Groundwater quality and health assessments based on heavy metals and trace elements content in Dakhla Oasis, New Valley Governorate, Egypt

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ABSTRACT
This study is searching for some crucial physicochemical properties of groundwater samples collected from eleven outlets in Dakhla Oasis, Egypt, including the pH-value, electrical conductivity (EC), total dissolved solids (TDS), in addition to the concentrations of heavy metals and trace elements. In total 21 elements were analyzed using inductively coupled plasma spectrometry (ICP-OES). To categorize the water class: Chronic daily intakes (CDI), water quality index (WQI) and hazard risk (HR) were computed for the 21 elements in the water samples. Some biological parameters such as levels of urea, creatinine, and the tumor marker CEA were measured. The obtained results showed that the pH-values (6.12 to 6.56) for water samples are within the acceptable limits of the WHO. Results showed, also, that EC (274 to 532 μS/cm), TDS (175 to 340 ppm) besides, the level of measured 21 elements were lower than the values allowed by World Health Organization (WHO) and US Environmental Protection Agency (USEPA). Additionally, the reached data were comparable to other internationally published figures. It is emphasized that the data obtained for WQI confirmed that water from all the sampling points was of expedient quality.

Based on the obtained data and the evaluated parameters, it can be concluded that the groundwater samples of the studied areas are of excellent quality; they do not pose any health risks to the local citizens, and are safe for their domestic consumption. Moreover, the results of urea, creatinine, and CEA analyses showed very few abnormal cases, which confirmed, again, that the groundwater in the studied areas did not pose a risk to human health.

Introduction
Water is one of the main components of humankind’s ecology. It is considered the most crucial element for all living and inanimate systems on our planet. It is needed every day for all anthropogenic activities including the drinking water supply. Treatment of wastewater needs many analytical processes for examination (Aglan, Hamed, & Saleh, 2019; Aglan, Mahmoud, Rashad, & Saleh, 2021) and purification from heavy metals (Saleh, Aglan, & Mahmoud, 2019a; Saleh, Mahmoud, Aglan, & Bayouni, 2019b) or other hazardous elements (Saleh & Eskander, 2020; Saleh et al., 2020a, 2020b) to be suitable for reuse, furthermore, the solid residues generated during the treatment process must be disposed of after stabilization using cost-effective materials such as cement (Saleh, 2014; Saleh et al., 2020a, 2019b; Saleh and Eskander, 2019). Especially groundwater is an important source of water in Egypt. However, essential elements such as phosphorus have to be removed from surface water bodies for the growing of plants and the rearing of animals (Nkansah, Donkoh, Akoto, & Ephraim, 2019). Therefore, assessment of groundwater quality for domestic and irrigation uses is one of the most important issues (Houria, Mahdi, & Zohra, 2020; Hussain & Abed, 2019).

Egypt is strongly committed to evaluate and guarantee water quality for use in agriculture and manufacturing activities. Therefore, physical, chemical, bacteriological, and biological characterizations of water are decisive requirements to be considered before its use, especially for domestic purposes.

The Western Desert of Egypt has various geomorphologic characteristics comprising highland, plains-dunes, and depressions. A large number of desert oases are distributed in this region, which depends essentially on Nubian aquifers. This area is high about 400 m above sea level.

Dakhlahas located about 750 km from the Egyptian capital Cairo; this oasis is one of the western desert oases. The study area covers five locations of the oasis, namely, Mut, Rashda, Bhdkhulu, Qalamoun, and Qasr as shown in the attached map, Figure 1.

Dakhla Oasis, the site under investigation, is a part of the New Valley (Al Wady Al Gadded) Governorate (Saleh, Mahmoud, Abdou, & Eskander, 2021). Most of the citizens in the oases are farmers and animal herders. The area is inhabited by about 250,000 people who cultivate mainly dates, cucumbers, beans, maize, and other crops. Ground and pond waters, in addition to very rare

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where, Figure 2 illustrates the flowchart of the methodologies. The contents of essential trace elements as well as precarious dissolved heavy metals were analyzed and compared to the WHO guidelines published by World Health Organization (WHO) and other organizations concerned in offering safe drinking water to the citizens. Moreover, the hazards to some important biological functions, e.g. renal diseases, in the population of a defined sampling point of the area concerned, namely the Mut point, were evaluated. Consequently, it was intended to affirm the suitability of water of the area under study for all human activities, particularly for domestic usage.

Medical and environmental scientists from the Radioisotopes Department of the Egyptian Atomic Energy Authority (EAEA) visited Dakhla Oasis in late summer 2014. Eleven random sampling points in five locations in Dakhla Oasis, namely Mut, Rashda, Bdikhulu, Qalamoun, and Qasr were selected for groundwater sampling. The pH-value of water from different outlets was measured using a portable consort pH meter (Model P 314). The collected water samples were acidified with nitric acid (Sigma Aldrich), and then stored at 4°C in polyethylene bottles produced especially for preserving water samples till their analysis. The collected groundwater samples were sent for complete assay to the Central Laboratory for Elemental and Isotopic Analysis, Egyptian atomic energy authority.

The samples were filtered using filter membrane Simsii PES (Diameter 47 mm and 0.1 μm pore size). Some physicochemical parameters including electrical conductivity (EC) and total dissolved solids (TDS) were evaluated using a conductivity meter (Orion model 162, USA), where both are in a direct proportionality relationship (Sharaky & Abdoun, 2020). The anions Cl\(^-\), SO\(_4\)\(^{2-}\) and NO\(_3\)\(^-\) were determined by using a BTXAN-5 separating column in a GBC ion

Materials and methods

Figure 1. Map of the study area in Dakhla Oasis, including the sample location points.

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chromatography, with the chromatographic conditions reported in Table 1, while HCO₃ was determined by titration method.

Twenty-one elements, namely, As, Cd, Cs, Pb, Se, Ag, Sr, Zn, Cu, Cr, Al, V, Na, K, Ca, Mg, Fe, Ni, Mn, Ba, and Co were measured in the mg/L using a Prodigy Axial High Dispersion inductively coupled plasma optical emission spectrometer (ICP-OES) TELEDYNE Leeman Labs, USA, at wavelengths (λ) in nm range as indicated in Table 2. According to Hall (Hall, 1998), values for the relative standard deviation percent (RSD %) for the considered elements were calculated and represented in Table 2.

### Table 1. Analytical conditions for the determination of anions (Cl, SO₄ and NO₃)

| Parameter                  | Value |
|----------------------------|-------|
| Sample volume              | 100 μl|
| Separation column          | BTXAN-5 |
| Eluent                     | 3.5 mM Na₂CO₃, 0.5 mM NaHCO₃ |
| Eluent flow rate           | 1 ml/min |
| Auto suppressor            | Alltech, ERIS™ 1000 HP |
| Detection                  | Altech, 550 conductivity detector |

### Table 2. Wavelength (λ) in nm and relative standard deviation percent (RSD %) for different elements analyzed with below detection limit (BDL).

| Elements | λ (nm) | RSD [%] | BDL |
|----------|--------|---------|-----|
| As       | 193.76 | 1.20    | 0.0099 |
| Cd       | 226.5  | BDL     | 0.0006 |
| Cs       | 193.35 | 0.45    | 40.0 |
| Pb       | 217.00 | 1.86    | 0.0033 |
| Se       | 196.09 | 0.6     | 0.002 |
| Ag       | 328.07 | BDL     | 0.0003 |
| Sr       | 407.77 | 0.52    | 0.00005 |
| Zn       | 202.55 | 1.45    | 0.0015 |
| Cu       | 224.70 | BDL     | 0.0024 |
| Cr       | 267.72 | BDL     | 0.0003 |
| Al       | 396.15 | 2.48    | 0.0018 |
| V        | 310.23 | BDL     | 0.0009 |
| Na       | 589.59 | 0.01    | 0.0219 |
| K        | 766.49 | 0.44    | 0.001 |
| Ca       | 317.93 | 1.5     | 0.006 |
| Mg       | 279.55 | 0.54    | 0.0009 |
| Fe       | 240.49 | 0.23    | 0.0036 |
| Ni       | 232.00 | BDL     | 0.0039 |
| Mn       | 257.61 | 0.72    | 0.0021 |
| Ba       | 455.40 | 0.37    | 0.0006 |
| Co       | 228.62 | BDL     | 0.0002 |

BDL = below the detection limit of the samples
During the campaign, blood samples from a random population were collected inside Mut central hospital from 280 males and females with a ratio present 36:64, respectively, and an age range of 30–70 years old. Some biological parameters were measured including kidney function (urea and creatinine levels), and the level of the general tumor marker Carcinoembryonic antigen (CEA) was quantified. Urea and creatinine were measured using spectrophotometric techniques according to the method of Tietz (1990). CEA was measured using a radioimmunoassay (RIA) procedure according to Westgard, Barry, Hunt, and Groth (1981).

Results and discussion

Evaluation of groundwater in comparison to standard values

The groundwater quality in a certain area is largely depending on the type and extent of industry, planting, and other anthropogenic activities in a geographical area (Banejad & Olyaie, 2011). 

Table 3 represents the measured water quality parameters for the groundwater samples collected randomly from the 11 different sampling sites. It is obvious from this table that levels of most elements, viz. As, Cd, Cs, Pb, Ag, Cu, Cr, V, Ni, and Co were below the detection limit (BDL). On the other hand, Se was detected in samples Nos. 3 & 5, while Al and Zn were found in samples Nos. 3 & 4. It is worth mentioning that Sr, Na, K, Ca, Mg, Mn, and Ba were detected in all of the first five collected samples. On the other hand, Ba, Fe, Mg, Ca, K, Na, Sr were found in the six outlets samples, whereas Mn and Se were not detected in samples Nos. 6, 8, 9, & 11. Moreover, Pb, As, and Cs were found only in samples Nos. 7 & 8.

The eleven water samples were free from the most hazardous heavy metal pollutants, viz. Cd, Ag, Cr, Cu, V, Ni, and Co, and all the results were found to be within the permissible limit according to WHO. It can be stated that the levels of Ba and Sr that were found in collected samples from the eleven sites are below the levels that have been reported to cause adverse effects in the scientific literature (WHO, 2016).

It could be stated that concentrations [mg/L] for all the elements detected in the groundwater samples collected from the 11 sampling outlets were lower than the maximum limits permitted for drinking water quality as recommended by (WHO, 2004), (WHO, 2011) (CCME, 2001). Therefore, water in the area under consideration is safe even for drinking usages regarding the heavy metal concentrations found.

Table 4 presents the analyses data for EC, TDS, and the most interesting anions in water samples collected from the eleven sampling points. It is clear from Table 4 that the parameters ranged as follows: TDS (175–340 mg/L), EC (261–507 μS/cm), HCO₃⁻ (34.5–87.34 mg/L), Cl⁻ (25–37 mg/L), NO₃⁻ (0.88–3.22), and SO₄²⁻ (33–39 mg/L).

Those figures are very low compared to WHO, (2006) standards, which confirms again that the groundwater in the area under consideration is safe even for drinking purpose.

Based on total dissolved solids (TDS), and according to (Hem, 1985), the groundwater in the studied area can be classified as “fresh groundwater,” where TDS is less than 1000 mg/L.

As shown in Table 4 all of the analyzed groundwater samples have the anionic concentration sequence: HCO₃⁻ > SO₄²⁻ > Cl⁻ > NO₃⁻. In groundwater under consideration, hydrogen carbonate is dominant, followed by sulfate, chloride, and nitrate anions which might refer to rock origin. The differences in the most interesting cations dominancy, viz. K⁺ > Na⁺ > Mg²⁺ > Ca²⁺ > Fe²⁺ > Mn²⁺, may be due to exchange processes or mixing with other resources.

Table 5 indicated the calculated Pearson’s correlation coefficients (R) between the different parameters in the groundwater samples. The matrix indicated perfect correlation between EC & TDS (R = 1), which confirmed that

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**Table 3. Elemental analysis of 11 ground water samples in mg/L.**

| Sample | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | WHO, 2004 | WHO, 2011 | CCME, 2001 |
|--------|---|---|---|---|---|---|---|---|---|----|----|-----------|----------|------------|
| As     | BDL | BDL | BDL | BDL | BDL | BDL | 0.0099 | BDL | BDL | BDL | 0.01 | 0.01 | 0.01 |
| Cd     | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | 0.01 | 0.003 | 0.005 |
| Cs     | BDL | BDL | BDL | BDL | BDL | BDL | 0.0013 | BDL | BDL | BDL | 0.1 | 0.01 |
| Pb     | BDL | BDL | BDL | BDL | BDL | BDL | 0.007 | BDL | BDL | BDL | 0.1 | 0.01 |
| Se     | BDL | BDL | 0.005 | BDL | 0.005 | 0.0165 | 0.002 | 0.0178 | BDL | 0.0058 | BDL | 0.01 | 0.04 | 0.01 |
| Ag     | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | 0.05 |
| Sr⁺    | BDL | 0.1011 | 0.113 | 0.0708 | 0.067 | 0.0845 | 0.0891 | 0.0873 | 0.0941 | 0.1184 | 0.1169 | 0.1164 |
| Zn     | BDL | BDL | BDL | BDL | BDL | BDL | 0.0376 | BDL | BDL | BDL | 3 | 5 |
| Cu     | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | 2 | 1.5 | 1 |
| Cr     | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | 0.5 | 0.05 | 0.05 |
| Al     | BDL | BDL | BDL | BDL | BDL | BDL | 0.0086 | BDL | BDL | BDL | 0.2 |
| V      | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | 0.3 |
| Fe     | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | 0.3 | 0.3 | 0.3 |
| Ni     | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | 0.02 |
| Mn     | BDL | BDL | BDL | BDL | BDL | BDL | 0.0563 | 0.0763 | 0.1015 | 0.0146 | 0.1454 | BDL | 0.1119 | BDL | 0.0945 | 0.0095 | 0.0058 | 0.5 | 0.05 |
| Ba     | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | 0.7 | 1 |
| Co     | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL |

*Maximum acceptable concentration is 7 mg/L according to (CDW, 2018) BDL = below detection limit
Table 4. Concentrations of cations and anions in mg/l, EC and TDS with a minimum, maximum and average values.

| Sample | EC [μS/cm] | TDS (mg/L) | K⁺ | Na⁺ | Mg²⁺ | Ca²⁺ | Cl⁻ | SO₄²⁻ | HCO₃⁻ | NO₃⁻ | Cl⁻ + Mg²⁺ |
|--------|------------|------------|-----|-----|------|------|-----|-------|-------|------|-------------|
| 1      | 462.7      | 310        | 12.15 | 7.14 | 4.75  | 3.69 | 34.52 | 37.21 | 87.34 | 3.11 | 8.44        |
| 2      | 346.2      | 232        | 11.58 | 10.49 | 5.57  | 3.85 | 27.63 | 34.26 | 68.11 | 1.94 | 9.42        |
| 3      | 261.2      | 175        | 14.46 | 8.91 | 4.66  | 3.61 | 25.41 | 32.54 | 34.5  | 0.88 | 8.27        |
| 4      | 332.8      | 223        | 14.31 | 8.89 | 4.56  | 3.37 | 26.87 | 35.68 | 62.36 | 1.85 | 7.93        |
| 5      | 335.7      | 241        | 14.15 | 10.45 | 5.44  | 3.72 | 28.75 | 33.92 | 47.73 | 2.23 | 9.16        |
| 6      | 414.9      | 278        | 6.12  | 20.86 | 6.28  | 4.51 | 31.29 | 35.81 | 46.64 | 2.82 | 10.79       |
| 7      | 507.5      | 340        | 14.81 | 5.66 | 4.61  | 3.12 | 36.77 | 38.56 | 54.13 | 3.22 | 7.73        |
| 8      | 365.6      | 245        | 15.64 | 6.09 | 4.87  | 3.72 | 28.46 | 34.85 | 60.5  | 1.41 | 8.59        |
| 9      | 329.9      | 221        | 9.99  | 7.86 | 5.68  | 4.15 | 27.13 | 32.12 | 40.68 | 1.32 | 9.83        |
| 10     | 422.4      | 283        | 9.96  | 7.84 | 5.68  | 3.87 | 31.25 | 37.51 | 56.5  | 1.43 | 9.55        |
| 11     | 313.4      | 210        | 9.71  | 7.57 | 5.51  | 4.40 | 27.13 | 35.11 | 60.14 | 0.97 | 9.91        |
| min    | 261.2      | 175        | 6.12  | 3.66 | 4.56  | 3.12 | 25.41 | 32.1  | 34.50 | 0.88 | 7.73        |
| max    | 507.5      | 340        | 15.64 | 20.86 | 6.28  | 4.51 | 34.52 | 38.56 | 87.34 | 3.22 | 10.79       |
| mean   | 374.2      | 251        | 12.08 | 9.25 | 5.24  | 3.82 | 29.5  | 35.2  | 56.2  | 1.92 | 9.05        |
| WHO Standards | 600 | 500 | 10 | 20 | 50 | 25 | 45 | 500 | 250 | 125 |

EC is a function of total dissolved solids in the groundwater (Masoud, El-Horiny, Atwia, Gemail, & Koike, 2018).

The table shows strong positive correlations, i.e. greater than 0.7, among TDS and all the analyzed parameters except for SO₄²⁻ & HCO₃⁻, for which moderate correlation values were 0.64 and 0.55, respectively. It is well known that; the developed groundwater salinity can be attributed mainly to those strong positive correlations. It is worthy to notify that high correlation coefficients exist between Cl⁻, NO₃⁻, SO₄²⁻, Ca²⁺, Mg²⁺, Na⁺, K⁺, Fe²⁺, and Mn²⁺ (Table 5). This can confirm that the various water samples have similar geochemical characterizations (Masoud et al., 2018). Moreover, weak correlation coefficients are found between HCO₃⁻ and Mg²⁺, K⁺, besides Mn²⁺ cations. This suggested that the hydrogen carbonate of these cations originated from oxidative carbon dioxide dissolution of carbonate-bearing rocks in the aquifer. A similar explanation for hydrogen carbonate occurrence in water samples was provided by Massmann, Tichomirowa, Merz, and Pekdeger (2003). On the other hand, the small correlation coefficients between HCO₃⁻ and SO₄²⁻ anions could be due to the very low ion exchange process between them in the aquifer environment.

**Groundwater interactions**

The levels of the soluble ions in groundwater are a factor of the hydro-geochemical processes acting on the water during its route to the final basin as well as processes taking place in the aquifer (Nayak & Sahood, 2011). The levels of the different major elements in groundwater are used in the determination of geochemical processes. Various physical, chemical, and mechanical processes occur during rock-water interaction, which include erosion, freeze-thaw, dissolution/precipitation, ion exchange processes, oxidation, and reduction. The number of relationships covering Na relation with each of K, Ca, and Mg are discussed in the illustrations below.

*Figure 3(a)* represents the scatter diagram for Na⁺ versus Ca²⁺ [meq/L] in groundwater from the 11 sampling places. Most points are located below the equiline of 1:1, which indicates a reduction in Ca²⁺ concentration compared with Na⁺ contents in groundwater, even when the area under study geologically is mainly limestone formation. This can be due to cation exchange during which Ca²⁺ is replaced by Na⁺ (Ogunibido and Kehinde-Philips, 2012).

It is clear from the scatter diagram for the relationship between potassium versus calcium [meq/L] in groundwater from the 11 sampling places that it follows the same trend as seen for the relation between Na⁺ and Ca²⁺, Figure 3(b). Most points are located below the equiline of 1:1, indicating a reduction in Ca²⁺ concentration compared with K⁺ contents in groundwater. This can also be related to cation exchange, during which Ca²⁺ is replaced by K⁺.

The scatter diagrams for the relationships between sodium versus magnesium [meq/L] shown in *Figure 4(a)* and potassium versus magnesium [meq/L], *Figure 4(b)*, in groundwater from the 11

Table 5. Pearson’s correlation coefficients (r) for some parameters of interest for the water samples collected from the area under study.

|       | TDS | EC   | Ca²⁺ | Mg²⁺ | Na⁺ | K⁺ | Fe²⁺ | Mn²⁺ | Cl⁻ | NO₃⁻ | SO₄²⁻ | HCO₃⁻ |
|-------|-----|------|------|------|-----|----|------|------|-----|------|-------|-------|
| TDS   | 1   |      |      |      |     |    |      |      |     |      |       |       |
| EC    | 0.97| 1    |      |      |     |    |      |      |     |      |       |       |
| Ca²⁺  | 0.93| 0.97| 1    |      |     |    |      |      |     |      |       |       |
| Mg²⁺  | 0.93| 0.93| 0.9  | 1    |     |    |      |      |     |      |       |       |
| Na⁺   | 0.85| 0.85| 0.8  | 0.83 | 1   |    |      |      |     |      |       |       |
| K⁺    | 0.92| 0.92| 0.92 | 0.91 | 0.69| 1  |      |      |     |      |       |       |
| Fe²⁺  | 0.87| 0.87| 0.82 | 0.8  | 0.95| 0.65| 1    |      |     |      |       |       |
| Mn²⁺  | 0.91| 0.91| 0.89 | 0.9  | 0.92| 0.78| 1    | 1    |     |      |       |       |
| Cl⁻   | 0.98| 0.98| 0.92 | 0.91 | 0.87| 0.84| 0.84 | 1    |     |      |       |       |
| NO₃⁻  | 0.84| 0.84| 0.78 | 0.76 | 0.68| 0.72| 0.72 | 0.76 | 1   |      |       |       |
| SO₄²⁻ | 0.64| 0.64| 0.83 | 0.77 | 0.75| 0.77| 0.78 | 0.78 | 0.84| 0.62 | 1     |       |
| HCO₃⁻ | 0.55| 0.55| 0.57 | 0.35 | 0.51| 0.27| 0.64 | 0.31 | 0.59| 0.58 | 0.48 | 1     |
sampling places, exhibited a similar trend. Most points are located above the equiline of 1:1, which indicates a higher Mg$^{2+}$ concentration compared with both the two alkali metal ions Na$^+$ and K$^+$ in groundwater. This can be attributed to anthropogenic mining activities not only in Bahariya oasis, where the Mg content in iron stone in this area ranges from 0.7% to 7.66% (Abouzeid & Khalid, 2011), but also to many other developed mining projects in the Western desert.

As the dissolution of Na$^+$ and K$^+$[meq/L] is prominent, in general, both contents were not far from the equiline (1:1) as shown in Figure 5. According to World Health Organization (WHO, 2009), human’s sodium and potassium intake balance is very crucial; an excess sodium intake can result in depletion of potassium levels. Also, magnesium deficiency can result in failure to retain potassium in sufficient quantities, while an excess intake of potassium can interfere with magnesium uptake.

Moreover, it is clear from Figure 5 that there is a more or less balanced distribution for both sodium and potassium along their equiline of 1:1 in the tested waters. This indicates that there is a limited or equal ionic exchange between the two alkali elements, which consequently confirms the suitability of the water under consideration, based on the contents of Na$^+$ and K$^+$, for the different usage including drinking water.

The results depicted in Figure 6 indicate that the Mg$^{2+}$ contents in the all samples test are higher than that of Ca$^{2+}$. The contents of those two alkali elements in the drinking water of the area under study are significantly lower than the limits established by the WHO (2011) (50 mg/L for Mg$^{2+}$ and 75 mg/L for Ca$^{2+}$) and the Canadian standards (50 mg/L for Mg$^{2+}$ and 200 mg/L for Ca$^{2+}$). However, drinking water has acceptable values for both Ca$^{2+}$ and Mg$^{2+}$, which can be a source for diet, and is highly required for people with insufficient intake of Mg$^{2+}$ and Ca$^{2+}$.

The health risks of hard water are mainly attributed to the impact of the salts dissolved in it, basically Ca$^{2+}$ and Mg$^{2+}$ salts. Hence, and according to Sengupta (2013), the water samples collected from the 11 sampling positions can be considered soft water since their average dissolved Ca$^{2+}$ and Mg$^{2+}$ concentrations were lower than the upper limit for soft water (60 mg/L) (Table 4). Therefore, the population in the studied area who are dependent on the groundwater for satisfying their drinking water are not in need for extra intakes of both Ca and Mg elements. Consequently, they do not suffer from the known adverse health impacts of the hard water consumption.

The characterization of the groundwater in the area under investigation using Rader diagram (Figure 7) shows that, for all the eleven sampling points, the Na$^+$+ K$^+$ percentages are more

Figure 3. The relationship between the average dissolved calcium and sodium contents or Potassium contents [meq/L] in ground water from the 11 sampling points.

Figure 4. The relationship between the average dissolved magnesium and sodium contents or potassium contents [meq/L] in ground water from the 11 sampling positions.
dominant than Ca^{2+} + Mg^{2+} percentages. Therefore, the water samples taken in this area can be categorized as alkali rather than alkaline type. This again confirms that the groundwaters in Dakhla Oasis are nearly first grade soft water and suitable for all the citizens in that area and can be safely used for all their daily activities.

Concerning the most hazardous group of contaminants, five heavy metals are concerned namely As, Cd, Cr, Pb, and Mn. Those elements were selected based on the information provided by the USEPA (2007) which mentioned that they exert carcinogenic effects.

**Groundwater quality**

To evaluate the quality and acceptability of water in Dakhla Oasis for human consumption, water quality index (WQI) was established on some parameters computed following equations adapted from RadFard et al. (2019). According to equation (1), weight of each parameter (Wi) was calculated according to:

$$Wi = \frac{\sum wi}{\sum_{i=1}^{n} wi}$$  \hspace{1cm} (1)

Where

- $Wi =$ weight of each parameter.
- $wi =$ the relative weight for each parameter.
- $i =$ the number of parameters.

The quality rating scale for each parameter ($Qi$) is determined based on equation (2).

$$Qi = \frac{Cm/qi}{100}$$  \hspace{1cm} (2)

Where

- $Cm =$ the concentration of the element in groundwater in mg/L.
- $qi =$ is the World Health Organization (WHO) guideline for each parameter in mg/L.

Finally, equation (3) is applied to evaluate Water Quality Index

$$WQI = \sum Si$$  \hspace{1cm} (3)

Where

$$Si = WixQi$$

According to the Water quality Index Classification Ranges reported by RadFard et al. (2019), the water quality classification ranges and types of water are categorized as follows: the value <50 is excellent and good for human health. Between 50 and 100 is good and fit for human consumption. Range 100–200 is poor water and not in good condition while between 200 and 300 is very poor and needs attention before use. Finley >300 is inappropriate and needs attention before use. Therefore, it can be stated that the calculated WQI’s value for the groundwater of Dakhla Oasis is less than 50 (Table 6).

**Figure 5.** The relationship between the average dissolved sodium and potassium contents [meq/L] in ground water from the 11 sampling positions.

![Figure 5](image)

**Figure 6.** The average concentrations of Ca^{2+} and Mg^{2+} in the ground waters collected from the 11 sampling positions.

![Figure 6](image)

**Figure 7.** Rader diagram describing the relationships between the sums of K^{+} + Na^{+} % versus sums of Mg^{2+} % + Ca^{2+} % in the waters collected from the eleven outlets under investigation in Dakhla Oasis.

![Figure 7](image)
Hence, the water samples collected from the eleven locations under consideration are categorized as excellent water classes; consequently, they are recommended as good and safe for human utilization.

The total dissolved solids (TDS) in drinking water can affect its taste (Dietrich & Gallagher, 2013). The mean value of TDS in the water samples collected from the eleven outlets in the area under study amounted to 286 mg/L (Table 7). It was reported that the palatability of drinking water has been rated by panels of tasters in relation to its TDS level where the excellent water grade contains less than 300 mg/L (WHO, 2003). On the other hand, water with very low level of TDS may also be rejected because of its flat, insipid taste. As a result, the Dakhla Oasis’ groundwater with TDS = 286 mg/L is very close to the limit of WHO rating, definitely to be categorized as an excellent water. This confirms the same conclusion previously stated based on WQI calculations.

**Human health risk assessment**

**Chronic Daily Intake (CDI) and Health Risk indices (HR) for some selected elements**

According to the United States Environmental Protection Agency (USEPA) ingestion, inhalation and dermal contact are the main pathways for toxic and heavy metals to enter into the human body (USEPA, 2012). The presence of those metals inside the body can be a source of health risks. CDIs were computed for Sr, Na, K, Ca, Mg, Fe, and Ba. To quantify the HR accompanied by Fe, Mn, and Ba in drinking water sources of the area under investigation within Al Dakhla Oasis, a group of parameters were evaluated.

Chronic Daily Intakes (CDI) through the samples of the groundwater was calculated applying equation (4) adapted from Masok, Masiteng, Mavunda, and Maleka (2017).

\[
CDI = \frac{(Cm \times Ir)}{Bw} \tag{4}
\]

Where

- CDI = Chronic Daily Intake in mg/(kg- day).
- Cm = The concentrations of elements in groundwater in mg/L.
- Ir = Daily water ingestion rate in l, average value is 2.2 l.
- Bw = The mean body weight for the area residence is assumed to be 70 kg.

The chronic daily intake (CDI) values for the selected elements, namely, Sr, Na, K, Ca, Mn and Ba are depicted in (Table 7).

The CDIs of Sr in terms of groundwater consumption for adults are in the range of 0.002–0.0037 with mean value 0.00297 (mg/kg/day), Table 8. The lowest Na CDI value for adults was computed at 0.1758 from the sampling point No (7), while the highest Na CDI 0.64679 (mg/kg/day) for adults was found for the sampling outlet No (6). The mean value for Na CDI was 0.28682 (mg/kg/day). Similarly, the computed mean CDI for K was 0.37477 (mg/kg/day) for adult citizens in the area under investigation. The mean Ca CDIs in terms of groundwater consumption for adults in the eleven locations ranged from 0.99685 to 0.13997 (mg/kg/day). The highest Mg of 0.1415257 (mg/kg/day) for adults was analyzed for the sampling outlet No (4) with mean Mg CDI value of 0.16245 (mg/kg/day). The mean CDIs for Fe, Mn and Ba in terms of groundwater consumption for adults were very low and amounted to 0.00428, 0.000166, and 0.00419 (mg/kg/day), respectively. However, it should be noted that water from sampling points number (6) and (8) were Mn-free. (Table 8).

Comparing the data calculated for CDIs for the elements discussed with similar published results (Masok et al. (2017), Adesiyan, Bisi-Johnson,

**Table 6.** Calculated data for drinking groundwater quality index (WQI) of Dakhla Oasis based on (RadFard et al., 2019).

| Parameter No. | Factor | Factor weight | Factor content, average value | WHO, 2018 standard, qis | Wi | Qi | Si |
|---------------|--------|---------------|-------------------------------|--------------------------|-----|----|----|
| 1             | Na     | 3             | 9.3 mg/L                      | 20                       | 0.14286 | 4.65 | 0.66429 |
| 2             | K      | 2             | 12.1 mg/L                     | 12                       | 0.09524 | 100.8 | 9.6  |
| 3             | Ca     | 3             | 3.8 mg/L                      | 75                       | 0.14286 | 5.1  | 0.72857 |
| 4             | Mg     | 2             | 5.2 mg/L                      | 50                       | 0.09524 | 10.4 | 0.99048 |
| 5             | EC     | 3             | 37.4 μS/cm (mean value)        | 1500 μS/cm               | 0.14286 | 16.7 | 2.38571 |
| 6             | TDS    | 5             | 250.7 mg/L (mean value)        | 500 mg/l                 | 0.2381  | 57.2 | 13.619 |
| 7             | pH-value | 3          | 6.34 (mean value)              | 7.5                      | 0.14286 | 84.5 | 12.0714 |
|               | Ground Water Quality (WQI) |               |                               |                          | 40.0595   |     |     |

**Table 7.** Chronic Daily Intake (CDI) in mg/kg (BW) per day for the predominated elements through drinking water from the 11 outlets in Dakhla Oasis.

|          | 1     | 2     | 3     | 4     | 5     | 6     | 7     | 8     | 9     | 10    | 11    |
|----------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Sr       | 0.00313 | 0.00305 | 0.00219 | 0.002 | 0.00261 | 0.00276 | 0.0027 | 0.00291 | 0.00367 | 0.00362 | 0.00361 |
| Na       | 0.22129 | 0.32535 | 0.27616 | 0.27561 | 0.32889 | 0.64679 | 0.17658 | 0.18939 | 0.24371 | 0.24298 | 0.23464 |
| K        | 0.37664 | 0.35898 | 0.44828 | 0.4438 | 0.43879 | 0.18964 | 0.45906 | 0.46504 | 0.30994 | 0.3089 | 0.30101 |
| Ca       | 0.11466 | 0.11959 | 0.11192 | 0.10458 | 0.11552 | 0.13997 | 0.09685 | 0.1155 | 0.12884 | 0.12001 | 0.1364 |
| Mg       | 0.1473 | 0.17275 | 0.14454 | 0.14152 | 0.16883 | 0.19474 | 0.14298 | 0.15109 | 0.17622 | 0.17611 | 0.1709 |
| Fe       | 0.02211 | 0.00029 | 0.0015 | 0.0007 | 0.00593 | 0.00023 | 0.00143 | 0.0003 | 0.001135 | 0.00097 | 0.00231 |
| Mn       | 0.00264 | 0.00236 | 0.00314 | 0.00045 | 0.00345 | 0.00109 | 0.000505 | 0.000346 | 0.000293 | 0.00003 | 0.00018 |
| Ba       | 0.00479 | 0.00582 | 0.00422 | 0.0032 | 0.00345 | 0.00109 | 0.000505 | 0.000346 | 0.000293 | 0.00003 | 0.00018 |
| Sum      | 0.89256 | 0.98864 | 0.99195 | 0.97186 | 1.06352 | 1.17522 | 0.88721 | 0.94741 | 0.88219 | 0.8573 | 0.85398 |
Aladesanmi, Okoh, and Ogunfowokan (2018) and RadFard et al. (2019) it can be concluded that the groundwater samples from the studied area are very safe for consumption by the population in Dakhla Oasis. Moreover, the CDI data approved the results previously obtained for WQI and TDS and confirmed the safety and suitability of water at the studied location for human consumption.

The annual exposure to the element due to ingestion (EPX\textsubscript{ing}) or dermal (EPX\textsubscript{der}) were calculated using equations (5) and (6), respectively (USEPA, 2007).

\[
\text{EXP}_{\text{ing}} = \frac{(\text{Cm} \times \text{Ir} \times \text{Ef} \times \text{Ed})}{(\text{Bw} \times \text{At})} \tag{5}
\]

\[
\text{EXP}_{\text{der}} = \frac{(\text{Cm} \times \text{Ir} \times \text{Ef} \times \text{Ed} \times \text{Sa} \times \text{Pc} \times \text{Cf})}{(\text{Bw} \times \text{At})} \tag{6}
\]

Where

\[
\text{EXP}_{\text{ing}} = \text{annual exposure to the metals due to ingestion in (mg/kg/day)}.
\]

\[
\text{EXP}_{\text{der}} = \text{annual exposure to the metals due to dermal exposure in (mg/kg/day)}.
\]

\[
\text{Cm} = \text{The concentrations of element in groundwater in mg/L}.
\]

\[
\text{Ef} = \text{the exposure frequency in days/year, 365 days is the considered value}.
\]

\[
\text{Ed} = \text{the exposure duration in years, the mean value is 70 years and 30 years for calculating EXP}_{\text{ing}} \text{and EXP}_{\text{der}}, \text{respectively}.
\]

\[
\text{Sa} = \text{skin surface area in cm}^2 \text{proposed mean value as 28,000 cm}^2 \text{for adult}.
\]

\[
\text{Pc} = \text{dermal permeability coefficient in cm/hour}.
\]

\[
\text{Cf} = \text{unit conversion factor l/cm}^3 \text{and puts as 0.001}.
\]

\[
\text{Bw} = \text{The mean adult body weight for the area residence, assumed to be 70 kg}.
\]

\[
\text{At} = \text{average exposure time in days and puts as 25,550 day for adult}.
\]

Hazard Indices (HIs) for three elements viz Fe, Mn, and Ba that were detected in groundwater from the eleven sampling points and are susceptible to be potential sources of hazards for the residents in the area for ingestion and dermal pathways were computed according to the equations (7) and (8).

\[
\text{H}_{\text{ing}} = \sum_{i=1}^{n} \text{EXP}_{\text{ing}}(n) / \text{RD}_{\text{ing}}(n) \tag{7}
\]

Where

\[
\text{H}_{\text{ing}} \text{is the Hazard Index (unitless) post ingestion of the n different elements and } \text{Exp}_{\text{ing}}(n), \text{RD } (n) \text{are the values for individual element}.
\]

\[
\text{H}_{\text{der}} = \sum_{i=1}^{n} \text{EXP}_{\text{der}}(n) / \text{RD}_{\text{der}}(n) \tag{8}
\]

The variable values of parameters for Fe, Mn and Ba required to evaluate their HIs are represented in (Table 9).

\text{HI der} \text{is the Hazard Index (unitless) due to dermal exposure with the n different elements in water and Exp (der) } n, \text{RD (der) } n \text{are the values for individual element.RDing and RDder are reference doses for ingestion (ing) and dermal (der) pathways, respectively, in units of (mg/kg/day).}

It is well known that the hazard index values were scaled as follows: if RI is \textless 1, it means no health risk upsets; while RI \textgreater 1 indicates health risk due to the element’s presence. Masok et al. (2017).

(Table 10) presents the hazard indexes for ingestion and dermal pathways in all sampling locations. Both HI
ing and HI
der for individual element, namely: Fe, Mn & Ba. Therefore, it can be stated that at present there is no hazard risks concern for the population when consuming the water under consideration, even for drinking purposes.

The noted low hazard indices for all water sources collected from the area under investigation can be attributed to the non-detected concentrations of most hazardous elements, also to the low contents of the detected elements in water samples. Table 4. This can be referred to the ability of groundwater in this area to purify itself by the residence time in its aquifer as a consequence of natural interaction processes as dilutions, ion exchanges, precipitation, and sedimentations, which was previously stated (IAEA, 2013; Saha, Singh, Srivastavai, Dwivedi, & Mukherjee, 2014).

A comparison between the percentage of numbers of the normal and abnormal levels of urea, creatinine, and CEA for males and females are represented in the following diagrams in Figure 8. The biological results show a low percentage of abnormal kidney biomarkers in

| Table 8. Minimum, maximum, and average values for chronic daily intake (CDI) in mg/kg (BW-day) for the predominant elements through drinking water from the 11 outlets. |
|-----------------|-----------------|-----------------|-----------------|
| Element | Minimum* | Maximum* | Mean |
| Sr | 0.002 (4) | 0.00367 (9) | 0.00297 |
| Na | 0.17568 (7) | 0.64679 (6) | 0.28682 |
| K | 0.18964 (6) | 0.48504 (8) | 0.37455 |
| Ca | 0.09685 (7) | 0.13997 (6) | 0.11853 |
| Mg | 0.14152 (4) | 0.19744 (6) | 0.16245 |
| Fe | 0.00023 (6) | 0.02211 (1) | 0.00428 |
| Mn/9 or 11 | 0 (668) | 0.00045 (5) | 0.00166 |
| Ba | 0.00109 (6) | 0.00582 (2) | 0.00419 |
| Sum | 0.85398 (1) | 1.17522 (9) | 0.95562 |

* The number in brackets refers to the number of sample outlet position

| Table 9. Dermal permeability coefficient and RD\textsubscript{ing} and RD\textsubscript{der} pathways for Fe, Mn and Ba. |
|-----------------|------------------|------------------|------------------|
| Element | Reference doses (RD), mg/ (kg·day) | Dermal permeability, cm/hour |
| Fe | 0.70 | 0.140 | 0.001 |
| Mn | 0.024 | 0.001 | 0.001 |
| Ba | 0.07 | 0.014 | 0.001 |
males and 100% normal females, since the normal urea level is 5–20 mg/dL, and the normal creatinine level is 0.5–1.5 mg/dL (Tietz, 1990). Males and females CEA were by 100% in the normal range, since all results were less than 5 mg/mL (Westgard et al., 1981). These results confirm the previous conclusion that the groundwater in the areas under study has no health threats to the citizens there.

**Conclusion**

Based on the experimental analysis carried out for chosen 21 elements in groundwater samples collected from eleven locations within the Dakhla Oasis, it can be concluded that six elements, viz. the heavy metals Ag, Cd, Cu, Cr, Co, and Ni not detected at all. Eight elements, namely: Sr, Na, K, Ca, Mg, Fe, Mn and Ba were found in nearly all the investigated water samples. The remaining seven elements Al, Pb, Se, Cs, As, Zn and V were detected in some, but not in all samples. Anyhow, for the last fifteen elements, their concentrations were monitored in all the water samples, noteworthy, they were lower than the permitted values recommended by WHO and other associations, even lower than concentrations recommended for drinking water. The obtained results further depicted that anthropogenic activities in or near the Dakhla Oasis exert non-significant health risks to the local population in terms of elements assumed to cause health threats when taken up through water consumption. Moreover, groundwater supplies in the studied area can be a precious source of Mg and Ca for Dakhla Oasis’ population in their diet, especially for those who are insufficiently supplied with these two elements. Through the Water Quality Index (WQI), Chronic Daily Intake (CDI), and Health Risk Index (HR) parameters calculated, the present study can be helpful for both residents, in taking protective measures.

| Element | Cm,<sup>*</sup> mg/ kg. day | EPX ing, mg/ kg. day | EXP der, mg/ kg. day | EXPing RDing | EXPder RDder |
|---------|-----------------|-----------------|-----------------|------------|------------|
| Fe      | 0.0744          | 2.3 E-3         | 2.81E-5         | 0.0033     | 20.07E-5   |
| Mn      | 0.0058          | 1.8E10-4        | 0.219E-5        | 0.0078     | 228.13E-5  |
| Ba      | 0.1589          | 0.00499         | 5.99E-5         | 0.0713     | 427.9E-5   |
| Sum     | 0.1589          | 0.00499         | 5.99E-5         | 0.0713     | 427.9E-5   |

**Table 10.** Hazard indices assessment of elements through ingestion and dermal pathways.

![Figure 8](image_url). The ratio percentage numbers between normal and abnormal of serum urea (a), creatinine (b) and CEA (c) for males and females in random population samples from Mut point.
measures before water consumption, and for the local authorities, to evaluate the various fundamental contributions for safety in rural drinking groundwater supplies.

The authors, according to the outcomes of their experimental work, recommend that regular monitoring is essential in order to secure excellent drinking water quality, according to the WHO, to consumers in the studied areas. There are insufficient data suggested for minimum and maximum uptake levels for various elements; moreover, there are no official guideline values to be followed. Therefore, further studies are needed to ensure up-to-date data for both residents and officials. However, it is also recommended that considerable efforts must be made to sustain and further improve environmental analyses techniques, in addition, safety regulations need to be introduced by governorate, official services, and industrial managements aiming at keeping all elements concentrations in groundwater bodies within its aquifers specification at the levels permitted. In addition, consumers should be informed about the elemental composition of their water when it has been altered by piped suppliers or treatment plants.

Abbreviations

EC: Electrical Conductivity; TDS: Total Dissolved Solids; ICP-OES: Inductively Coupled Plasma Optical Emission Spectrometer; LD: Low Detection Limit; BDL: Below Detection Limit; RSD: Relative Standard Deviation Percent; CDI: Chronic Daily Intake; WQI: Water Quality Index; HR: Hazard Risk; HI: Hazard Index; RD: Reference Doses; CKD: Chronic Kidney Disease; CEA: Carcinoembryonic Antigen; RIA: Radioimmunoassay; WHO: World Health Organization; USEPA: Environmental Protection Agency, USA; EAEA: Egyptian Atomic Energy Authority.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Data availability statement

The data used to support the findings of this study are included within the article.

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