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Environmental Monitoring and Assessment of Groundwater Quality in Abu Rawash Electric Generation Plant, Egypt

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Abstract

Groundwater in Abu Rawash area has particular importance where it is the source of water used for agricultural, domestic and industrial purposes. Nine groundwater samples from shallow wells were available during summer 2019 and were analyzed for physicochemical characteristics. The physicochemical parameters indicated that the water type is dominance of Na-K- Cl-SO4. These data has been used for preliminary evaluation of suitability of groundwater for irrigation purposes using groundwater quality indices which are irrigation water quality index IWQI, Sodium Adsorption Ratio (SAR), Residual Sodium Carbonate (RSC), and Permeability Index (PI). The average obtained values of IWQI, SAR, RSC, PI respectively were 32.91, 25.35, -31.17, and 76.55 mg/l. According to the IWQI classification, approximately 67% of the groundwater samples were served restriction with no toxicity risk for most plants, while about 33% of samples were high restriction on their use for irrigation. According to the SAR classification, approximately 44% of the groundwater samples were fairly poor, while about 56% of samples were Unsuitable on their use for irrigation. Based on the RSC and PI classification all ground water samples were more suitable for irrigation.

Keywords: Abu Rawash, Egypt, Irrigation indices, Physicochemical data, Water Quality

Introduction

Groundwater is considered as one of the main sources for both rural and agriculture water supplies in many areas in Egypt especially in the desert regions. Over recent years, increasing abstraction to meet rising demand for domestic supplies and expansion in reclamation in desert fringes has raised concerns for the sustainability of the groundwater resource and the livelihoods it supports. Shortage of irrigation water sources in Egypt bring out the issue of using Non-conventional water resources include agricultural drainage water, desalinization of brackish groundwater and municipal wastewater (**ElArabi, 2012**) groundwater plays an essential role in global drinking water supply. In Egypt, fresh groundwater resources contribute to less than 20% of the total potential of water resources (**Allam et al., 2003**). The imitative techniques including Piper diagram, Chadah diagram In order to understand the hydrogeochemical properties of the sample area and water, the analytical values were plotted on the Piper diagram to (**Piper, 1944**). A new diagram was developed by (**Chadha, 1999**) for geochemical classification of natural waters and chemical data analysis. The viability of any water resource for irrigation purposes is evaluated through several irrigation water quality indices (IWQIs) (**Bora and Goswami, 2017**). These indices, which are based on several physiochemical variables of water, include IWQI, SAR, RSC and PI. This study aims to groundwater quality assessment based on the hydrogeochemical properties and determine the suitability for irrigation.

Materials and Methods

Study area

The project area lies to the west of the Nile Delta and Cairo City, especially in Abu Rawash area, and bounded by longitudes 31^{o} 02\` 34.08\`\` and 31$^{o}$ 02\` 53.73\`\` E and latitudes 30^{o} 03\` 4.34\`\` and 30$^{o}$ 04\` 00\`\` N. It's located in the Kilometer 23 to east and extends parallel to the Cairo-Alexandria desert road (**Fig. 1**).

Methodology

Sampling and analyses

Nine groundwater samples from shallow wells (< 60 m) were collected during summer 2019 in refined plastic bottles, and the sample bottles were rinsed with deionized water before sampling. The samples were acidified with nitric acid to a pH

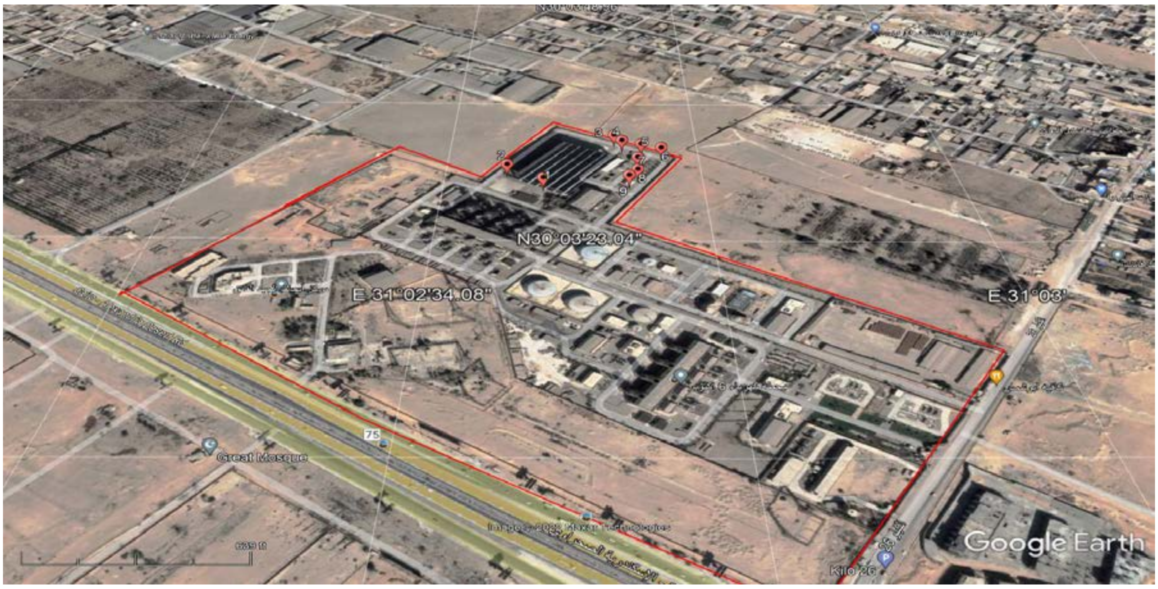

Fig. 1. Location map of the groundwater wells in the study area.

less than 2. All samples were preserved at temperature less than 4 °C until analyzing processes as required by standard procedures. Groundwater samples were bottled 0.45 mm polypropylene filter membranes, and then, the chemical analysis was performed using different apparatus and techniques. Trace element test samples of ultrapure HNO_3 is acidified to below pH 2. The groundwater samples were analyzed for significant ions and trace elements. Twelve physicochemical parameters, including water temperature, pH, total dissolved solids (TDS), electrical conductivity (EC), K^+, Na^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, HCO_3^-, CO_3^{2-} were analyzed using standard analytical techniques (**APHA, 2012**). Water temperature, total dissolved solids (TDS), pH, and electrical conductivity (EC) were measured in situ using a portable calibrated salinity multi-parameter instrument (Hanna HI 9811-5, Hanna Instruments Italia Srl, 35030 Sarmeola di Rubano-PD, Italy). Calcium , Mg^{2+}, HCO_3^-, CO_3^{2-}, and Cl^- were analyzed by volumetric titration, and K^+, Na^+ were analyzed by flame photometer (ELEX 6361, Eppendorf AG, Hamburg, Germany). While, a UV/visible spectrophotometer was used to analyze SO_4^{2-}. These procedures are highlighted in American Public Health Association (**APHA, 2012**). Quality monitoring of analytical data was undertaken by evaluating ion balances. The ionic charge balance defect was below five percent. Inside 5 percent was the ionic charge balance defect.

Indexing approach

To ascertain the suitability of groundwater for irrigation purposes, quality variables in **Table 1**, such as IWQI, SAR, RSC and PI were used.

Table 1. Irrigation water quality indices and classification of water quality for irrigation.

Irrigation indices	**Range**	**Water classification**	**References**
$IWQI = \sum_{i=1}^{n} Q_i W_i$	85–100	No restriction for use	(Brown et al., 1970)
	70–85	Low restriction for use	
	55–70	Moderate restriction for use	
	40–55	High restriction for use	
	0–40	Serve restriction for use	
$SAR = \frac{Na}{\sqrt{\frac{(Ca+Mg)}{2}}}$	<10	Excellent	(Todd, 1980)
	10-18	Good	
	18-26	Doubtful	
	>26	Unsuitable	
$RSC = (CO_3 + HCO_3) - (Ca+Mg)$	<1.25	Good	(Guan et a1., 1999)
	1.25–2.5	Doubtful	
	>2.5	Unsuitable	
	<1	Suitable	
$PI = \frac{(Na+\sqrt{HCO3})}{(Ca+Mg+Na)} \times 100$	>75	Class-I	(Ramesh, 2011)
	25–75	Class-II	
	<25	Class-III	

Results and Discussion

Physicochemical parameter

In water quality evaluations, physiochemical parameters play a decisive role and are considered a valuable guide for understanding the essence of water chemistry and related control mechanisms. The analytical results of physicochemical parameters of the ground water wells (PH, TDS, Na^+, K^+, Mg^{2+}, Ca^{2+}, Cl^-, SO_4^{2-}, HCO_3^-, CO_3^{2-}) in the study area were presented in **Table 2**.

Table 2. Analytical results of physicochemical parameters for the collected groundwater samples in the study area.

Parameter	Min	Max	Mean
Temp	27	33.7	30
PH	7.11	8.15	7.60
EC	11594	17719	13753.13
TDS	7420	11340	8802
K^+	11	18	14
Na^+	1990	3000	2366.88
Ca^{2+}	388	684.1	522.65
Mg^{2+}	54.15	145	87.933
SO_4^{2-}	1003.78	2094.85	1330.88
Cl^-	2982.99	4607	3498.59
HCO_3^-	95	190	133.33
CO_3^{2-}	0.0	0.0	0.0

Assessment of groundwater quality for drinking

Groundwater type

According to the chemical composition of the analyzed groundwater samples, one groundwater type was presented by Na^+–k^+–Cl^-–SO_4^{2-} water type (**Fig. 2**). The major ion concentrations are powerful tools to detect the solute sources, where the wide ranges of the determined ions in the groundwater samples indicated the influence of various recharging sources (**Jalali, 2007**). The prevailing water type in the study area as shown by Piper diagram **(Fig. 2)** indicated that high salinity and the second and the last stage of water evolution.

The existence of three hydrochemical water facilities was seen by plotting the analyzed water samples in the diagram: water type 1, water type 2, water type 3 and water type 4 (**Fig. 2**).

Chadah's classification is applied to the collected groundwater samples to identify the hydrochemical processes and groundwater facies (**Fig. 3**). The groundwater samples can be related to fields 3, which revealed mixing with saline water (Na-Cl water type) and rock water interaction.

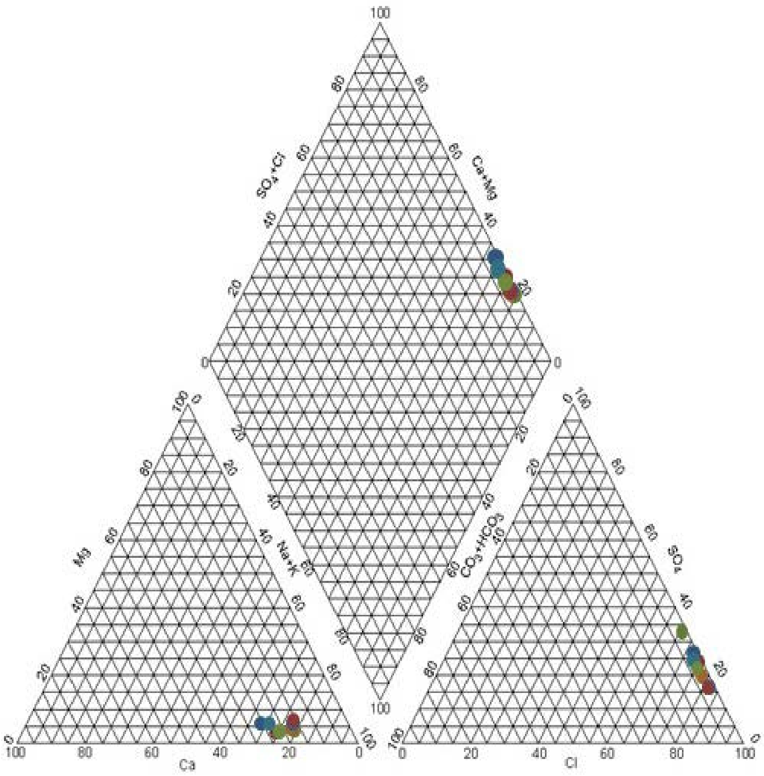

Fig. 2. Piper Tri Linear Diagram Showing Groundwater Types in the Study Area.

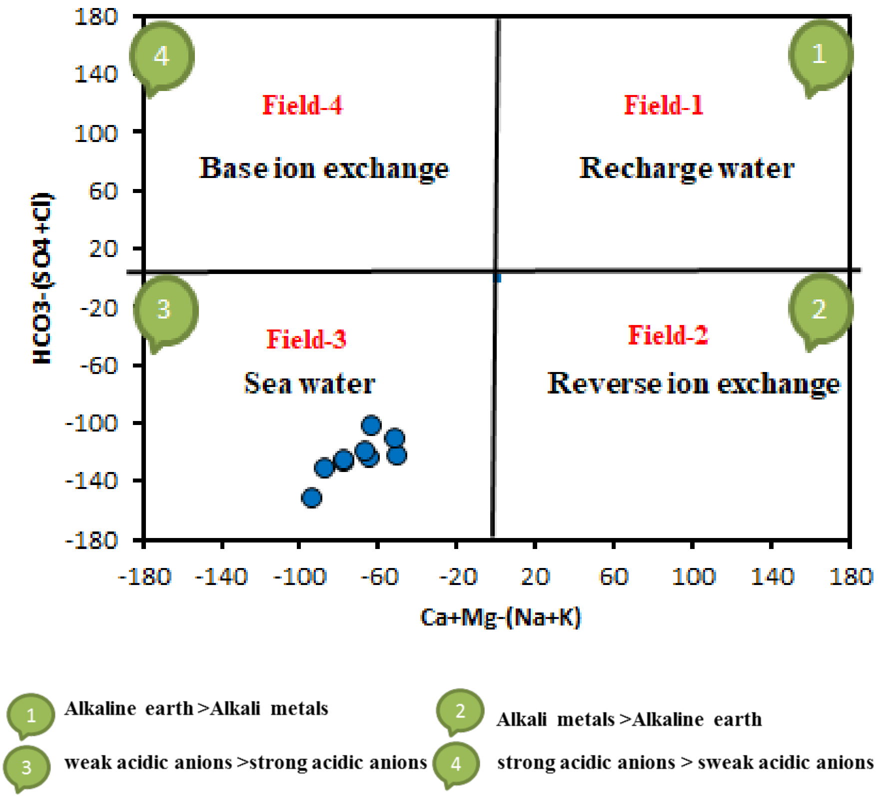

Fig. 3. Geochemical controlling mechanisms and water facies (**Chadha, 1999**).

Water quality assessment

In this twenty-first century, fresh water is a basic requirement for the economic development of nations and regions (**Khadri and Pande, 2016; Moharir et al., 2017**). One of the major issues challenging humanity is the quality and quantity of water resources required to satisfy the needs of humans and ecosystem (**Disli, 2017; Pande and Moharir, 2018**). Alarming the growth rates of population, industrialization, extensive agricultural practices and rapid urbanization have not only increased the exploitation of water resources but have also contributed towards the deterioration of its quality. Overexploitation and unabated pollution are threatening our ecosystems and even the life of future generations (**Pande et al., 2017**). The viability of water resource for irrigation purposes is evaluated through several irrigation water quality indices (IWQIs). These indices, which are based on several physiochemical variables of water (**Table 3**), include IWQI, SAR, RSC and PI.

Table 3. Summary of the descriptive statistics of the determined IWQIs.

Parameter	Min	Max	Mean
IWQI	14.14	41.50	32.91
SAR	19.967	30.05	25.35
RSC	-40.81	-22.23	-31.17
PI	69.45	80.13	76.55

Irrigation Water Quality Index (IWQI)

The IWQI is a dimensionless computed index that reflects the composite influences of overall water quality. It transforms several parameters and their concentrations in a water sample into a single value, which is a quantitative and extensive interpretation of overall water quality and its suitability for various purposes (**Meireles et al., 2010; Sener et al., 2017; Kachroud et al., 2019**). The IWQI was calculated as the sum of the individual values of each parameter (Q_i) weighted by the importance of this parameter to the evaluation of the overall water quality (W_i) using the following equation (**Brown et al., 1970**):

$$IWQI = \sum_{i=1}^{n} Q_i W_i \qquad (1)$$

where, Qi is the relative quality of the ith individual parameter, Wi is the relative weight of the i th parameter, and i is the number of parameters, which are including EC, Na^+, Cl^-, HCO_3^- and SAR. The weight of water quality parameters including: the water quality measurement parameter value (Q_i), and the W_i is the standardized weight of the ith value and finally taking account into the criteria which were proposed by (**Ayers and Wescot, 1999**). The value of Q_i was calculated according to the following equation:

$$Q_i = Q_{imax} - [(X_{ij} - X_{inf}) \text{ x } Q_{iamp} / X_{amp}] \qquad (2)$$

where, Q_{imax} is the maximum value of Q_i for each class to which the parameter belongs; the observed value of each parameter is represented by X_{ij}; also X_{inf} refers the lower limit value of the class; q_{imap} represents the class amplitude and X_{amp} is corresponds to class amplitude. In this regard, the upper limit was considered to be the highest value determined in analysis of the water samples which is required in order to evaluate X_{amp} of the last class of each parameter. The accumulation weight of individual parameters used to in the IWQI determination was adopted from (**Meireles et al., 2010**). The values of W_i were normalized and their final sum equal to one according to the following equation:

$$W_i = \frac{\sum_{j=1}^{k} F_j A_{ij}}{\sum_{j=1}^{k} \sum_{i=1}^{n} F_j A_{ij}} \qquad (3)$$

where, i is the number of parameters selected in IWQI and ranging from 1 to n; j is the number of factors to choose in IWQI and varying from 1 to k; A_{ij} is the explain ability of parameter i by factor j; and F is a constant value of component 1.

The obtained results of IWQI of the groundwater samples indicated that the IWQI values ranged from 14.14 to 41.50 with a mean value of 32.91 (**Table 3**). According to the IWQI classification defined by (Meireles, et al. 2010), approximately 67% of the groundwater samples were serve restriction with no toxicity risk for most plants, while about 33% of samples were high restriction on their use for irrigation, which should be used for irrigation of plants with moderate to high tolerance to salts with special salinity control practice, except water with low Na^+, Cl^- and HCO_3^- values. Based on (**Meireles et al., 2010**) (**Table 1**), limits on water use groups have been characterized.

Sodium Adsorption Ratio (SAR)

Sodium adsorption ratio is an important parameter to determine the sodium hazard in connection with calcium and magnesium contents. SAR values predict the degree to which irrigation water involved in cation exchange reaction in soil. Excess sodium concentration decreases the soil structure and soil permeability via clay particle dispersion making the soil compact and impervious (**Todd, 1980**). The suitability of surface and groundwater samples was evaluated for the determination of SAR shown in (**Table 1**). According to SAR classification water attaining <10 is to be of excellent quality. In the study area SAR values ranged from 19.96to 30.056 (**Table 3**), approximately 44% of the groundwater samples were Doubtful or fairly poor, while about 56% of samples were Unsuitable on their use for irrigation.

Residual Sodium Carbonate (RSC)

The groundwater and surface water for irrigation purpose can be evaluated using the sum of carbonates and bicarbonates over the sum of calcium and magnesium in water, excessive presence of carbonates and bicarbonates tends to alter the soil properties and form, precipitates and increase soil salinity thus decreases its fertility. Generally any source of water in which RSC is higher than 2.5 is not considered suitable for agriculture purpose, and water < 1.25 is recommended as safe for irrigation purpose (**Table 1**). A negative value of RSC reveals that concentration of Ca^{2+} and Mg^{2+} is in excess. A positive RSC denotes that Na^{+} existences in the soil are possible. The RSC calculation is also important in context to calculate the required amount of gypsum or sulfuric acid per acre-foot in irrigation water to neutralize residual carbonates effect.

The RSC negative values due to excess concentration of Ca^{2+} and Mg^{2+} (**Table 3**) ranges from -40.81 to -22.23 with an average value of -31.17 fall under suitable category for irrigation purposes.

Permeability Index (PI)

Irrigation water depends on various factors like total soluble salt, sodium, calcium, magnesium, and bicarbonate content of water. (**Doneen, 1964**) evaluated the suitability of water for irrigation based on permeability index (PI). Permeability Hazard is evaluated using the permeability index (PI), where the PI values of the groundwater samples ranged from 69.45 to 80.13with a mean value of 76.55 (**Table 3**). Based on the PI classification of irrigation water quality (**Table 1**), all the groundwater samples are suitable for irrigation.

Conclusion

The study presents a general overview of hydrochemistry and water quality in Abu Rawash area. The type of water that predominates in the study area is Na^{+}–k^{+}–Cl^{-} SO_4^{2-} water type. The plots of studied samples on piper diagram indicated that high salinity and the second and the last stage of water evolution while, Chadah's classification revealed mixing with saline water (Na-Cl water type) and rock water interaction. To evaluate the groundwater for irrigation purposes IWQI, SAR, RSC and PI was determined. Based on calculated IWQI, the water samples were assessed into two groups of "serve" and "high" restriction for irrigation purpose. Irrigation water classified based on SAR were assessed into two groups of " Doubtful or Fairly poor " and "unsuitable" for irrigation purpose. As per the RSC and PI ground water is more suitable for irrigation.

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