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RESEARCH ARTICLE

GROUNDWATER QUALITY AND ENVIRONMENTAL INVESTIGATIONS IN SIWA OASIS, EGYPT

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ABSTRACT

Siwa Oasis is one of the most promised locations in the Western Desert of Egypt for future agricultural projects as a result of groundwater availability. In addition, it has historical, medical and environmental tourism importance. However, the uncontrolled abstraction and use of groundwater may lead to much environmental deterioration for soil and groundwater aquifer. This study dealt with the water quality of both shallow and deep aquifers in Siwa. The hydrochemical studies indicated the meteoric origin of deep aquifer and its suitability for different uses. Also, this water is free of As, Cd and Pb as well as contains acceptable levels of Cu and Zn. On the other hand, the shallow aquifer was very saline with TDS≥1651 ppm. Accordingly, this water is unsuitable for drinking. The main process controlling salinity of this aquifer was evaporation process. The salinity of water makes it detrimental for irrigation except under certain conditions. The most advantage of this water its acceptable SAR in most samples as well as acceptable levels of the studied harmful heavy metals. So it is restricted for the irrigation suitability. Unfortunately, the surface area of lakes was duplicated in the last 13 years as a result of uncontrolled irrigation. The application of new irrigation technology and cultivation of salt tolerant plants is recommended.

INTRODUCTION

Siwa Oasis is considered the virgin oasis of Egypt located in the Western desert (Fig. 1). It contains unique geological features which can flourish geologic tourism (Sallam *et al.,* 2018). Also, it contains important historical monuments like Ammon temple and Gebel Elmoata. Siwa has a unique environment, makes it a good place for medical tourism. Many peoples, suffered from joint and skin diseases, visit Siwa annually for natural therapy. Siwa contains different natural resources which use in natural therapy; sand (Psammotherapy), salt ponds (Thalassotherapy) and springs (Spa) (Fig. 2). The most important natural resource in Siwa oasis is the groundwater which is considered the only source of drinking and irrigation water. Siwa contains two groundwater aquifers; the Miocene carbonate aquifer and the Nubian aquifer. The expected agriculture expansion in Siwa oasis from 2010 to 2028 was 83.97 to 129.23 km^2 (Samy 2010). Accordingly, about 1350 wells were drilled in the oasis to abstract water from the carbonate aquifer (Elnagar 2008). The structure elements control the surface and subsurface features in Siwa. It controls the movement of water between the lakes and the subsurface aquifers (Masoud and Koike 2006). The overexploitation of water may cause the degradation of water quality in the oasis (Aly *et al.,* 2016). The quality of irrigation water is an important issue due to its impact on crop production and soil quality as well as human and animal health. The determination of water salinity and chemical constituents reveals the suitability of water for different purposes. It gives a good indication of rock-water interaction and anthropogenic impact. In addition, harmful elements (e.g. As, Cd, Pb and Cu) determination becomes a necessary aspect in the recent years as a result of their adverse health impact. Many health problems were linked to the use of polluted water with heavy metals (Salem *et al.,* 2000, Melegy *et al.,* 2014). So, the current work was conducted to determine the quality of groundwater and the impact of overexploitation of it on the groundwater resources on the environment in Siwa Oasis, Egypt.

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MATERIALS AND METHODS

Two types of water samples, 8 samples (D1-D8) from the Nubian aquifer (deep wells) and 48 samples (1-48) from the Limestone aquifer (shallow wells) were collected from different sites at Siwa Oasis during October 2014 (Fig. 1). The samples were collected in 1L polyethylene bottle transferred to the lab in an ice box. The temperature, pH and total dissolved solids (TDS) were determined at the site with the help of digital HANNA pH meter (HI 991300) which was calibrated prior to take readings. At the lab, the samples were filtered and analyzed for chemical constituents by using standard procedures (APHA 1995). Titrimetric methods were used for the determination of total hardness (TH) as $CaCO_3$, calcium (Ca), magnesium (Mg), carbonate (CO_3), bicarbonate (HCO_3) and chloride (Cl).

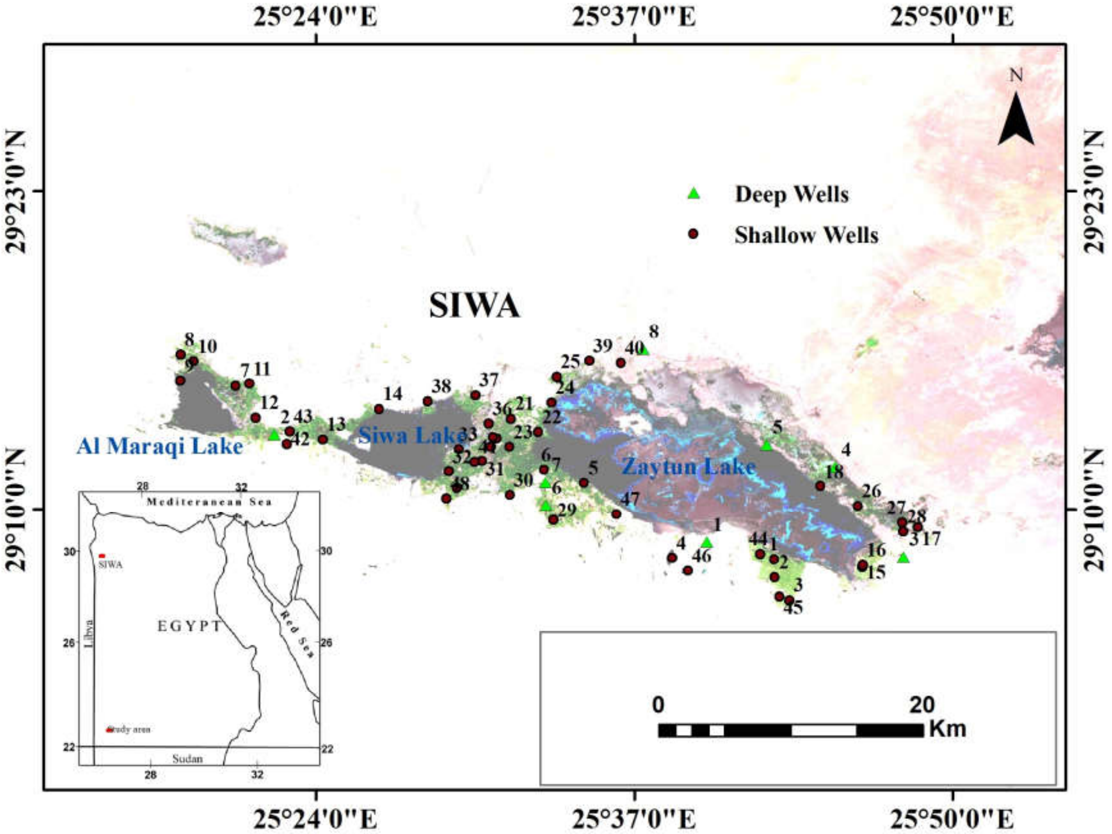

Fig. 1. Location map of Siwa oasis and sampling points

Fig. 2. Natural therapy in Siwa Oasis (a) salt pond (b) spring (Cleopatra's Pool) and (c) sand bath

Table 1. Descriptive statistics of the studied physicochemical parameters of deep groundwater at Siwa Oasis

	pH	TDS ppm	EC µS/cm	T °C	TH ppm	Ca ppm	Mg ppm	Na ppm	K ppm	HCO_3 ppm	Cl ppm	SO_4 ppm	NO_3 ppm	Cu µg/l	Zn µg/l	SAR
Mean	7.42	338	492.4	27.4	138.8	22.3	29.5	68.2	17.2	238.5	86.0	18.9	4.2	63.8	15.0	2.2
Median	7.42	312	447.3	27.5	135.0	20.0	26.5	71.3	16.4	240.0	73.7	3.2	3.6	25.0	0.0	2.4
SD	0.43	92.5	140.0	0.6	56.9	10.2	12.7	24.6	4.9	52.9	40.1	41.7	2.5	106.2	20.7	0.7
Min	6.83	234	344.9	26.6	50.0	12.0	16.2	28.0	10.9	171.1	35.5	0.8	1.0	0.0	0.0	0.9
Max	8.11	442	660.8	28.3	220.0	40.1	48.6	93.8	23.5	335.5	152.9	121.5	9.3	320.0	40.0	3.2
Q1	7.15	260	375.5	27.0	100.0	13.5	19.2	53.1	13.4	197.8	65.3	1.1	3.1	15.0	0.0	1.9
Q3	7.72	442	647.7	27.8	177.5	29.0	38.3	89.2	21.8	258.5	101.5	8.2	5.2	55.0	40.0	2.5
90%	7.84	442	652.2	28.0	206.0	34.5	45.2	90.6	23.1	296.0	142.7	46.4	6.4	145.0	40.0	2.9

Table 2. Descriptive statistics of the studied physicochemical parameters of shallow groundwater at Siwa Oasis

	pH	TDS ppm	EC µS/cm	T °C	TH ppm	Ca ppm	Mg ppm	Na ppm	K ppm	HCO_3 ppm	Cl ppm	SO_4 ppm	NO_3 ppm	Cu µg/l	Zn µg/l	SAR
Mean	7.14	3754.3	5536.8	27.3	965.2	184.9	181.4	946.4	44.0	314.4	2028.9	209.4	5.1	25.0	50.6	11.5
Median	7.07	3640.0	5369.9	27.3	1005.0	177.9	158.8	960.1	41.3	302.0	1653.2	195.2	4.1	0.0	50.0	12.1
SD	0.20	1672.9	2497.4	0.6	387.8	83.7	81.4	486.1	17.6	53.4	1113.7	128.2	4.1	39.7	39.6	4.1
Min	6.70	1651.0	2432.7	26.0	440.0	60.1	80.6	296.0	16.2	234.9	665.1	42.3	0.0	0.0	0.0	4.3
Max	7.61	8489.0	12603.4	28.7	1900.0	490.7	420.9	2269.4	104.5	580.2	4776.9	585.6	26.8	170.0	140.0	20.2
Q1	7.03	2145.0	3139.0	26.9	577.5	119.2	111.4	484.7	30.5	291.9	996.6	119.4	2.8	0	15	7.5
Q3	7.31	4862.0	7220.4	27.5	1170.0	230.5	219.6	1299.4	54.3	328.8	2648.5	254.9	6.4	32.5	72.5	14.6
90%	7.41	5865.6	8452.5	28.1	1442.0	280.6	283.1	1530.6	64.5	350.6	3699.9	333.9	8.0	83	110	16.4

TDS: Total Dissolved Solids; EC: Electric conductivity; SD: Standard Deviation; Min: Minimum; Max: Maximum; Q1: 1st Quartile; Q3: 3rd Quartile
90%: 90 percent of studied samples

Sodium (Na) and potassium (K) were determined by flame photometer. Nitrate and sulphate metals were estimated by using determined by using HANNA Spectrophotometer instrument model HI 83215. Heavy metals (As, Cd, Cu, Pb and Zn) were determined by using the atomic absorption spectroscopy (AAS). The suitability of water for irrigation was determined by determination sodium absorption ratio (SAR) according to Wilcox (1955) equation (All values in meq/l):-

$$SAR = Na^+ / [(Ca^{2+} + Mg^{2+})/2]^{½}$$

Two satellite images were used from "https://glovis.usgs.gov"; the first one in 9-8-2005 (Landsat 4-5 Thematic Mapper (TM) Level-1 Data Products) and the second one in 23-4-2018 (Landsat 8 OLI/TIRS C1 Level-1 data). The data is with Path 180 and Row 040 and ArcGIS 10.4.1 software is used to calculate the lakes and agriculture areas.

RESULTS AND DISCUSSION

The Nubian sandstone aquifer contains water with TDS doesn't exceed 442 ppm (Table 1) in the study area and accordingly considered good potable water according to Chebotarev (1955). The EC of the studied samples ranged from 344.9 to 660.8 µS/cm. According to Detay (1997), water classification based on EC; four samples (Nos. 1 - 4) are slightly mineralized, one sample (No. 8) is moderately mineralized and three samples (Nos. 5 - 7) are highly mineralized water. These characteristics support the use of this water in the industry of bottled water in the oasis. Also, the hardness of this groundwater is less than 220 ppm. WHO (2011) pointed out the acceptance of water with less than 500 ppm hardness by consumers. The concentrations of the studied ions in water are within the WHO specification for drinking water (Table 1). Furthermore, the studied heavy metals are in the acceptable range for drinking water. Generally, this water is considered one of the highest quality water resources in Egypt. So, this aquifer needs more studies and controls for water abstraction and uses to prevent the deterioration of this important and unique freshwater resource in the most parts of the Egyptian Desert.

The uncontrolled abstraction and unplanned expansion in the desert reclamation and application of agricultural fertilizers, pesticides and herbicides may adversely impact the aquifer quality. On the other hand, the studied groundwater samples collected from the Miocene aquifer were brackish water with TDS of about 3754.3 ppm (Table 2). According to Chebotarev (1955) classification of water based on TDS; more than 75% of the studied samples are brackish water (TDS< 5000 ppm) and the rest of samples are salt water. The high TDS of this water makes it unsuitable for human consumption. So these wells are used for irrigation purposes in the study area. This high salinity may have resulted from the scarce rainfall, high evaporation and the marine sediments in the aquifer recharge area (Abo EL-Fadl *et al.,* 2015). The prevailing ions in the studied water samples are Na and Cl with concentrations of about 946.4 and 2028.9 ppm respectively. The high levels of these two ions are referred to the recorded halite mineral (Ibrahim and Kamh 2006) in the sediment of the study area. This aquifer water mostly is characterized by undetectable concentrations of As, Cd and Pb as well as low concentrations of Cu and Zn. Generally, the uncontrolled abstraction (from more than 1300 wells) and use of groundwater resources, as well as flooding irrigation (Fig. 3a) in Siwa, has led to many environmental problems in the oasis. The lakes surface area was increased dramatically and the level of water table was increased (waterlogging) (Fig. 3b and 3c). These problems led to the degradation of soil and adversely impacted the agriculture productivity. King and Thomas (2014) mentioned that uncontrolled irrigation led to land desertification. The lakes invade the cultivated land (Fig. 3b) and waterlogging led to the salinization of soil (Fig. 3d). In addition, many buildings have affected, especially old building and monuments (Fig. 3e). The change in the surface area of lakes and agriculture lands in Siwa oasis were calculated from satellite images. Lakes area were duplicated through the period from 2005 (52 km^2) to 2018 (105 km^2) (Fig. 4). This increase may cause groundwater degradation of groundwater quality owing to the structure of hydraulic connection between lakes and subsurface aquifer. The cultivated area was expanded (41.7%) from 2005 to 2018 from 60 km^2 to 85 km^2 respectively (Fig. 5).

Table 3. Classification of groundwater samples for Irrigation use based on electrical conductivity (After Wilcox 1955)

EC µS /cm	class	usage	Samples
<250	Excellent (C1)	Most crops and soil types	-
250 – 750	Good (C2)	Moderate drainage soil and salt tolerant plant without any special control for salinity	D1-D8
750 – 2250	Permissible (C3)	Good drainage soil and salt tolerant plants with required practice for salinity control	-
>2250	Unsuitable (C4)	Used only at high conditions; good permeable soil, good drainage system, very salt tolerant plant and soil washing.	1-48

Table 4. Classification of irrigation water based on SAR values (After Wilcox 1955)

Class	SAR Values	Quality	Usage	Samples
S1	0-10	Low sodium water	Most crops and soil types	D1:D8, 1:4, 6, 8, 15:17, 23, 24, 28:30, 42, 44:46, and 48
S2	10-18	Medium sodium water	Coarse texture soil and organic soil with good permeability	5, 7, 9:11, 13, 14, 19:22, 25:27, 31:41, 43 and 47
S3	18-26	High sodium water	Require special soil management, good drainage, high leaching and organic matter condition.	12 and 18
S4	>26	Very high salinity	Is generally unsatisfactory for irrigation purposes except at certain conditions	

Fig.3. (a) Uncontrolled irrigation (b) Invades of road and farm by lake (c) Wetting of soil as result of waterlogging (d) Salt formation on soil surface and (e) Soil swelling and destruction of old buildings

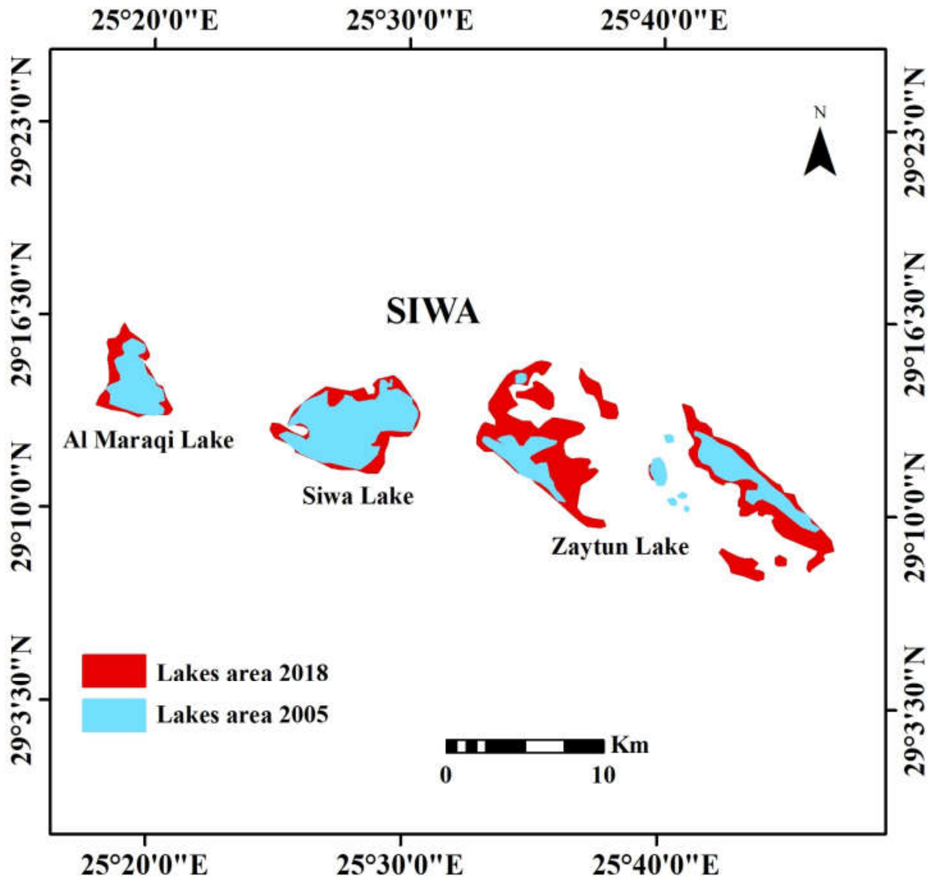

Fig. 4.The change in surface area of Siwa Oasis Lakes

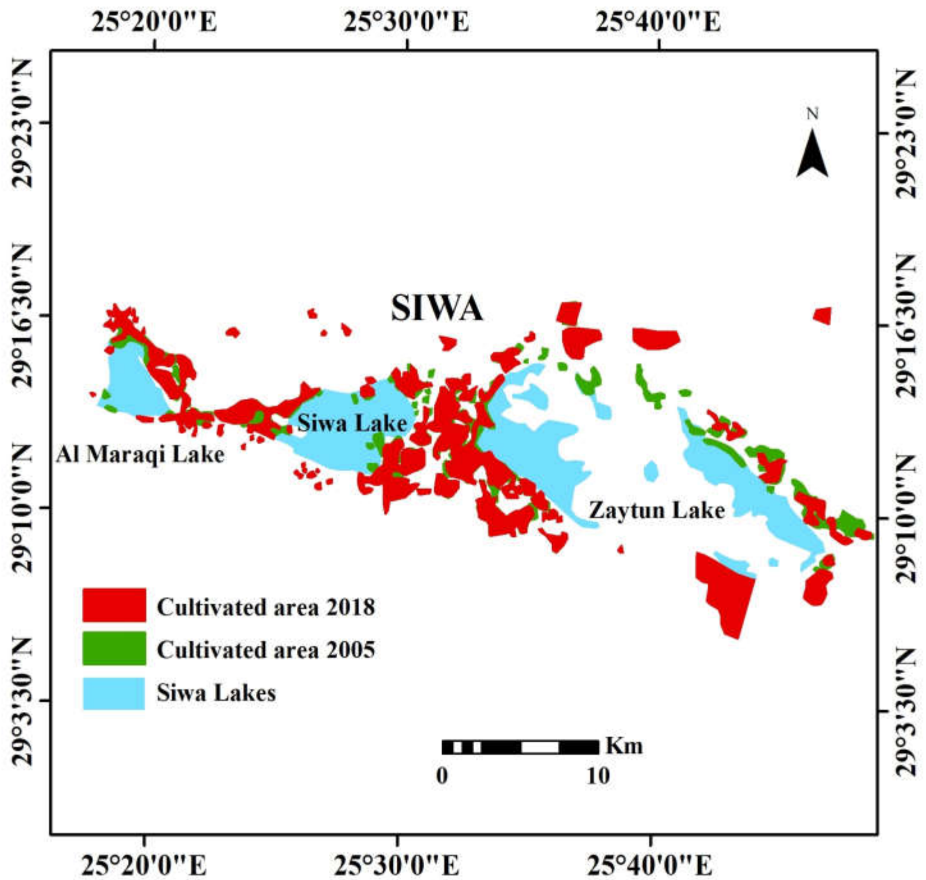

Fig. 5. The change in surface area of the cultivated land in Siwa Oasis

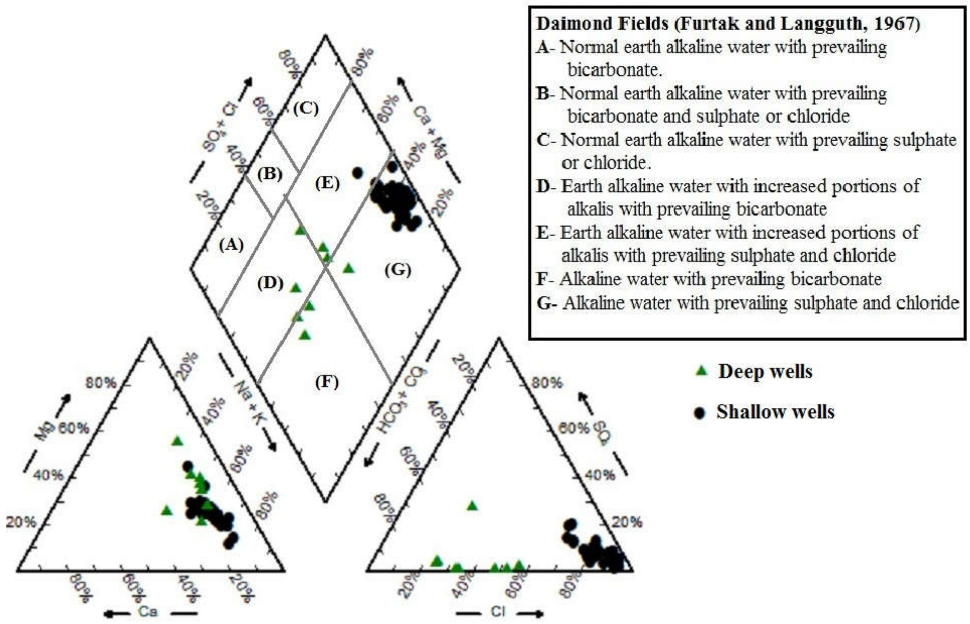

Fig.6: Piper diagram for classification of groundwater samples

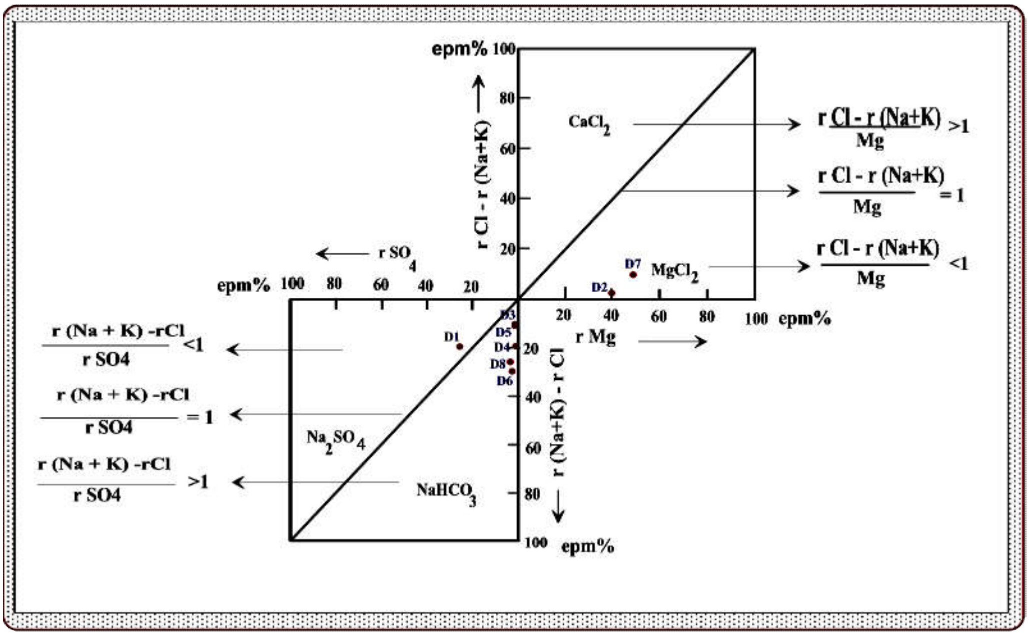

Fig. 7. Sulin's graph classification of groundwater

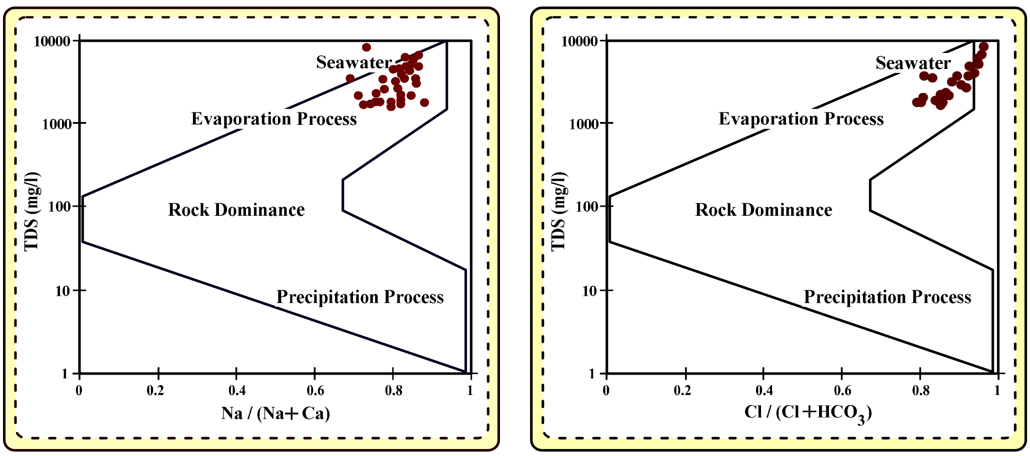

Fig. 8. Gibbs diagrams representing the mechanism controlling the chemistry of groundwater

Hydrochemical facies and genetic type of groundwater

Hydrochemical facies of the studied groundwater can be estimated by using Piper diagram (Piper 1944) which was applied by many authors (Ravikumar and Somashekar 2017). In this diagram, many analyses results can be plotted and resulted in grouping of samples of the same facies (Kresic 2006). The Nubian aquifer water samples fall in four fields of Piper diagram (Fig. 6). Shifting the samples into the center of the diamond shape indicted the contamination of this aquifer (Ikhlil, 2009). Some authors pointed out the adverse impact of the overexploitation of limestone aquifer on the quality of Nubian sandstone aquifer (Aly *et al.,* 2016). The limestone aquifer water is alkaline with prevailing SO_4 and Cl (Fig. 6). The diagram indicated the dominance of Na and Cl ions in the samples. The samples were clustered in the right apex of the diamond shape indicating their similarity to sea water. The proposed diagram by Sulin (1946) was applied widely by many authors (e.g. Hamza *et al.,* 2000; Al-Tememi 2015; Basyoni and Aref 2016) to predict the genetic type of water. By plotting the obtained data on Sulin Diagram, it is indicated the meteoric origin of the deep groundwater and the marine origin of the shallow groundwater aquifer (Fig. 7). The plot of D2 and D7 in the MgCl2 field may be attributed to the mix with the upper marine aquifer and sediments. In addition, the plotting of data on Gibbs (1970) diagram (Fig. 8) indicated the evaporation process impact on the aquifer. This is may be referred to the geographic location of the study area and rigid desert climate. The evaporation process is supported by the low molar Na^+/Cl^- ratio <1 (Belkhiri *et al.,* 2018).

Evaluation of water for irrigation

Siwa Oasis is one of the promised areas for agriculture expansion in the current years. Groundwater is the unique source of water in the oasis as a result of its long distance from the River Nile as well as its scarce rainfall. The most important characteristics of irrigation water which control its suitability for irrigation are salinity, trace elements content and sodium hazard. The measured salinity (EC) of deep wells fall into the good category of Wilcox (1955) classification (Table 3), while the shallow aquifer water was unsuitable for irrigation. Also, the calculated SAR indicted the good quality of deep aquifer water and about 40% of studied shallow aquifer samples (Table 4). The plotting of EC and SAR data on the United States Salinity Laboratory (USSL) diagram (Wilcox 1955) (Fig. 9) showed that the deep groundwater was of a good class for irrigation on all types of soil and plants. While the shallow groundwater has very high salinity hazard and fall in three classes: C4-S2, C4-S3 and C4-S4. C4-S2 can be used for high permeability soils and very salt-tolerant crops. C4-S3 and C4-S4 are not suitable for irrigation under ordinary conditions and can cause harmful levels of exchangeable sodium in soils (Ebrahimi *et al.,* 2016).

The studied harmful heavy metals As, Cd and Pb weren't detected in both deep and shallow groundwater in Siwa Oasis. Also, these water contains acceptable concentrations of Cu and Zn for drinking according to WHO (2011) and irrigation according to NAS-NAE (1972). These results indicated the quality of groundwater in the study area with respect to their content of heavy metals. The result supports the virginity of the oasis which related to the absence of industrial activities and the controlled application of chemical fertilizers and pesticides.

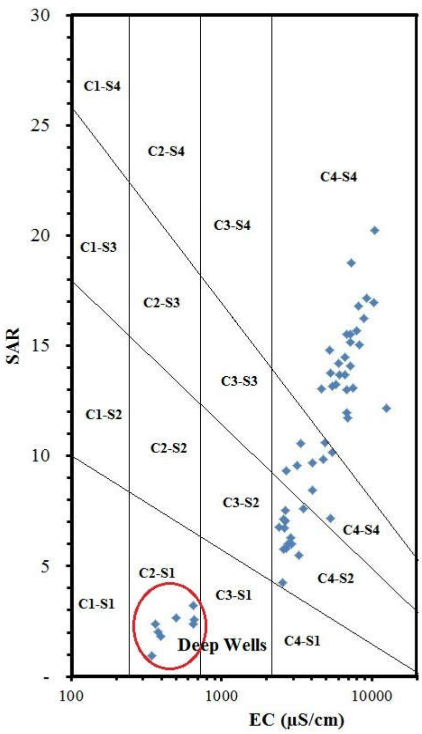

Fig. 9. USSL diagram for irrigation water classification

Conclusion

Siwa Oasis has agriculture, touristic and environmental importance. The uncontrolled development of agricultural projects can cause many environmental problems. The groundwater overexploitation and ordinary irrigation may be representing the most hazards in the study area. The degradation of groundwater and soil quality is the widest aspect. In addition, the destruction of buildings and monuments as a result of soil swilling and salinization is another problem. The Nubian aquifer has excellent quality and can be used safely for all purposes. While the Carbonate aquifer has high salinity and must be used under certain conditions.

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