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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 qualityof 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 feascal 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 $29^0 30^{\backslash\backslash}$to 31^0 $00^{\backslash\backslash}$ E and 30^0 $00^{\backslash\backslash}$ to 31^0 $00^{\backslash\backslash}$ 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^{0}C in months of July and Augus. The location of Western Nile Delta is shown in Figure1.

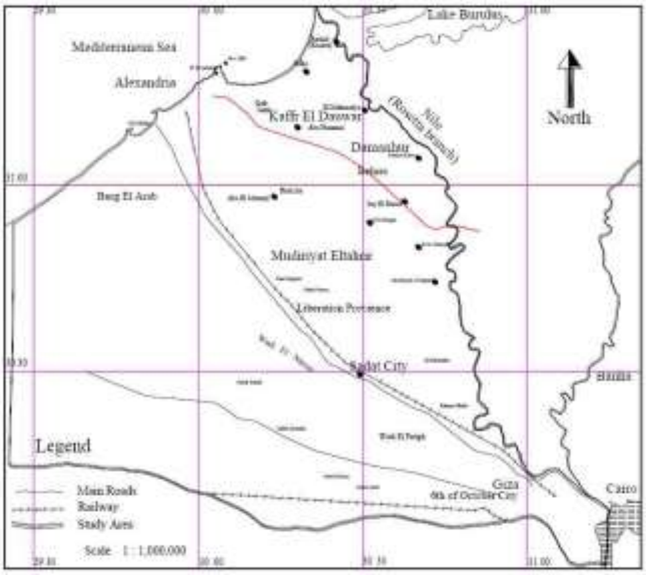

Figure 1: Domain of Study – Western Nile Delta

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), 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^{o} meter (Cyber scan 200 CON).
iv) The determination 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 λ =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.	Feascal 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(μs/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^{2-}(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: $Na^+ > Ca^{2+} > Mg^{2+} > K^+ > NH_4^+$, while those of the anions are in the following order: $HCO_3^- > Cl^- > SO_4^{2-} > CO_3^- > PO_4^{3-} > NO_3^-$(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 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 to39 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 than10 mgL^{-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 feascal 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, 11and 7.9 in well No. 5 and indicate alkaline water in all wells under study (Table2 and Fig3).

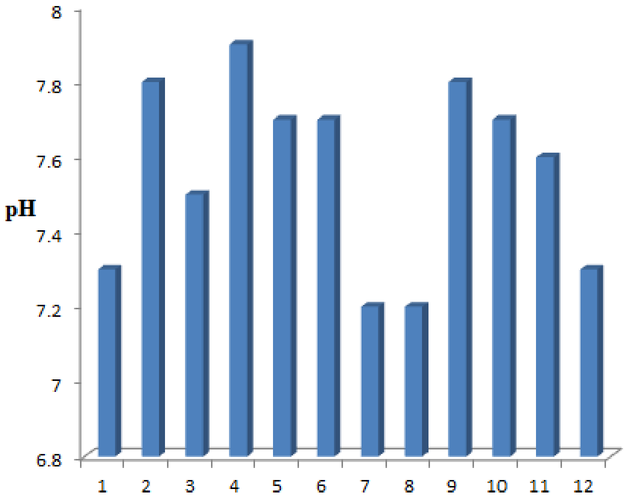

Figure 3: Variation of pH in the wells under consideration

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).

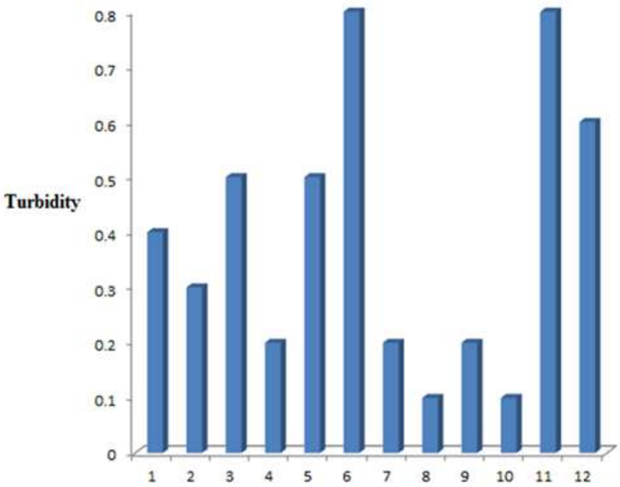

Figure 4: Variation of turbidity in the wells under consideration

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

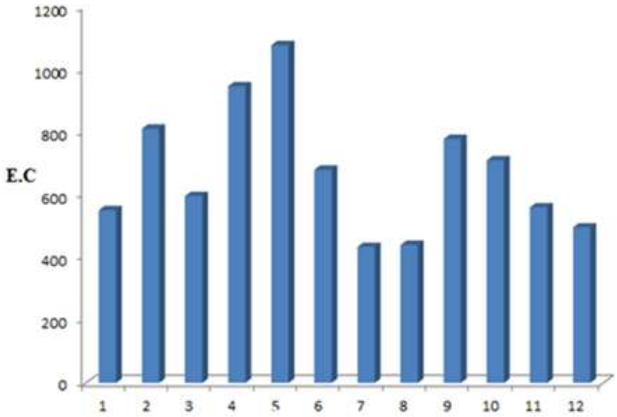

Figure 5: Variation of electrical conductivity in the well under consideration

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

Tables 2, 4 and Fig 5show that the electrical conductivity (EC) ranged from 434 for well No. 7 to 1077 µs 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 162mg L^{-1} in well No. 11 to 400 mg L^{-1} in well No. 7, with mean value of 286.03mg L^{-1}(Table3,4 and Figure 7).

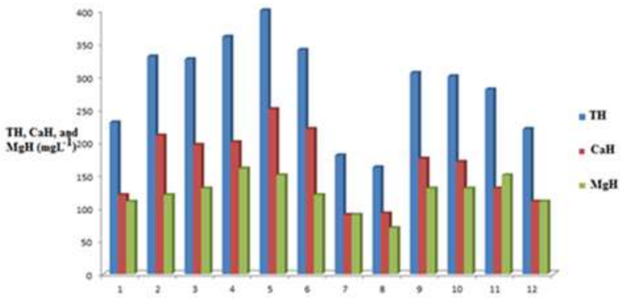

Figure 7: Variation of TH, CaH and MgH in the wells under consideration

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 (Table3,4 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 (Table3,4 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. 7with mean value of 451.08 (Table2,4 and Fig 6).
Fig 8 shows the variation of Ca, Mg, Na, and K ions in the wells under consideration.

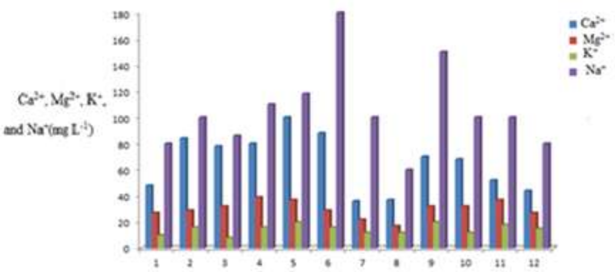

Figure 8: Variation of Ca, Mg, Na and K in the wells under consideration

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).

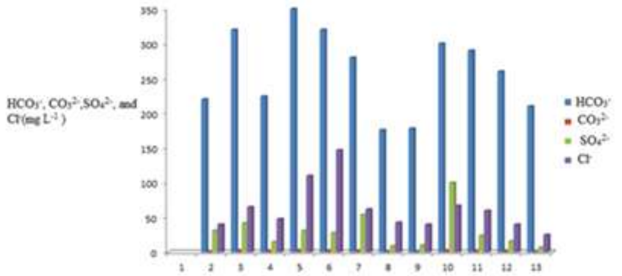

Figure 9: Variation of $HCO3^-$, $CO3^{2-}$, $SO4^{2-}$ and Cl^- in the wells under consideration

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 $H^+ and\ HCO_3^-$. 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 Fig9). 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 Fig10).

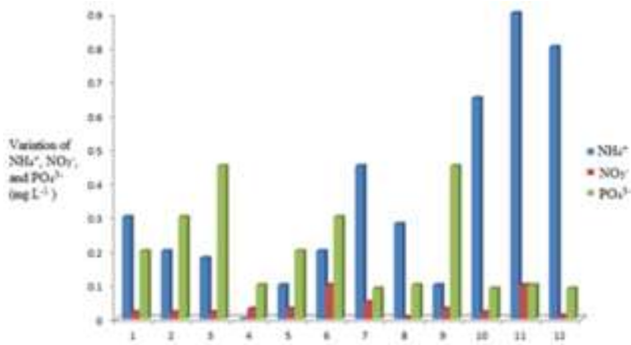

Figure 10: Variation of NH4+, NO3- and PO43 in the wells under consideration

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 sulpher species [38]. As shown in Table 6, the values of Fe concentration in the ground water wells are ranged between zero and 0.148mg L^{-1}(Fig11).

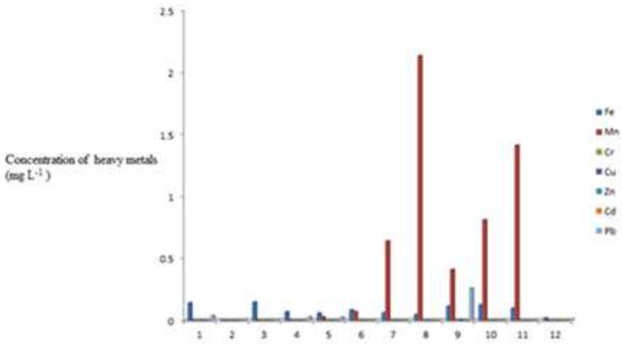

Figure 11: Variation of heavy metals in the wells under consideration

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 mgL^{-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}(Table6 and Fig11).

According to WHO[24] and EMH[25],the standard of Pb in drinking water is 0.01 and 0.05 mgL^{-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} (Table6 and Fig11). All wells under study do not contain chromimum (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 ifit's 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 (Wi)
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
				Σwi = 66	ΣWi=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,[NO_3^-], [Pb^{2+}], and weight of 4 is assigned to [SO_4^{2-}], TH, [Mn^{2+}] and [Cr^{3+}], weight of 3 is assigned to , pH, [Cl^-], [Na^+] and [Cd^{2+}]and weight of 2 is assigned to [K^+],[Mg^{2+}], [Ca^{2+}], [CO_3^{2-}], [HCO_3^-] ,(Fe^{2+}), [Cu^{2+}] and [Zn^{2+}][46].

3.2.1 Suitability of Groundwater for drinking purpose via WQI

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

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

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 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	Goo 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.

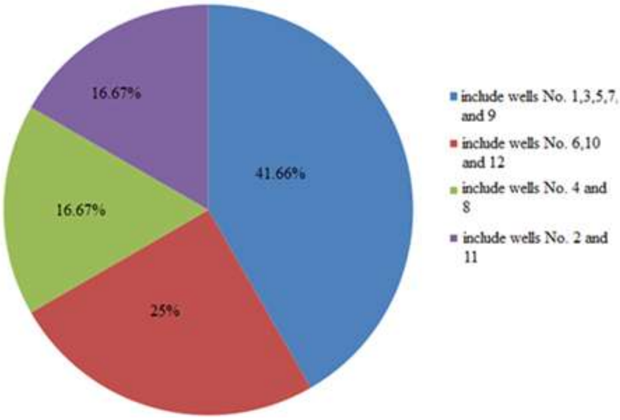

Figure 12: Classes of water quality of wells under consideration according to WHO

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.

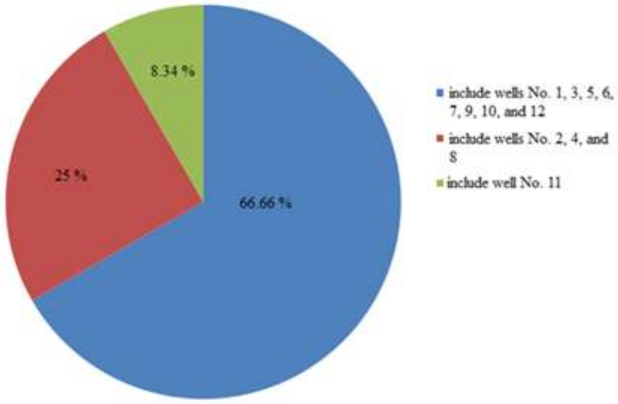

Figure 13: Classes of water quality of wells under consideration according to EDWS

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:

$$\text{HPI} = \frac{\sum_{i=1}^{n} W_i Qi}{\sum_{i=1}^{n} W_i} \qquad (4)$$

where: $Q_i = \sum_{i=1}^{n} \frac{[M_i(-)I_i]}{(S_i - I_i)}$ x 100 n is the number of parameters, W_i is the unit weightage of the ith parameter, Qi is the sub-index of the ith parameter, M_i is the recorded value of heavy metal concentration of ith parameter in ppb, I_i is the ideal value of the ith parameter in ppb, and S_i is the standard value of the ith parameter in ppb. The unit weightage (Wi) 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 (Wi) was taken as the inverse of MAC, Si was taken as the WHO standard for drinking water and Ii 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 µg/L, I Highest permissible in µg/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 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 (HEI < 400), Moderate to heavy metals (400 < HEI < 800) and high heavy metals (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 ith parameter and Hmac is the maximum admissible concentration of the ith 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: $Na^+ > Ca^{2+} > Mg^{2+} > K^+ > NH_4^+$, while those of the anions were in the following order: $HCO_3^- > Cl^- > SO_4^{2-} > CO_3^{2-} > PO_4^{3-} > NO_3^-$.

The concentrations of all parameters for all wells are below than the recommended levels except wells numbers 2, 4, 6, 8 and 11which 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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References

[1] Pichiah S., Senthil Kumar G.F., Srinivasamoorthy K., Sarma V. S., Hydrochemical characterization and quality assessment of groundwater in TirupurTaluk, Tamil Nadu, India: Emphasis on irrigation quality journal of academic and industrial research, **2013**, Vol.1 (12), 805-812.

[2] Santhosh P., Revathi D., Geochemical Studies on the Quality of Ground Water in Tirupur District, Tamilnadu, India. Journal of Chemical, Biological and Physical Sciences,**2014**, 4(2), 1780-1786.

[3] Prasanna M.V., Chidambaram S., Srinivasamoorthy K., Statistical analysis of the hydrogeochemical evolution of groundwater in hard and sedimentary aquifers system of Gadilam river basin, South India. Journal of King Saud University (Science),**2010**, 22(3), 133-145.

[4] Mtoni Y., Mjemah I.C., Bakundukize C., van Camp M., Martens K., Walraevens K., Saltwater intrusion and nitrate pollution in the coastal aquifer of Dares Salaam, Tanzania. Environmental Earth Sciences,**2013**, 70(3), 1091–1111.

[5] Triki I., Trabelsi N., Zairi M., Dhia H.B., , Multivariate statistical and geostatistical techniques for assessing groundwater salinization in Sfax, a coastal region of eastern Tunisia. Desalin, water treatment,**2014,** 52(10-12), 1980 – 1989.

[6] Chaudhuri S., Ale S., Long term (1960–2010) trends in groundwater contamination and salinization in the Ogallala aquifer in Texas. Journal of Hydrology,**2014**, 513(26), 376–390.

[7] Su A., Chen Z., Liu J., Wei W., Sustainability of intensively exploited aquifer systems in the North China Plain: Insights from multiple environmental tracers, Journal of Earth Science,**2014**, 25(3), 605–611.

[8] Mudiam M.K., Pathak S.P., Gopal K., Murthy R.C., Studies on urban drinking water quality in a tropical zone. Environmental Monitoring and Assessment,**2012**, 184(1), 461–469.

[9] Pradhan J.K., Kumar S., Informal e-waste recycling: Environmental risk assessment of heavy metal contamination in Mandoli industrial area, Delhi, India. Environmental Science and Pollution Research International,**2014**, 21(13), 7913–7928.

[10] Ardani R, Yari AR, Fahiminia M, Hashemi S, Fahiminia V, SaberiBidgoli M., Assessment of influence of landfill leachate on groundwater quality: A case study Albourz landfill (Qom, Iran). Archives of Hygiene Sciences, **2015**, 4(1):13-21.

[11] SaralaThambavani D, Uma Mageswari T.S.R., Metal pollution assessment in ground water. Bulletin of Environment, Pharmacology and Life Sciences, **2013**, 2(12):122-129.

[12] Abdul Jameel A., Sirajudeen J. , Abdul vahith R., Studies on heavy metal pollution of ground water sources between Tamilnadu and Pondicherry, India, Advances in Applied Science Research, **2012**, 3 (1):424-429.

[13] Maria-Alexandra H, Roman C, Ristoiu D, Popita G, Tanaselia C., Assessing of water quality pollution indices for heavy metal contamination. A study case from Medias City ground waters. Agriculture-Science and Practice,**2013**, 3-4:25-31.

[14] Naik S, Purohit KM., Physico-chemical analysis of some community ponds of Rourkela. Indian Journal of Environmental Protection,**1996**, 16(9):679-684.

[15] Zhu L.; Fuzzy Hu H.,complex index in water quality assessment of municipalities.Journal of Water Resource and Protection, **2010,**2, 809–813. Available online: http://www.highbeam.com/doc/1P3-2312125411.html (accessed on 19 October 2011).

[16] Alobaidy A.H.M.J., Bahram, M., Abass K,Evaluating raw and treated water quality of Tigris River within Baghdad by index analysis (Report). Journal of Water Resource and Protection, **2011**, 2, 629–635. Available online: http://www.highbeam.com/doc/1G1-265290979.html (accessed on 19 October 2011).

[17] Love J.W., May E.B.,Relationships between fish assemblage structure and selected environmental factors in Maryland's Coastal Bays. Northeast. national, **2007,** 14, 251–268. Available online: http://www.highbeam.com/doc/1P3-1302555801.html (accessed on 19 October 2011).

[18] Horton, R.K., An index-number system for rating water quality. Journal of the Water Pollution Control Federation, **1965,** 37, 300–306.

[19] Simoes, F.S., Moreira A.B., Bisinoti M.C. Gimenez M.N.S. Yabe M.J.S.,Water quality index as a simple indicator of aquaculture effects on aquatic bodies. Ecological Indicators.**2008**, 8, 476–484.

[20] Abassi S.A., 1999. Water Quality Indices, State-of-the art. J.IPHE., No.1.

[21] Sahu P., Sikdar P.K., Hydrochemical framework of the aquifer in andaround East Kolkata wetlands, West Bengal. India Environmental Geology,**2008**, (55): 823-835.

[22] American Public Health Association (APHA), Standard Methods for examination of water, and waste water, 22nd Edn.APHA, AWWA, WPCF, Washington DC, USA. **2012**, 1360 pp. ISBN 978-087553-013-0.

[23] Masoud M. S., Zayed M. A., El Hdad A.M. A., Study of ground water quality in Kom Hamada area, Behira Governorate, Egypt" Journal of Bulletin of the Chemists and Technology of Macedonia,**2003**, 22(2), PP. 143-154

[24] World Health Organization, Guidelines for drinking water quality,Recommendations, 4th Ed. WHO, Geneva, Switzerland, **2011**, v. 1, 541

[25] Egyptian Ministry of Health and Population, Standards and specifications of water Quality for drinking and domestic uses. Internal report: 8, **2007**.

[26] Olayinka A. I., Abiombola A. F., ISibor R. A., Rafiu A. B., "A geoelectric Hydrochemical Investigation of Shallow ground water occurrence in Ibadam, southwestern Nigeria," Environmental Geology vol. **1999**, 37, (1-2), pp. 31 –37.

[27] El Hdad A.M.A.,Study on physicochemical changes and water treatment for Kom Hamada sector – El-beheira governor, Egypt. Ph.D. Thesis, Faculty of Science, Alexandria University, Egypt, **2006**,241p

[28] Sharaky A. M., Atta S. A., El Hassanein A. S., Khallaf K. M. A, 2nd International Conference on the Geology of Tethys, 19-21 March, , Cairo University, Hydrogeochemistry of Groundwater in the Western Nile Delta Aquifers, Egypt, **2007**, 1-23

[29] El Abd E.A., The geological impact on the water bearing formations in the area southwest Nile Delta, Egypt. Unpublished Ph.D. Thesis, Faculty of Science, Menufiya University, Egypt, **2005**, 319 p.

[30] World Health Organization, Geneva, guidelines for drinking-water quality [electronic resource]: incorporating 1st and 2nd addenda, Recommendations, 3rdedn. **2008**, v. 1, 515

[31] Sirajudeen J., KaharMohidheen M., Abdul Vahith R., Physico-chemical contamination of ground water in

and around Tirunelveli district, Tamil Nadu, Pelagia Research library Advances in Applied Scientific Research,**2014**, 5(2): 49-54

[32] Sawyer C. N., McCartly P. L., Chemistry for sanitary engineers. 2nd edition. (New York McGraw Hill), **1967**, 38, p. 3899 – 3908

[33] Obiefuna G .I. Sheriff A., Assessment of Shallow Ground Water Quality of Pindiga Area, Yola Area, NE, Nigeria for Irrigation and Domestic Purposes. Research Journal of Environmental and Earth Sciences,**2011**, 3 (2): 131-141

[34] Ishaku J.M.I., Ahmed A.S., Abubakar M.A., Assessment of groundwater quality using chemical indices and GIS mapping in Jada area, Northeastern Nigeria. Journal of Earth Sciences and Geotechnical Engineering,**2011**, Vol. 1, no. 1, 35-60

[35] Gardner K.K., Vogel R.M., Predicting ground water nitrate concentration from land use, Ground Water,**2005**, 43(3), 343–352.

[36] Oberdorfer J.A., Valentino M.A., Smith S.V., Groundwater contribution to the nutrient budget of Tomales Bay, California. Biodegradation,**1990**, 10, 199–216.

[37] Seiler H.G., Sigel H., Sigel A., Hand Book on Toxicity of Inorganic Compounds, Marceel Dekker, Inc., New York, **1988**, p. 622

[38] Mohamed S.M., EL-Bady, Spatial Distribution of some Important Heavy Metals in the Soils South of Manzala Lake in Bahr El-Baqar Region, Egypt, Nova Journal of Engineering and Applied Sciences, **2014**, Vol. 3(2), 1-12

[39] Klinchuch A.L., Defino A.T., Reductive Dissolution and Precipitation of Manganese Associated with biodegradation of petroleum hydrocarbons, Journal of Environmental Geosciences,**2000**, 7(2), 69-79

[40] Bent S., Bohm K., Copper induced liver cirrhosis in a 13-month-old boy.Gesundheitswesen,**1995**, V. 57 (10): 667-9.

[41] Jennings G. D., Sneed R. E., Clair M. B. St., Metals in drinking water. Published by: North Carolina Cooperative Extension service Publication no.:AG-473-1. Electronic version, 3, **1996**.

[42] Agency for Toxic Substances and Disease Registry (ATSDR). Toxicological Profile for Copper. U.S. Department of Health and Humans Services, Public Health Service, Centers for Diseases Control. Atlanta, 2004.

[43] Tslalom H., Kiflom G., Hazards of Heavy Metal Contamination In Ground Water, International Journal of Technology Enhancements and Emerging Engineering Research, **2015**, Vol. 3, ISSUE 02, P1-6.

[44] Harrison, N. Inorganic contaminants in food, In: Food Chemical SafetyContaminants, Watson, D.H. (Ed.), 2001, pp. 148-168, Ltd, first Edition, WoodheadPublishing ISBN 1-85573-462-1, Cambridge.

[45] Apostoli P.,Catalani S., Metal ions affecting reproduction and development. Metal Ions in Life Science, 2011, 8, 263-303.

[46] Abbasi T., Abbasi S.A. Water Quality Indices,Elsevier B. 2012, V., pp. 19-28.

[47] Edet AE, Offiong OE., Evaluation of water quality pollution indices for heavy metal contamination monitoring. A study case from Akpabuyo-Odukpani area, Lower Cross River Basin (southeastern Nigeria). GeoJournal, 2002, 57: 295-304.

[48] Mohan S.V, Nithila P., Reddy S.J., Estimation of heavy metals in drinking water and development of heavy metal pollution index. Journal of Environmental Science & Health Part A., **1996**, 31:283-289.

[49] Siegel F.R., Environmental geochemistry of potentially toxic metals. Springer-Verlag, Berlin.,**2002**, 218p.

[50] Nasrabadi T., An index approach to metallic pollution in river waters. International Journal of Environmental Research, **2015**, 9 (1):385-394.

[51] Edet A.E., Merkel B.J., Offiong O.E., Trace element hydrochemical assessment of the Calabar Coastal Plain Aquifer, southeastern Nigeria using statistical methods. Environmental Geology.;**2003**, 44:137-149.

[52] Hosseinpour M. M, Lashkaripour GR, Dehghan P., Assessing the effect of heavy metal concentrations (Fe, Pb, Zn, Ni, Cd, As, Cu, Cr) on the quality of adjacent groundwater resources of Khorasan steel complex. International Journal of Plant, Animal and Environmental Sciences.;**2014**, 4(2):511-518.

[53] Nazari S, Sobhanardakani, S., Assessment of pollution index of heavy metals in groundwater resources of QalehShahin plain (2013-2014). Journal of Kermanshah University of Medical Sciences.,**2015**, 19(2):102-108. (in Persian)