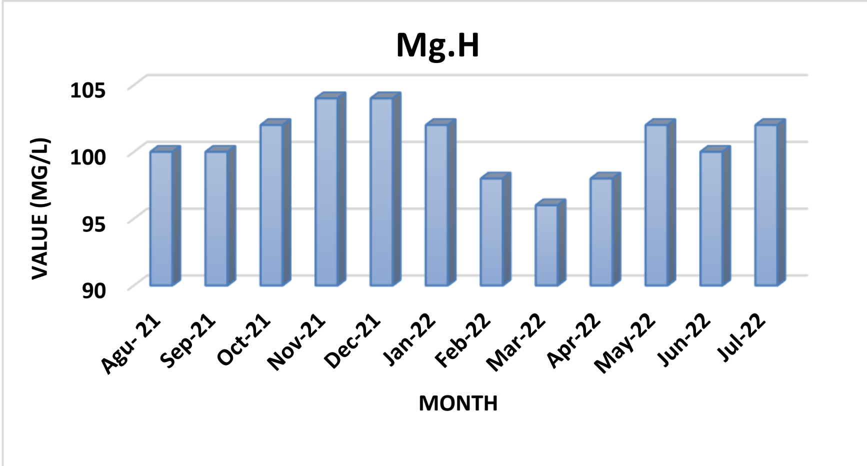

Fig. 11. Variations of magnesium concentrations (mg/L) in Habaisha well groundwater during the study period (2021-2022)

Total hardness (T.H)

The total hardness (T.H) of the groundwater collected from Habaisha well ranged from 268mg/ L in March 2022 to 276mg/ L in November and July 2022. These results showed monthly variations (Fig. 12). The values of T.H in all samples are lower than the guide value of the WHO standards (500mg/ L) **(Belghyti, 2013)**.

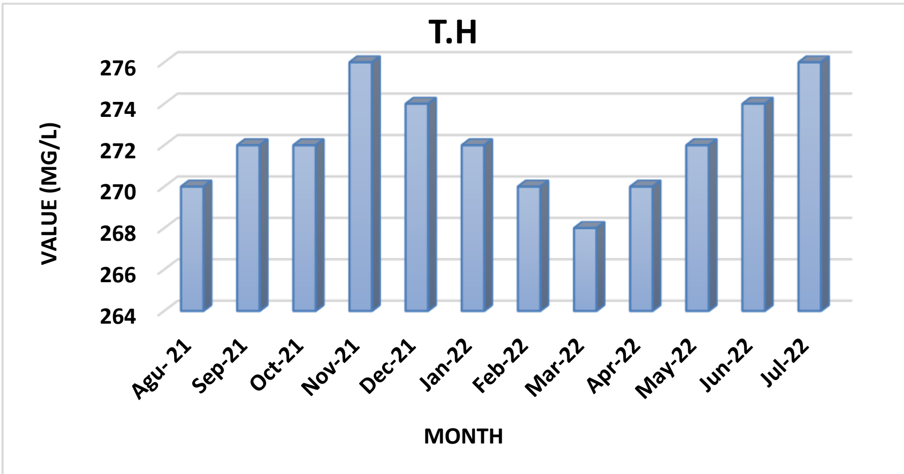

Fig. 12. Variations of total hardness (T.H) in Habaisha well groundwater during the study period (2021-2022)

Sulfates (SO4-)

During the current study, the minimum value of sulfate concentrations (86mg/ L) was recorded in February 2022, while the maximum value (96mg/ L) was recorded in November 2021 (Fig. 13). Compared to Moroccan standard levels (400mg/ L), we can conclude that the present results are below the maximum permissible limits.

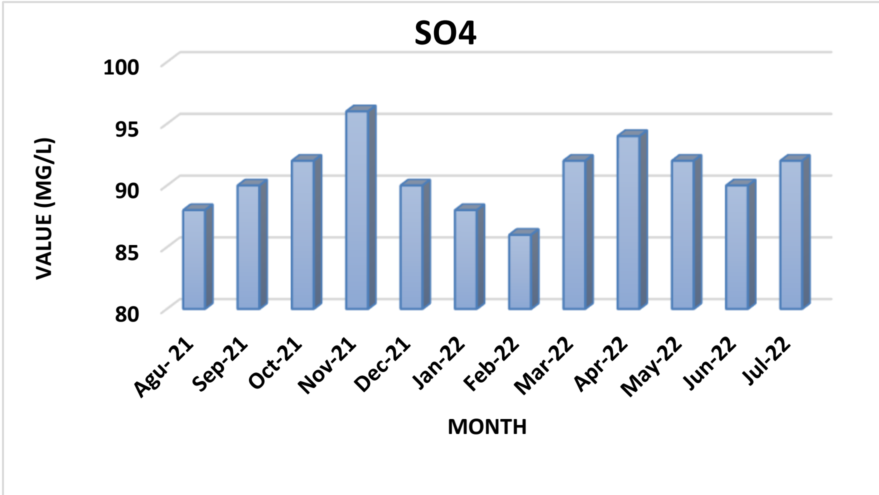

Fig. 13. Variation of sulfates (mg/L) in Habaisha well groundwater during the study period (2021-2022)

Sodium concentrations

The concentrations of sodium in the current study ranged from 222 to 232mg/ L. the minimum value was recorded in February 2022 and March 2022, while the maximum value was recorded in December 2021 (Fig. 14). The sodium results in the current study did not exceed the levels of the Moroccan (175mg/ L) or Egyptian (175mg/ L) requirements for human consumption **(El Haissoufi *et al.*, 2011)**, which classified these waters as acceptable for human use.

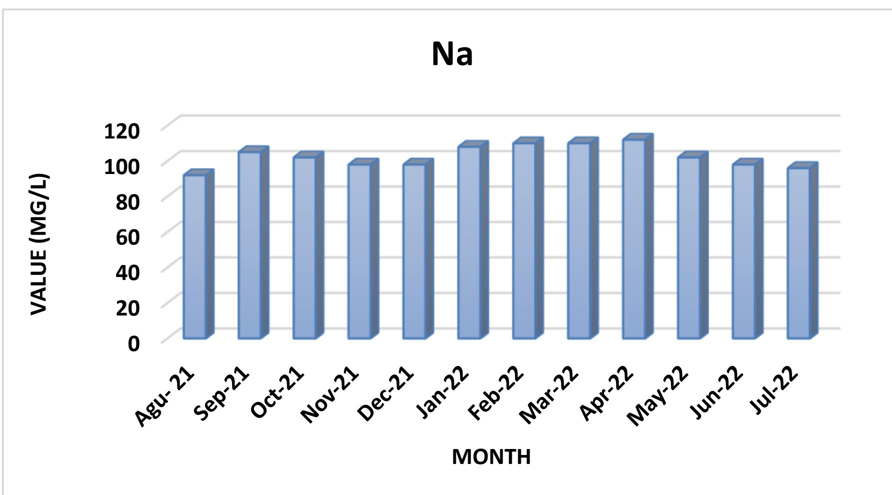

Fig. 14. Variation of sodium concentrations (mg/L) in Habaisha well groundwater during the study period (2021-2022)

Total iron (Fe^{2+})

The results of total iron in the groundwater of the investigated well showed no obvious monthly variations during study period (Fig. 15). Their values fluctuated between 0.01 and

0.03mg/ L. The results of the total iron concentrations recorded in the studied groundwater are within the acceptable levels according to the Moroccan standard **(Laafou *et al.*, 2013)**.

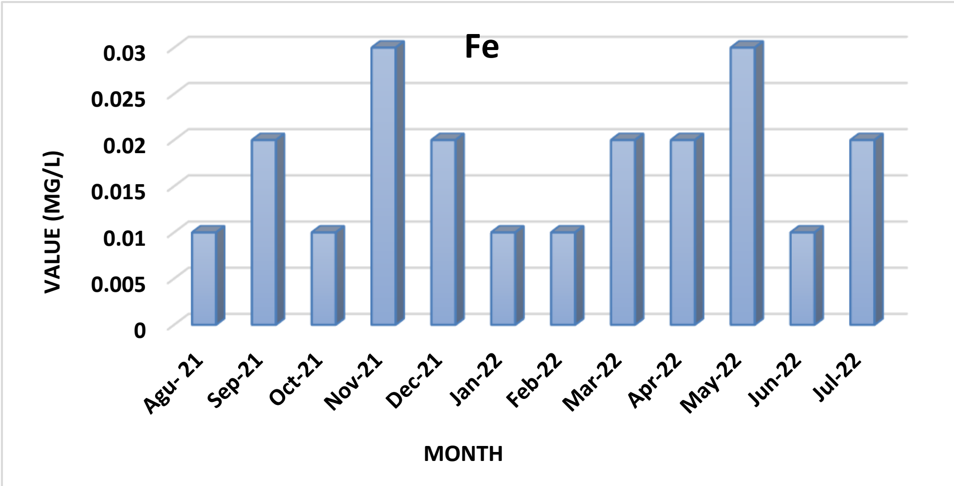

Fig. 15. Variation of total iron concentrations (mg/L) in Habaisha well groundwater during the study period (2021-2022)

Manganese (Mn^{2+})

The recorded manganese values [Mn^{2+}] were low in all samples throughout the period of study. These values fluctuated between 0.01 and 0.03mg/ L (Fig. 16) suggesting that the groundwater of the studied well is below the maximum admissible limits for manganese concentrations (0.5mg/ L) of the Moroccan drinking water standards **(Laafou *et al.*, 2013)**. Table (2) summarizes the chemical properties of Habaisha well groundwater.

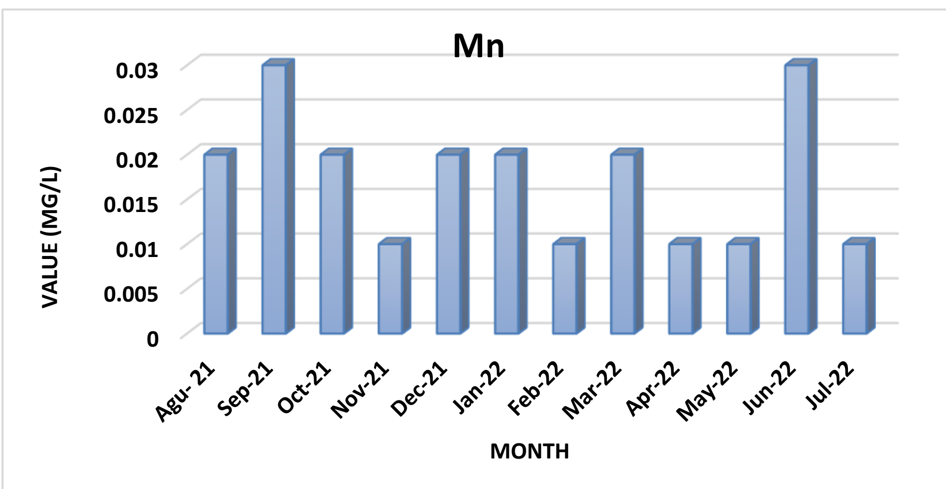

Fig. 16. Variations of manganese concentrations (mg/L) in Habaisha well groundwater during the study period (2021-2022)

Table 2. Chemical properties of Habaisha well groundwater during the study period

(2021-2022)

Date	Cl	HCO_3	T.Alk	Ca.H	Mg.H	T.H	Na	SO4	Fe	Mn
Agu 2021	224±4	280±5	280±8	170±4	100±2	270±4	92±4	88±4	0.01±0.004	0.02±0.001
Sep 2021	230±6	282±4	282±8	172±4	100±2	272±3	105±4	90±4	0.02±0.004	0.03±0.002
Oct 2021	228±3	290±4	290±6	170±3	102±3	272±5	102±3	92±3	0.01±o.oo1	0.02±0.002
Nov.2021	228±6	292±3	292±6	172±4	104±1	276±3	98±2	96±4	0.03±0.002	0.01±0.002
Dec 2021	232±5	290±4	290±6	170±2	104±2	274±4	98±2	90±4	0.02±0.001	0.02±0.002
Jan 2022	224±4	300±4	300±7	168±3	102±3	272±2	108±3	88±3	0.01±0.002	0.02±0.002
Feb 2022	222±4	310±4	310±6	172±4	98±4	270±2	110±4	86±2	0.01±0.002	0.01±0.001
Mar 2022	222±2	306±3	306±5	172±2	96±3	268±3	110±4	92±2	0.02±0.001	0.02±0.002
Apr 2022	224±3	294±4	294±8	172±4	98±2	270±5	112±3	94±4	0.02±0.002	0.01±0.002
May 2022	226±2	288±6	288±6	170±3	102±2	272±4	102±4	92±2	0.03±0.001	0.01±0.002
Jun 2022	226±6	296±4	296±4	174±4	100±2	274±3	98±2	90±3	0.01±0.002	0.03±0.002
Jul 2022	224±4	286±4	286±4	174±5	102±2	276±2	96±2	92±2	0.02±0.002	0.01±0.002

Microbiological analysis

As demonstrated in Table (3), the bacteriological analyses of the studied water samples using the presumptive test indicated that there were no coliform bacteria observed in the samples and that the groundwater quality was in accordance to the standards set by SASO (Saudi Standards, Metrology and Quality Organization), G.C.C.S (Gulf Cooperation Council Standardization Organization), WHO and USEPA (United States Environmental Protection Agency) **(WHO, 2017)**.

Table 3. Microbiological analysis of Habaisha well groundwater during the study period (2021-2022)

	Total bacteria count, Cfu/mL 48	Of coliform bacteria, Cfu/mL 48
Aug 2021	<1.1	<1.1
Sep 2021	<1.1	<1.1
Oct 2021	<1.1	<1.1
Nov 2021	<1.1	<1.1
Dec 2021	<1.1	<1.1
Jan 2022	<1.1	<1.1
Feb 2022	<1.1	<1.1
Mar 2022	<1.1	<1.1
Apr 2022	<1.1	<1.1
May 2022	<1.1	<1.1
Jun 2022	<1.1	<1.1
July 2022	<1.1	<1.1

A total bacterial count of 48 cfu/mL indicates a relatively low level of bacteria. acceptable microbial concentrations can range from less than 10 cfu/mL to 10,000 cfu/mL.
Explanation:

- CFU/mL: This stands for colony forming units per milliliter. It's a way of measuring the number of bacteria in a sample.
- 48 cfu/mL: This means that in a sample of 1 milliliter, there are 48 colonies of bacteria that can grow when plated on a culture medium.

Low level: A count of 48 is relatively low, especially compared to some typical ranges like 10,000 cfu/mL or higher.

Acceptable ranges: Depending on the context (e.g., water quality, food, medical samples), different levels of bacteria are considered acceptable. Situ Biosciences suggests that some systems can tolerate up to 10,000 cfu/mL. WCS Group mentions that counts of 50 one month and 5000 the next month may be considered a significant change.

In summary: A bacterial count of 48 cfu/mL is considered a low level of contamination and is within the range considered acceptable in some systems.

Groundwater quality evaluation

An assessment of the groundwater quality and its suitability for different purposes was conducted. The results of this evaluation are listed in Table (4) and illustrated graphically in Figs. (16-21) as follows:

Kelly's ratio (KR)

The results of Kelly's Ratio (KR), or sometimes stated as Sodium Ratio (SR), ranged from 0.74 to 0.90 (Fig. 17) recorded in August 2021 and April 2022, respectively. Water with a KR value less than 1 is appropriate and considered safe for irrigation purposes **(Kelly, 1963)**, as such low KR levels indicate also low sodium hazard relative to calcium and magnesium concentrations. From our results we concluded that all samples were less than unity and therefore this well is suitable for irrigation.

Sodium adsorption ratio (SAR)

The minimum absolute value (0.55) of Sodium Adsorption Ratio (SAR) was recorded in August 2021 and July 2022, while the maximum value (0.67) was recorded in March 2022 and April 2022 (Fig. 18). According to **Ayers and Westcot (1985)**, SAR values between 0 and 10 indicate normal water quality for irrigation. The present results confirm the suitability of Habaisha well groundwater for irrigation, posing minimal salt damage risk to agricultural soil.

Magnesium hazard (MH)

As listed in Table (4), our results indicated that magnesium hazard (MH) ranged mostly between 35.96% and 38.10%, with the lowest and highest values recorded in March 2022 and December 2021, respectively (Fig. 19). In addition, since the MH values in the current study are less than 50%, the Habaisha well groundwater is suitable for agricultural uses **(Gupta, 2011)**.

Permeability index (PI)

The present findings indicated that the permeability index (PI) values ranged from 65.36 to 69.25%. The minimum value was recorded in August 2021, while the maximum value was recorded in March 2022 (Fig. 20). According to **Deneen (1964)**, the acceptable PI value for irrigation water should not exceed 65% so that water can efficiently penetrate the ground and promote the development of plants. While most values in this study slightly exceeded this threshold, the groundwater remains generally suitable for agricultural use.

Aquaculture and other applications

For the secondary uses of the wells after human uses and drinking purposes are the developing applications as the aquaculture and its role in development. The water quality is crucial for fish production and exert an immense influence on the maintenance of a healthy aquatic environment **(Sunny *et al.*, 2017)**. The current items of water quality have included parameters such as Ph, turbidity, TDS, total hardness and iron, and those may be indicators for suitability in aquaculture. By comparing the current findings with those of the **WHO (2003)**, **Carballo *et al*. (2008)**, **Ibrahim and Ramzy (2013)**, **Ezeanya *et al*. (2015)**, **FAO (2016)** and **Osman *et al.* (2021)** it was noticed that, the current parameters are located in the suitable and safe range of aquaculture, and this indicates that this well is suitable for other developing applications such as aquaculture as well as the human uses.

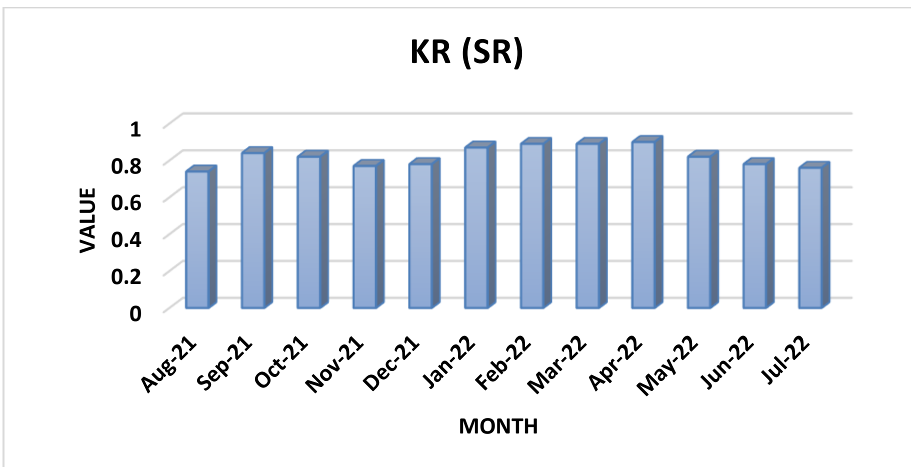

Fig. 17. Variations of the Kelly's ratio (KR) in the Habaisha well groundwater during the study period (2021-2022)

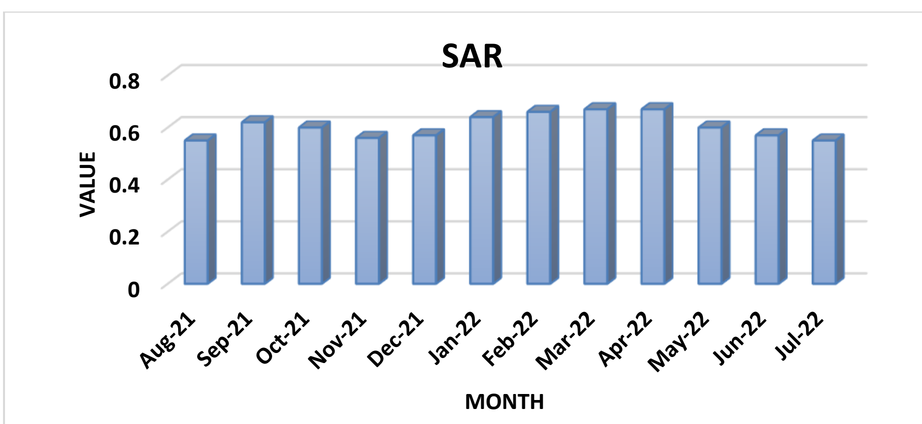

Fig. 19. Variations of magnesium hazard (MH) in the Habaisha well groundwater during the study

period (2021-2022)

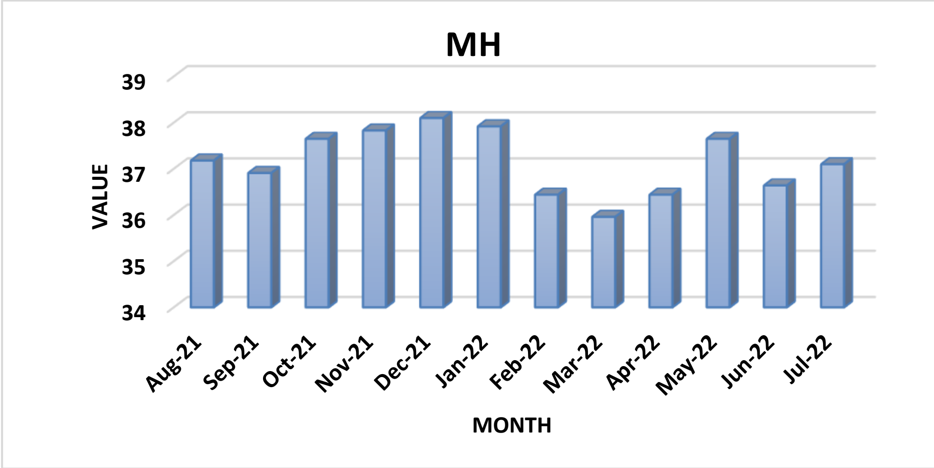

Fig. 19. Variations of magnesium hazard (MH) in Habaisha well groundwater during the study period (2021-2022)

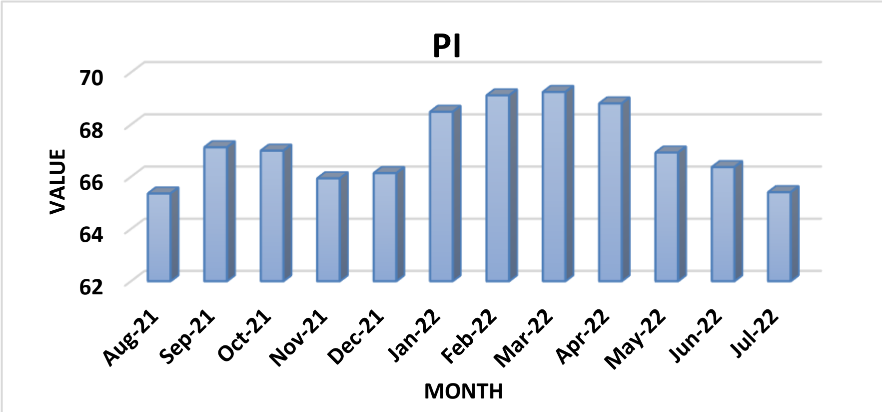

Fig. 20. Variations of permeability index (PI) in Habaisha well groundwater during the study period (2021-2022)

Table 4. Groundwater quality evaluation: Suitability for human consumption and irrigation usage

Date	KR (SR)	SAR	MH	PI
Aug. 2021	0.74	0.55	37.18	65.36
Sep 2021	0.84	0.62	36.91	67.13
Oct 2021	0.82	0.60	37.65	67.00
Nov 2021	0.77	0.56	37.83	65.94
Dec 2021	0.78	0.57	38.10	66.14
Jan 2022	0.87	0.64	37.92	68.49
Feb 2022	0.89	0.66	36.44	69.12
Mar 2022	0.89	0.67	35.96	69.25
Apr 2022	0.90	0.67	36.44	68.81
May 2022	0.82	0.60	37.65	66.93
Jun 2022	0.78	0.57	36.64	66.37
July 2022	0.76	0.55	37.10	65.41

*Potential Soil Salinity Classification of Ground Water, *Permeability Index (PI)
*Sodium Adsorption Ratio) SAR), *Magnesium Hazard (MH) *Kelly’s Ratio (KR)

CONCLUSION

The present study evaluated the groundwater quality variability of a well within Assiut Governorate, through monitoring different physicochemical parameters, assessing its compliance with the Egyptian and WHO drinking water standards. The monitoring and analysis of the well water parameters in Sahel Sleem City revealed temporal variability in groundwater characteristics during the study period. Generally, all parameters' values are not higher than the maximum admissible value of the Egyptian and WHO standards for the quality of drinking water. The findings showed low concentrations of trace elements (Fe^{2+}, Mn^{2+}), indicating no obvious heavy metal pollution. Further, the results of the irrigation indices (KR, SAR, MH, and PI) demonstrated that the groundwater of the investigated well is appropriate for agricultural use. Moreover, the quality parameters of the investigated well gave the suitability indices for aquaculture exploitation among the applications after human uses.

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