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THE IMPACT OF SECONDARY WASTEWATER TREATMENT ON THE QUALITY OF GROUNDWATER AT GABEL EL ASFER FARM

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الملخص العربي:

تم ري مزرعة جبل الأصفر، الواقعة شمال شرق القاهرة الكبرى، باستخدام مياه الصرف الصحي الأولية و / أو حتى غير المعالجة من عام 1915 إلى عام 1998. في عام 1998، تم إنشاء محطة معالجة مياه الصرف الصحي الجديدة بجبل الأصفر (GAWWTP) وبدأت في العمل. ونتيجة لذلك، لوحظ تحسن كبير في جودة مياه الصرف الصحي المعالجة التي يتم تصريفها في مصرف جبل الأصفر حيث يتم استخدام مياه الصرف الصحي هذه المعالجة ثانويا للري.

الهدف الرئيسي من هذه الدراسة هو تقييم كل من الآثار السلبية والإيجابية المحتملة الناتجة عن تغيير معالجة مياه الصرف الصحي من الابتدائية إلى الثانوية على نوعية المياه الجوفية في منطقة الدراسة .استندت تحليلات الدراسة الحالية بشكل أساسي إلى تحليلات البيانات للعينات التي تم جمعها من آبار المياه الجوفية تحت منطقة الدراسة. حيث تم تحليل العناصر التي تضم درجة الحموضة، التوصيل الكهربي، المواد الذائبة الكلية ،الأنيونات، الكاتيونات، النترات، الأمونيا، الفوسفات، المعادن الثقيلة، احتياجات الأكسجين الكيميائي وبكتريا القولون البرازي والكلي. تمت مقارنة البيانات التي تمت معالجتها مؤخرا بالسنة المرجعية 1991 لتقييم التغيير البيئي - من حيث الجودة- على نظام المياه الجوفية الذي حدث خلال هذه الفترة (1991 إلى 2020/2017). تم أيضا تحديد نوع المياه الجوفية بواسطة مخطط بايبر الثلاثي الخطوط. بينما تم فحص أصل مصدر المياه بواسطة مخطط سولن.

تشير الاستنتاجات التي تم الحصول عليها إلى أن الآثار الإيجابية لاستخدام مستوى أعلى من معالجة الصرف الصحي مقارنة بالمستوى السابق أدت إلى انخفاض كبير في معظم أحمال الملوثات في المياه الجوفية خاصة احتياجات الأكسجين الكيميائي، النترات، الأمونيا، والمعادن الثقيلة نتيجة فائض تصريف الري في نظام الخزان الجوفي. بالإضافة إلى ذلك، تم تسجيل انخفاض ملحوظ في إجمالي المواد الذائبة الكلية في الأجزاء الشرقية والجنوبية من المزرعة. يشير مخطط بايبر إلى أن نوع المياه الجوفية تغير من نوع كلوريد الصوديوم في عام 1991 إلى النوع المختلط في 2020/2017. معظم هذه المياه مصدرها مياه جوية قارية وفقا لمخطط سولن. بينما التأثير السلبي أن هناك تلوث في المياه الجوفية مؤخرا بسبب القولون البرازي والكوليفورم الكلي والذي قد يشكل خطرا على صحة الإنسان في حالة الاستخدام المنزلي أو ري المحاصيل الطازجة.

الكلمات المفتاحية:

مزرعة الجبل الأصفر، الري بمياه الصرف الصحي، المعالجة الثانوية، جودة المياه الجوفية، مخطط بايبر، مخطط سولن

Abstract:

Gabel El Asfar farm, located northeast of Greater Cairo, was irrigated by using primary and/or even untreated wastewater from 1915 to 1998. In 1998, the new Gabel Al Asfer Wastewater Treatment Plant (GAWWTP) was installed and started operating. As a result, the quality of such treated wastewater discharged into Gabel El Asfer drain was noticed to have a significant improvement. This secondary treated wastewater has been applied for irrigation. The main objective of the present study is to evaluate both the potential negative and positive impacts resulted from changing wastewater treatment from primary to secondary on the quality of groundwater at the area of interest. The analyses of the current study mainly were based on the data analyses of collected samples from groundwater wells taping the aquifers system under the area of study. Samples were analyzed for pH, Electric Conductivity (EC), Total Dissolved solids (TDS), major cations and anions, Nitrate (NO_3^-), Ammonium (NH_4^+), Phosphate (PO_4^{3-}), heavy metals, Chemical Oxygen Demand (COD), Total Coliform (TC) and Fecal Coliform (FC).The recently processed data were compared to the reference year 1991 to dedicate the environmental change, in terms of quality, on the groundwater system occurred throughout such period (1991 to 2017/2020). The definition of the groundwater type was performed by Piper trilinear diagram; while water geneses was investigated by Sulin's graph.

The obtained conclusions indicate that positive impacts of the use of higher level of treated wastewater than that of the previous, led to a significant decrease in most of the threatening pollutant loads in groundwater especially COD, NO_3^-, NH_4^+, and heavy metals as a result of the irrigation drainage surplus into the aquifer system. In addition, a remarkable decrease in the TDS at the eastern and southern parts of the farm was recorded. The Piper diagram indicates that groundwater type changed from Sodium-Chloride type in 1991 to Mixed type in 2017/2020. Most of this water is of a deep meteoric genesis according to Sulin's graph. While for the negative impact, there is recently a groundwater pollution by Fecal and Total coliform which may pose risk to human health in case of domestic use or irrigation of fresh-eaten crops.

Key words:

Gabel El Asfar farm, Wastewater irrigation, Secondary treatment, Groundwater quality, Piper diagram, Sulin graph

1. INTRODUCTION

The water consumption in Egypt is causing an increase of wastewater effluents draining into treatment plants and overcoming their capacities. From the other side, there is a shortage of irrigation water sources in Egypt as general, especially in the northern fringes of Greater Cairo and the southern portion of Eastern Nile Delta. So the water reuse solution imposes itself in order to manage the two problems. Wastewater reclamation, recycling and reuse are in the general area of water resource systems and reflect societies increasing demand for water. They require implementation of advanced technology for water quality control, public acceptance, and improved understanding of public health risk (Asano and Levine, 1996; Rose and Gerba, 1991).

Egypt is one of pioneering countries in water reuse. Since the year 1915, about 3,000 feddans in Gabal El Asfar farm, located about 20 km north east of Cairo, have been irrigated using treated wastewater (RIGW/ IWACO,1992). In 1991, farmers used primary treated wastewater that was discharged into El Seil drain for irrigation. El Seil drain was the main effluent of El Berka Wastewater Treatment Plant (BWWTP), located east of the farm, which treated about 600,000 m3 of wastewater daily. Gabel Al Asfer Wastewater Treatment Plant (GAWWTP), one of the biggest plants in the Middle east and Africa, has been constructed in 1998 west of the farm with total capacity of 1.5 million m3/d in 1998 that was increased to 2.5 million m3/din 2018. Gabel El Asfer drain became the main outlet of the secondary treated effluent of GAWWTP and is used by farmers for irrigation. The main objective of this study is to compare the recent groundwater quality in Gabel El Asfer farm with that of 1991 to investigate the changes occurred due to long term irrigation with wastewater.

2. METHODOLOGY

A previous study of Gabel El Asfer Farm was conducted, in 1991, by the Research Institute of Groundwater (RIGW, Cairo, Egypt) and (IWACO, Netherlands) to assess the groundwater quality at the farm. In the present research, a comparison between recent groundwater quality (2017/2020) will be compared to that in 1991as well as investigating change in water type. Based on the RIGW/IWACO report, 1992, samples from 7 wells with screens of depths from 18 to 25 m (to be compatible with well screen depths at 2020) were chosen to represent the situation in 1991. For the recent situation, field trips to the farm in 2020 were performed to collect samples and survey the important hydrogeological parameters beside some information from 2017 to help filling the missing data. Groundwater samples from 7 wells, in addition to surface samples from El Seil and Gabel El Asfer drains, were collected. Information about wastewater secondary treatment at GAWWTP and BWWTP were also collected. The samples were analyzed for:

- pH, Electric Conductivity (EC),Total Dissolved Solids (TDS)
- Major cations: Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Sodium (Na^{+}), and Potassium (K^{+})
- Major anions: Bicarbonate (HCO_3^-), Sulphate (SO_4^{2-}), Nitrate (NO_3^-) and Chloride (Cl^-)
- Ammonium (NH_4^+), Phosphate (PO_4^{3-}).
- Trace elements: Iron (Fe), Copper (cu), Manganese (Mn) and Zinc (Zn).
- Chemical Oxygen Demand (COD), Total Coliform (TC) and Fecal Coliform(FC).

The results of groundwater analysis were compared to the Food and Agriculture Organization of the United Nations (FAO) guidelines for irrigation water and other guidelines. Their statistics and Radar charts were performed with Microsoft Excel. Spatial distribution maps of EC and TDS were performed with Surfer 9. Maps of distribution pattern difference, between the years 1991 and 2017/2020, for Nitrate, Ammonium, Phosphate, and COD were performed also with Surfer 9. Water-types were investigated in 1991 and 2017/2020 using Piper trilinear diagram that was performed by Grapher 13 program. For water genesis, Sulin's graph was applied. Physical characteristics of the study area in 1991 and in 2020 were investigated with the help of the Google Earth Pro application.

3.HYDROGEOLOGY OF THE STUDY AREA

3.1 Physical Setting of the Study Area

The Study area is located at northeast 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° 21' 57" E and 31° 24' 51" E longitude and 30° 11' 37" N and 30° 14' 40" N Latitude with a total area of about 17.6 km^2. The area is dissected by Gabal el Asfar and El Seil drains. West of the farm there is GAWWTP. According to Google Earth maps, borders and land use of Gabel El Asfer farm has changed and decreased during the period from 1991 to 2020. In addition, the agriculture became very limited in the western part of the farm due to the construction of GAWWTP and the soil degradation next to it as shown in **figure 2**. The study area represents a part of the Suez-Cairo Foothills desert area (RIGW/IWACO , 1992).Elevations range from 25 m+msl at the east to about 15 m+msl at the west.

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 unconfined aquifer, as shown in **figure 3.a,** consists of Quaternary graded sand and gravel, with some intercalation of clay lenses. The hydraulic conductivity of the aquifer in the study area ranges from 40 to 50 m/day.

The levels of the base is approximately from 0 m, at the east, to about -50 m, at the west, relative to mean sea level (msl), sloping in the western direction. Those levels together with the ground elevations comprise an aquifer thickness of about 25 m at the east to about 65 m at the west of the study area. Water levels in 1991 ranged from about 25 m+msl at the east to about 14 m+msl at the west as shown in **figure 3.b**. Those levels decreased in 2020 to about 22 m+msl east of the farm and to about 10 m+msl west of it as shown in **figure 3.c**. The main direction of the deep groundwater flow is mainly from east to west.

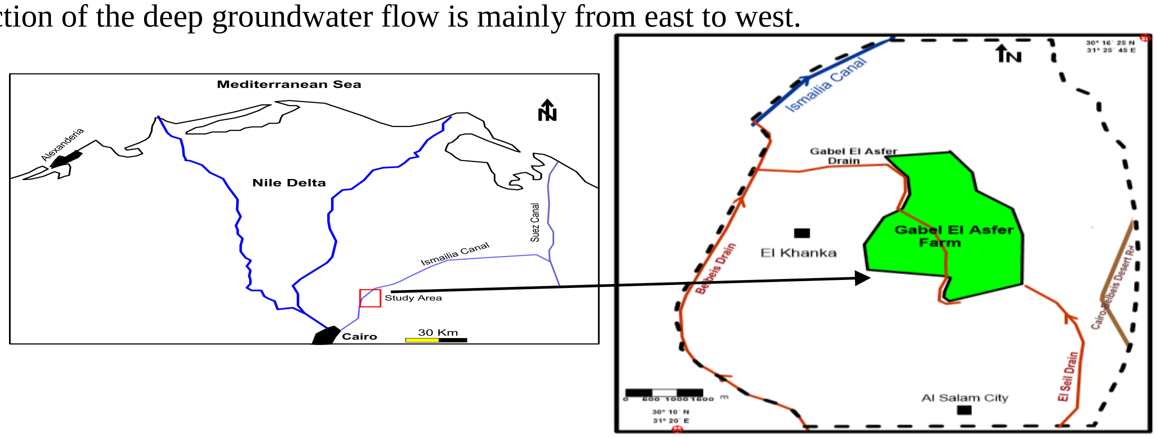


Figure 1: Location of Gabel El Asfer Farm

(a)

(b)

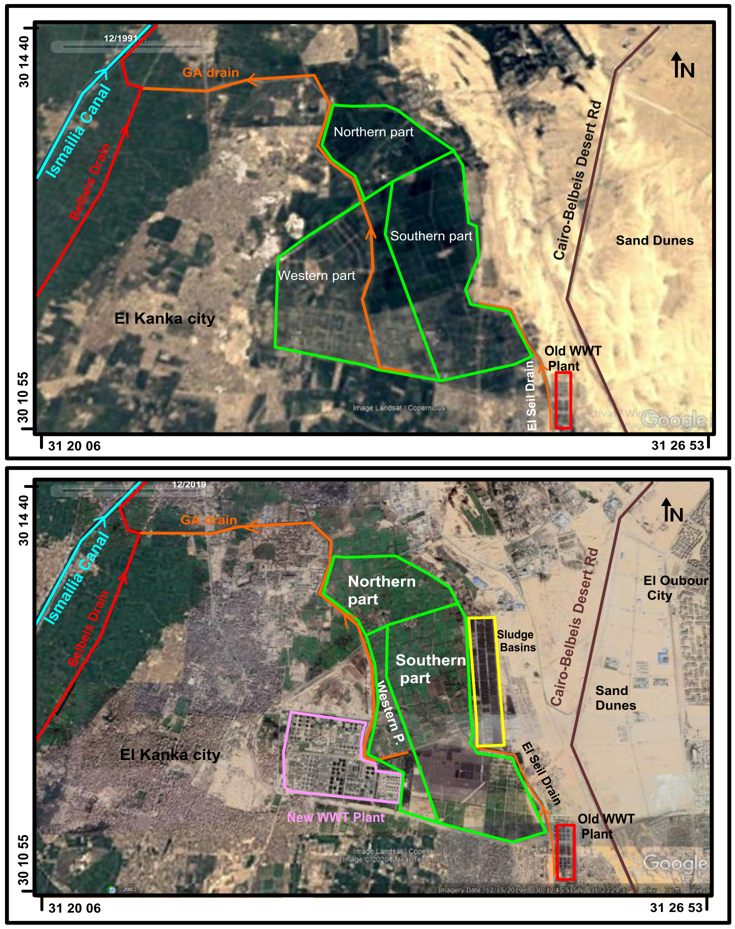
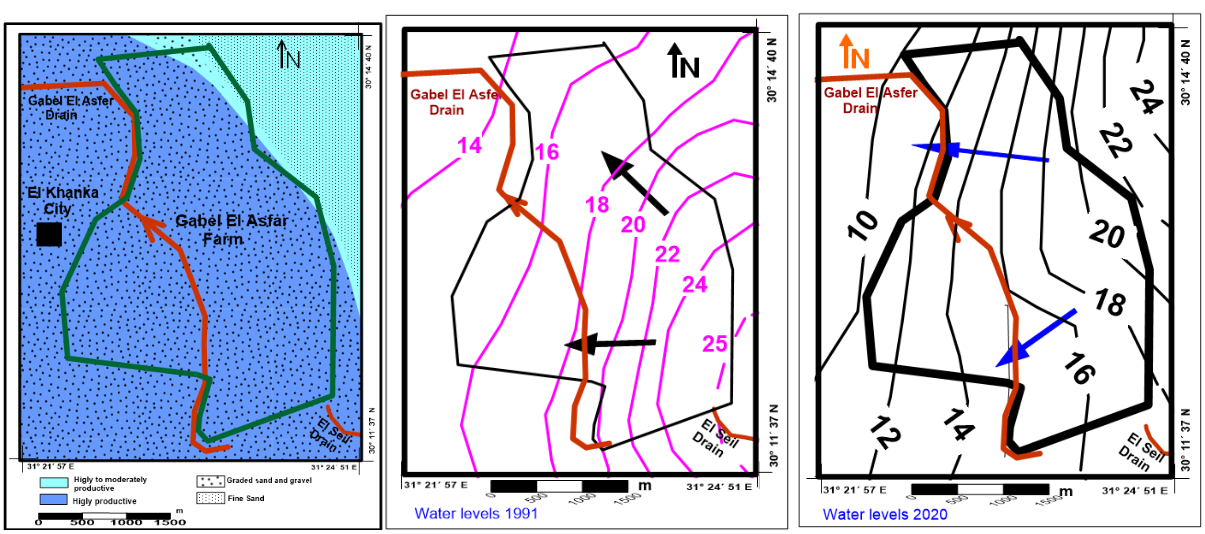


Figure 2: Gabel El Asfer Farm Borders (a) in 1991, (b) in 2020



(a) (b) (c)

Figure 3: Aquifer System (a) and Water Levels in Gabel El Asfer Farm in 1991 (b) & in 2020 (c)

4. RESULTS AND DISCUSSION

4.1 Wastewater Treatment at GAWWTP and BWWTP

Physical primary treatment of wastewater removes the suspended solids that can be easily settled. The typical materials that are removed during primary treatment include fats, oils, and greases, sand, gravels and rocks, larger settleable solids including human waste, and floating materials (Metcalf, 2003). Primary treatment removal efficiency could achieve:

- 25-50% of Biological Oxygen Demand (BOD)
- 50 to 70% of Total Suspended Solids (TSS)
- 65 % of oil and grease.

Over the years, primary treatment alone has been unable to meet many communities' demands for higher water quality. To meet them, cities and industries normally treat to a secondary treatment level (EPA, 1998).

Secondary treatment is designed to substantially degrade the biological content of the sewage such as are derived from human waste, food waste, soaps, and detergent. The bacteria and protozoa consume biodegradable soluble organic contaminants and bind much of the less soluble fractions into floc. (Metcalf, 2003). Secondary treatment typically removes about 85 % of organic matter. Primary and secondary treatments together remove an average of 75-85% of Chemical Oxygen Demand (COD).

As mentioned before, the area recently includes two wastewater secondary treatment plants GAWWTP with 2.5 million m3/d of treated water which is discharged into Gabel El Asfer drain; and BWWTP with 600,000 m3/d which is discharged into El Seil drain. The average laboratory results of TSS, BOD, and COD removal at GAWWTP (Gable El Asfer Wastewater Treatment Plant) and BWWTP (Berka Wastewater Treatment Plant) in 2015 and 2016 respectively are shown in **table 1**. It is listed that BOD and TSS removal efficiencies reached about 88-94 % and 88-96% respectively. COD removal efficiency reached about 88-89 % which would affect COD levels in groundwater in (2017/2020) as will be mentioned later.

Table 1: Average Laboratory Results of TSS, BOD and COD Removal at GAWWTP in 2015 and BWWTP in 2016

Parameter (mg/l)	GAWWTP (2015)			BWWTP (2016)		
	Influent	Effluent	Removal %	Influent	Effluent	Removal %
BOD	187	11	94 %	263	31	88 %
TSS	213	8	96 %	504	59	88 %
COD	354	40	89 %	278	35	88 %

Modified from (El Rawy, 2017)

4.2 Surface Water Quality

Agriculture is the major user of water and can accept lower quality water than domestic and industrial users (FAO, 1994). It is therefore inevitable that there will be a growing tendency to look toward irrigated agriculture for solutions to the overall effluent disposal problem. Because wastewater contains impurities, careful consideration must be given to the possible long-term effects on soils and plants from salinity, sodicity, nutrients and trace elements that occur normally in wastewater (FAO, 1994). Since El Seil and Gabel El Asfer drains are the main sources for irrigation water in the area as they are the main effluents of El Berka and Gabel El Asfer WWTPs respectively, it was necessary to investigate their recent water quality and compare them to that of 1991.Results of surface water samples from El Seil and Gabel El Asfer drains in 1991 and 2020, are shown in **tables 2**.

As mentioned before, the secondary treatment applied recently in wastewater plants beside increasing their capacity that tries to eliminate bypass of raw sewage into drains, should have a good reflection on pollutant loads in the drains in 2020. On the contrary, poorly treated or untreated sewage is used to be discharged into the drains in 1991 due to the limited capacity of primary treatment in 1991 at the old WWTP. Results of surface samples show that levels of EC and TDS are lower than the FAO guideline which are 3 mmoh/cm and 2000 mg/l respectively. Sodium adsorption ratio (SAR) has increased to 6.23 in Gabel El Asfer drain in 2020 while SAR decreased in El Seil drain to 2.79, both records still lower than FAO guideline which is 9 as shown in **tables 2**.

On the other hand, a noticeable decrease in the concentrations of Nitrate was recorded in 2020 surface samples. Heavy metals as well had high concentrations in 1991 and many samples exceeded FAO limits for Cu and Mn; while in 2020 they were significantly decreased in the drains. Unfortunately, COD analysis was not included in those surface samples but COD high removal efficiency at GAWWTP and BWWTP in 2015 and 2016 (see section 4.1) could give an indication that their recent concentrations in the drains are low.

4.3 Groundwater Quality in Gabel El Asfer Farm

Groundwater samples' locations in 1991 in 2017/2020 are shown in **figure 4**. The descriptive statistics of the chemical constituents of all groundwater samples are presented in **table 3;** while **figure 5 and 6** are radar charts for better visualization of most of those statistics in 1991 and in 2017/2020 respectively. The pH values of groundwater samples ranged from 7.2 to 8.3 with an average value of 7.83 in 1991; while it ranged from 7.2 to 7.93 with an average value of 7.63 in 2017/2020. This is compatible to FAO guidelines, as pH in irrigation water should range from 6.5 to 8.4. The rest of the constituents are as follows:

Salinity

According to the relative tolerance of crop plants to groundwater salinity (Eltrabily, 2018), groundwater of EC Class 1 (0-.95 mmohs/cm) is suitable for sensitive crops irrigation, Class (0.95-1.9 mmohs/cm) can be used to irrigate moderately sensitive crops, Class 3 (1.9-4.5

mmohs/cm) can be used to irrigate moderately tolerant crops, and Class 4 (4.5-7.7 mmohs/cm) can be used to irrigate Salt tolerant crops. EC (in mmohs/cm) varied in 1991 from 0.7 to 2.1 with an average value of about 1.31**;** while it varied in 2017/2020 from 0.77 to 1.79 with an average value of about 1.18 as listed in **table 3.** According to FAO guidelines, EC in irrigation water should not exceed 3 mmohs/cm. As shown from the spatial distribution of relative tolerance of crop plants according to EC (**Figure 7**), the farm in 1991 included three classes 1, 2 and 3 at North, middle and South of it respectively; while in 2017/2020 those three classes were decreased to only one class (class 2) in most of the farm. This means that an enhancement in EC levels has occurred due to irrigation with wastewater south of the farm which enabled groundwater to be used to irrigate moderately sensitive crops.

Table 2: Chemical Analysis of Surface Water Samples (1991 & 2020) and FAO Guidelines

Parameter	pH	EC	TDS	SAR	NO_3^-	NH_4^-	Fe	CU	Mn	Zn
		mmoh/ cm	mg/l		mg/l	mg/l	µg/l	µg/l	µg/l	µg/l
Gabel El Asfer Drain 1991*	7.7	1	747	4.01	22.3	20.5	420	220	200	80
Gabel El Asfer Drain 2020	7.82	1.33	860	6.23	0.78	17**	103	6	74	5
El Seil Drain 1991*	7.8	1.3	914	4.14	26.7	9.79	360	80	220	100
El Seil Drain 2020	7.88	0.71	453	2.79	8.16	ND	8	6	7	5
FAO	6.5-8.4	3	2000	9	30	40***	5000	200	200	2000

* (RIGW/IWACO), 1992
** El Rawy, 2020
*** Common concentrations from several countries (Water, 2020)

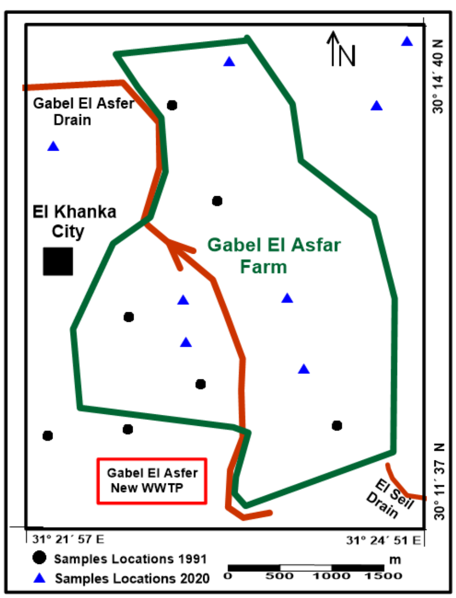


Figure 4: Groundwater Samples' Locations in 1991 and in 2017/2020

On the contrary, EC has increased in the northwest of the farm from class1 to class 2; for that, sensitive crops are no longer suitable to be cultivated in northwest areas.

TDS in the study area in 1991 varied from 540 to 1885 mg/l with an average value of about 1027 mg/l**;** while it varied in 2017/2020 from 627 to 1151 mg/l with an average value of about 785 mg/l as listed in **table 3.** In 1991, TDS ranged from 525 to 1400 mg/l east of the farm which is "Permissible" for irrigation (Eltrabily, 2018); while it ranged from 1400 to 2100 mg/l west of it which is "Doubtful" for irrigation as shown from the spatial distribution of TDS in **figure 8**. According to FAO guidelines, TDS in irrigation water should not exceed 2000 mg/l. In 2017/2020 TDS was classified "Permissible" with a range from 525 to 1400 mg/l all over the farm. This means that irrigation with wastewater helped in refreshment of the aquifer by decreasing its TDS west of the farm. On the other hand, TDS has increased north-east of the study area as groundwater was classified " Good" in 1991 with TDS range of 175-525 mg/l. That was increased to the range of 525 to 1400 mg/l in 2017/2020 at northwest.

Table 3: Summary of Statistics of The Chemical Constituents of Groundwater Samples in 1991and in 2017/2020

		Groundwater samples 1991				Groundwater samples 2017/2020				FAO Guide-lines
	Unit	Min.	Max.	Av.	Stdev.	Min.	Max.	Av.	Stdev.	
PH		7.20	8.30	7.83	0.484	7.20	7.93	7.63	0.219	6.5-8.4
EC	mmohs /cm	0.70	2.10	1.31	0.490	0.77	1.79	1.18	0.340	3
TDS	mg/l	540.00	1885.00	1026.83	469.575	627.00	1151.00	784.86	191.400	2000
SAR		2.63	6.43	4.43	1.46	0.44	5.56	2.58	1.63	9
Ca^{2+}	mg/l	20.00	140.00	79.33	56.266	59.20	169.62	92.35	35.994	
Mg^{2+}	mg/l	21.60	46.80	32.20	9.522	21.67	30.13	24.57	3.144	
Na^{+}	mg/l	93.60	345.00	184.85	87.996	18.00	300.00	113.57	90.923	
K^{+}	mg/l	12.90	62.40	27.63	17.866	5.00	23.00	13.39	6.140	
Cl^{-}	mg/l	106.50	340.80	193.87	77.908	49.28	274.00	141.73	77.670	350
$SO4^{2-}$	mg/l	50.90	480.00	167.68	161.342	62.00	185.00	127.15	41.395	
$HCO3^{-}$	mg/l	150.70	432.50	273.80	117.032	115.90	449.00	283.54	108.537	520
$NO3^{-}$	mg/l	15.50	61.40	30.18	17.536	0.20	32.00	11.06	11.417	30
$PO4^{3-}$	mg/l	0.07	3.25	1.40	1.566	0.20	0.30	0.25	0.050	-
$NH4^{+}$	mg/l	0.34	15.58	7.59	6.950	0	12.36	4.76	5.808	-
COD	mg/l	312.00	491.00	378.50	83.867	8.00	33.20	23.93	13.86	-
T.C	CFU/ 100mL	ND	ND	ND	ND	17000	105000	46333	50807	-
FC	CFU/ 100mL	ND	ND	ND	ND	960	23000	8353	12685	1000*

*Under certain conditions

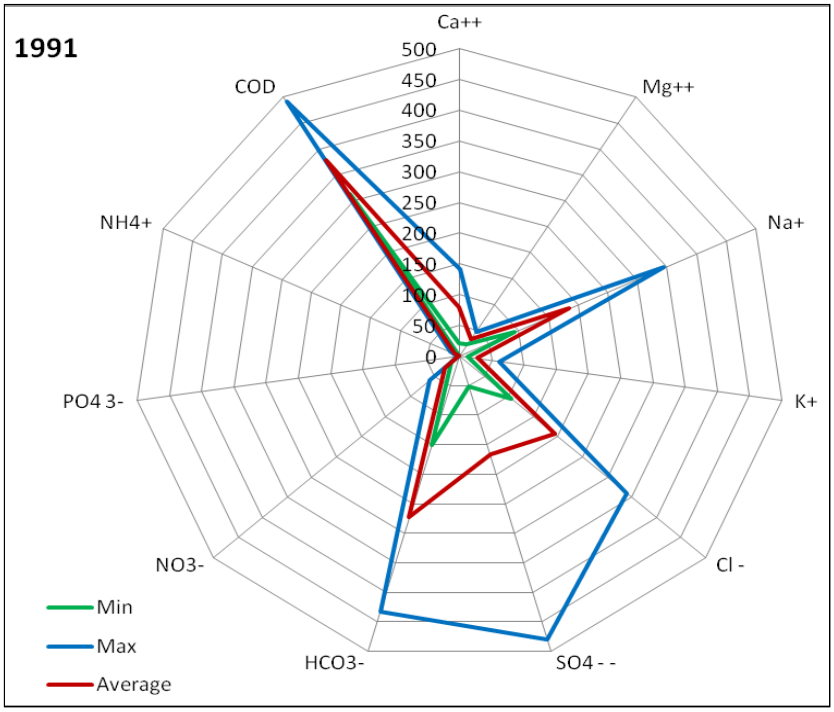


Figure 5: Radar Charts of Statistics of Groundwater Chemical Analysis in 1991

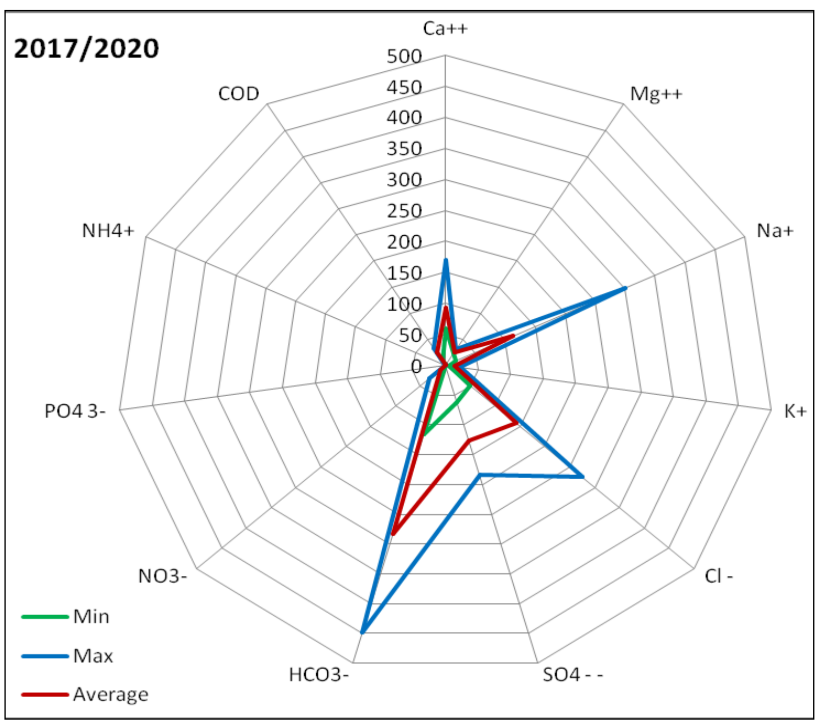
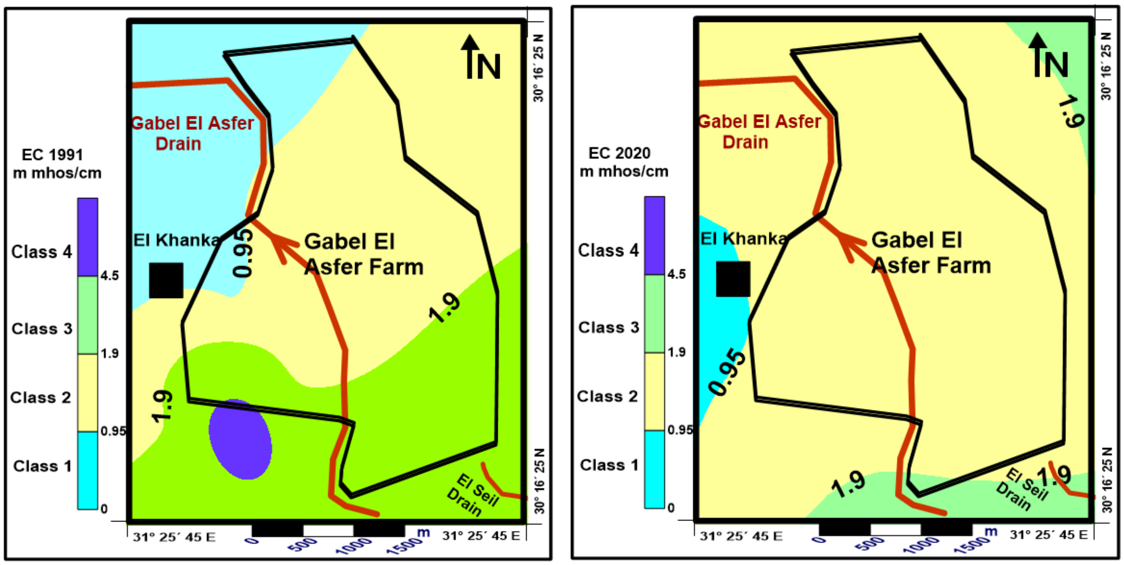
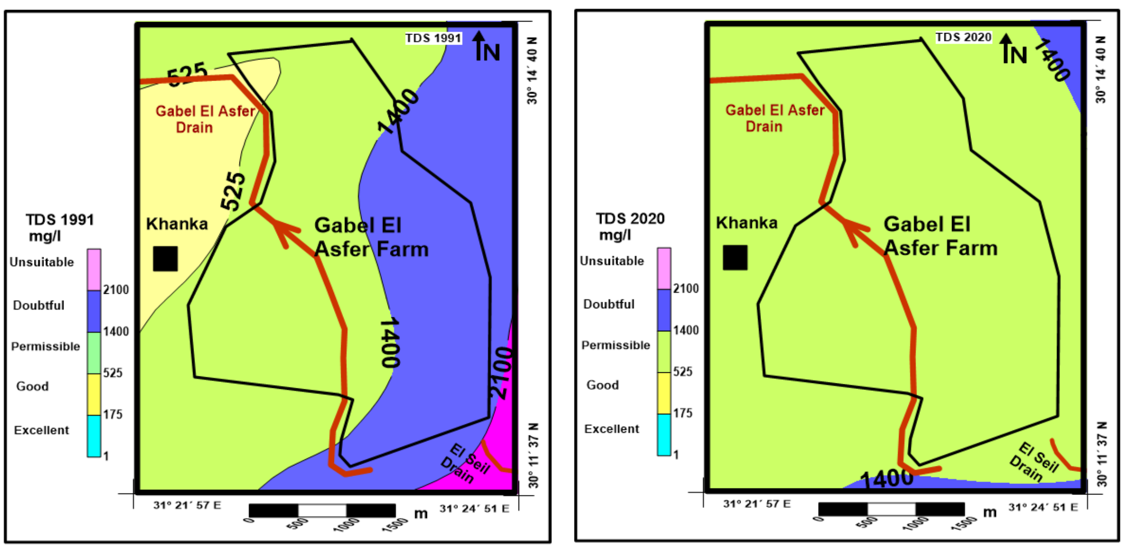


Figure 6: Radar Charts of Statistics of Groundwater Chemical Analysis in 2017/2020



(a) (b)

Figure 7: Spatial Distribution of Crop Classes According to EC in 1991(a)and in 2017/2020 (b)



(a) (b)

Figure 8: Spatial Distribution of TDS in 1991(a) 2017/2020 (b)

Major Ions and Piper Diagram

Chemical analyses were conducted for cations and anions to recognize the change in groundwater type in Gabel El Asfer farm between the years 1991 and 2017/2020 using Piper trilinear diagram; but before applying it, a check for the correction for the accuracy of the groundwater analyses for cations and anions were achieved. It was conducted using the criterion for acceptance which is (sum of cations - sum of anions) / (sum of cations+ sum of anions) x 100%. The error should be within ± 5% (Matthess, 1982). The results of percentage errors are shown in **table 4**.

It is noticed that well 7/ in 2017/2020 showed an error of -26.68 % which exceeded the permissible error limit; for that, the results of well 7/ were neglected when performing Piper diagram and Sulin's graph.

Table 4: Percentage Error of Chemical Analyses for Groundwater in Gabel El Asfer Farm in 1991 and in 2017/2020.

	Well	Σ Cations (meq)	Σ Anions (meq)	Error %
1991 samples	1	16.45	15.98	1.45
	2	7.75	7.47	1.83
	3	14.50	13.44	3.79
	4	11.78	11.35	1.87
	5	14.39	13.14	4.53
	6	27.50	26.69	1.49
2017/2020 samples	1/	12.11	11.33	3.36
	2/	24.63	22.43	4.66
	3/	10.50	10.00	2.44
	4/	9.83	9.80	0.15
	5/	7.55	7.38	1.14
	6/	11.44	11.02	1.90
	7/	7.56	13.07	-26.68

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; this procedure was born under the statement that most natural waters contain cations and anions in chemical equilibrium (Piper, 1944). In order to apply this procedure, both cations and anions should be appreciated in percentage (meq%) as shown in **table 5**.

For water type, results show that most of groundwater samples occupied Sodium- Chloride type in 1991 as shown in the diamond in **figures 9**; while most of it occupied Mixed type (neither cations nor anions exceed 50%)in 2017/2020 as shown in **figures 10**. For anions, most of samples occupy No dominant type category in both 1991 and 2017/2020. For cations, a change has occurred as most of the samples in 1991 were in the zone of Sodium and Potassium type; while it changed to No Dominant type of cations in 2017/2020.
When talking about major ions, Sodium Adsorption Ration (SAR) is of a great importance. As listed in **table 2**, SAR average in groundwater decreased from 4.43 in 1991 to 2.58 in 2017/2020. Both values still below FAO guidelines for SAR in irrigation water which is 9.

Water Genetic Type (Sulin's graph):

Sulin's graph (Sulin, 1946) consists of two equal squares; the upper right one represents the marine water genesis($MgCl_2$ and $CaCl_2$) with ((rNa /rCl) < 1); while the lower left square represents the meteoric water genesis ($NaHCO_3$ and Na_2SO_4) with ((rNa/rCl) > 1 (Salman, 2013). The two squares are subdivided where each one has two triangles. The hydrochemical composition of most of groundwater samples in 1991 and 2017/2020 lies in the category where ((rNa/rCl) > 1) and ((rK + rNa) - rCl) / rSO4 <1) which corresponds to Na_2SO_4 salt that reflects deep meteoric water genesis as shown in **figures 11**.

Nitrate, Ammonium and Phosphate

Although Nitrogen is the most important nutrient for crop growth, high concentrations of this nutrient may result in over stimulation of plant growth, lodging, poor crop quality, maturity postponement, and excessive foliar growth(Azar, 2004). Phosphorous is also important for crop and livestock production. However, excess amounts of Phosphorous can increase the rate of eutrophication (FAO, 1992). The common concentrations of Nitrate (NO_3^-)and Ammonium in irrigation water are 0-30 mg/L and 5-40 mg/L respectively (Lazarova, 2004). Nitrate in FAO guidelines does not exceed 30 mg/l in irrigation water.For Ammonium, all of the existing regulations and guidelines require lower levels of Ammonium than its common concentration in wastewater (Azar, 2004). **Table 6** shows nutrients thresholds in agricultural water reuse regulations and guidelines.

Table 5: Results of the Percentage Ratios of the Ions Concentration in Gabel El Asfer Farm in 1991 and in 2017/2020

	Well	Na+K	Ca	Mg	Cl	So4	HCo3
		meq%	meq%	meq%	meq%	meq%	meq%
1991 samples	**1**	51.37	37.69	10.94	33.17	25.03	41.80
	2	58.70	12.90	28.39	40.16	14.20	45.65
	3	65.52	14.48	20.00	44.71	24.63	30.66
	4	62.66	10.18	27.16	57.97	14.49	27.54
	5	41.63	43.78	14.59	45.01	17.95	37.04
	6	60.36	25.45	14.18	35.97	37.47	26.56
2017/2020 samples	**1/**	46.88	37.27	15.84	29.35	21.15	49.50
	2/	55.36	34.44	10.20	40.77	20.36	38.88
	3/	46.76	33.90	19.33	41.60	33.07	25.33
	4/	46.49	30.11	23.40	30.31	26.84	42.86
	5/	24.73	50.99	24.28	18.81	17.50	63.69
	6/	44.70	39.52	15.78	28.76	20.65	50.59

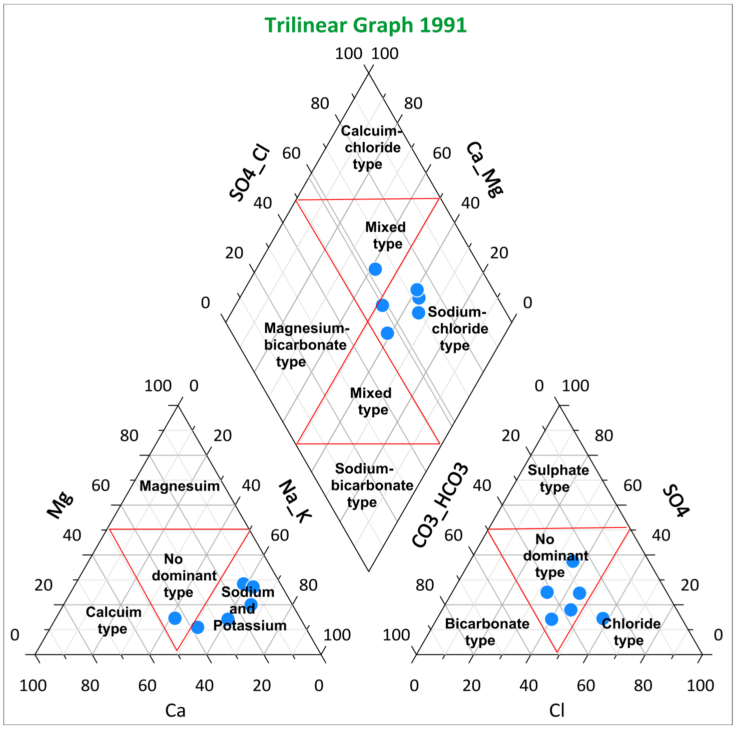


Figure 9: Water Type of Groundwater at Gabel El Asfer farm (Piper Trilinear Diagram) in 1991

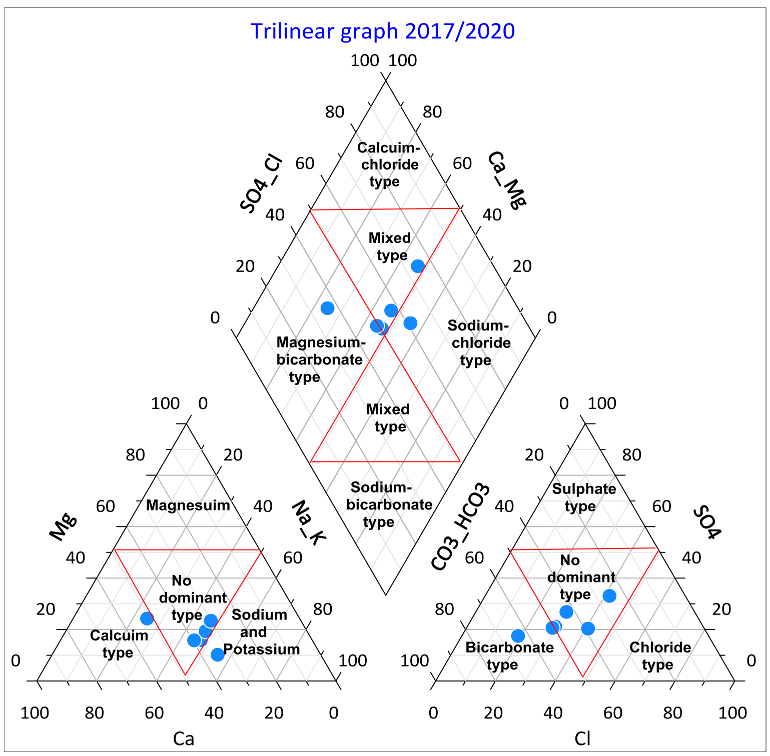


Figure 10: Water Type of Groundwater at Gabel El Asfer Farm (Piper Trilinear Diagram) in (2017-2020)

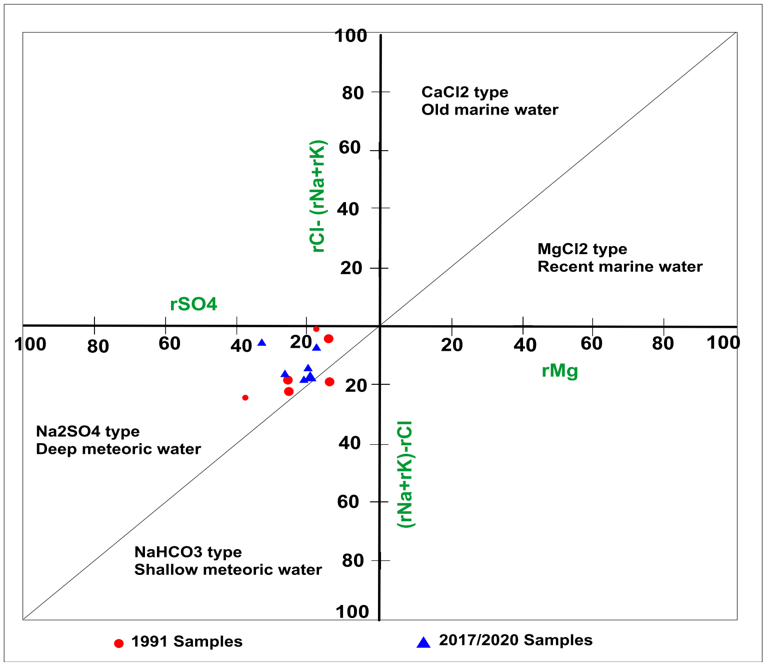


Figure 11: Classification of Groundwater Genesis (Sulin's graph) of Samples in 1991 and in 2017/2020

Table 6: Nutrients Thresholds in Agricultural Water Reuse Regulations and Guidelines

Guidelines	NO_3^-	NH_4^+	PO_4^{3-}
FAO	30	-	-
Iran	-	5	50
Kuwait	-	15	30
Italy	15	2	2
Jordan	16.1	-	30
Saudi Arabia AGWR	10	5	-

Modified from (Azar, 2020)

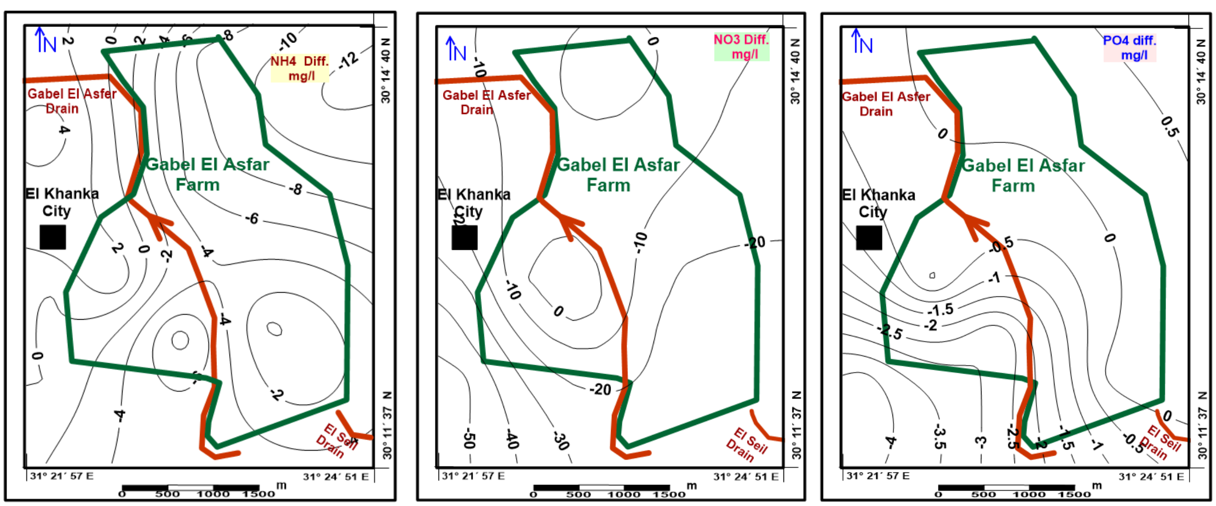
In Gabel El Asfer farm, **Ammonium NH_4^+** average concentration decreased from 7.6 mg/l in 1991 to 4.76 in 2020 as listed in **table 2**. The distribution pattern (Dp) difference of concentration of NH_4^+ between 2017/2020 and 1991 reveals a recent decrease in concentrations ranges from about 2 mg/l south of the farm to about 10 mg/l in the northeast of the farm as shown in **figure 12.a**. The nitrate average was 30.18 mg/l in 1991 as half of the samples exceeded FAO limits (30 mg/l). In 2020, this average decreased to 11.06 mg/l. Dp difference of NO_3^-, shows a decrease in concentration up to 25 mg/l south of the farm as shown in **figure 12.b**. Phosphate average decreased from 1.4 mg/l in 1991 to 0.25 mg/l in 2017/2020. Dp of PO_4^{3-} shows a decrease ranges from 0.5 to 2.5 mg/l in concentrations occurred in the middle and west of the farm; while almost no change at the eastern parts of it as shown in **figure 12.c.**

Heavy Metals

Due to insufficient data in 1991 relating to heavy metals concentrations in the study area, distribution pattern difference maps could not be contoured. Alternatively, two wells in the western part of the farm (A and B) and another two at the eastern part (C and D) were chosen to give an indication of the impact of wastewater irrigation during the period from 1991 to 2017/2020 as listed in **table 7**.

High levels of iron (Fe) can cause irritability in the gastrointestinal tract and can affect water's taste by enhancing the growth of iron bacteria (Al-Bagawi, 2019). Iron is not toxic to plants in aerated soils, but can contribute to soil acidification and loss of availability of essential phosphorus and molybdenum (FAO, 1994). In the western part of the farm, Fe concentration in well A was 160 µg/L in 1991 and decreased to 19 µg/L in the nearby well B in 2020 as shown in **figure 13**; while east of the farm it was 330 µg/L in well C in 1991 that was decreased to 130 µg/L in the nearby well D in 2017 as shown in **figure 14**. All records are much lower than the FAO guidelines for iron which is 5000 µg/L.

Copper (Cu) is an essential nutrient, but long-term exposure at such concentrations may cause liver or kidney damage (Al-Bagawi, 2019). Cu concentration was 100 µg/L in 1991 in well A and decreased to 20 µg/L in 2020 in well B as shown in **figure 13**; while east of the farm it was 1160 µg/L in well C in 1991 which was much higher than FAO limits (200 µg/l). It was decreased significantly to 95 µg/L, in the nearby well D, in 2017 as shown in **figure 14**.Manganese (Mn) is an essential nutrient, and eating a small amount of it each day is important to health (ATSDR, 2012).



(a) **(b)** **(c)**

Figure 12: Distribution Pattern Difference in Concentrations between 2017/2020 and 1991 of NH_4^+(a), NO_3^-(b), and PO_4^{3-}(c)

Table 7: Heavy Metals Concentrations in Wells A, B, C and D with FAO Guidelines

	Well A 1991 (West)	Well B 2020 (West)	Well C 1991 (East)	Well D 2017 (East)	FAO Guidelines
Fe (μg/L)	160	19	330	130	5000
Cu (μg/L)	100	20	1160	95	200
Mn (μg/L)	200	191	170	196	200
Zn (μg/L)	1110	34	919	81	2000

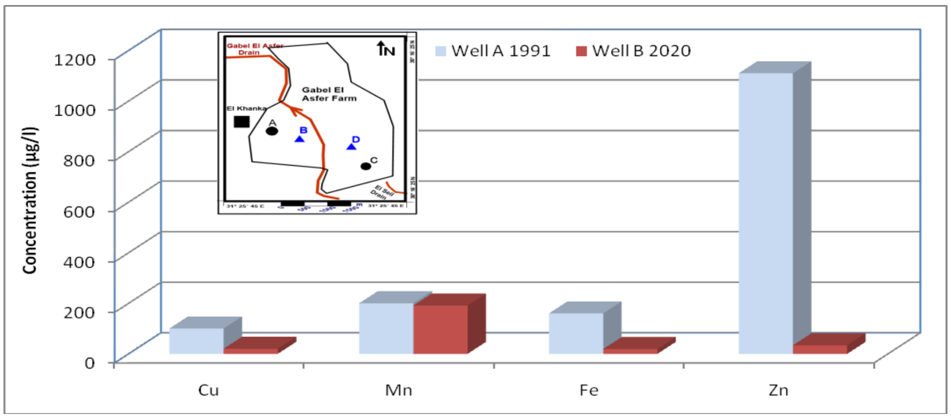


Figure 13: Chart of Heavy Metals Concentrations in Wells A and B West of the Farm

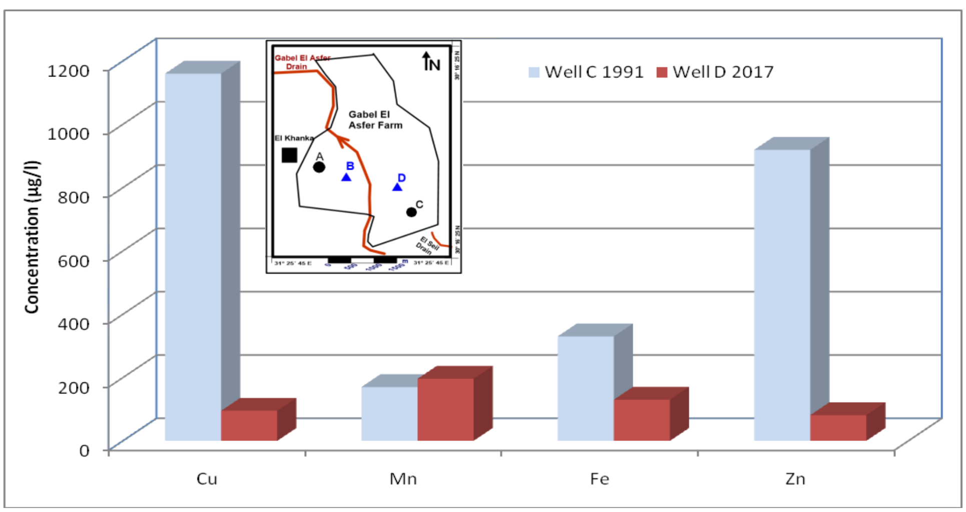


Figure 14: Chart of Heavy Metals Concentrations in Wells C and D East of the Farm

In the western part of the farm, Mn concentration in well A was 200 μg/L in 1991 that had a slight decrease to 191 μg/L in the nearby well B in 2020 as shown in **figure 13**. East of the farm Mn concentration was 170 μg/L in well C in 1991 as shown in **figure14**; while it was increased to 196 μg/L in nearby well D in 2017. Thus, Mn records did not show a significant change and are slightly near the FAO guideline which is 200 μg/L.

Although Zn is an essential trace element, high levels can cause harmful health effects (Al-Bagawi, 2019). Zinc concentration was 1110 μg/L in 1991 in well A which was high but still under FAO limits (2000 mg/l). It was decreased significantly to 34 μg/L in 2020 in well B as shown in **figure 13**. East of the farm, Zn concentration was 919 μg/L in well C in 1991. It was decreased to only 81 μg/L in the nearby well D in 2017 as shown in **figure 14**.

COD and Coliforms

Chemical oxygen demand (COD) is one of many indicators of organic matter in water. Organic matter in the water may alter the water's color and odor, provide nutrients for microbial growth, and negatively impact the disinfection process (Jeong, 2016). To prevent these adverse effects, different organizations and agencies have included COD thresholds in their regulations and guidelines (Azar, 2020). The highest COD threshold is issued by Jordan (500 mg/l) for fruit trees, landscaped roadsides of highways, industrial crops, and forest trees. It also issued 100 mg/l for cooked vegetables, parks, playgrounds, and cut flowers irrigation (WHO,2006).

The average value of COD in 1991 was about 378 mg/l that had a significant decrease in 2017/2020 to an average of about 24 mg/l as listed in **table 2**. As mentioned before, COD removal efficiency reached about 88 & 89 % at GAWWTP and BWWTP in 2015 and 2016 respectively. This enhancement in wastewater secondary treatment contributes effectively to reduce COD levels in ground water. The difference of distribution pattern (Dp) of COD reveals a considerable decrease that ranges from 300 to 450 mg/l in the farm between the years of 2017/2020 and 1991 as shown in **figure 15**.

Total Coliforms and Fecal coliforms are among the most frequent indicators to assess the microbial quality of the reclaimed water for irrigation (FAO, 1994). Egypt threshold for Fecal coliforms in irrigation water is 1000 CFU/100 mL in case of plants and trees grown in residential areas; while it is 5000 CFU/100 mL for fodder/feed crops, trees producing fruit, afforestation of highways, cut flowers, and fiber crops (Abdel-Shafy, 2013). FAO limit of Fecal Coliform for irrigation of crops likely to be eaten uncooked is 1000 CFU/100 mL (FAO, 1994). As the Total coliform threshold was mentioned in a few regulations, the maximum threshold for it was included in Idaho, United States, regulations as 2300 CFU/100 mL (Idaho, 2019).

Total and Fecal coliforms had not enough data in 1991 for comparison. Total coliform ranged from 17000 to 105000 CFU/100 mL in three samples collected from 2017 to 2020 as shown in **figure 16**; while fecal coliforms ranged from 960 to 23000 CFU/100 mL. This could be of high risk especially if crops likely to be eaten uncooked are cultivated on the farm.

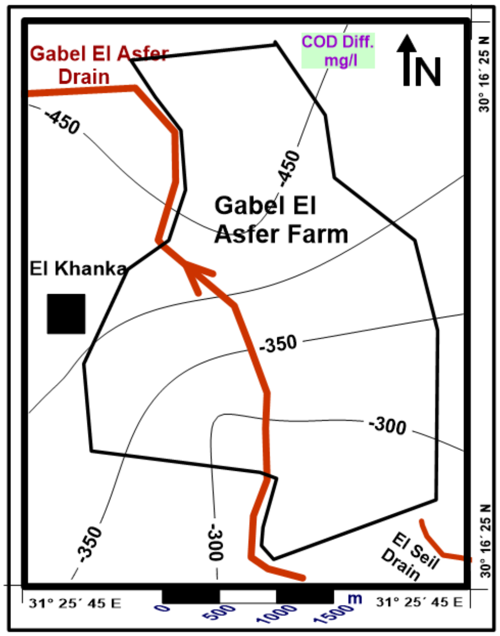


Figure 15: Distribution Pattern Differences of COD Between 2017/2020 and 1991

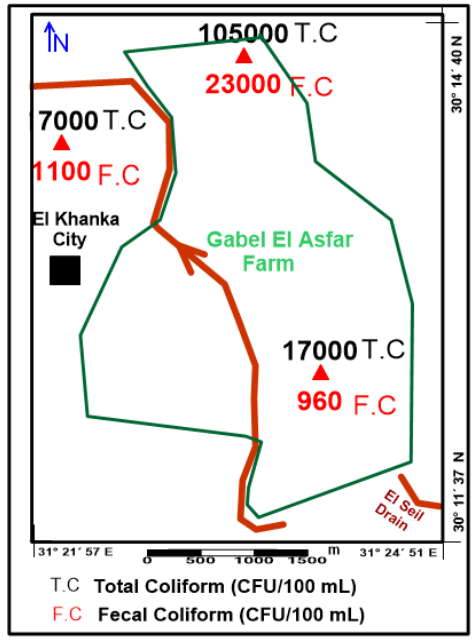


Figure 16:Total and Fecal Coliforms in 2017/2020

5. CONCLUSIONS

The current research mainly focuses on the analyses of the collected samples from both groundwater, in Gable El Asfer farm, and surface water from Gable El Asfer and El Seil drains in 1991 and 2017/2020; for assessing both potentially positive and negative impacts of the pollution load in wastewater, as a result of the change of wastewater treatment from primary to secondary treatment level, in term qualitatively, on the groundwater potential under the area of study. The conclusions were drawn as follows:

- It was possible to enhance the assessment by selecting suitable and effective methodologies for analyses such as the statistical analysis, Piper-trilinear diagram, Sulin' graph, and thematic maps using Surfer 9 program.
- Improving the efficiency of treatment of wastewater at GAWWTP and BWWTP from primary to secondary treatment has significantly contributed to reducing most of the pollutant loads in the discharged water into Gabel El Asfer and El Seil drains; subsequently, reducing them in groundwater especially COD, Ammonium, Phosphate, Nitrate, and heavy metals.
- The replenishment of the excess irrigation surplus drainage into the aquifer system led to fast positive impacts on the aquifer system during the period from 1991 to 2017/2020 by decreasing its TDS range south and east of the farm from 1400-2100

mg/l in 1991 to 525-1400 mg/l in 2017/2020 which is compatible with FAO limit for TDS (2000 mg/l) and allow moderately sensitive crops to be cultivated.

- Sodium Adsorption Ration (SAR) average in groundwater decreased from 4.43 in 1991 to 2.58 in 2017/2020. Both values still below FAO guidelines for SAR in irrigation water which is 9.
- For water type, the Piper diagram shows that most of the groundwater samples occupied Sodium- Chloride type in 1991 that changed to Mixed type in 2017/2020; while Sulin's diagram showed that most of this water is of deep meteoric genesis.
- The most important negative impact that has been detected recently is groundwater pollution with Fecal and Total Coliforms which poses risk to human health in case of domestic use or irrigating of fresh eaten crops. EC and TDS levels also were increased northwest of the farm but still within the permissible limits according to FAO.

6. RECOMMENDATIONS

- It is highly recommended to design a periodical monitoring program for evaluating the environmental change in the water quality especially in risky areas; in addition to allocating new drilling wells in the area with information gaps.
- There is imperative to construct digital theme mapping with any change of the hydrogeological environment for decision-makers.

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