

Assessment of Groundwater Pollution with Heavy Metals based on Pollution Index and Investigation of Groundwater Quality Using Water Quality Index in Western Nile Delta, Egypt

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Abstract: Evaluation of ground water in Al-Beheira Governorate (Western Nile Delta), Egypt; assessment of groundwater quality of 12 wells for drinking purposes, assessment of heavy metals, estimation of water quality index, heavy metal pollution index, and heavy metal evaluation index had been carried out. Biological and physico-chemical parameters of different wells at different zones were analyzed. All wells under consideration are free from fecal coliform and organisms. The values of all physico-chemical parameters for 12 wells under consideration are found to be less than the maximum permissible limits except wells No.2, 4, 6, 8 and 11. They are containing greater manganese than the recommended level in drinking water as listed by World Health Organization (WHO) and Egyptian Ministry Health (EMH) Water Quality Standards. Well No. 2 also has greater lead content than the recommended level in drinking water as listed by WHO and EMH. Removal of manganese of wells No.2, 4, 6, 8 and 11 and lead of well No. 2 is recommended before using these wells for drinking purposes. According to WHO standards and on the basis of the WQI values, in the parts including wells No.1, 3, 5, 7, and 9 of the study area, water fall into good water category; which is 41.66% of the total area. The excellent water in the study area is about 25% including wells 6,10, and 12. Wells No. 4 and 8 are classified as poor water quality; whereas wells No. 2 and 11 are classified as very poor water quality in the study area; which is about 33.34 %.According to EDWS, in the parts which include wells No. 1, 3, 5, 6, 7, 9, 10, and 12 of the study area, water fall into excellent water category which is 66.66 % of the total area; while good water is about 25 % of the total area and include wells No. 2,4 and 8. The well No. 11 is classified as poor water quality, which is about 8.34 % of the total area, thus all wells under consideration are suitable for drinking, except well No. 11.According to heavy metal pollution index (HPI); all wells in study area were classified as low heavy metals, except well No. 2; where heavy metal pollution is high and its water not potable. While, according to heavy metal evaluation index (HEI), all wells under consideration are classified as low heavy metals content.

Keywords: Groundwater, Assessment, Pollution index, Water quality index, Western Nile, Egypt

1.Introduction

Ground water is an important source of water supply throughout the world; the most important reasons are the non-availability of potable surface water [1]. Water quality refers to the physical, chemical and biological characteristics of water[2]. The quality of ground water is controlled by several factors including climate, soil characteristics, rock types, topography of the area, human activities [3]. Most of ground water researches focused on the salt water intrusion [4, 5], ground water salinization [6], the sustainability of aquifer exploitation [7], ground water quality evaluation [8], arsenic and other heavy metals in ground water [9]. Groundwater can be polluted by entering of contaminated surface water [10].In the last few years, pollution of water by heavy metals has been a global concern [11].Sources of heavy metals in water may be natural or human resources. The main human sources of heavy metals in water are wastewater, and the industrial wastes produced from mining and steel factories. Many of these heavy metals such as Hg, Ni, Cd, As, Sn, Zn, Co, Cu, Cr, Pb, Fe, and Mn,have a detrimental effect on human health[12].

Water contamination of heavy metals and the viability of water for human consumption were assessed using various pollution indices [13], such as Heavy metal pollution index

(HPI) and Heavy metal evaluation index (HEI). These indices can provide a single indicator of water quality based on some very important parameters[14]. Many researches about Water Quality indexes have been reported for lake environments [15], river flows [16], and coastal areas [17]. Horton, at the middle of the past century[18] was the first researcher to suggest the advantages of calculating a WQI. A WQI can be affected by physical, chemical and biological factors [19]. Water Quality Index (WQI) is a very useful tool for communicating the information on the overall quality of water [20], and to determine the suitability of the groundwater for drinking purposes [20, 21].

2.Experimental

2.1. Monitoring sites

Western Nile Delta region is located between 29°30' to 31° 00' E and 30° 00' to 31° 00' N. It occupies the area between Cairo at equator and Alexandria, west of Rosetta branch, and extends westward to the desert area from the west of Wadi el-Natrun up to the eastern edge of the Qattara Depressant. Topographic data is available from survey maps of scale 1:100,000 for most of Nile Delta area. The elevation of the area ranges from (0.00) mean sea level in the north to (150.00) above mean sea level in

the south. The existing irrigation networks in the study area consists of six main irrigation canals, namely the Rosetta branch, Rayah Behiri, Rayah Nasery, Nubaria canal, Mahmoudia canal and El Nasr canal. The climate of the study area can be classified as predominantly Mediterranean. The average temperature varies from 14 to 32°C in months of July and Augus. The location of Western Nile Delta is shown in Figure1.

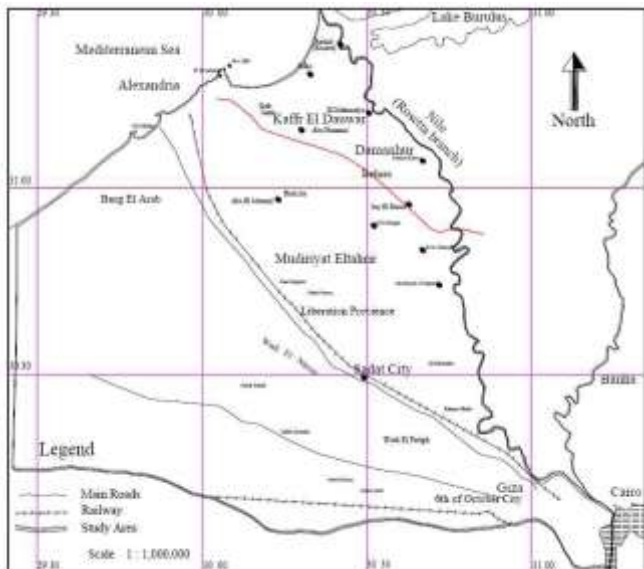


Figure 1: Domain of Study – Western Nile Delta

Beheira governorate is a costal governorate in Egypt, it is located in northern part of the country in the Nile Delta, and its capital is Damanhur. Beheira governorate enjoys an important strategically place in west of the Rosetta branch of the Nile. It is bounded by Mediterranean (north), by Alexandria Governorate (north western), by Matrouh Governorate (west) and by Giza (south Western), by Menoufia(east) and by Kafr Al Sheikh governorate (north eastern) ; two main Roads runs through the Beheira Governorate are Cairo-Alexandria desert Road and agricultural Road (Fig2).



Figure 2: The geographical location of Al- Beheira governorate

2.2. Collection and analysis of water samples

Twelve wells of different villages in Beheira governorate were selected for the studies (Table 1).

Table 1: Locations of wells under consideration

| Well No. | Location |
|----------|----------------|
| 1,2,3 | Magnine |
| 4,5 | Zawyet El Bahr |
| 6,7,8 | El Toude |
| 9 | El Hadain |
| 10 | Kerbeta |
| 11 | Netma |
| 12 | El Negila |

Water samples were collected using poly ethylene bottles; which were washed with tap water at the first and then were rinsed using double deionizes water. Sterile bottles were used to collect samples used in the analysis of feascal coliform and organisms. The water samples were collected from varies places at the studied area. Temperature, pH, E.C, and TDS were measured immediately. Then the samples were transported to the laboratory for further analyses after its treatment with 0.5 % chloroform as a preservative material [22]. For analyses, all the instruments were calibrated using international grade calibration standards prior to the measurements. The used instruments are:

- i) The pH value was measured immediately after the sample collection, using a calibrated pH meter instrument (Hanna instrument HI 8519 N).
- ii) Turbidity was measured using turbidity meter {potable water analysis instrumentation (HACH)}.
- iii) E.C, TDS, and temperature were measured after the sample collection using the con. TDS. C° meter (Cyber scan 200 CON).
- iv) The determenation of Na and K concentration was made by the flame photometer model 410, England.
- v) The determination of heavy metals concentration was made by Pinnacle 900H atomic absorption spectrometer.
- vi) The concentration of sulfate was determined turbidmetrically (Standard methods, 1995) using the acetic-acetate buffer media at pH=10.1 by measuring the absorbance at $\lambda = 420$ nm by the aid DR/2000 spectrophotometer (HACH, GERMANY).

The samples were analyzed for feascal coliform, organisms, pH, total hardness (TH), calcium hardness (CaH), magnesium hardness (MgH), electrical conductivity (EC), total dissolved solids (TDS), calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), potassium (K^{+}), bicarbonate alkalinity (HCO_3^{-}), carbonate (CO_3^{2-}), chloride (Cl^{-}), sulfate (SO_4^{2-}), NO_3^{-} , NH_4^{+} , dissolved inorganic orthophosphate, copper, cadmium, chromium, zinc, lead, iron and manganese using the standard methods by the American Public Health Association (APHA) [22, 23]. The taste, color, odor, and turbidity were observed organoleptically. All analyses were done in will equipped laboratories of El-Beheira Governorate Water Company by specialized technicians; through projects ascertained to search for new potable water resources.

3.Results and Discussion

3.1 Assessment of groundwater quality for drinking purposes

Tables (2, 3) show the analyses parameters data of the water samples.

Table 2: Some physicochemical and biological parameters of ground water samples for wells under consideration

| Well No. | Faecal Coliform and Organisms | Temp. (°C) | Color | Taste | Odors | pH | Turbidity NTU | E.C (µS cm ⁻¹) | TDS (mg L ⁻¹) |
|----------|-------------------------------|------------|-----------|-----------|----------|-----|---------------|----------------------------|---------------------------|
| 1 | Nil | 25 | Colorless | Tasteless | Odorless | 7.3 | 0.400 | 551 | 369 |
| 2 | Nil | 27 | Colorless | Tasteless | Odorless | 7.8 | 0.300 | 811 | 543 |
| 3 | Nil | 26 | Colorless | Tasteless | Odorless | 7.5 | 0.500 | 596 | 399 |
| 4 | Nil | 26 | Colorless | Tasteless | Odorless | 7.9 | 0.200 | 946 | 634 |
| 5 | Nil | 26 | Colorless | Tasteless | Odorless | 7.7 | 0.500 | 1077 | 722 |
| 6 | Nil | 26 | Colorless | Tasteless | Odorless | 7.7 | 0.800 | 680 | 456 |
| 7 | Nil | 27 | Colorless | Tasteless | Odorless | 7.2 | 0.200 | 434 | 291 |
| 8 | Nil | 26 | Colorless | Tasteless | Odorless | 7.2 | 0.100 | 440 | 295 |
| 9 | Nil | 25 | Colorless | Tasteless | Odorless | 7.8 | 0.200 | 778 | 521 |
| 10 | Nil | 27 | Colorless | Tasteless | Odorless | 7.7 | 0.100 | 710 | 476 |
| 11 | Nil | 25 | Colorless | Tasteless | Odorless | 7.6 | 0.800 | 560 | 375 |
| 12 | Nil | 26 | Colorless | Tasteless | Odorless | 7.3 | 0.600 | 496 | 332 |

NTU = nephelometric turbidity unit(s)

Table 3: Some Chemical parameters of ground water samples for wells under consideration

| Concentrations of chemical parameters (mg L ⁻¹) | | | | | | | | | | | | | | |
|---|-----|-----|-----|------------------|------------------|----------------|-----------------|-------------------------------|-------------------------------|-------------------------------|-----------------|------------------------------|------------------------------|-------------------------------|
| Well No. | TH | CaH | MgH | Ca ²⁺ | Mg ²⁺ | K ⁺ | Na ⁺ | HCO ₃ ⁻ | CO ₃ ²⁻ | SO ₄ ²⁻ | Cl ⁻ | NH ₄ ⁺ | NO ₃ ⁻ | PO ₄ ³⁻ |
| 1 | 230 | 120 | 110 | 48 | 27 | 10 | 80 | 220 | 0.20 | 31 | 40 | 0.3 | 0.02 | 0.20 |
| 2 | 330 | 210 | 120 | 84 | 29 | 16 | 100 | 320 | 3.00 | 42 | 65 | 0.20 | 0.02 | 0.30 |
| 3 | 326 | 196 | 130 | 78 | 32 | 8.00 | 86 | 224 | 2.1 | 15 | 48 | 0.18 | 0.020 | 0.45 |
| 4 | 360 | 200 | 160 | 80 | 39 | 16 | 110 | 350 | 3.3 | 31 | 110 | 0.00 | 0.03 | 0.10 |
| 5 | 400 | 250 | 150 | 100 | 37 | 20 | 118 | 320 | 3.00 | 28 | 147 | 0.10 | 0.03 | 0.20 |
| 6 | 340 | 220 | 120 | 88 | 29 | 16 | 180 | 280 | 2.6 | 54 | 62 | 0.2 | 0.1 | 0.30 |
| 7 | 180 | 90 | 90 | 36 | 22 | 12 | 100 | 176 | 0.17 | 9.00 | 43 | 0.45 | 0.05 | 0.09 |
| 8 | 162 | 92 | 70 | 37 | 17 | 12 | 60 | 178 | 0.17 | 10 | 40 | 0.28 | 0.004 | 0.10 |
| 9 | 305 | 175 | 130 | 70 | 32 | 20 | 150 | 300 | 2.8 | 100 | 67 | 0.1 | 0.03 | 0.45 |
| 10 | 300 | 170 | 130 | 68 | 32 | 12 | 100 | 290 | 2.7 | 24 | 60 | 0.65 | 0.02 | 0.09 |
| 11 | 280 | 130 | 150 | 52 | 37 | 18 | 100 | 260 | 2.44 | 16 | 40 | 0.90 | 0.10 | 0.10 |
| 12 | 220 | 110 | 110 | 44 | 27 | 15 | 80 | 210 | 0.20 | 7.00 | 25 | 0.80 | 0.01 | 0.09 |

The physicochemical parameters of the ground water quality data were statistically analyzed and the results are recorded in Table 4 in form of minimum, maximum, mean and standard deviation.

Table 4: Statistical summary of the Hydro geochemical parameters

| Parameters | Min. | Max. | Mean | SD |
|---|-------|-------|---------|---------|
| Temp. | 25 | 27 | 26 | 1.00 |
| Turbidity | 0.1 | 0.8 | 0.391 | 0.249 |
| pH | 7.2 | 7.9 | 7.558 | 0.254 |
| EC($\mu\text{s}/\text{cm}$) | 434 | 1077 | 673.25 | 201.259 |
| TDS(mg L^{-1}) | 291 | 722 | 451.08 | 134.92 |
| TH(mg L^{-1}) | 162 | 400 | 286.03 | 73.62 |
| CaH(mg L^{-1}) | 90 | 250 | 163.58 | 53.84 |
| MgH(mg L^{-1}) | 90 | 160 | 122.5 | 39.15 |
| HCO_3^- (mg L^{-1}) | 176 | 350 | 260.66 | 55.8 |
| CO_3^{2-} (mg L^{-1}) | 0.17 | 3.3 | 1.89 | 1.13 |
| Cl^- (mg L^{-1}) | 25 | 147 | 62.25 | 32.84 |
| SO_4^{2-} (mg L^{-1}) | 7.00 | 100 | 30.58 | 24.41 |
| Ca^{2+} (mg L^{-1}) | 36 | 100 | 65.4 | 20.544 |
| Mg^{2+} (mg L^{-1}) | 17 | 39 | 30.00 | 5.82 |
| Na^+ (mg L^{-1}) | 60 | 180 | 105.3 | 23.24 |
| K^+ (mg L^{-1}) | 8 | 20 | 14.58 | 10.6 |
| Fe^{2+} (mg L^{-1}) | 0000 | 0.148 | 0.0810. | 0.063 |
| Mn^{2+} (mg L^{-1}) | 0000 | 2.13 | 0.458 | 0.67 |
| Cr^{3+} (mg L^{-1}) | 0000 | 0000 | 0000 | 0.00 |
| Cu^{2+} (mg L^{-1}) | 000 | 0.04 | 0.0003 | 0.001 |
| Zn^{2+} (mg L^{-1}) | 0000 | 000 | 0000 | 0.000 |
| Ni^{2+} (mg L^{-1}) | 0000 | 000 | 0000 | 0.00 |
| Pb^{2+} (mg L^{-1}) | 0000 | 0.26 | 0.031 | 0.068 |
| NO_3^- (mg L^{-1}) | 0.004 | 0.10 | 0.036 | 0.03 |
| PO_4^{3-} (mg L^{-1}) | 0.09 | 0.45 | 0.205 | 0.13 |
| NH_4^+ (mg L^{-1}) | 0.00 | 0.90 | 0.346 | 0.273 |

The results give the abundance of the cations in the following order: $\text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+ > \text{NH}_4^+$, while those of the anions are in the following order: $\text{HCO}_3^- > \text{Cl}^- > \text{SO}_4^{2-} > \text{CO}_3^{2-} > \text{PO}_4^{3-} > \text{NO}_3^-$ (Table 3). Sodium is the dominant cation in the ground water of the study area, its concentration ranges from 60 to 180 mg L^{-1} , with mean value of 105.30 mg L^{-1} (Tables 3 and 4). The minimum value of sodium concentration was recorded in well No.11; while the maximum value was recorded in well No. 3. The high values of sodium concentration may be due to excess bicarbonate anion which causes a release of the alkali ions (Na^+) into the water by exchanger such as clay materials and other related minerals that form part of the aquifer minerals [23-26]. The values of sodium concentration in all wells under consideration are below the listed recommendation of WHO [24] standards (200 mg L^{-1}) and Egyptian Ministry Health (EMH) [25] Water Quality Standards (200 mg L^{-1}). The high value of calcium concentration was recorded in well No. 7, this high value of calcium concentrations, probably due to: i) the discharge of calcium rich effluents, ii) domestic, agricultural and industrial wastes [27]. The decreasing of calcium content ($< 44 \text{ mg L}^{-1}$) is due to the seepage of freshwater from the river Nile and irrigation system [28]. According to EMH Water Quality Standards [25], the values of calcium concentration for all wells in our study zones are below the recommended guideline of Egypt (200 mg L^{-1}). The concentration values of magnesium of the wells at the studied zones are in the range between 17 to 39 mg L^{-1} , with mean value of 30 mg L^{-1} (Tables 3 and 4).

The increasing of magnesium concentration may be due to mixing with of Moghara aquifer [24]. Leaching processes of clay that is lagoon and marine in origin add more magnesium [29]. According to the listed recommendation of WHO [24], the maximum acceptable level of magnesium in drinking water is 30 mg L^{-1} , thus all wells under consideration are suitable for drinking except wells No. 2,4,5,6,7 and 10; While according to EMH Water Quality Standards[25], the maximum acceptable level of magnesium in drinking water is 150 mg L^{-1} , and, the values of magnesium content for all wells at our study zones are less than this level. Potassium with concentration values ranges from 8.00 mg/l in well No. 10 to 20 mg L^{-1} in wells No. 2 and 7, while the mean value is 10.6 mg L^{-1} (Table 3, 4 and Figure 8). The High level of potassium may be attributed to the ground water contaminated by Potassium fertilizers [27]. The WHO [24] and Egyptian Ministry Health (EMH) Water Quality Standards[25] list 10 mg L^{-1} as a guideline for potassium in drinking water. Thus, only wells No. 1 and 2 are below the listed recommendation, while the remaining wells are higher than 10 mg L^{-1} .

3.1.1 Assessment of physicochemical and biological parameters

The results showed that all water samples of all wells in all zones were colorless, odorless, and tasteless. Also samples of all wells under consideration are negative for faecal coliform and organisms. The pH values of all wells under test are given in Fig (3). The pH values ranged between

7.2 in wells No. 8, 11 and 7.9 in well No. 5 and indicate alkaline water in all wells under study (Table 2 and Fig 3).

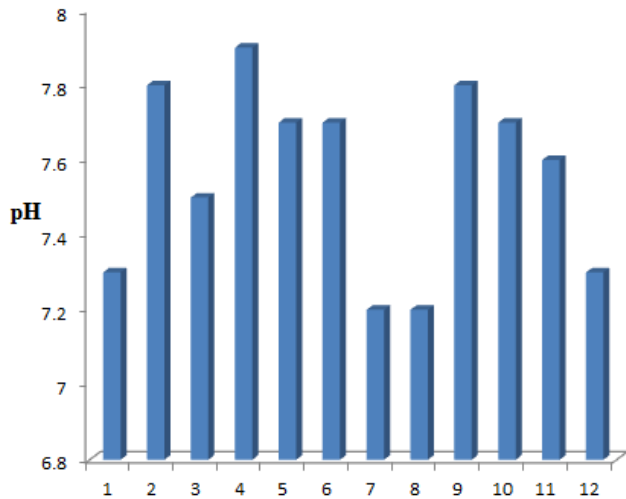


Figure 3: Variation of pH in the wells under consideration

Generally the deviations in the pH value from 7 are primarily the result of the hydrolysis of salts not originated from strong bases and strong acids [23].

The variation of turbidity values in all wells under consideration are given in Fig 4; the turbidity ranged from 0.100 (NTU) for wells No. 4, 11 to 0.80 (NTU) for wells numbers 3, 6. According to WHO [24] and EMH Water Quality Standards [25], the turbidity and pH values for all wells under consideration are lower than the prescribed limits (Table 2 and Figure 4).

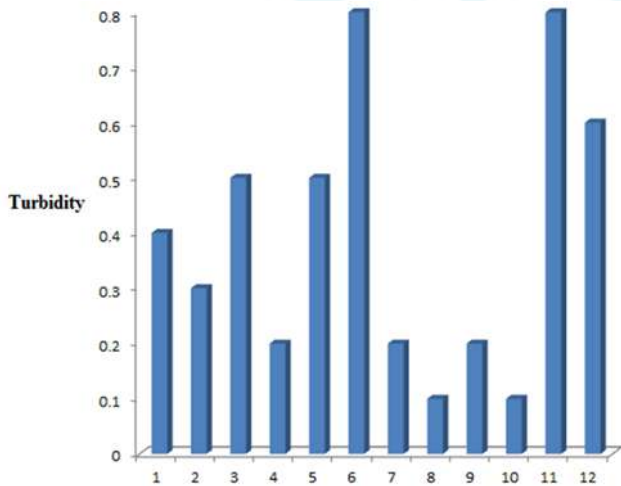


Figure 4: Variation of turbidity in the wells under consideration

Figs 5 and 6 show the variation of Electrical conductivity (EC) and Total Dissolved Solid (TDS) values respectively.

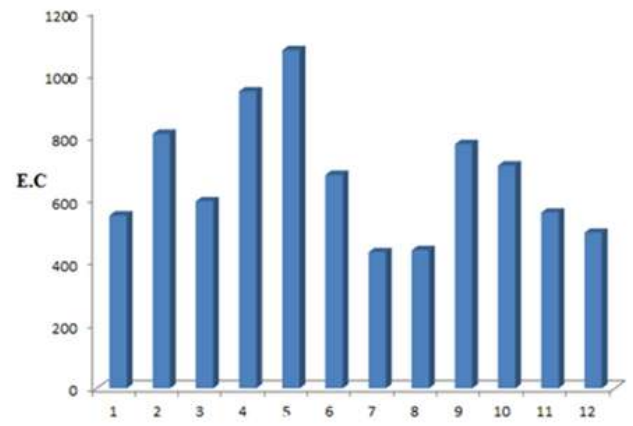


Figure 5: Variation of electrical conductivity in the well under consideration

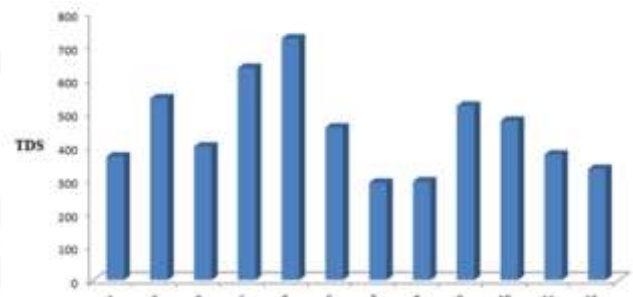


Figure 6: Variation of total dissolved salts in the wells under consideration

Tables 2, 4 and Fig 5 show that the electrical conductivity (EC) ranged from 434 for well No. 7 to 1077 $\mu\text{S cm}^{-1}$ for well No. 5. The increase of EC value is mainly related to the effect of pollution; which increases the concentrations of Ca^{2+} , Mg^{2+} , HCO_3^{2-} and Cl^- [23]. The WHO and EMH did not list any recommendation for the permissible or maximum level of electrical conductivity in drinking water.

Hardness of water limits its use for domestic, industrial and agricultural activities. Water hardness can cause scaling of pots, boilers and irrigation pipes; it may also cause health problems to humans such as kidney failure [30]. Water hardness mainly depends upon the amount of calcium or magnesium salts or both [31]. In the present study the total hardness values varied from 162 mg L^{-1} in well No. 11 to 400 mg L^{-1} in well No. 7, with mean value of 286.03 mg L^{-1} (Table 3, 4 and Figure 7).

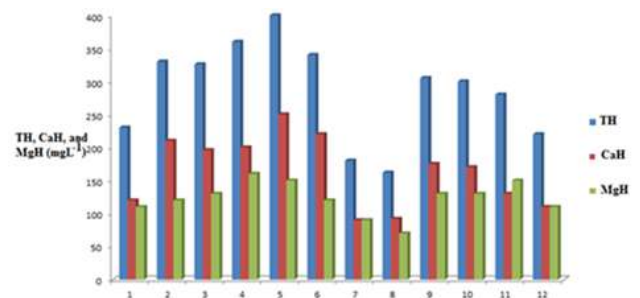


Figure 7: Variation of TH, CaH and MgH in the wells under consideration

Table 5 indicates hardness of the ground water under consideration ranged from hard to very hard water [32].

Table 5: Ground water classification based on total hardness (Sawyer and McCarty 1967)[32]

| Total hardness as CaCO ₃ (mg L ⁻¹) | Classification |
|---|-----------------|
| <75 | Soft |
| 75-150 | Moderately hard |
| 150-300 | Hard |
| >300 | Very hard |

The wells 2, 3, 5, 7, 9, and 10 of the study area are characterized by very hard water while the wells No. 1, 4, 6, 8, 11 and 12 are characterized by hard water. The high total hardness would lead to heart disease and kidney stone formation [31]. Calcium hardness in our study ranged between 90 mg L⁻¹ for well No. 8 and 250 mg L⁻¹ for well No. 7 with mean value of 163.58 (Table 3,4 and Fig 7). Also magnesium hardness in all wells under consideration was ranged between 70 mg L⁻¹ for wells No. 11 and 160 mg L⁻¹ for well No. 5 with mean value of 122.5 (Table 3,4 and Figure 7). TDS in our study ranged between 291 mg L⁻¹ for well No. 8 and 722 mg L⁻¹ for well No. 7 with mean value of 451.08 (Table 2,4 and Fig 6).

Fig 8 shows the variation of Ca, Mg, Na, and K ions in the wells under consideration.

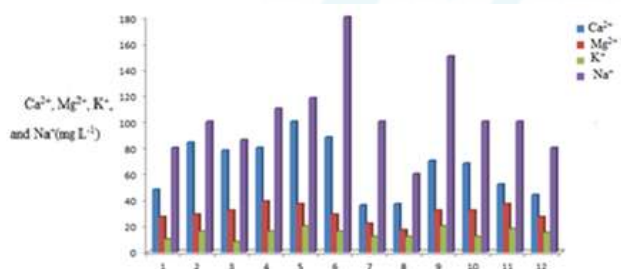


Figure 8: Variation of Ca, Mg, Na and K in the wells under consideration

Salts of calcium, magnesium, sodium and potassium present in irrigation water may pose to be injurious to plants [33]. The authors went further to stress that salts from the major ions when present in excess quantities can affect the osmotic activities of the plants and may prevent adequate aeration [34]. The higher groundwater nitrate concentrations can originate from different sources, such as sewage leaks, chemical facilities, or animal feedlots [35]. Numerous studies [36] have linked the raise of nitrate concentrations in groundwater to high population densities and urban development.

Bicarbonate dominates the anionic components of the ground water under consideration, the bicarbonate concentration in the ground water under consideration are ranged between 176 mg L⁻¹ of well No. 8, and 350 mg L⁻¹ for well No. 5 with mean value 260.66 (Tables 3 and 4, Fig 9).

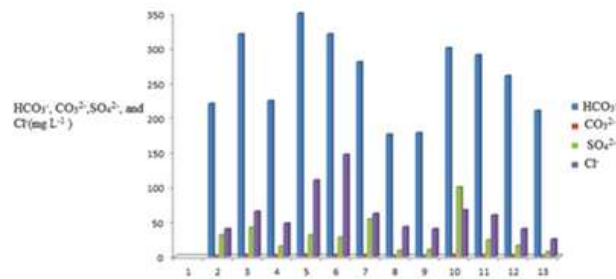


Figure 9: Variation of HCO₃⁻, CO₃²⁻, SO₄²⁻ and Cl⁻ in the wells under consideration

The source of the bicarbonate in the wells can be attributed to the carbon dioxide gas which renders the ground water slightly acidic by the formation of carbonic acid which subsequently dissociates [23] to produce H⁺ and HCO₃⁻. The values of carbonate ion concentration are low for all wells under study and are in the range between 0.17 to 3.3 mg L⁻¹ with mean value of 1.89 (Table 3,4 and Fig 9). The values of chloride concentrations were observed in the range between 25 mg L⁻¹ for w No. 12 and 147 mg L⁻¹ for w No. 7, with mean value of 62.25 mg L⁻¹. The high Cl⁻ value may be due to leaching from upper soil layers and inputs from domestic, agricultural runoffs [31]. The presence of sulfate in drinking water may cause noticeable taste and contribute the corrosion of distribution system [22]. Table 3 shows the values of sulfate concentration in the range from 7.00 to 100 mg L⁻¹ in wells No. 12, 2 respectively, with mean value of 30.58 mg L⁻¹ (Table 4). The higher value of sulfate in water of well No. 2 can be attributed to the salt water intrusion to the aquifer [23]. The sulfate and chloride values for all wells under investigation are below the listed recommendation of WHO [24] standards and also below than the EMH Water Quality [25] standards (Table 3 and Fig 9); therefore the water of all wells under study are tasteless.

The nitrate concentration values of ground water wells under consideration are reported in Table 3. The values are ranging from 0.004 mg L⁻¹ to 0.10 mg L⁻¹ for well No. 11 and wells No. 3, 6 respectively with mean of 0.030 mg L⁻¹ (Tables 3,4 and Fig 10).

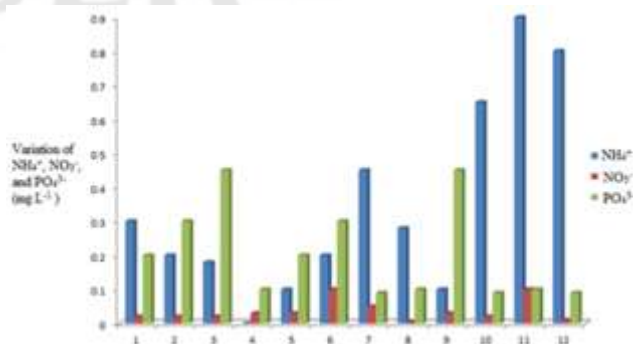


Figure 10: Variation of NH₄⁺, NO₃⁻ and PO₄³⁻ in the wells under consideration

Thus, the TDS, total hardness and nitrate values of all wells under consideration are less than maximum permissible limit set by WHO [24] and EMH Water Quality Standards [48]. Phosphate concentrations in groundwater are often considerably higher than in surface waters [36]. The phosphates concentrations in the wells

under consideration are recorded in Table 3, and the lowest value was observed in the wells No. 4, 8 and 12; while the highest value was found in well No. 10 (Table 3 and Figure 10). The decrease of phosphate concentrations may be due to the availability of strongly soil absorption of phosphate ions [37]. The increase in phosphate ion concentrations can be attributed to agricultural activities [27]. WHO [24] and EMH [25] Water Quality Standards did not give a guideline value for phosphate ions. Ammonia in drinking water can cause taste and odor problems [27]. The ammonia concentrations are reported in Table 3. The highest value is 0.80 mg L^{-1} at well No. 12, while the lowest value was recorded zero at well No. 5 (Table 3 and Fig 10). WHO and EMH do not give a guideline value for ammonia. Soil absorption of ammonia and ease of oxidation of ammonia to nitrite and nitrate by bacteria are the main causes leading to low ammonia content in water [27].

3.1.2 Assessment of heavy metals

The main variable factors affected the solubility of Fe include pH, redox potential (Eh), and concentrations of the dissolved carbon dioxide and sulphur species [38]. As shown in Table 6, the values of Fe concentration in the

ground water wells are ranged between zero and 0.148 mg L^{-1} (Fig11).

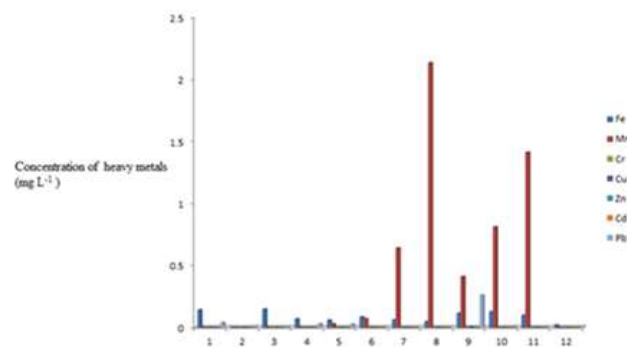


Figure 11: Variation of heavy metals in the wells under consideration

Thus, all wells are below the recommended guideline (0.3 mg L^{-1}) of WHO [24]. According to EMH[48] Water Quality Standards, the maximum acceptable level of iron in drinking water is (1.00 mg L^{-1}), and all wells under consideration are below this level.

The heavy metal contents of the wells under study are given in Table 6.

Table 6: Heavy metals concentrations in wells under consideration

| Well No. | Fe | Mn | Cr | Cu | Zn | Cd | Pb |
|----------|-------|------|-----|-------|-----|-----|-------|
| 1 | 0.141 | Nil | Nil | Nil | Nil | Nil | 0.04 |
| 2 | Nil | Nil | Nil | Nil | Nil | Nil | 0.009 |
| 3 | 0.148 | Nil | Nil | Nil | Nil | Nil | 0.009 |
| 4 | 0.069 | Nil | Nil | Nil | Nil | Nil | 0.03 |
| 5 | 0.059 | 0.03 | Nil | Nil | Nil | Nil | 0.026 |
| 6 | 0.085 | 0.07 | Nil | Nil | Nil | Nil | Nil |
| 7 | 0.063 | 0.64 | Nil | Nil | Nil | Nil | Nil |
| 8 | 0.048 | 2.13 | Nil | Nil | Nil | Nil | Nil |
| 9 | 0.116 | 0.41 | Nil | 0.004 | Nil | Nil | 0.26 |
| 10 | 0.127 | 0.81 | Nil | Nil | Nil | Nil | 0.003 |
| 11 | 0.099 | 1.41 | Nil | Nil | Nil | Nil | Nil |
| 12 | 0.019 | Nil | Nil | Nil | Nil | Nil | 0.003 |

The range of Mn concentration in the wells under consideration is found to be in-between zero and 2.13 mg L^{-1} (Table 6 and Fig 11). The wells No. 2, 4, 6, 8 and 11 are of greater Mn contents than the recommended level in drinking water (0.10 mg L^{-1}) as listed by WHO [24] and EMH [25] Water Quality Standards, but all the remaining wells are below this level. Therefore, it is necessary to focus on the removal of Mn from wells No. 2, 4, 6, 8 and 11 in an appropriate manner, such as the oxidation of manganese by aeration method, then water is passed on sand filters to get rid of the deposited oxide. Mn ion concentrations increased with rising ground water levels, then decreased as the water table dropped [39]. The higher concentrations of Mn in ground water may be due to manganese bearing minerals in contact with ground water under reducing conditions and active bacterial action. The presence of Mn soluble form under the ground anaerobic conditions is due to its release from the sediment, and due to the biochemical transformation processes [27]. The range of Pb concentration in the wells under consideration is found to be between zero and 0.26 mg L^{-1} (Table 6 and Fig11).

According to WHO[24] and EMH[25], the standard of Pb in drinking water is 0.01 and 0.05 mg L^{-1} respectively; thus all wells under consideration are of less Pb content than the standard except well No. 2 in which the Pb value is 0.26 mg L^{-1} . The sources of Pb contamination of the ground water are entry from industrial effluents, old plumbing, household sewages, and agricultural run-off containing phosphatic fertilizers, human and animal excreta [13].

The contamination of drinking water by Cu can result in the increasing of anemia, liver and kidney damage [40]. The presence of copper in drinking water can be attributed to copper pipes, industrial waste, as well as from additives designed to control algal growth. Abdominal pain, vomiting, headache, nausea, and diarrhea are the health effects caused by the contamination of drinking water caused by copper [41]. It is present within a wide range of food sources such as beef/calf liver, shrimp, nuts, avocados, and beans [42]. All wells under study do not contain copper except No. 2 contains 0.004 mg L^{-1} (Table 6 and Fig11). All wells under study do not contain

chromium (Table6 and Figure11). 0.05 mg L⁻¹ is the recommended level of chromium in drinking water set by WHO[24] and EM H [25].

Cd is considered to be toxic if its content in both drinking and irrigation water exceeds 0.01mgL⁻¹[43]. Depending on experimental evidences in both humans and animals, the locally advanced Laryngeal Cancer (LALC) has classified cadmium as a human carcinogen [43]. Mines, metal smelters and industries using cadmium compounds for alloys, batteries, pigments and in plastics are the main sources of pollution of air by Cd[44]. The increasing of Cd concentration in water can be attributed to industrial discharges, plating bath or the deterioration of galvanized plumbing [43]. Cd can cause the damages on reproductive, and development toxicity, hepatic, hematological and immunological effects [45]. All wells under study did not

containing Cd(Table6 and Fig11); which shows that these wells quite far from any sources of Cd pollution.

In aquatic life the toxicity of Zn is dependent on the hardness of the water, where it decreases with rising hardness [24]. All wells under study do not contain Zn (Table.6 and Fig11), which shows that these wells quite far from any sources of Zn pollution.

3.2 Estimation of Water quality Index (WQI)

The calculated WQI for the 21 selected parameters of groundwater quality; and values of desirable and maximum allowable limits of different parameters, according to WHO [23] and according to Egypt drinking water standards [24], are listed in Table 7.

Table 7: The calculated WQI for the 21 selected parameters of groundwater quality

| Parameters | WHO Standards | WHO allowable limit | Egypt Limit (mgL ⁻¹) | Weight (w _i) | Relative weight (W _i) |
|-------------------------------|----------------------------|---------------------------|----------------------------------|--------------------------|-----------------------------------|
| TDS | 500 (mgL ⁻¹) | 1000 (mgL ⁻¹) | 1200 (mgL ⁻¹) | 5 | 0.0724 |
| pH | 6.5 – 8.5 | 8.5 | 6.5 – 8.5 | 3 | 0.0435 |
| EC | 1500 (µscm-1) | 1500 (µscm-1) | ----- | 5 | 0.0724 |
| TH | 500 (mgL ⁻¹) | 500 (mgL ⁻¹) | 500 (mgL ⁻¹) | 4 | 0.0579 |
| Ca ²⁺ | 75 (mgL ⁻¹) | 75 (mgL ⁻¹) | 200 (mgL ⁻¹) | 2 | 0.0289 |
| Na ⁺ | 200 (mgL ⁻¹) | 200 (mgL ⁻¹) | 200 (mgL ⁻¹) | 3 | 0.0435 |
| Mg ²⁺ | 30 (mgL ⁻¹) | 30 (mgL ⁻¹) | 150 (mgL ⁻¹) | 2 | 0.0289 |
| K ⁺ | 10 (mgL ⁻¹) | 10 (mgL ⁻¹) | 10 (mgL ⁻¹) | 2 | 0.0289 |
| Cl ⁻ | 200 (mgL ⁻¹) | 200 (mgL ⁻¹) | 200 (mgL ⁻¹) | 3 | 0.0435 |
| SO ₄ ²⁻ | 200 (mgL ⁻¹) | 200 (mgL ⁻¹) | 400 (mgL ⁻¹) | 4 | 0.0579 |
| HCO ₃ ⁻ | 100 (mgL ⁻¹) | 100 (mgL ⁻¹) | ----- | 2 | 0.0289 |
| CO ₃ ²⁻ | 100 (mgL ⁻¹) | 100 (mgL ⁻¹) | ----- | 2 | 0.0289 |
| NH ₄ ⁺ | 0.50 (mgL ⁻¹) | 0.50 (mgL ⁻¹) | ----- | 2 | 0.0289 |
| NO ₃ ⁻ | 50 (mgL ⁻¹) | 50 (mgL ⁻¹) | 45 (mgL ⁻¹) | 5 | 0.0724 |
| Cr ³⁺ | 0.05 (mgL ⁻¹) | 0.05 (mgL ⁻¹) | 0.05 (mgL ⁻¹) | 4 | 0.0579 |
| Cu ²⁺ | 1.00 (mgL ⁻¹) | 1.5 (mgL ⁻¹) | 1.00 (mgL ⁻¹) | 2 | 0.0289 |
| Cd ²⁺ | 0.005 (mgL ⁻¹) | 0.003(mgL ⁻¹) | 0.005 (mgL ⁻¹) | 3 | 0.0435 |
| Fe ²⁺ | 0.30 (mgL ⁻¹) | 0.20 (mgL ⁻¹) | 1.00 (mgL ⁻¹) | 2 | 0.0289 |
| Pb ²⁺ | 0.1 (mgL ⁻¹) | 0.01 (mgL ⁻¹) | 0.05 (mgL ⁻¹) | 5 | 0.0724 |
| Mn ²⁺ | 0.1(mgL ⁻¹) | 0.5(mgL ⁻¹) | 0.1 (mgL ⁻¹) | 4 | 0.0579 |
| Zn ²⁺ | 5.00 (mgL ⁻¹) | 3.00 (mgL ⁻¹) | 5.00 (mgL ⁻¹) | 2 | 0.0289 |
| | | | | Σw _i = 66 | ΣW _i =1 |

Each parameter is assigned as a weight according to its relative importance for quality of water for drinking purposes, as shown in (Table 7). Maximum weight of 5 is assigned to Total Dissolved Solids (TDS), EC,[NO₃⁻], [Pb²⁺], and weight of 4 is assigned to [SO₄²⁻], TH, [Mn²⁺] and [Cr³⁺], weight of 3 is assigned to , pH, [Cl⁻], [Na⁺] and [Cd²⁺]and weight of 2 is assigned to [K⁺],[Mg²⁺], [Ca²⁺], [CO₃²⁻], [HCO₃⁻], [Fe²⁺], [Cu²⁺] and [Zn²⁺][46].

3.2.1 Suitability of Groundwater for drinking purpose via WQI

The WQI values are calculated according to the following Equations (1-3):

$$WQI = \sum Qi \times Wi \quad (1)$$

In which Qi is the ith quality rating and is given by equation (2),

$$Qi = (Ci/Si) \times 100 \quad (2)$$

Where Ci is the ith concentration of water quality parameter and Si is the ith drinking water quality standard according to the guidelines of WHO [24] and Egypt drinking water standards [28] in mg/l. Wi is the ith relative weight of the parameter i and is given by equation (3).

$$Wi = w_i / \sum_{i=1}^n w_i \quad (3)$$

Where w_i the weight of ith parameter and n is the number of chemical parameters.

The calculated values by water WQI according to WHO [24] and Egypt drinking water standards [25] are tabulated in Table 8.

Table 8: Water quality index values and suitability of ground water for drinking purposes

| No. of Wells | WQI according to WHO | Types of water according to WHO | WQI according to EDS | Types of water according to EDS |
|--------------|----------------------|---------------------------------|----------------------|---------------------------------|
| 1 | 60.82 | Good water | 16.90 | Excellent water |
| 2 | 295.57 | Very poor water | 82.13 | Good water |
| 3 | 54.139 | Good water | 21.84 | Excellent water |
| 4 | 144.8 | Poor water | 61.06 | Good water |
| 5 | 71.01 | Good water | 21.27 | Excellent water |
| 6 | 43.07 | Excellent water | 12.53 | Excellent water |
| 7 | 58.63 | Good water | 48.12 | Excellent water |
| 8 | 108.65 | Poor water | 50.23 | Good water |
| 9 | 50.07 | Good water | 17.27 | Excellent water |
| 10 | 42.99 | Excellent water | 14.79 | Excellent water |
| 11 | 284.4 | Very poor water | 136.93 | Poor water |
| 12 | 36.40 | Excellent water | 9.82 | Excellent water |

Table 8 shows the values of WQI according to WHO and EDWS for wells under consideration.

WQI values are usually classified into five categories (Table 9): excellent, good, poor, very poor and unsuitable for drinking [21].

Table 9: Classes of water quality

| Range | Type of water |
|-----------|-------------------------------|
| <50 | Excellent water |
| 50 – 100 | Good water |
| 100 – 200 | Poor water |
| 200 – 300 | Very Poor water |
| >300 | Water unsuitable for drinking |

According to WHO [24] standards and on the basis of the WQI values, wells No. 1, 3, 5, 6, 7, 9, 10, and 12 are classified into two types of water: excellent water, and good water, where WQI values are in the range <50 – 100 . Thus wells No. 1, 3, 5, 6, 7, 9, 10, and 12 from the study area are acceptable quality for human consumption. While all the remaining wells are not suitable for human consumption where the wells No. 2 and 11 were with a WQI more than 200 and classified as very poor water, and also, WQI of wells No. 4 and 8 was more than 100 and less than 200; which indicate that these wells include poor water. In the parts including well No.1, 3, 5, 7, and 9 of the study area, water fall into good water category which is 41.66% of the total area. The excellent water in the study area is about 25% including wells 6, 10, and 12. Wells No. 4 and 8 are classified as poor water quality which is of about 16.666 % of the total area, whereas the very poor water quality in the study area is about 16.666 % and include wells No. 2 and 11, as shown in Fig 12.

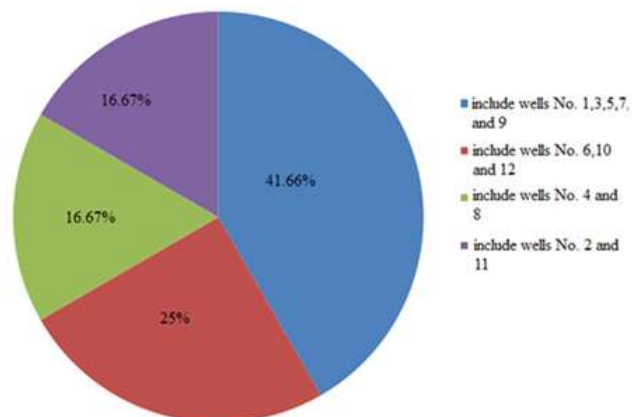


Figure 12: Classes of water quality of wells under consideration according to WHO

According to EDWS, all wells are classified between excellent and good water, except well No. 11, where its water quality is poor. Thus all wells under consideration are suitable for drinking, except well No. 11. In the parts which include wells No. 1, 3, 5, 6, 7, 9, 10, and 12 of the study area, water fall into excellent water category which is 66.66 % of the total area; while good water is about 25 % of the total area and include wells No. 2, 4 and 8. The well No. 11 is classified as poor water quality; which is about 8.34 % of the total area, as shown in Figure 13.

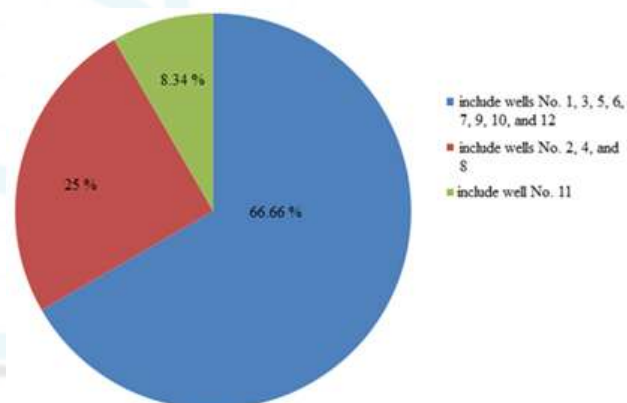


Figure 13: Classes of water quality of wells under consideration according to EDWS

3.3 Evaluation methods

Two evaluation methods are used in this study; they are heavy metal pollution index (HPI) and the heavy metal evaluation index (HEI)[47].

3.3.1 Heavy metal pollution index (HPI)

The HPI is used to reflect the extent of the effect of heavy metals on water quality [48] and it is calculated by the following equation 4:

$$HPI = \frac{\sum_{i=1}^n W_i Q_i}{\sum_{i=1}^n W_i} \quad (4)$$

where: $Q_i = \sum_{i=1}^n \frac{[M_i(-)I_i]}{(S_i - I_i)} \times 100$

n is the number of parameters, W_i is the unit weightage of the i th parameter, Q_i is the sub-index of the i th parameter, M_i is the recorded value of heavy metal concentration of i th parameter in ppb, I_i is the ideal value of the i th parameter in ppb, and S_i is the standard value of the i th parameter in ppb. The unit weightage (W_i) as a value inversely proportional to the maximum admissible concentration (MAC) of the corresponding parameter [49]. In the present study, Cr, Cd, Zn, Pb, Cu, Fe, and Mn were used for estimating the HPI and HEI. The weightage (W_i) was taken as the inverse of MAC, S_i was taken as the WHO standard for drinking water and I_i was taken as the guide value for the chosen element (Table 10).

Table 10: Standards used for the index computation

| Heavy metal | W | S | I | MAC |
|-------------|--------|------|------|------|
| Cd | 0.300 | 5 | 3 | 3 |
| Cr | 0.020 | 50 | 50 | 50 |
| Cu | 0.001 | 1000 | 2000 | 1000 |
| Fe | 0.005 | 300 | 200 | 200 |
| Mn | 0.020 | 100 | 500 | 50 |
| Pb | 0.700 | 100 | 10 | 1.5 |
| Zn | 0.0002 | 5000 | 3000 | 5000 |

W Weightage (1/MAC), S Standard permissible in $\mu\text{g/L}$, I Highest permissible in $\mu\text{g/L}$, MAC Maximum admissible concentration

The values of HPI and HEI are recorded in Table 11.

Table 11: Heavy metal pollution index and heavy metal evaluation index for wells under consideration

| No. of well | HPI | HEI |
|-------------|-------|--------|
| 1 | 68.61 | 27.37 |
| 2 | 238.7 | 182.11 |
| 3 | 53.58 | 1.82 |
| 4 | 50.5 | 18.835 |
| 5 | 61.48 | 20.345 |
| 6 | 55.82 | 28.69 |
| 7 | 58.38 | 18.22 |
| 8 | 52.3 | 13.115 |
| 9 | 47.52 | 6.00 |
| 10 | 47.64 | 6.74 |
| 11 | 59.56 | 142.84 |
| 12 | 51.99 | 2.00 |

These values showed that $\text{HPI} < 100$ for all wells under consideration except well No. 2, where the HPI has a value greater than 100, which means low heavy metal pollution for all wells except well No. 2, where heavy metal pollution is high and its water not potable [50].

3.3.2 Heavy metal evaluation index (HEI)

Heavy metal evaluation index (HEI) was proposed by Edet and Offiong [47], and it is a way to evaluation the water quality via heavy metals in water [51].

The water quality index classify into three categories which include: Low heavy metals ($\text{HEI} < 400$), Moderate to heavy metals ($400 < \text{HEI} < 800$) and high heavy metals ($\text{HEI} > 800$). The Heavy metal evaluation index is calculated from the following equation [85]: HEI

$= \sum_{i=1}^n \frac{HC}{Hmac}$ where Hc is the monitored value of the i th parameter and Hmac is the maximum admissible concentration of the i th parameter [47, 51]. According to Table (11), heavy metal evaluation index for all wells under consideration less than 400, thus all wells were classified as low heavy metals. Also some studies on water in different places around the world have proved that the HPI and HEI lower than critical index value for drinking water [13,47,50,52,53].

4. Conclusion

The results give the abundance of the cations in the following order: $\text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+ > \text{NH}_4^+$, while those of the anions were in the following order: $\text{HCO}_3^- > \text{Cl}^- > \text{SO}_4^{2-} > \text{CO}_3^{2-} > \text{PO}_4^{3-} > \text{NO}_3^-$.

The concentrations of all parameters for all wells are below than the recommended levels except wells numbers 2, 4, 6, 8 and 11 which are with Mn content greater than the recommended level. Well number 2 is also with greater lead content than the recommended level in drinking water. According to WHO standards and on the basis of the WQI values, wells numbers 1, 3, 5, 6, 7, 9, 10, and 12 from the study area are acceptable quality for human consumption, while all the remaining wells are not suitable for human consumption. But according to EDWS, all wells under consideration are suitable for drinking, except only well No. 11. According to Heavy metal pollution index (HPI); all wells in study area were classified as low heavy metals, except well No. 2, where heavy metal pollution is high and its water not potable, while, according to Heavy metal evaluation index (HEI), all wells under consideration were classified as low heavy metals.

5. Recommendation

It is strongly recommended research required to find new underground water resources as an alternative of limited River Nile source to overcome problem of increasing population rate in Egypt.

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