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# SPATIAL ASSESSMENT OF GROUNDWATER QUALITY FOR IRRIGATION IN BAHARIYA OASIS, EGYPT

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**Abstract-** Development of agricultural projects out of the Nile Valley and Delta in Egypt is a necessity nowadays to overcome the over increasing population. However, the availability of water resources and their quality are the major limiting factors for these projects. Consequently, secondary water resources have to be evaluated for their quality and availability. The major objective of this work was to evaluate the quality of groundwater in Bahariya Oasis for irrigation. This is in addition to studying the spatial variability of water salinity within the Oasis using geostatistical analyses. For these purposes, georeferenced 17 representative water samples were collected from governmental wells in the Oasis. This is in addition to 448 georeferenced water samples from private wells in the Oasis were tested for their Electrical Conductivity (EC). Water samples from governmental wells were analyzed for their chemical properties.

EC values of private wells varied from 296 to 1020 $\mu Sm^{-1}$ and these values increased from the south to the north direction. Chemical analyses of governmental wells indicated that the EC values ranged between 240 and 550 $\mu Sm^{-1}$. The SAR values varied from 0.99 to 2.08. The adj.SAR values varied from 0.76 to 1.95. The ESP values ranged between 0.20 and 1.78%. The RSC values were negative and ranged between -0.69 and -0.13 meq $L^{-1}$. Total Hardness (TH) varied from 49.9 to 125.4 ppm.

It conclusion, groundwater in Bahariya Oasis is acceptable for crop irrigation; however certain concerns have to be given for its availability and management for optimal usage.

**Keywords-** Water quality, Electrical conductivity, Sodium adsorption ratio, Residual sodium carbonates, Geostatistics, Bahriya Oasis

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## Introduction

The groundwater bearing strata in Bahariya Oasis belong to the Nubian aquifer, which represents one of the largest groundwater systems within the eastern Sahara in northeast Africa. It extends under Egypt, the eastern parts of Libya, the north and north eastern parts of Chad and the north and north western parts of Sudan. The Nubian aquifer is generally a closed system. However, only in the south-eastern parts there is groundwater inflow from the Blue Nile/ Main Nile rift system [1].

Nowadays, groundwater is given a great interest, especially for use in agricultural activities. Groundwater represents the main water resource in Bahariya Oasis. The main water-bearing succession in the Bahariya Oasis belongs to the Early Cenomanian and Pre-Cenomanian times [2,3]. The thickness of water-bearing sandstone in Bahariya Oasis ranges between 400 and 1400 m. The flow direction of groundwater in the Oases is generally from the southwest to the northeast [4,5]. The chemical composition of groundwater is mainly affected by the mineralogical composition of the water bearing strata. Also, the movement of groundwater within the aquifer increases the dissolution and most of major ions normally become more dominant [6].

In Bahariya Oasis there are some springs in addition to shallow and deep drilled wells. Most of agricultural areas and villages in the Oasis are spotted around these points. In the last decade, Bahariya Oasis was suggested as a proposed area for agriculture reclamation projects due to its location and the availability and good quality of groundwater as reported by Ibrahim [7] & Serag El-Din [8]. The amount of the reclaimed land in Bahariya Oasis is about 23,100 acres; most of these areas are located in the northern parts of the Oasis. Groundwater in Bahariya Oasis needs to be evaluated for its availability on the long-term and its quality. Also, there is an urgent need to develop an effective management program and adequate staff to maintain groundwater production over an extended period of years.

Nowadays, GIS techniques are extensively used in studying the spatial variability of metals in groundwater at different areas of the world to develop a decision making system [9-11]. The main objectives of this work were to evaluate the quality of groundwater in Bahariya Oasis for irrigation and to study the spatial variability of groundwater salinity within the Oasis using geostatistical analyses (Kriging).

## Material and Methods

### Description of the Studied Area

Bahariya Oasis is a topographic depression in the western desert of Egypt. It is located between 27° 48' and 28° 30' N and between 28° 35' and 29° 10' E, about 180 km west of the Nile valley and about 360 km southwest of Cairo [Fig-1]. It covers an area of about 2200 $km^2$. Surface elevation varies from 73 to 358 m above the sea level. Surface slope varies from zero to 57% with a mean value of 3%. Bahariya Oasis is considered as an extremely arid region, where the total annual precipitation is about 4 mm. Maximum air temperature varies from 20.1ºC in winter to 36.9ºC in summer, with mean value of 29.6ºC. Minimum air temperature ranges between 4.9ºC in winter and 21.0ºC in summer, with mean value of 13.7ºC [12].

Geology of Bahariya Oasis consists of the Bahariya formation, which forms the floor of the depression and the major part of the surrounding scarp and the isolated hills in the depression. Other geological formations include El-Heiz formation, El-Hefhuf formation, and Quaternary deposits [13,14].

Native vegetation in Bahariya Oasis, which commonly associated with dry salt marshes, could be divided into four communities dominated by *Sporobolus spicatus, Alhagi maurorum, Desmostachya bipinnata and Tamarix nilotica*. The last three communities represent more than 80% of the natural vegetation of the Oasis [15]. Date palm *(Phoenix dactylifere*) is the main crop in Bahariya oasis, where date is the main production.

All cultivated crops in the Oasis have to be irrigated and groundwater is the only readily available source of water for irrigation and other human activities in the Oasis.

### Water Sampling and Analysis

About 19 representative water samples were collected from governmental wells in Bahariya Oasis. This is in addition to 448 private wells were located in the Oasis and tested only for their Electrical Conductivity (EC) by using the EC meter (Model TDScan 3). Water samples were freshly collected after several hours of pumping. Well locations were georeferenced using the Global Positioning System (GPS) (Garmin etrex Legend). The spatial distribution of the studied governmental and private wells in the Oasis is illustrated in [Fig-1]. EC was directly measured in the collected samples using the EC meter. Water samples collected from governmental wells, were sent to the lab and analyzed for their cations, anions, and pH according to the methods described by Chapman & Pratt [16]. Na and K were determined using the flame photometer (Jenway, PFP7). Ca and Mg were measured using the atomic absorption (Perkin Elmer-2380). Chloride, carbonate and bicarbonates were determined by titration. Sodium Adsorption Ratio (SAR) and Residual Sodium Carbonates (RSC) were calculated from the obtained data using the following equations [Eq-1, 2]:

$$SAR = \frac{Na^{+}}{\sqrt{(Ca^{2+} + Mg^{2+})/2}} \quad (1)$$

$$RSC = (CO_3^{2-} + HCO_3^{-}) - (Ca^{2+} + Mg^{2+}) \quad (2)$$

Where; $Na^+$, $Ca^{2+}$ and $Mg^{2+}$ are the concentrations in meq $L^{-1}$ of sodium, calcium, and magnesium ions in water samples. $CO_3^{2-}$ and $HCO_3^-$ are the concentrations in meq $L^{-1}$ of carbonate and bicarbonates in water samples.

Total Hardness (TH) was calculated from the obtained results using the following equations [Eq-3] as described by APHA [17].

$$\text{Total Hardness } (\sim \text{ to } CaCO_3 \text{ mg } L^{-1}) = 2.5Ca^{2+} + 4.1Mg^{2+} \quad (3)$$

The estimated equilibrium Exchangeable Sodium Percentage (ESP) was calculated from the SAR using the following relationship [Eq-4] as described by Richards [18].

$$ESP = \frac{100(-0.0126 + 0.01475SAR)}{1 + (-0.0126 + 0.01475SAR)} \quad (4)$$

Where; $Ca^{2+}$ and $Mg^{2+}$ are the concentrations of calcium and magnesium ions in water samples, represented in mg $L^{-1}$.

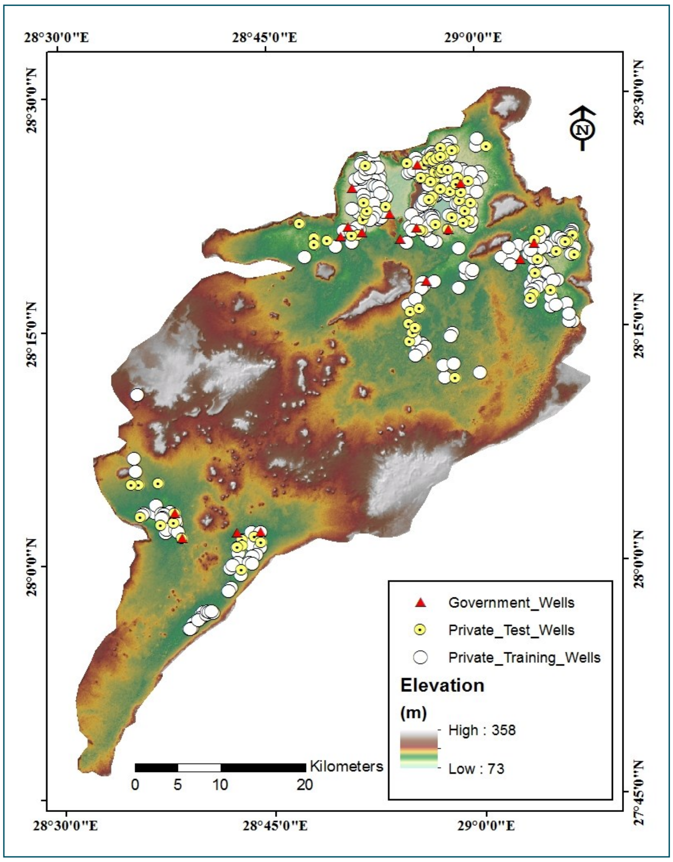


**Fig. 1-** Topography of Bahariya Oasis and locations of the studied wells.

### Spatial Interpolation using Kriging

Spatial distribution of salinity in groundwater of private wells in Bahariya Oasis was interpolated using ordinary Kriging under Geostatistical analyst in ArcGIS software package 10.1. The private wells were subset into two portions (testing and training wells) as represented in [Fig-1]. The training wells (about 80% of the wells) were used to train or develop the geospatial model used in the spatial interpolation of EC values in the Oasis. The testing wells (about 20% of the wells) were used to test the correlation with the developed model.

## Results and Discussions

### General Characteristics of Water in Governmental Wells of Bahariya Oasis

Chemical characteristics of water in 17 of the Governmental wells in Bahariya Oasis are represented in [Table-1]. These analyses indicate that the $Na^+$ concentration was varied from 0.81 to 2.34 meq $L^{-1}$, with an average of 1.34 meq $L^{-1}$. Potassium ions ($K^+$) were varied from 0.27 to 0.69 meq $L^{-1}$, with an average of 0.40 meq $L^{-1}$. Calcium ions ($Ca^{2+}$) were varied from 0.38 to 0.88 meq $L^{-1}$, with an average of 0.58 meq $L^{-1}$. Magnesium ions ($Mg^{2+}$) were ranged between 0.63 and 1.65 meq $L^{-1}$, with an average of 1.02 meq $L^{-1}$. Bicarbonate ions ($HCO_3^-$) were varied from 0.81 to 1.84 meq $L^{-1}$, with an average of 1.21 meq $L^{-1}$. Chloride ions ($Cl^-$) were varied from 1.15 to 2.98 meq $L^{-1}$, with an average of 1.64 meq $L^{-1}$. Sulfate ions ($SO_4^{2-}$) were varied from 0.19 to 0.75 meq $L^{-1}$, with an average of 0.49 meq $L^{-1}$. However, Sodium was the dominant cation and bicarbonates were the dominant anion in these water samples. The pH values were ranged between 7.1 and 8.2, with an average of 7.6. Highly significant correlations were observed between the EC values of groundwater in the studied governmental wells and $Na^+$, $K^+$, $Ca^{2+}$, $Mg^{2+}$, $Cl^-$, $HCO_3^-$ and $SO_4^{2-}$ (r= 0.98, 0.97, 0.95, 0.97, 0.97, 0.97 and 0.91, respectively). Correlation coefficients and the linear relationships between these ions and the EC values are represented in [Table-2].

**Table 1-** Chemical analyses of water samples collected from governmental wells in Bahariya Oasis.

| Site | Longitude | Latitude | Well Name | Cations (meq $L^{-1}$) | | | | Anions (meq $L^{-1}$) | | | | pH | EC dS $m^{-1}$ | SAR | Adj. SAR | ESP % | RSC | TH ppm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | $Na^+$ | $K^+$ | $Ca^{+2}$ | $Mg^{+2}$ | $CO_3^=$ | $HCO_3^-$ | $Cl^-$ | $SO_4^{=*}$ | | | | | | | |
| 1 | 28.8364 | 28.3491 | Embash | 0.97 | 0.3 | 0.41 | 0.85 | -- | 0.99 | 1.15 | 0.39 | 7.1 | 0.26 | 1.22 | 0.99 | 0.54 | -0.27 | 62.3 |
| 2 | 28.8458 | 28.3594 | Almaftla | 1.2 | 0.34 | 0.49 | 0.84 | -- | 1.05 | 1.45 | 0.38 | 8 | 0.3 | 1.47 | 1.19 | 0.9 | -0.29 | 66 |
| 3 | 28.8506 | 28.4015 | Algazareen | 1.02 | 0.28 | 0.38 | 0.63 | -- | 0.88 | 1.24 | 0.19 | 7.2 | 0.24 | 1.44 | 1.11 | 0.86 | -0.13 | 49.9 |
| 4 | 28.8956 | 28.3728 | Alamrecan | 1.6 | 0.37 | 0.66 | 1.31 | -- | 1.38 | 1.99 | 0.58 | 8.2 | 0.4 | 1.61 | 1.43 | 1.11 | -0.59 | 97.7 |
| 5 | 28.8617 | 28.3531 | Albeshmo | 2.18 | 0.61 | 0.79 | 1.41 | -- | 1.68 | 2.58 | 0.72 | 7.8 | 0.49 | 2.08 | 1.91 | 1.78 | -0.51 | 108.5 |
| 6 | 28.9378 | 28.3009 | Algefara | 1.81 | 0.58 | 0.65 | 1.35 | -- | 1.62 | 2.11 | 0.66 | 8.04 | 0.46 | 1.81 | 1.64 | 1.39 | -0.38 | 98.9 |
| 7 | 28.9275 | 28.3574 | Ain hamra | 1.19 | 0.37 | 0.54 | 0.73 | -- | 0.94 | 1.43 | 0.46 | 7.9 | 0.29 | 1.49 | 1.19 | 0.94 | -0.33 | 62.8 |
| 8 | 28.9073 | 28.3457 | Alagoz Algharbie | 1.02 | 0.34 | 0.45 | 0.74 | -- | 1.04 | 1.19 | 0.32 | 8.04 | 0.27 | 1.32 | 1.07 | 0.69 | -0.15 | 58.9 |
| 9 | 28.9294 | 28.4254 | Kasaa 2 | 2.34 | 0.69 | 0.88 | 1.65 | -- | 1.84 | 2.98 | 0.75 | 8 | 0.55 | 2.08 | 1.95 | 1.78 | -0.69 | 125.4 |
| 10 | 28.9812 | 28.4042 | Kasaa 5 | 2.05 | 0.61 | 0.8 | 1.39 | -- | 1.77 | 2.36 | 0.71 | 7.7 | 0.49 | 1.96 | 1.81 | 1.61 | -0.41 | 108.1 |
| 11 | 28.9654 | 28.3552 | Alkabala Alsharke | 1.23 | 0.42 | 0.7 | 1.28 | -- | 1.48 | 1.55 | 0.6 | 7.4 | 0.37 | 1.24 | 1.11 | 0.57 | -0.49 | 97.7 |
| 12 | 29.0508 | 28.3219 | Ain Alwadi 1 | 1.28 | 0.41 | 0.71 | 1.15 | -- | 1.45 | 1.57 | 0.53 | 7.2 | 0.37 | 1.33 | 1.19 | 0.7 | -0.41 | 91.9 |
| 13 | 29.0678 | 28.3389 | Ain Yousof | 0.81 | 0.29 | 0.52 | 0.82 | -- | 0.86 | 1.21 | 0.36 | 8.1 | 0.25 | 0.99 | 0.76 | 0.2 | -0.48 | 66.1 |
| 14 | 28.6417 | 28.0292 | Alaza wa Alshiek | 0.89 | 0.27 | 0.44 | 0.76 | -- | 0.81 | 1.19 | 0.35 | 7.3 | 0.24 | 1.15 | 0.88 | 0.43 | -0.39 | 59.2 |
| 15 | 28.6332 | 28.0553 | Alkarah | 1.1 | 0.3 | 0.47 | 0.76 | -- | 0.91 | 1.31 | 0.41 | 7.2 | 0.28 | 1.4 | 1.09 | 0.8 | -0.32 | 60.9 |
| 16 | 28.7073 | 28.034 | Ain Gomaa | 1.02 | 0.3 | 0.45 | 0.8 | -- | 0.89 | 1.29 | 0.39 | 7.1 | 0.27 | 1.29 | 1 | 0.64 | -0.36 | 61.9 |
| 17 | 28.7354 | 28.0344 | Tabl Amoon | 1.15 | 0.32 | 0.49 | 0.9 | -- | 1.02 | 1.23 | 0.61 | 7.3 | 0.3 | 1.38 | 1.12 | 0.77 | -0.37 | 68.8 |
| Minimum | | | | 0.81 | 0.27 | 0.38 | 0.63 | -- | 0.81 | 1.15 | 0.19 | 7.1 | 0.24 | 0.99 | 0.76 | 0.2 | -0.69 | 49.9 |
| Maximum | | | | 2.34 | 0.69 | 0.88 | 1.65 | -- | 1.84 | 2.98 | 0.75 | 8.2 | 0.55 | 2.08 | 1.95 | 1.78 | -0.13 | 125.4 |
| Mean | | | | 1.34 | 0.4 | 0.58 | 1.02 | -- | 1.21 | 1.64 | 0.49 | 7.6 | 0.34 | 1.49 | 1.26 | 0.92 | -0.39 | 79.1 |

* $SO_4$ = was calculated by difference between cations and anions

**Assessment of Water Quality based on Its Electrical Conductivity (EC)**

Water quality for irrigation purposes is mainly depending on its salt content. Where, the higher the salt content, the lower the water quality for plant growth. Water quality is classified into four classes based on the EC values according to USDA laboratory [18]. These classes are: very good (EC < 250 μS$m^{-1}$), good (EC ranges between 250 and 750 μS$m^{-1}$), poor (EC ranges between 750 and 4000 μS$m^{-1}$), and non-suitable (EC > 4000 μS$m^{-1}$). Electrical conductivity (EC) of private wells was varied from 296 to 1020 μS$m^{-1}$, with an average value 512 μS$m^{-1}$. However, EC values in the 17th governmental wells varied from 240 to 550 μS$m^{-1}$, with an average value of 340 μS$m^{-1}$. These values in governmental wells were lower than that in private wells, however they were highly correlated (r= 0.80, P= 0.0001). This could be attributed to the difference in depths between the two types of wells. Governmental wells have an average depth of about 650 m, whereas private wells have an average depth of about 150 m. Therefore, private wells are more influenced by the higher soil salinity and the poor drainage in the Oasis [19]. In conclusion, groundwater in the Oasis either from governmental wells or private wells is good for crop irrigation.

The spatial variability of EC values in Bahariya Oasis [Fig-2] was derived from the geospatial model developed from using the EC values of water in 358 (80% of the wells) of the private wells. The obtained model was tested using the EC values of water in 90 (20% of the wells) of the private wells other than those used in developing the model. A highly significant correlation (r= 0.81, P= 0.001) was found between the measured EC values in the tested wells and the predicted values using the geospatial model as illustrated in [Fig-3]. This indicates that water salinity in the groundwater of Bahariya Oasis was spatially correlated and therefore its spatial variability can be predicted using spatial interpolation techniques such as Kriging.

Data illustrated in [Fig-2] indicate that most of groundwater in the Oasis is within the lower water salinity range (< 500 μS$m^{-1}$). This class covers an area 1421 $km^2$ (about 65% of the Oasis). The 2nd water salinity class (500 – 750 μS$m^{-1}$) covers an area of about 689 $km^2$ (about 31.5% of the Oasis). The 3rd water salinity class (750 –

1000 µSm-1) covers an area of about 77 km$^2$ (about 3.5%). [Fig-2] also reveals that water salinity in private wells of Bahariya Oasis increases from the south to the north and the north east directions. These results are in agreement with those obtained by [7,8,20].

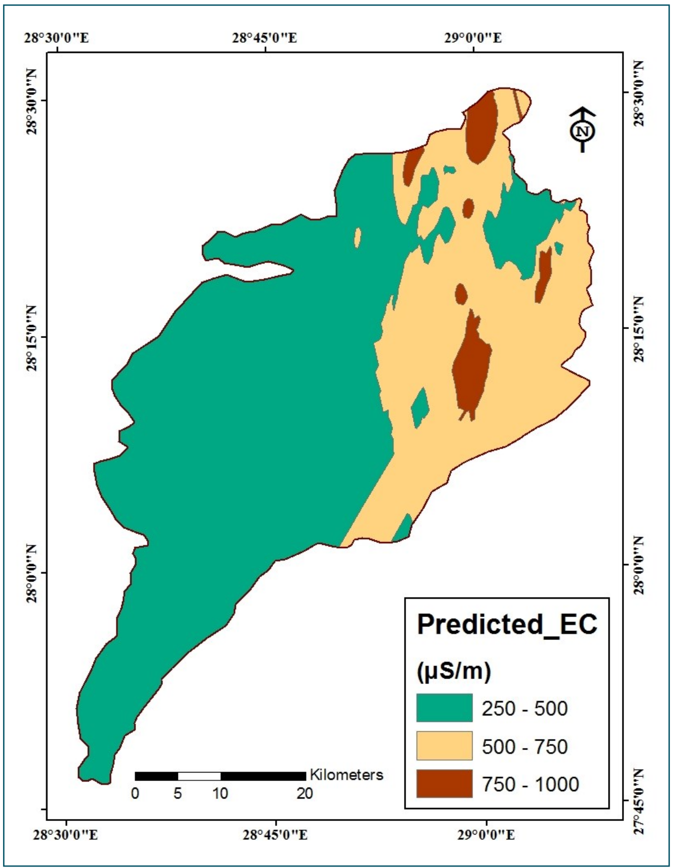


**Fig. 2-** Classification of the predicted EC values (µsm-1) of groundwater in the private wells of Bahariya Oasis.

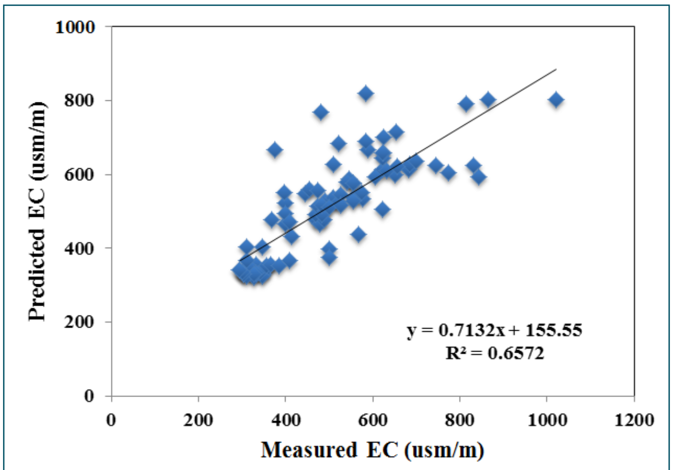


**Fig. 3-** Linear regression between measured and predicted EC values (µsm-1) in private wells in Bahariya Oasis.

**Assessment of Water Quality based on Sodium Adsorption Ratio (SAR)**

Higher concentrations of sodium ions in irrigation water create a plant growth hazard. SAR is the common method for estimating sodium hazard in irrigation water. SAR refers to the proportion of sodium (Na) ions compared to the concentration of calcium (Ca) plus magnesium (Mg). When the SAR rises above a certain level, serious soil problems occur and plants have difficulty in absorbing water. Sodium ions can also produce adverse effects on soil structure even when the SAR is near 5 depending on the type and content of clay. Montmorillonite, vermiculite, illite and mica-derived clays are more sensitive to $Na^+$ than other clays. SAR values of 15 or greater indicate that an excess amount of sodium will be adsorbed by the soil clay particles. Excess of $Na^+$ can cause soil to be hard and blocky when dry, to crust badly, and to infiltrate water very slowly [21].

Results of chemical analyses for water samples collected from governmental wells in Bahariya Oasis are represented in [Table-1]. SAR values of these water samples were varied from 0.99 to 2.08, with an average value of 1.49. This indicates higher quality of irrigation water and low hazard of soil alkalinity when this water is used for crop irrigation.

Sodium in water and soil solution is usually expressed as SAR because of its close relationship with the exchangeable sodium percentage (ESP) on the exchange complex. The proportions of $Ca^{2+}$, $Mg^{2+}$ and $Na^+$ on the exchange complex are not identical to the proportions in the soil solution because the divalent cations are preferentially adsorbed onto the clay exchange surfaces.

The ESP values were calculated from the SAR values in water samples collected from the studied governmental wells. The ESP values were varied from 0.20 to 1.78%, with an average of 0.92%. These results also indicate a very low probability for sodium to dominate the exchange complex when this water is used in irrigation. This hazard is also very low in Bahariya Oasis, where the majority of soils in the Oasis are coarse-textured soils [19].

Both the SAR and the ESP values showed highly significant correlations with the EC values of groundwater in governmental wells (r=0.88 for both parameters) as represented in [Table-2].

**Table 2-** Linear regression of the relationships between EC values and other water parameters in governmental wells.

| Parameter | Equation | r |
|---|---|---|
| Na | Na = 4.5668 * EC - 0.2144 | 0.98** |
| K | K = 1.2948 * EC - 0.0428 | 0.97** |
| Ca | Ca = 1.449 * EC + 0.0824 | 0.95** |
| Mg | Mg = 3.0024 * EC - 0.0043 | 0.97** |
| Cl | Cl = 5.3879 * EC - 0.2036 | 0.97** |
| $HCO_3$ | $HCO_3$ = 3.4584 * EC + 0.031 | 0.97** |
| $SO_4$ | $SO_4$ = 1.4711 * EC - 0.0081 | 0.91** |
| SAR | SAR = 2.8076 * EC + 0.5283 | 0.88** |
| AdjSAR | AdjSAR = 3.3479 * EC + 0.1182 | 0.95** |
| ESP | ESP = 4.0483 * EC - 0.4598 | 0.88** |
| RSC | RSC = -0.993 * EC - 0.0471 | -0.70** |

** Highly significant at 0.01 significance level.

**Assessment of Water Quality based on Adjusted Sodium Adsorption Ratio (Adj.SAR)**

Water analyses received from analytical laboratories should also provide the Adj.SAR in addition to the SAR. The Adj.SAR takes into account the carbonate and bicarbonate ions in water. This is because, these ions cause the Ca ions to precipitate out of water resulting in higher sodicity. The Adj.SAR should be used when determining if the water is appropriate for irrigation purposes. The Adj.SAR of irrigation water should be less than 10, especially if young plants are to be grown [22].

The Adj.SAR values of water in the governmental wells of Bahariya Oasis were varied from 0.76 to 1.95 meq $L^{-1}$, with an average value of 1.26 meq $L^{-1}$. The Adj.SAR had a highly significant correlation with the EC values of groundwater in governmental wells (r=0.95) as represented in [Table-2].

### Assessment of Water Quality based on its Residual Sodium Carbonate (RSC)

RSC is expressed in meq $L^{-1}$ and it should not be higher than 1 and preferably less than +0.5 for considering the water use for irrigation. The RSC values in governmental wells were negative and ranged between -0.69 and -0.13 meq $L^{-1}$, with an average value of -0.39 meq $L^{-1}$, which indicates higher water quality for irrigation. The RSC values had a negative but highly significant correlation with the EC values of groundwater in governmental wells (r=-0.70) as represented in [Table-2]. This parameter also reveals higher quality of irrigation water and low hazard of soil sodicity when this water is used in crop irrigation.

### Assessment of Water Quality based on its Total Hardness (TH)

There are two types of water hardness temporary and permanent hardness. The total permanent hardness was calculated in this work. It includes both of calcium hardness and magnesium hardness. The total permanent water hardness is expressed as equivalent of $CaCO_3$. The concentrations less than 60 mg $L^{-1}$ indicate soft water; 60 to 120 mg $L^{-1}$ indicate moderately hard water; 120 to 180 mg $L^{-1}$ indicate hard water, and values greater than 180 indicate very hard water according to the USGS.

Total Hardness (TH) of water in governmental wells was varied from 49.9 to 125.4 ppm, with an average value of 79.1 ppm. These results indicate that water hardness in the studied wells ranged between soft to moderately hard water.

It could be concluded from the above mentioned results that water in both private and governmental wells in Bahariya Oasis is good for crop irrigation.

## Conclusion

It could be concluded that water salinity in private wells of Bahariya Oasis were spatially correlated. It was accurately estimated using spatial interpolation techniques (Kriging). Water salinity in both private and governmental wells in the Oasis was highly correlated; however it was lower in governmental wells. Chemical analyses of water samples collected from both private and governmental wells in Bahariya Oasis and water quality parameters indicated that groundwater in the Oasis is good for crop irrigation. However, in order to sustain this water resource, certain concerns have to be given for its availability and its management. Some of these concerns are: the use of more efficient irrigation systems such are sprinkler and drip irrigation, the implementation of drainage systems in the Oasis and the cultivation of drought resistant crops.

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**Conflicts of Interest:** None declared.

## References

[1] Salama R.B. (1985) *J. of African Earth Sci.*, 33, 381-390.

[2] Korany E.A. (1984) *On the demonstration of the hydrogeological control by local geologic structures*, *Bahariya Oases, Egypt*. E.G.S. Proc. of 3rd Annual Meeting, 341-335.

[3] Shehata M.A. (1992) *Geohydrological studies on the Central part of Western Desert, Egypt*, Ph.D. Thesis, Faculty of Science, Zagazig University, Egypt, 268.

[4] El-Shazly M.M., El-Ramly I.M., Guindy Kh.A. & Abdel Aati A. (1991) *Bahariya formation water quality characteristics and its relationship to the hydrothermal activity in Bahariya Oasis, Western Desert,* Egypt. Geol. Soc. Egypt. 29th Annual Meeting, Cairo, Egypt.

[5] Korany E.A. (1981) *Analysis and evaluation of step-drawdown and recovery tests, Bahariya Mines area, Western Desert*, Egypt. 6th Int. Conf. on Stat. Soc., Cairo, Egypt, 217-240.

[6] Freeze R.A. & Cherry J.A. (1979) *Groundwater*, Prentice-Hall, Englewood Cliffs, NJ, 604.

[7] El-Sisi Z., Hassaouba M., Odani M.J. & Dolson J.C. (2002) *The Geology of Bahariya Oasis in the Western Desert of Egypt and its Archeological Heritage*. Field Trip No. 8, Cairo International Conference and Exhibition, October 27-30.

[8] Serag El-Din H.M. (1999) *Egyptian J. Geol*., 43(2), 269-280.

[9] Armah F.A., Odoi J.O., Afrifa E.K.A., Pappoe A.N.M., Yawson D.O. & Essandoh P.K. (2011) *Res. J. Environ. Earth Sci*., 3(5), 546-554.

[10] Minakshi D.M., Sharma P.K., Tur N.S., Singh H. & Kang G.S. (2006) *J. Environ. Sci. Eng*., 48(2), 91-96.

[11] Satapathy D.R., Salve P.R. & Katpatal Y.B. (2009) *Environ. Geol*., 56, 1323-1352.

[12] EMA (2012) *Egyptian Meteorological Authority (EMA)*, Annual reports, Cairo, Egypt.

[13] El-Sisi Z., Hassaouba M., Odani M.J. & Dolson J.C. (2002) *The Geology of Bahariya Oasis in the Western Desert of Egypt and its Archeological Heritage*, Field Trip No. 8, Cairo International Conference and Exhibition, October 27-30.

[14] Khalifa M.A., Catuneanu O. & Wanas H.A. (2006) *Sequence stratigraphy of the lower cenomanian bahariya formation, Bahariya Oasis, Western Desert, Egypt*, Geology Dept., Fac. of Sci., Menoufia Univ., Shebin El-Kom, Egypt, 190(1-4), 121–137.

[15] Zahran M.A. & Willis A.J. (2009) *The Vegetation of Egypt*, 2nd ed., Springer Science Business Media B.V., 44.

[16] Chapman H.D. & Pratt F.P. (1982) *Determination of minerals by titration method. Methods of Analysis for Soils*, Plants and Water, 2nd ed., Agriculture Division, California University, USA, 169-170.

[17] APHA (1998) *Standard Methods for the Examination of Water and Wastewater*, 20th ed., Washington, DC, USA, 179.

[18] Richards L.A. (1954) *Agriculture Handbook* No. 60, USDA, Washington, DC, 69-82.

[19] Elnaggar A.A., El-Hamdi Kh.H., Belal A.B.A. & El-Kafrawy M.M. (2013) *J. Soil Sci. and Agric. Eng.*, Mansoura Univ., 4(9), 921-947.

[20] El-Arafy R.A.E. (2010) *Composition and Radioactivity of groundwater and some Quaternary Sabkha sediments in Bahariya Oasis, Egypt*, M.Sc. Thesis, Geology Dept., Fac. of Sci., Mansoura University, Egypt, 107.

[21] Munshower F.F. (1994) *Practical Handbook of Disturbed Land Revegetation*, Lewis Publishers, Boca Raton, Florida, USA, 7.

[22] Korany E.A. (1981) *Analysis and evaluation of step-drawdown and recovery tests, Bahariya Mines area, Western Desert*, Egypt. 6th Int. Conf. on Stat. Soc., Cairo, Egypt, 217-240.