Al-Azhar University Civil Engineering Research Magazine (CERM)
Vol. (43) No. (2) April . 2021

ASSESSMENT THE ENVIRONMENTAL IMPACT OF THE PREVAILING HYDROGEOLOGICAL STATUS FOR THE IRRIGATION SUITABILITY OF GROUNDWATER (CASE STUDY: GABEL EL ASFER AREA)

Amany Tammam M. Eid [*1], Maha Abdel Salam[2], Gamal Abd El Nasser [3] and Tarek El Sayed[4]

[1]Research Assistant, Research Institute of Groundwater (RIGW), NWRC, Cairo, Egypt.
[2]Professor of Groundwater Hydrology, Research Institute of Groundwater, NWRC, Cairo, Egypt.
[3]Professor of Soil Science and Water Quality, Research Institute of Groundwater, NWRC, Cairo, Egypt.
[4] Lecturer of Hydraulic Engineering, Department of Civil Engineering, Faculty of Engineering of Mataria, Helwan University, Cairo, Egypt.
*Corresponding Author E-mail:atmee_rigw@yahoo.com

الملخص العربي :

تروى مزرعة جبل الأصفر- الواقعة شمال شرق القاهرة، مصر - باستخدام مياه الصرف الصحي المعالجة منذ عام 1915. تم دراسة الأثر البيئي للوضع الهيدروجيولوجي لهذا النوع من مياه الري على جودة المياه الجوفية خلال الفترة من 2017 إلى 2020 من خلال المعايير الفيزو- كيميائية للوصول إلى تقييم سليم لمدى ملاءمتها الحالية للري من أجل استدامة إنتاج المحاصيل. الهدف الرئيسي هو إجراء تقييم موثوق به وتعزيز ملائمة المياه الجوفية للري بناء على الوضع الهيدروجيولوجي البيئي طوال الفترة من 2017 إلى 2020 في منطقة دراسة جبل الأصفر. في البحث الحالي، تم تطبيق برنامج SPSS الإحصائي لتحديد التحليل العاملي للبيانات الممثلة لجودة المياه الجوفية ولتحديد العوامل الأكثر تأثيرا و التي تتحكم في تطور المياه الجوفية، مع التركيز بشكل خاص على التوزيع المكاني للملوثات. كما تم تطبيق مخطط بايبر الثلاثي لمعرفة نوعية المياه.

توضح الاستنتاجات فاعلية المنهجية المختارة لتقييم ملائمة المياه الجوفية للري اعتمادا على معايير التكامل للتحليل النوعي السائد للمياه الجوفية. حيث تشير معظم المعايير الفيزو- كيميائية إلى ملائمة المياه الجوفية للري في منطقة الدراسة؛ على الرغم من أن المحاصيل الحساسة غير مناسبة بشكل عام للزراعة بسبب المستويات العالية من التوصيل الكهربائي والكلوريد. كما أظهر مخطط بايبر الثلاثي أن 57.7٪ من عينات المياه الجوفية تشكل نوع المياه المختلط. أظهر التحليل العاملي أن محتويات الأمونيا والنترات والصوديوم هي العناصر الرئيسية التي تتحكم في التباين الهيدروكيميائي.

الكلمات المفتاحية: الجبل الأصفر، الري بمياه الصرف الصحي، جودة المياه الجوفية، المعايير الفيزو- كيميائية، مخطط بايبر الثلاثي، التحليل العاملي

ABSTRACT:

Gabel El Asfer farm, which is located northeast of Cairo in Egypt, has been irrigated using treated sewage since 1915. The environmental impact of the hydrogeological status of this type of irrigation water on groundwater quality was studied through the period 2017 to 2020.

Focusing on the physicochemical quality parameters which are major ions, EC, TDS, SAR, RSC, TH, PI, MH, Na%, TH, KI, and CAI. To reach a sound evaluation of its current suitability for irrigation for sustainability of the crop production. **The main objective** is to perform a reliable assessment and enhancement the irrigation groundwater suitability based on the environmental hydrogeological situation throughout the period 2017 to 2020 at Gabal El Asfar study area.In the current research, the SPSS program of multivariate statistics was applied to determine the factor analysis for groundwater quality data and to identify the most influential factors that control the groundwater evolution, with a particular emphasis on the spatial distribution of the contaminants. Piper trilinear diagram was applied to determine the water type.

The conclusions show the effectiveness of the selected methodology for the evaluation of the reliable groundwater irrigation suitability assessment based on the integration criteria for analyses of the prevailing groundwater quality. Most physiochemical parameters indicate that the groundwater in the study area is suitable for irrigation; although the sensitive crops are generally not suitable to be cultivated because of the higher levels of EC and Chloride. Piper Trilinear diagram revealed that 57.7 % of groundwater samples occupy Mixed water type. Factor Analysis showed that Ammonia, Nitrate, and Sodium contents are the main majors that control the hydro-chemical variability.

KEYWORDS: Gabel El Asfer Farm, Sewage Irrigation, Groundwater Quality, Physiochemical Parameters, Piper Trilinear, Factor Analysis

1. INTRODUCTION

Water resources in Egypt are becoming scarce. Surface-water resources originating from the Nile are now fully consumed. Egypt is facing increasing water needs because of rapidly growing population, urbanization and higher standards of living. Accordingly, agricultural policy emphasizes on expanding the food production and redistributing the population by establishing new communities where groundwater sources are being excessively withdrew more than its relevant aquifer potential. In Egypt, the concept of expansion of water reuse nowadays is becoming a big challenge for policy makers. As the situation is changing rapidly in the major cities of Egypt due to the installation of modern Wastewater Treatment Plants (WWTPs) that provide secondary treatment that offers an opportunity for water resources planners to overcome the gap between water supply and water demand.

The oldest and most well-known formal reuse scheme of sewage is at Gabal El Asfar governmental farm located North-East of Cairo (RIGW/ IWACO,1992). Since the year 1915, about 3,000 feddans (1 feddan = 4200 m2) in the farm have been irrigated using treated sewage from an old Wastewater Treatment Plant that discharged its effluent into El Seil drain (RIGW/ IWACO,1992). In 1998, the new Gabel El Asfer Wastewater Treatment Plant (GAWWTP) has been constructed west of the farm with a capacity of 1.5 million m3/d which was increased in 2018 to 2.5 million m3/d. This secondary treated effluent is discharged into Gabel El Asfer Drain and is used by farmers for irrigation. As this procedure had been used for decades in Gabel el Asfer Farm; the objective of this research is to investigate and evaluate groundwater quality, at the area from 2017 to 2020, whereupon its current suitability for irrigation can be determined.

In 1990, the Research Institute for Groundwater (RIGW) selected Gabal el Asfar farm area to assess the impact of sewage effluent irrigation on groundwater quality (RIGW/ IWACO,1992). The main conclusions of that study in the Gabal el Asfar area concluded that irrigation with sewage effluent had a decreasing impact on the salinity of the groundwater and that reclamation of new areas within or adjacent to the farm would affect groundwater flow systems and subsequently groundwater quality (Farid, 1993; RIGW/IWACO,1992).
In 1994, another study was performed to analyze and explain changes in groundwater quality between1991 and 1994. The study is executed within the framework of the Environmental Management Groundwater Resources project. The main conclusions of that study included that the eastern part of the area shallow groundwater showed a constant quality. It included also that deep groundwater in a production well just west of the Gabal el Asfar farm showed an increasing content of $S0_4^{-2}$and Cl^-, which was explained either by upcoming of brackish water from the deeper part of the aquifer or by horizontal displacement of brackish water from the eastern part of the area. Finally, it showed that both salinization and pollution by effluent water might cause limitations on water use west of the area (Rashed, 1995).
In 2014, Effect of surface water system on groundwater composition was studied. The results showed that the groundwater salinity is controlled by dissolution of minerals and salts in the aquifers matrix along flow paths and mixing of chemically different waters (Gomaa, 2014).

2. DATA COLLECTIONS AND METHODOLOGY

Previous and recent data for quality of groundwater were collected from the database of RIGW, previous studies, and field investigation through field trips to the study area to survey the important hydrogeological parameters. 26 samples of groundwater, as shown in **figure 1,**were collected to represent the recent situation at Gabel El Asfer area from 2017 to 2020. These years were chosen due to the availability of information that was transformed into processing data.
Samples were analyzed for pH and major ionic species in groundwater. The major cations are calcium (Ca^{+2}), sodium (Na^+), magnesium (Mg^{+2}) and potassium (K^+) while the most common anions are bicarbonate (HCO_3^-), sulphate (SO_4^{-2}), as well as chloride (Cl^-). The Type of water concerning cations and anions are then described with Piper Trilinear Diagram which was plotted with Grapher 13 program. Samples were also analyzed for Nitrate (NO_3^-), Phosphate (PO_4^{-3}), Ammonium(NH_4^+) and Iron (Fe^{+3}).The results of the chemical constituents of the collected groundwater samples were compared to the available limits of FAO guidelines for irrigation water.

Then, physiochemical parameters related to groundwater quality were also investigated to assess suitability of groundwater for the purpose of irrigation. Spatial distribution maps were performed with the help of Surfer 9. Physiochemical parameters included Electric Conductivity (EC), Total Dissolved Solids (TDS), Sodium Adsorption Ratio (SAR), Residual Sodium Carbonate (RSC), Total Hardness (TH), Permeability Index (PI), Sodium Percentage (Na %), Magnesium Hazard (MH), Kelly's Index (KI), Chloro Alkaline Indices (CAI), and Chloride Toxicity (Cl^-).

Statistical analysis of hydro-chemical data was performed with Statistical Packages for Social Science (SSPS).The first step is defining the correlation matrix, which is used to account the degree of mutually shared variability between individual pairs of groundwater quality variables (Eltarabily, 2018). Thus, the Factor Analysis is applied to extract the most significant factors and to reduce the contribution of less important factors (Templ, M, 2008).Pearson correlation matrix, Eigen values, Scree plot curve and Rotated Component Matrix were performed for Factor Analysis. Sixteen variables (pH, EC, TDS, Ca^{+2} Mg^{+2}, Na^+, K, Cl^-, $SO4^{-2}$,NO_3^-,HCO_3^-,PO_4^{-3}, NH_4^+, Fe_3^+, SAR and PI) were selected for factor analysis calculations.

3.HYDROGEOLOGY OF THE STUDY AREA

3.1 Physical Setting of The Study Area

The study area is located at north-east of Cairo in the eastern desert area at the fringes of the Nile Delta flood plain as shown in **figure 1**. The area extends between 31° 20'00"E and 31° 25' 45" E longitude and 30° 10' 00"N and 30° 16' 25"N latitude. The area is dissected by Gabal El Asfar, Belbies and ElSeil drains. Ismailia Canal passes at north-east of the area. West of the farm there is Gabel El Asfer Wastewater treatment plant (GAWWTP) which is one of the biggest facilities in Africa and the Middle East (ADB, 2009).

The Study area represents a part of the Suez-Cairo Foothills desert area (RIGW/IWACO, 1992). The land surface has steep slopes at the east while it takes a gentle slope towards the west. Elevations ranges from 60 m+msl at the east to about 14 m+msl at the west where flood plain takes place.

3.2 Hydrogeological Setting and Aquifer System

The main aquifer system at the study area is the Nile Delta Aquifer which comprises the Quaternary alluvial deposits (RIGW,1989). The highly productive aquifer at the western parts of the study area consists of Quaternary graded sand and gravel as shown in **figure 2**, with some intercalation of clay lenses. The aquifer at Gabel El Asfer area is unconfined at most parts. The hydraulic conductivity of the main aquifer ranges from 70m/day at the Nile floodplain, at the west, to 40 m/day near the middle of the study area where unconfined limited aquifer exists. The storativity (or specific yield) of the phreatic part of the aquifer amounts to approximately 0.1-0.15.East of the study area, there is a low or non-productive aquifer. Non-aquiferous igneous or metamorphic rocks are underlying the low productive and the semi-productive aquifers.

The levels of the base in the study area are approximately from 0 m, at the east, to about -100 m, at the west, relative to mean sea level (msl), sloping in the western direction (RIGW,1989). For Gabel El Asfer farm, in 2020, the main direction of the deep groundwater flow is mainly from east to west; while the flow direction in the south is towards the south-west. Maximum water level is about 26 meters above mean sea level (m+msl) at north-east of the study area. At the western parts, water level is about 10 m+msl as shown in **figure 2**.

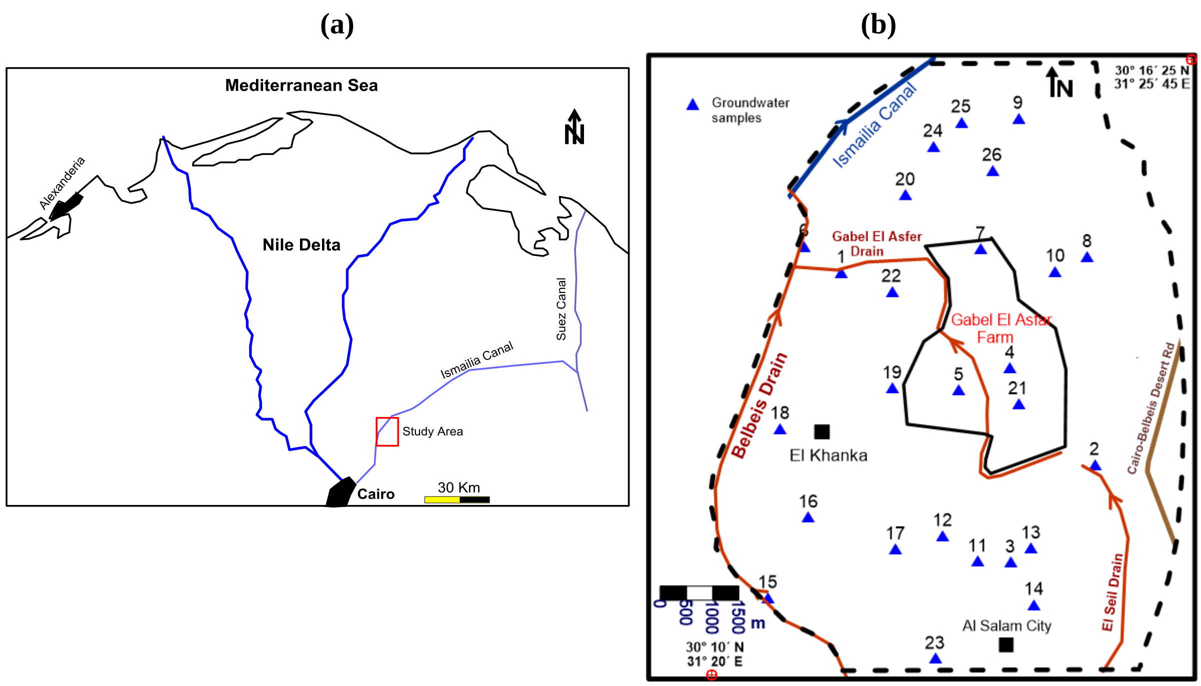


Figure 1: (a) General Location of the Study Area. (b) Location of Groundwater Samples in the Area of Interest (2017-2020)

4. RESULTS AND DISCUSSIONS

4.1 PH and Salinity

The descriptive statistics of the chemical constituents of the collected groundwater samples are presented in **table 1**. The pH values of groundwater samples reflect the neutral condition that ranged from 7.12 to 8 with an average value of 7.6. That is compatible with FAO guidelines for pH which range from 6.5 to 8.4 (FAO, 1994).

Electrical Conductivity (EC)

Electrical conductivity is ability of water to carry an electrical current; this ability mainly depends on presence of anion and cations in water and also depends on mobility, valence of ions and temperature (Meena, 2012). EC is an indicator of the degree of mineralization of water. EC ranges from 0.38 to 4.26 mmoh/cm with an average value of 1.6 mmoh/cm as shown in **table 1.** EC in FAO guidelines should not exceed 3 mmoh/cm. According to the relative tolerance of crop plants to groundwater salinity (Eltrabily, 2018) as shown in **table 2**, only about 15% of the analyzed groundwater samples were suitable for irrigation of class 1 (sensitive crops). About 57.7% of the samples can be used to irrigate moderately sensitive crops (class2). 26.9% of the samples can be used to irrigate moderately tolerant crops (class3). **Figure 3.a** shows the spatial distribution of relative tolerance of crop plants according to EC (mmoh/cm).

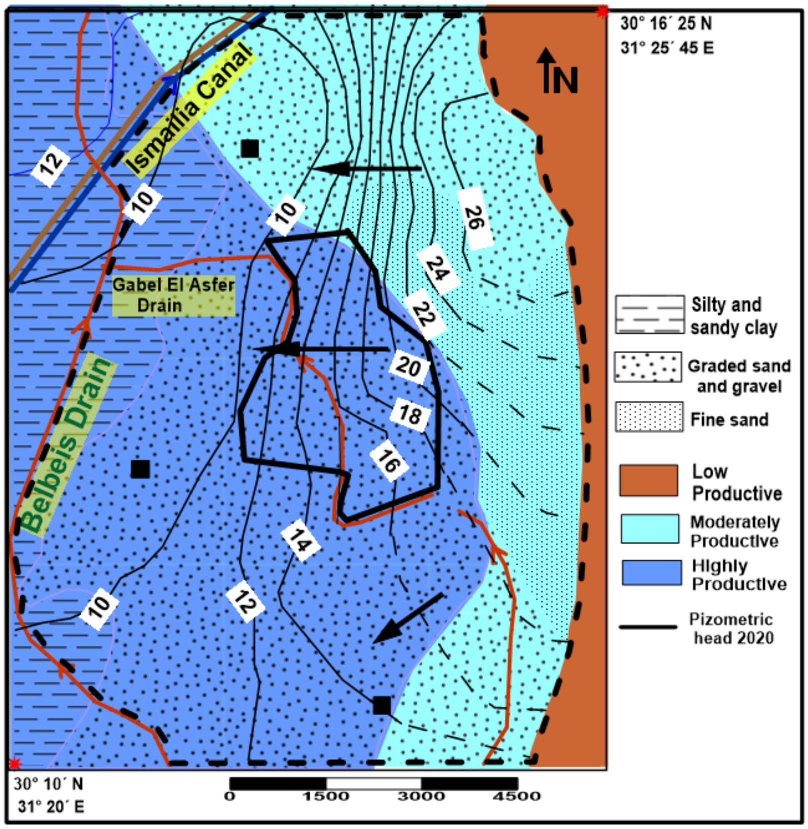


Figure 2: Groundwater Levels and Flow Directions Under the Prevailing Hydrogeological Setting at the Study Area, 2020

Total Dissolved Solids (TDS)

Total dissolved solids (TDS), is defined as the concentration of all dissolved minerals in the water (FAO, 1994). TDS average value of 500 mg/l is considered the desirable limit and 2000 mg/l as the maximum permissible limits for irrigation (FAO, 1994 &Jain, 2003).TDS in the study area varies from 245to 2726 mg/l with an average value of about 1060 mg/l as shown in **table 1.**The groundwater samples were classified according to TDS (Eltrabily, 2018) and results are listed in **table 3**. Most of the samples (69.2%) are permissible for irrigation use with TDS range from 525 to 1400 mg/l. 7.7% are classified "Good" while 15.4% are "Doubtful". There were only two groundwater samples that were classified as “Unsuitable” for irrigation with TDS more than 2100 mg/l with a percentage of 7.7%. **Figure 3.b** shows the Spatial distribution of TDS (mg/l).

4.2 Major Ions and Piper-Trilinear Diagram

The Spatial distribution of the concentrations of the most common cations (Ca^{+2} Mg^{+2}, Na^{+} and K^{+}) and the most common anions (Cl^{-}, $SO4^{-2}$, and HCO_3^{-}) in groundwater in the study area are shown in **figures 4 and 5** respectively.

Table 1: Summary of Statistics of The Chemical Constituents and Quality Parameters Groundwater Samples 2017/2020

	Unit	Min.	Max.	Avg.	Std. deviation	FAO limits
PH		7.120	8.010	7.613	0.214	**6.5-8.4**
EC	m moh/cm	0.383	4.260	1.596	0.974	**3**
TDS	mg/l	245.000	2726.000	1059.654	600.305	**2000**
Ca^{2+}	mg/l	22.000	329.300	127.123	89.387	
Mg^{2+}	mg/l	11.080	41.990	25.654	9.045	
Na^{+}	mg/l	18.000	650.000	169.796	135.313	
K^{+}	mg/l	3.000	35.000	13.535	7.355	
Cl^{-}	mg/l	28.600	521.500	182.955	122.832	**350**
$SO4^{2-}$	mg/l	19.000	1211.200	268.734	281.197	
$HCO3^{-}$	mg/l	115.900	610.000	353.390	147.525	**520**
SAR		0.438	9.030	3.344	1.901	**9**
KR		0.123	1.663	0.799	0.332	
Na%	%	15.771	63.329	44.008	10.485	
MH	%	6.423	51.471	30.847	13.987	
TH	mg/l as CaCo3	7.533	53.978	24.655	10.780	
PI	%	55.6	99.7	83.3	10.3	
CAI		-3.979	0.809	-0.595	0.784	
CR		0.536	4.698	2.098	1.062	
$NO3^{-}$	mg/l	0.200	32.000	9.625	8.742	**30**
$PO4^{3-}$	mg/l	0.200	0.360	0.238	0.057	
NH4+	mg/l	0.200	1.900	0.651	0.486	
Fe^{3+}	mg/l	0.006	0.338	0.076	0.092	**5**

The Type of water concerning cations and anions are then described with Piper Trilinear Diagram. In 1944, Arthur M. Piper, proposed an effective graphic procedure to segregate relevant analytical data to understand the sources of the dissolved constituents in water (Piper, 1944). This procedure was born under the statement that most natural waters contain cations and anions in chemical equilibrium. **Figure 6** shows that for cations, and anions most of the samples are in the zone of No Dominant type.

It can be seen also from the diamond that 57.7 % of groundwater samples occupy the category no. 9 which is characterized as a mixed type of water (where neither cations nor anions exceed 50%); while 23.7 % of samples is Magnesium bicarbonate type. Characterization of groundwater on the basis of Piper diagram is shown in **table 4**.

Table 2: Relative Tolerance of Crop Plants to Groundwater Salinity

Classes of crops	No. of Samples	Samples %	Remarks
Class1, Sensitive crops (EC < 0.95 m mhos/cm)	4	15%	
Class 2, Moderately Sensitive crops (EC =0.95–1.9 m mhos/cm)	15	57.70%	
Class 3, Moderately tolerant crops (EC =1.9–4.5 m mhos/cm)	7	26.90%	Field crops: Groundnut, rice, safflower Vegetables: Beet
Class 4, Salt tolerant crops (EC = 4.5–7.7 m mhos/cm)	0		Field crops: Sunflower, oats, soybean Fruits: Olive, peach
Class 5, Very Salt tolerant crops (EC =7.7–12.2 m mhos/cm)	0		Field crops: Cotton, sugar beet, sorghum, wheat
Class 6, Generally too saline crops (EC >12.2 m mhos/cm)	0		Field crops: Barley (grains) Forages: Tall wheat grass

Classification source: (Eltrabily, 2018)

Table 3: Classification of The Collected Groundwater Samples Based on Salinity

TDS Categories	TDS Range (mg/l)	No. Of Samples	Samples %
Class 1 Excellent	<175	0	0
Class2 Good	175-525	2	7.70%
Class3 Permissible	525-1400	18	69.20%
Class2 Doubtful	1400-2100	4	15.4%
Class2 Unsuitable	> 2100	2	7.70%

Classification source :(Eltrabily, 2018)

4.3 Physiochemical Quality Irrigation Parameters

Sodium Adsorption Ratio (SAR)

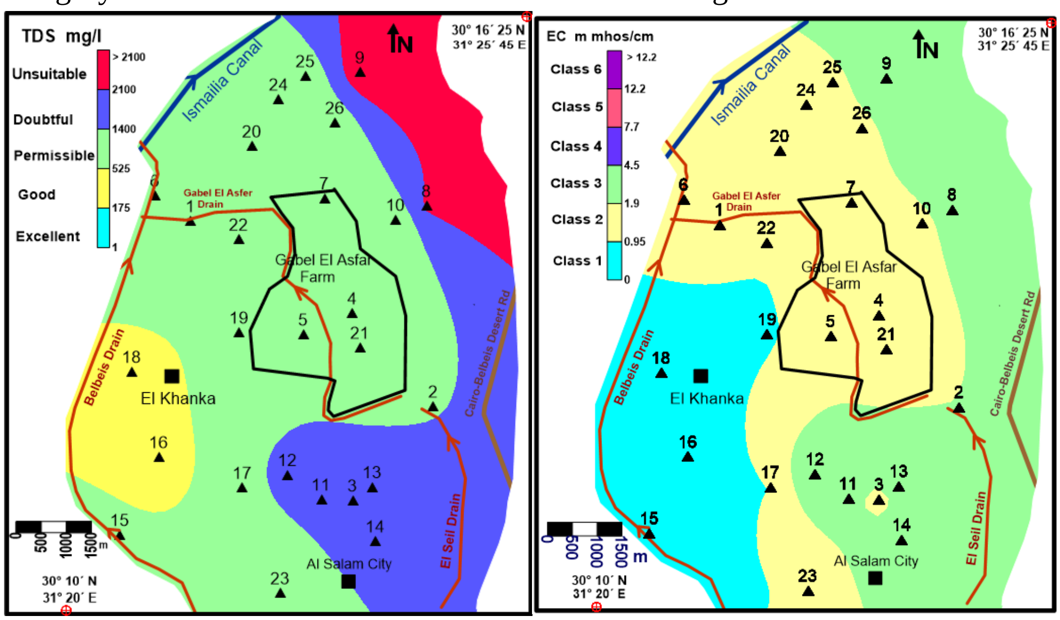
Sodium concentration is an important factor in classifying water for irrigation because it is a measure of alkali/sodium hazard to crops, because sodium reacts with soils and reduces its permeability which makes cultivation difficult (El Tahlawi, 2014).

SAR in the study area varies from about 0.44 to 9 with an average value of about 3.34 which is compatible with FAO guidelines (SAR=9) as shown in **table 1.**

According to SAR calculations and characterizations (Todd, 1980), it is obtained that all groundwater samples (100%) are categorized low SAR values (up to 10) which is an excellent water class as shown in **table 5**.

Residual Sodium Carbonate (RSC)

The hazardous effect of CO3 and HCO3 on the quality of water for agricultural was calculated through RSC. The classification of RSC considers wells that have RSC <1.25 are safe for irrigation, while it is considered unsuitable if it is greater than 2.5 (Ramesh, 2011). According to RSC calculations in the study area, it is obtained that all groundwater samples (100%) are in the category of low RSC values <1.25 which is safe for irrigation as shown in **table 5**.



(a) **(b)**

Figure 3: Spatial Distribution of Crop Classes According to EC (a),and TDS (b) in (2017-2020)

Total Hardness (TH)

Total Hardness is defined as water that is rich in Calcium (Ca^{+2}) and/or Magnesium (Mg^{+2}) (Todd, 1980). According to TH calculations in the study area, TH varies from 7.5 to 54 mg/l as $CaCo_3$ with an average value of about 10.8 mg/l as listed in **table 1.** All groundwater samples (100%) are in soft water zone where TH less than 75 mg/l, as $CaCo_3$ as shown in **table 5**.

Permeability Index (PI)

Soil permeability is affected by the long-term use of irrigation water (El Tahlawi, 2014). PI was classified into three categories (Doneen, 1964) as shown in **table 1.** According to PI calculations in the study area, PI varies from about 55.6% to 99.7 % with an average value of about 83.3 %**.** It is obtained that most of groundwater samples (91%) are in the category of Class-I > 75% which is categorized as “Good” for irrigation as shown in **table 5**.

Percent of Sodium (Na %)

Excess sodium in water produces the undesirable effects of changing soil properties and reducing soil permeability (Subba, 2006). Na % was classified into five categories (Ragunath, 1987). Na% in the study area varies from about 15.8 to 63.3% with an average value of about 44% as shown in **table 1.** The majority of the groundwater samples (80.77 %) have sodium between 40% and 60% which is in the permissible range as shown in **table 5**.

Magnesium Hazard (MH)

More Mg^{+2} present in waters affects the soil quality; converting it towards alkaline and decreases crop yield (Ramesh, 2011 & Narsimha, 2013). MH % in the study area varies from about 6.4 to51.5% with an average value of about 30.8% as shown in **table 1.** MH values >50% is considered harmful and unsuitable for irrigation purposes (Szabolcs, 1964). According to MH calculations, it is obtained that most of groundwater samples in the study are (96%) are less than 50 % which means that they are suitable for irrigation as shown in **table 5**.

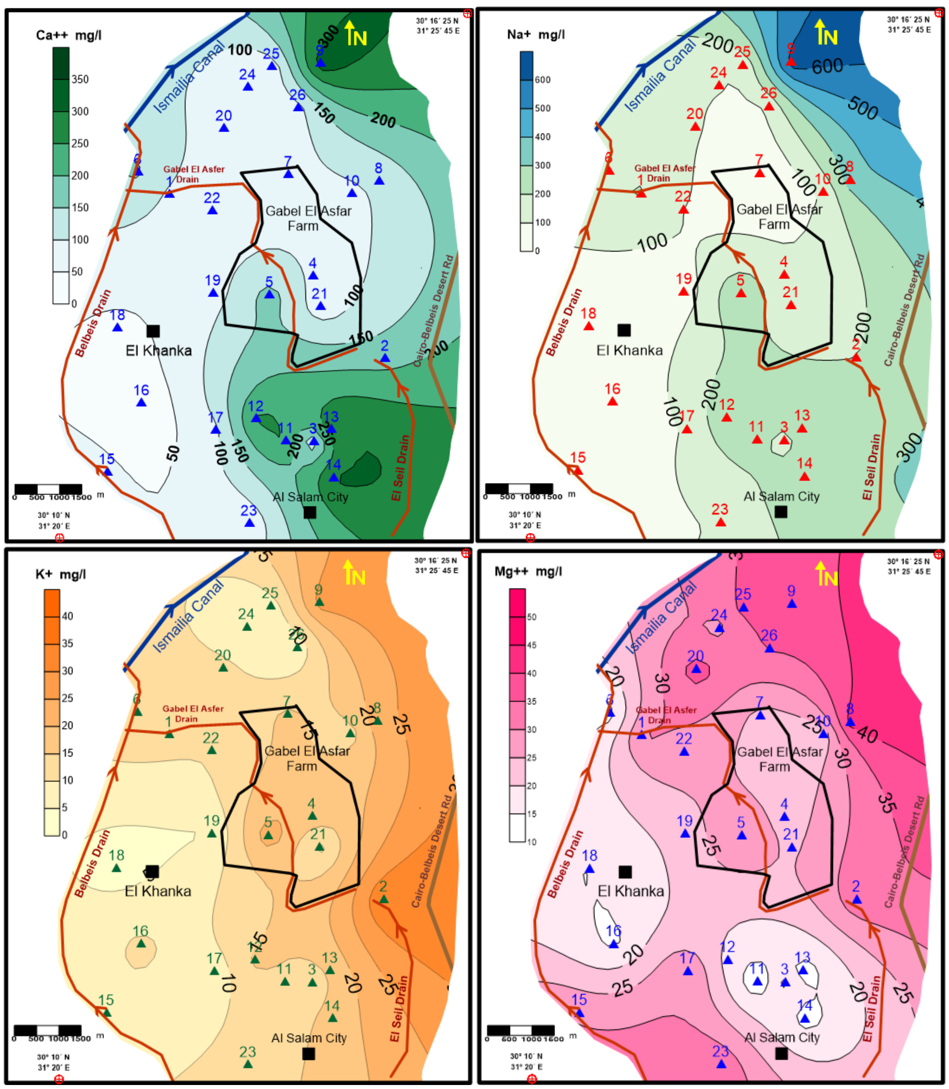


Figure 4: Spatial Distribution of Major Cations (Ca^{2+}, Na^{+}, $K^{+}$and Mg^{2+}) in (2017-2020)

Kelley Ratio

Kelly's ratio (KR) or Kelly's index (KI) of more than 1 indicates an excess level of sodium in waters (Kelley, 1940). Therefore, water with a KI less than 1 is suitable for irrigation, while those with greater ratio are unsuitable (Narsimha, 2013& El Tahlawi, 2014). KI in the study area varies from about 0.12 to 1.66 with an average value of about 0.8 as shown in **table 1.** According to KI calculations, it is obtained that most of groundwater samples (85 %) have KI<1 which is suitable for irrigation as shown in **table 5**. **Chloro Alkaline Indices (CAI)**

To know the ion exchange between the groundwater and its surroundings during residence or travelling in the aquifer, CAI can be measured; negative value of CAI indicates that there is exchange between sodium and potassium in water with calcium and magnesium in the rocks by a type of base-exchange reactions; while the positive value of CAI represents the absence of base-exchange reactions and existence of cation-anion exchange type of reactions (Schoeller,1967). According to CAI calculations, it is obtained that most of the groundwater samples (96%) have negative values which indicates that there are base-exchange reactions as shown in **table 5**.

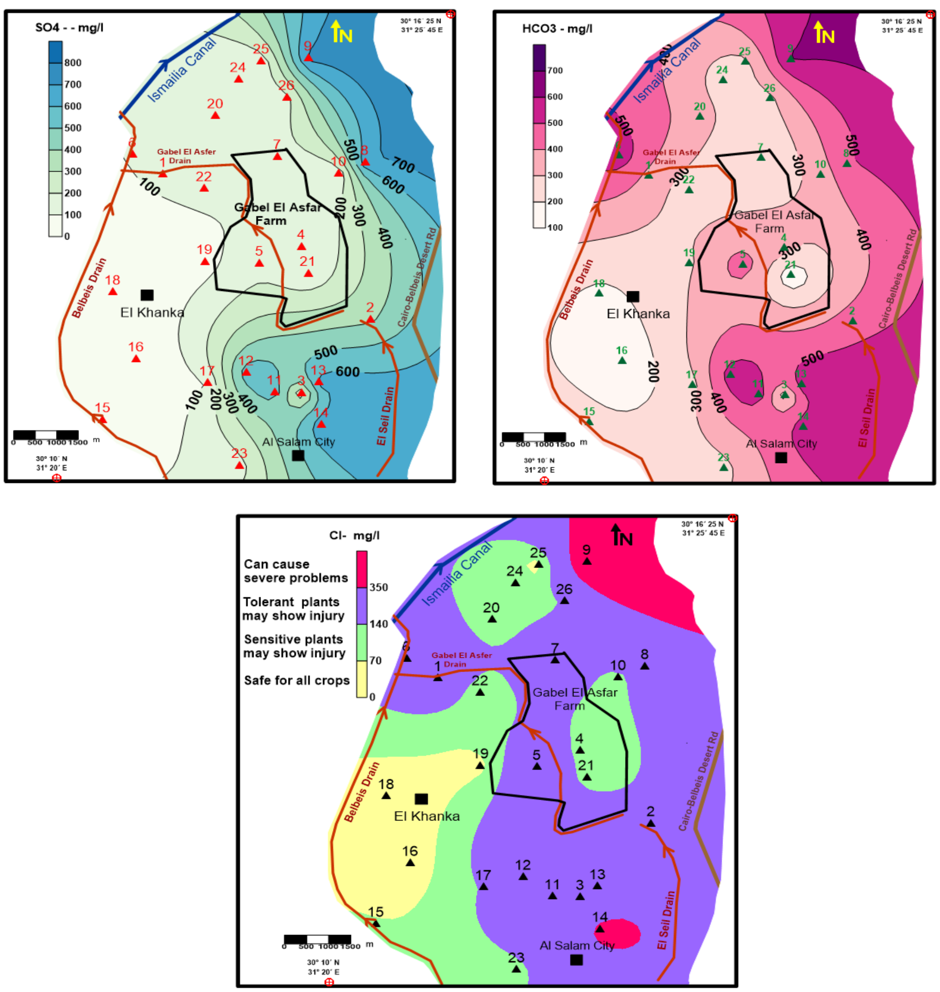


Figure 5: Spatial Distribution of Major Anions (HCO_3^-, SO_4^{2-}, and Cl^-) in (2017-2020)

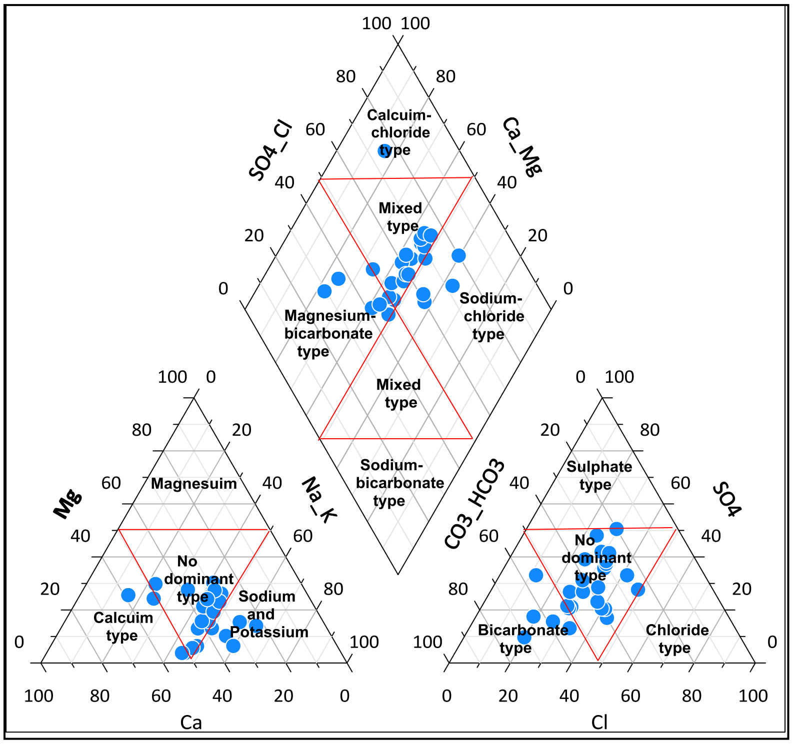


Figure 6:Water Type of Groundwater Relevant to The Quaternary Aquifer at The Study Area (Piper Trilinear Diagram) in (2017-2020)

Table4:Water Type of Groundwater of Gabel El Asfer Farm in (2017-2020) (The Basis of Piper Diagram)

Water type according to Diamond	No. of samples	Samples %
Magnesium bicarbonate type	6	23.1%
Calcium–chloride type	1	3.8%
Sodium–chloride type	4	15.4%
Sodium–bicarbonate type	0	0%
Mixed type (No cation–anion exceeds 50%)	15	57.7%

Classification source :(Piper, 1944)

Chloride Toxicity

Chlorides are necessary for plant growth, though in high concentrations they can inhibit plant growth, and can be highly toxic to some plant species (Zaman, 2018). Cl^- concentrations in the study area varies from 28.6 to 521.5 mg/l with an average value of about 183 mg/l as shown in **table 1.** It is noticed that only about 19% of groundwater samples have (Cl^-) anion concentrations less than 70 mg/l which is safe for all plants; while 68.5 % have Cl^- concentrations range of 141-350 mg/l which usually show slight to substantial injury on plants (Ludwick , 1990).

Table 5: Classification of the Groundwater Parameters to Evaluate Its Suitability for Irrigation in (2017-2020)

Parameter	Category	No. of Samples	Samples %
Sodium Adsorption Ratio (SAR)	Excellent (up to 10)	26	100%
	Good (10--18)	0	0
	Fair (18--26)	0	0
	Poor (>26)	0	0
Residual Sodium Carbonate (RSC) meq/l	Good <1.25	26	100%
	Doubtful 1.25-2.5	0	0
	Unsuitable > 2.5	0	0
Hardness, mg/l, as CaCo3	Soft (0 -75)	26	100%
	Moderately (75-150)	0	0
	Hard (150-300)	0	0
	Very Hard (Over 300)	0	0
Permeability Index (PI)	Class-I >75%	24	91%
	Class-II 25-75 %	2	8%
	Unsuitable <25%	0	0
Na%	Excellent 0-20	1	3.85
	Good 20-40	3	11.54
	Permissible 40-60	21	80.77
	Doubtful 60-80	1	3.85
	Unsuitable >80	0	0.00
Magnesium Hazard (MH)	Unsuitable > 50 %	1	4%
	Suitable < 50 %	25	96%
Kelley's Index (KI)	Unsuitable >=1	4	15%
	Suitable <1	22	85%
Chloro-Alkaline Indices (CAI)	Base exchange Reactions (-ve)	25	96%
	Cation-anion exchange (+ve)	1	4%
Chloride (Cl-) (mg/l)	Generally safe for all plants (<70)	5	19.20%
	Sensitive plants usually show slight to moderate injury (70-140)	8	30.80%
	Moderately tolerant plants usually show slight to substantial injury (141-350)	10	38.50%
	Can cause severe problems (350)	3	11.50%

Sources: El Tahlawi, 2014, SAR& TH (Todd, 1980), RSC (Ramesh, 2011),PI (Doneen, 1964),Na% (Ragunath, 1987), MH Szabolcs(1964), KI (Narsimha, 2013), CAI (Schoeller,1967), Cl^- (Zaman,2018).

4.4 Nitrate, Phosphate, Ammonium and Iron

Nitrate (NO_3^-)in groundwater ranged from 0.2 to 32mg/l with an average value of 9.625 mg/l. Most of NO_3^- concentrations are within the FAO guideline, which is 30 mg/l, except for limited areas in the middle of the study area as shown in **figure 7**. Phosphate (PO_4^{3-}) ranges from 0.2 to 0.36 mg/l with an average value of 0.238 mg/l; while Ammonium (NH_4^+) ranged from 0.2 to 1.9 mg/l with an average value of 0.651 mg/l as listed in **table 1**. Both PO_4^{3-} and NH_4^+do not have exact thresholds in FAO guidelines; however, their concentrations in the study area are generally lower than the standard guidelines of Saudi Arabia, Jordan, Kuwait, Iran and, Italy. Iron (Fe^{3+}) concentrations ranged from 0.006 to 0.338 mg/l with an average value of 0.076 mg/l which is lower than the FAO guidelines which is 5 mg/l.

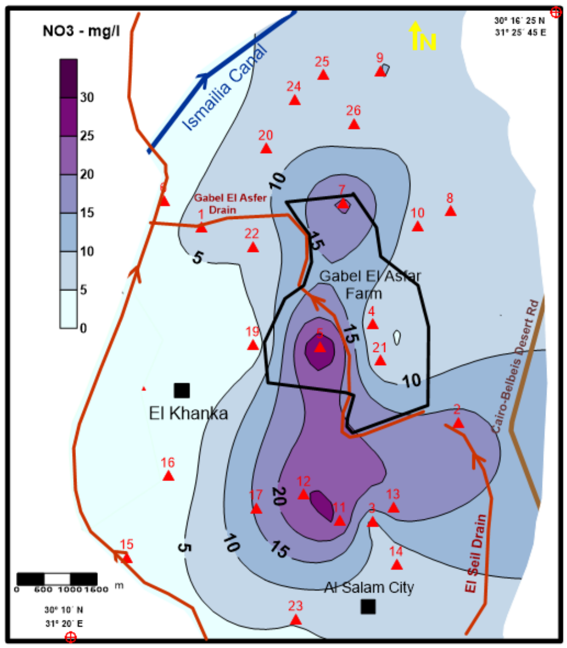


Figure 7: Spatial Distribution of Nitrate (NO_3^-) in Gabel El Asfer Area in (2017-2020)

4.5 Statistical Assessment with Factor Analysis

Factor analysis, a multivariate statistical method produces the general relationship between measured variables by rearrange them in a technique that better explains the structure of the underlying system that produced the data (Liu, 2003).

The first step of factor analysis is the correlation matrix. Data of 26 samples during the period from 2017 to 2020 has been used to build Pearson correlation matrix between the groundwater quality parameters as in **table 6**. The perfect correlation coefficient (r) ranges from 0.99 to 1.0, the strong correlation coefficient ranges from 0.80 to 0.98, Moderate correlation coefficients of r range between 0.5and 0.8, and finally a weak correlation coefficient is considered when r < 0.5 (Eltarabily, 2018). Negative values as well could indicate weak, moderate or strong inverse relationships between parameters.

Pearson correlation matrix shows a perfect relationship between EC and TDS (0.99) and a strong relationship between EC and Ca^{2+}(0.87), EC and Na^{+} (0.92), EC and Cl^{-} (0.92), EC and SO_4^{2-} (0.96), EC and $HCO3^{-}$ (0.84), EC and $NH4^{+}$ (0.89) and EC and SAR (0.87). It shows also a strong relationship between TDS and Ca^{2+} (0.87), TDS and Na^{+} (0.92), TDS and Cl^{-} (0.91), TDS and SO_4^{2+} (0.96), TDS and HCO_3^{-} (0.84), and TDS and SAR (0.85).A strong relationship was found also between $Ca^{2+}$and Na^{+} (0.81), $Ca^{2+}$and Cl^{-} (0.88), $Ca^{2+}$and SO_4^{2-} (0.86), $Ca^{2+}$and HCO_3^{-} (0.88), Na^{+} and Cl^{-} (0.88), Na^{+} and $SO4^{2-}$ (0.91), Na^{+} and $HCO3^{-}$ (0.81), Na^{+} and $NH4^{+}$ (0.93), Na^{+} and SAR (0.96), Cl^{-} and SO_4^{2-} (0.89), Cl^{-} and HCO_3^{-} (0.83), SO_4^{2-} and NH_4^{+} (0.85), SO_4^{2-} and SAR (0.81) and $NH4^{+}$and SAR (0.94). The correlations between the rest of variables are moderate, weak and negative.

Scree Plot and Eigenvalue

Scree plot is a graphical representation of the incremental variance accounted by each factor as shown in **figure 8**. Results indicate that four factors are responsible for the variance as they have Eigen values > 1 of the sixteenth parameters as shown in **figure 8**. Subsequently, the rotated component matrix is calculated to extract the factors which have the greatest amount of common variance. The larger Eigen value, the higher variance of the factor obtained. Each factor explains a portion of the remaining variance until a point of Eigen value of 1 is reached where it can be said that the factors no longer contribute to the model (Eltarabily, 2018).

Factor Analysis

In this study, Kaiser's varimax rotation scheme was employed (Kaiser, 1958). It revealed that four factors with Eigen values exceeding 1.0 are accounted for about 90.5% of the total variance. According to Liu, 2003, the terms are strong positive loadings when factor loading is over (0.75), moderate positive loadings when factor loading is between (0.75–0.5) and weak positive loadings when factor loading is between (0.5–0.3).

From the Rotated Component Matrix **(table 7)** and the calculation of Eigen values, it is found that **F1** is accounted for 37.5% of the variance. it is showing a strong positive relation with NH_4 (0.887), that means Ammonia is the major process controlling the hydro-chemical variability. The relationship between **F1** and other variables are; SAR (0.849), NO_3 (0.847), Na (0.797), and PO_4 (0.797). It also has moderate positive relation with EC (0.771), Cl (.696) and SO_4 (.672). **F2** explains about 25.3% of the total variance. It is considered strongly positive related with HCO3 (0.943), Mg (0.782) and TDS (0.769). **F2** has moderate positive relation with Ca (0.732), EC (0.624) and SO_4 (0.608). **F3** explains about 14.5% of the total variance. It has a strong loading of K (0.883). Finally, **F4** accounted for about 13.2% of the total variance with moderate positive relation with Ca (0.607) and TDS (0.552).

5. CONCLUSIONS

- The assessment of groundwater suitability for irrigation, is needed and become imperative based on an integration between: 1) The effective Physio-chemical characteristics; 2) Defining groundwater type by Piper diagram; 3) FAO as guidelines to compare the selected parameters within the desirable limits for irrigation purposes; 4) Define the mutual correlation among those parameters, through the results which were obtained from applying Pearson correlation matrix between parameters to assign their weights; and applying SPSS program of multivariate statistics to determine the factor analysis for groundwater quality data ; and 5) Use of Surfer 9 program as a helpful tool for construction theme maps.

- Data of 26 wells during the period from 2017 to 2020 has been investigated and compared to FAO guidelines for irrigation water. It is revealed that groundwater in most of the study area is within the permissible limits of FAO guidelines relative to pH, EC, TDS, SAR, Cl-, HCO3, NO3, and Iron.

- Piper Trilinear diagram, which is performed by Grapher 13 program, was used to recognize the type of water concerning cations and anions. It showed that for cations and anions, most of the samples are in the zone of No Dominant type. It is revealed also that % 57.7of groundwater samples occupy Mixed water type.

- Eleven elements' criteria were selected to evaluate groundwater quality and its suitability for irrigation purposes. Those elements are EC, TDS, Na%, SAR, RSC, Cl-, KI, PI, TH, MH, and CAI. According to EC classification and Chloride levels, groundwater in most parts of the study area is not suitable for irrigating sensitive crops especially those that are fresh eaten; while it is suitable for moderately, salt, very salt, and saline tolerant crops.

- TDS classification shows that about 92% of samples have TDS < 2000 mg/l which is a permissible limit according to FAO guidelines. Spatial distribution maps of EC and TDS helped in determining safe and risky zones as well. Results of the rest of the parameters especially, SAR and RSC indicate that groundwater in the study area is suitable for irrigation.

- Nitrate, Phosphate, Ammonium, and Iron concentrations in groundwater are within the permissible limits for irrigation except for limited areas in the middle of the study area where Nitrate slightly exceeded the FAO limit (30 mg/l).

-Correlation matrix, Scree plot, and Eigenvalue were performed for Factor Analysis for sixteen variables, using SPSS program, to produce a general mutual effective relationship between measured variables and their loadings for the sound evaluation of the irrigation suitability. Accordingly, it is shown that Ammonium, Nitrate, and Sodium contents are the major physic-chemical parameters that control the hydro-chemical variability of groundwater.

6. RECOMMENDATIONS

- It is recommended the reassessment of the groundwater irrigation suitability according to the environmental hydrogeology which may be encountered due to the increase of human activity.

- It is imperative to global the environmental hydrochemical through the physio-chemical parameters to enhance and inquiry all the possible pollution that may affect the groundwater irrigation suitability.

Table 6: Pearson Correlation Matrix between Groundwater Quality Parameters in 2017-2020

Parameter	PH	EC	TDS	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Cl^{-}	SO_4^{-2}	HCO_3^{-}	PO_4^{-3}	NH_4^{+}	Fe^{+3}	SAR	PI
PH	1.00														
EC	-0.24	1.00													
TDS	-0.25	**0.99**	1.00												
Ca^{2+}	-0.07	0.87	0.87	1.00											
Mg^{2+}	-0.23	0.09	0.10	-0.26	1.00										
Na^{+}	-0.13	0.92	0.92	0.81	0.19	1.00									
K^{+}	0.03	0.67	0.66	0.59	0.19	0.66	1.00								
Cl^{-}	-0.20	0.92	0.91	0.91	-0.08	0.88	0.61	1.00							
SO_4^{-2}	-0.23	0.96	0.96	0.86	0.07	0.91	0.62	0.89	1.00						
HCO_3^{-}	-0.04	0.84	0.84	0.88	-0.11	0.81	0.64	0.83	0.77	1.00					
NO_3^{-}	-0.02	0.49	0.46	0.56	-0.09	0.40	0.51	0.60	0.38	0.48					
PO_4^{-3}	-0.28	0.42	0.12	0.15	0.18	0.46	-0.25	0.53	0.38	-0.01	1.00				
NH_4^{+}	-0.63	0.89	0.53	0.49	0.68	0.93	0.20	0.67	0.85	0.23	0.58	1.00			
Fe^{+3}	0.13	-0.45	-0.43	-0.39	0.09	-0.31	-0.36	-0.40	-0.44	-0.41	-0.17	-0.33	1.00		
SAR	-0.10	0.87	0.85	0.68	0.30	0.96	0.64	0.80	0.81	0.76	0.51	0.94	-0.31	1.00	
PI	0.30	-0.18	-0.21	-0.26	-0.01	-0.03	-0.06	-0.27	-0.22	0.10	-0.20	-0.47	0.09	0.09	1.00

Perfect positive correlation

Strong positive correlation

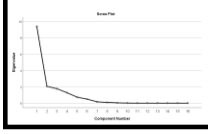


Figure 8:Scree Plot Curve to Determine the Factors Responsible for The Variance and Have Eigen Values >1

Table 7: Rotated Component Matrix Showing the Four Factors Responsible for The Variance and Their Loadings Related to Groundwater Parameters in 2017-2020

	F1 (37	F2	F3	F4
PH	-.776	-.178	.498	.079
EC	**.711**	**.624**	.133	.262
TDS	.276	**.769**	.090	**.552**
Ca++	.238	**.732**	-.117	**.607**
Mg++	.448	.782	.315	.189
Na+	**.797**	.439	.315	.259
K+	.026	.165	**.881**	-.234
Cl -	**.696**	.252	.193	.319
SO4 - -	**.672**	**.608**	.325	.187
HCO3-	.082	**.943**	-.005	-.194
NO3-	**.847**	.409	.220	.056
PO4 3-	**.797**	-.152	-.185	.186
NH4+	**.887**	.253	.174	.190
Fe3+	-.240	-.015	-.821	-.209
SAR	**.849**	.299	.365	.202
PI	-.263	-.058	.002	-.932

Strong Positive Loading (green) — Moderate Positive Loading (yellow)

REFERENCES:

- ADB, African Development Bank, 2009, Gabal El-Asfar Wastewater Treatment Plant, Phase II Project Country: Egypt Project Appraisal Report, June 2009.
- Arthur M. Piper, (1944), "A graphic procedure in the geochemical interpretation of water-analyses",Eos, Transactions American Geophysical Union ,Volume25 , Issue6 , June/September 1944.
- Doneen, L. D., (1964), "Water Quality for Agriculture", Department of Irrigation, University of Calfornia, Davis, 48 p.
- El Tahlawi, M.R., Mohamed, M. A., Boghdadi, G. Y., Rabeiy, R. E., Saleem, H. A., (2014), "Groundwater Quality Assessment to Estimate its Suitability for Different Uses in Assiut Governorate, Egypt", International Journal of Recent Technology and Engineering (IJRTE), ISSN: 2277-3878, Volume-3, Issue-5, November 2014.
- Eltarabily, M.G, Abdelazim M. Negmb, Chihiro Yoshimurac, Sommer Abdel-Abdel-Fattahd, and Oliver C. Saavedrae, (2018), Quality Assessment of Southeast Nile Delta Groundwater for Irrigation1, ISSN 0097-8078, Water Resources, Vol. 45, No. 6, pp. 975–991.
- FAO, (1994), Guidelines for Interpretations of Water Quality Forirrigation, Adapted from University of California Committee of Consultants 1974, Section 1.4, Table 1.
- Farid, M. S.M., AlUI, S., Rashid,M., Munnink, l.O. and Platenburg, R. (1993), Impact of the Reuse of Domestic Wastewater for Irrigation on Groundwater Quality, Wat. Sci. Tech. 27 (9), 147-157.
- Gomaa, M.A., El Naggar, I.M., Ali,I.M, OmarJ.A., and El Shahat M.F., (2014), Effect of surface water system on groundwater composition using geochemical modeling and geostatistical techniques, East Nile Delta (Case study), International Journal of Advanced Research, Volume 2, Issue 5, 475-497.
- Jain, C. K, Kumar, C. P., Sharma, M. K., (2003), Ground Water Qualities of Ghataprabha Command Area Karnataka, Indian Journal Environ and Ecoplan, Vol. 7, No. 2, pp. 251 - 262.
- Kaiser, H. F., (1958), The varimax criteria for analytical rotation in factor analysis, Psychometrika, 23(3): 187–200.
- Kelly, W. P., (1940), "Permissible Composition and Concentration of Irrigation Waters", Proc Amer.Soc.Civ.Engin., 66, pp. 607 - 613.
- Liu, C., Lin, K. and Kuo, Y. (2003), Application of factor analysis in the assessment of groundwater quality in a Blackfoot disease area in Taiwan, Sci Total Environ,313: 77–89.
- Ludwick AE, Campbell KB, Johnson RD, McClain LJ, Millaway RM, Purcell SL, Phillips IL, Rush DW, Waters JA (eds) (1990), “Water and plant growth”. In: Western Fertilizer Handbook – horticulture Edition, Interstate Publishers Inc, Illinois, pp 15–43.

- Meena, B. S., Bhargava, N., (2012), Physico-Chemical Characteristics Of Groundwater Of Some Villages Of Dag Block In Jhalawar District Of Rajasthan State (India), RASAYAN. J. Chem, Vol. 5, No. 4, pp. 438 – 444.
- Narsimha, A., Sudarshan, V., and Swathi, P., (2013), "Groundwater and Its Assessment for Irrigation Purpose in Hanmakonda Area, Warangal District, Andhra Pradesh, India", Int. J. Res. Chem. Environ, Vol. 3, pp. 195 - 199.
- Piper A. M., 1944, "A graphic procedure in the geochemical interpretation of water-analyses", Eos, Transactions American Geophysical Union , Volume25 , Issue6 , June/September 1944.Pract. 2013, 14, 17–25.
- Ragunath, H. M., (1987), "Groundwater.", Wiley Eastern Ltd, NewDelhi, 563 p.
- Ramesh, K., Elango, L., (2011), "Groundwater Quality and its Suitability for Domestic and Agricultural Use in Tondiar River Basin, Tamil Nadu, India", Environ Monit Assess.
- Rashed M, Awad S, Salam MA, Smidt E (1995), Monitoring of groundwater in Gabal El Asfar wastewater irrigation area (Greater Cairo), Water Sci Technol 32(11),163–169.
- RIGW maps, (1989), The hydrogeological map sheet of Cairo, with scale 1: 100,000.
- RIGW/IWACO (1992), Development and management of Groundwater resources in the Nile Valley and Delta; Monitoring and control of groundwater pollution; Groundwater quality study Gabal el Asfar (Internal Report).
- Schoeller, H., (1967), "Geochemistry of Ground Water. An International Guide for Research and Practice", NESCO, Vol. 15, pp. 1-18
- Subba, N., (2006), "Seasonal Variation of Groundwater Quality in a Part of Guntur District, Andhra Pradesh, India", Environ Geol., Vol. 49, pp. 413 - 429.
- Szabolcs, I., Darab, C., (1964), "The Influence of Irrigation Water of High Sodium Carbonate Content on Soils", In I. Szabolics (Ed.), Proc8th International Congress Soil Science Sodics Soils, Res Inst Soil Sci Agric Chem Hungarian Acad Sci, ISSS Trans II, PP 802–812.
- Templ, M., Filzmoser, P., and Reimann, C., Cluster, (2008), Analysis applied to regional geochemical data: problems and possibilities, Appl. Geochem., vol. 23, pp. 2198–2213.
- Todd,D.K., 1980. Groundwater Hydrology. Second Edition. John Wiley & Sons, New York, pp. 535.
- Zaman Mohammad, Shabbir A. Shahid, Lee Heng,(2018), "Guideline for Salinity Assessment, Mitigation and Adaptation Using Nuclear and Related Techniques", Irrigation Water Quality, pp 113-131