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Environmental and Hydro-chemical impact of El-Salhiya wastewater treatment plant, Qena, Egypt.

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Abstract: *Geoelectric resistivity survey and hydrochemical studies were conducted at and around the area of the Qena sewage treatment plant at wadi El-Shuweina, Eastern Desert, Egypt to understand the groundwater conditions as the determination of aquifer parameters, directions of groundwater flow, and the horizontal extension of the contamination with the sewage water. To achieve this aim, fourteen vertical electrical soundings were carried out and twenty-six samples of groundwater were collected from the wells tapping the Quaternary aquifer of the study area.*

The results of qualitative and quantitative interpretations reflect that the surface layer in the area of study is composed of sand, clay, and gravel. The stratigraphic column is composed of three to four layers in some sections. The depth of the water-bearing formation ranges from 4.5 to 32 m. The results also show that the aquifer thickness varies between 47.5 and 85.5m. The groundwater has a lower hydraulic gradient along the SW direction as the more infiltration of sewage water where the regional direction of topography and stratigraphy inclination.

Physio-chemical parameters including major anion and cation, TDS, BOD, COD, nitrate and heavy metals were used to assess the contamination of groundwater with sewage water by comparing with the WHO. The results showed that groundwater had evidences of contamination. The results of chemical analysis of groundwater samples indicated that the removal percentage by the soil particles through the vadose zone were 98.5% and 98% for BOD and COD. Moreover, the results also indicated that infiltrating effluent sewage water has been naturally treated by soil particles where Cd, Fe, Mn, Cu, and Pb were removed during soil percolation by about 80%, 98.3%, 98.8%, 100%, and 100% respectively

Key Word: *Hydrochemical; Environmental; Groundwater; Aquifer; VES; Sewage water.*

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I. Introduction

Groundwater resources are vital sources of agricultural, industrial, and domestic purposes, particularly in areas where there is an increasing demand for water [1]. Human activities, such as urban expansion and agricultural activities lead to the deterioration of groundwater quality primarily due to contamination with domestic sewage, industrial wastewater, landfill leachate, and fertilizers used on agricultural lands [2]

The most important advantages of Soil Natural Treatment (SNT) are reducing pollutants and enhanced water quality[3, 4, 5] groundwater level restoration in depleted aquifers[6, 7, 8] and the probability of partially treated wastewater storage in the aquifer[9, 10, 4, 5] for future use. The soil in the SNT system provides a medium for natural purification processes[11] and allows partially treated wastewater to infiltrate through several hundred meters of the unsaturated zone and the aquifer, through which the recharged wastewater quality is much improved[12, 13, 14, and 15]. During the recharge process, the heavy metals, Nitrate, and some hazardous ions are efficiently removed and consumed[16, 17, 3].

The Vadose zone acts as the medium in which biological and physicochemical reactions occur[18] to significantly reduce wastewater parameters such as biochemical oxygen demand (BOD), chemical oxygen demand (COD), nutrients, and heavy metals[19, 20, 21, 22] before reaching the aquifer. A minimum soil depth of 3 m to groundwater is usually recommended[23] to safeguard the underlying aquifer's quality. Some researchers showed the importance of the thin upper layer of the soil in the elimination process in SNT[24, 25, 26, 8, 27].

Location of the study area

The study area lies in the southern part of Upper Egypt between Latitude: 26° 8' 18.86" and 26° 11' 5.281" N, Longitude: 32° 45' 7.711" and 32° 48' 13.137" E east of the River Nile with an area about 25 Km^2. It is located on the plains which are generally descended from the north and west and are represented by the small plains which occupy the central part of the Nile Valley and the old reclaimed plain on the fringes of the valley[28].

The improper disposal of sewage in the Qena Water Station, built in 1981, is a source of environmental contamination. Here, raw wastewater is introduced directly to the land without any treatment which forms some ponds which formed due to human activities around the Qena sewage water treatment plant. (Fig. 1). Water quality is characterized by the chemical, physical and biological properties of water that measure their suitability for all needs and keep the health and safety of water ecosystems[29].

Geoelectrical techniques are used well to achieve a very wide contrast picture in features, comprising: heterogeneity of the lithology of aquifers, width of confined aquifer layers, the hydrostatic level position, aquifer layer depth, existence of clay lenses, and determination of the zone of fracture[30].

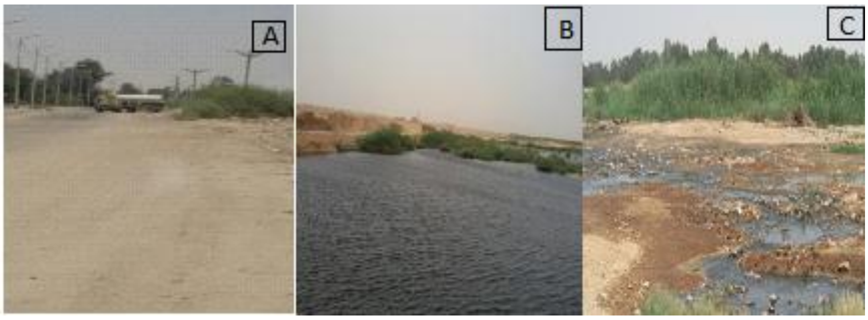

Fig. (1) Human activities around the Qena sewage water treatment plant.
A: Onsite and illegal dumping B: Treated sewage water storage C: seepages from untreated sewage water

II. Material and Methods

The fieldwork in this study was completed on a trip during March 2018 for accomplishing a geoelectrical resistivity survey and hydrochemical measurements. Therefore, 14 Schlumberger vertical electrical soundings (VES) were made with a maximum electrical current spacing AB/2 of 300 m. And 26 samples (25 of them were from groundwater wells and one "No. 26" was outflow wastewater) (Fig. 2) were collected around El-Salhiya wastewater treatment plant, in situ measurements were made immediately at each sample site, such as temperature (T), electrical conductivity (EC), total dissolved solids (TDS), salinity, pH, ground elevation, depths to groundwater (data obtained from farmers). In addition to these physical measurements, the property of Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD) had done. Some chemical measurements have been carried including the heavy metals, soluble cations, soluble anions, and alkalinity.

III. Results

Geophysical Data interpretation

The acquired resistivity soundings data is interpreted in two immediate stages (qualitative and quantitative).

Qualitative interpretation:

By examining the types of aggregated curves of apparent resistivity, Five iso- apparent resistivity contour map at AB/2 = 1, 20, 50, 100, and 200 m (Fig. 3) and four pseudo-geoelectric cross sections (Fig. 4) were created. These maps have been prepared to represent the lateral differences in the apparent electrical resistivity at a depth of about 0.5, 10, 20, 40, and 100 m respectively. The contour lines show high resistivity values in some northwest parts of the study area reflecting the desert fringes. The contour lines show low resistivity values with depth in most southwestern parts of the area of study reflecting the water flow direction.

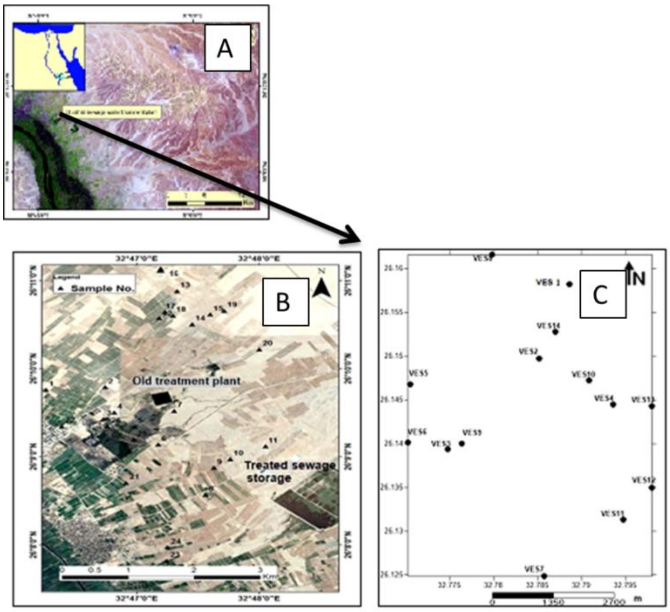

Fig. (2): Location map of the study area.
A: Landsat location map B: Groundwater sample sites C: VES location sites

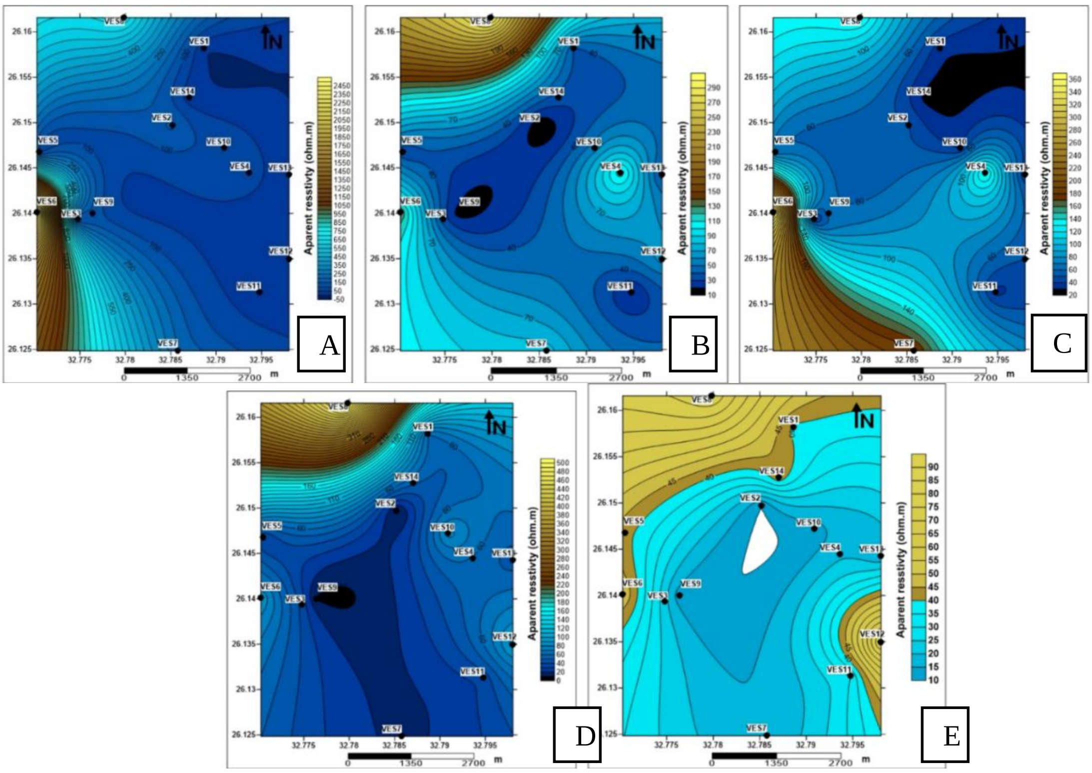

Fig. (3): Iso-apparent resistivity contour maps: (A, B, C, D, and E) at AB/2 = 1, 20, 50, 100, and 200 m respectively.

Four pseudo-geoelectrical sections were created along with profiles of the same directions, approximately towards N-S and encoded as (A-A), (B-B), (C-C), and (D-D) (Figs. 4). Downward, the contour lines reflect resistivity values ranging from 26 to 65 Ω.m which may reflect sand layer saturated freshwater with clay intercalation. This situation of resistivity with depth may show that the water flow direction may be towards the southwest.

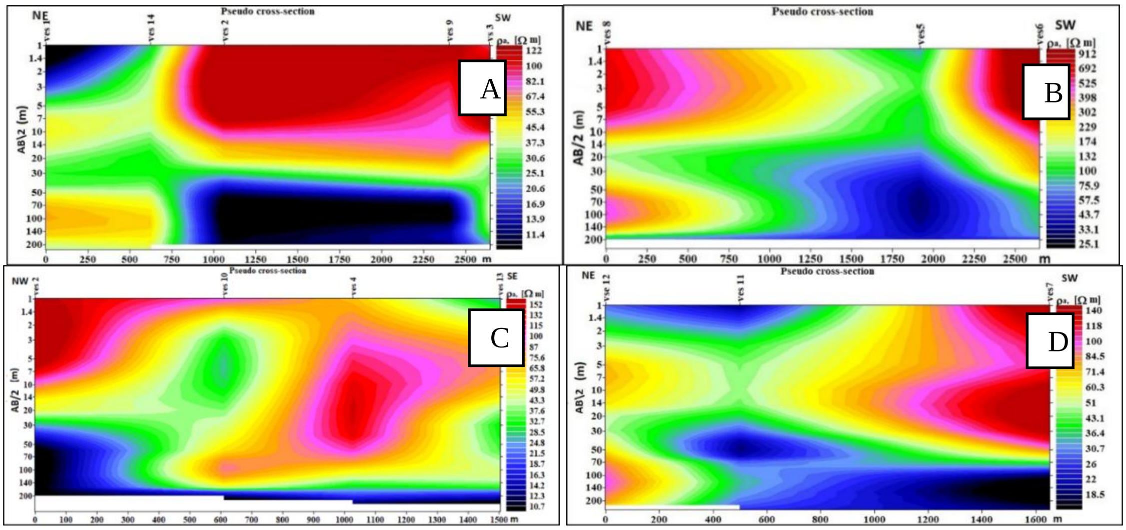

Fig. (4): Pseudo-geoelectric cross-sections: (A, B, C, and D) along A-A, B-B, C-C, and D-D profiles respectively.

Quantitative interpretation:

Four geoelectric cross-sections A-A, B-B, C-C, and D-D (Figs. 5) were created. From the geoelectric cross-sections, it's clear that the stratigraphic column in the study area is composed of four geoelectric layers in some parts and three in others. The first geoelectric layer is observed at all the VES stations. It has resistivity values ranging from 3 Ω.m to 2305 Ω.m. It is made of sand, clay, and gravel. The second geoelectric unit is a clay layer or sand aquifer with clay in other geoelectric cross-sections. The last geoelectric layer shows relatively low resistivity values reflecting a saline water or a pure clay layer. From the dip direction of the layers, the slope direction of the surface and the water table and the water depth gained from the wells penetrating some geoelectric cross-section, it is clear that the groundwater flows to the SW direction towards the Nile Valley.

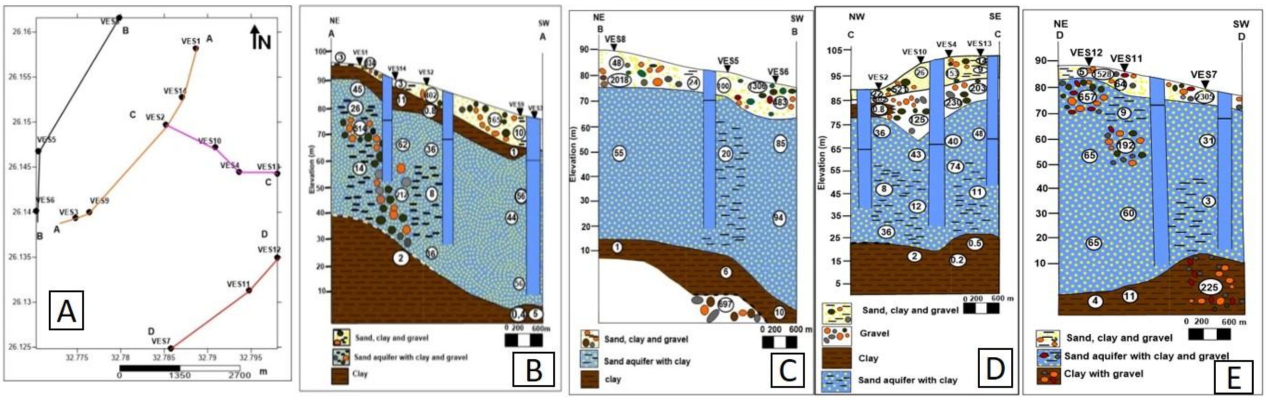

Fig. (5): Location map of geoelectric cross-sections: (A), and geoelectric cross-section: (B, C, D, and E): along (A-A, B-B, C-C, and D-D) profiles respectively.

Aquifer depth

Aquifer depth contour map based on geophysical data (Fig. 6a) points that the depth of the aquifer ranging from 5 m to 32 m, and the aquifer depth is decreasing towards the west south parts of the study area, towards the Nile Valley. This map helps in the detection of the groundwater flow direction which is towards the SW where the aquifer depth is decreasing.

In the study area, the quaternary deposits exhibit the principle aquifer in both flood plain and desert fringes. The precipitation of the quaternary aquifers consists of accumulated layers of fluvial sand and gravel with small clay intersections. In the area of our study, the Quaternary aquifer is essentially recharged by the leakage of irrigation canals, subsurface drainage of irrigated land and upward leakage of deep aquifers through fault planes. River serves as a discharge line for the quaternary aquifer, because groundwater levels are higher than the levels of the Nile River except in the upper part of the canals[31, 32, and 33]. The groundwater movement along the area of study is from the desert outer edges to the flood plain regions and the River Nile[34]; the groundwater flows in the aquifer decrease progressively near the Nile. Based on hydrological field works and collected data from irrigation wells (Table 1) in the study area it is shown that the groundwater depths are ranging between 10 and 53 m below ground level (Fig. 6-B&C). The groundwater in the studied area is discharged by extraction wells for irrigation activities.

From the water table depth contour map and groundwater depth contour map, it can be revealed that the general water flow direction in the area of study is from northeast to southwest, towards the River Nile coinciding with study of Hamdan 2013[34] and the present geophysical study.

Table (1): Groundwater depth (GWD) and Groundwater elevation (GWL) for studied Quaternary aquifer irrigation wells.

Sample No.	Latitude	Longitude	GSE (m)	GWD (m)	GWL (m)
1	26.16269	32.77092	97	20	77
2	26.16319	32.77897	98	20	78
3	26.15717	32.77872	86	11	75
4	26.15842	32.78019	88	11	77
5	26.155722	32.783	84	10	74
6	26.15233	32.78622	87	30	57
7	26.15869	32.78839	95	20	75
8	26.14283	32.79267	85	20	65
9	26.14794	32.79381	99	25	74
10	26.14956	32.79603	101	28	73
11	26.152	32.80083	111	35	76
12	26.17628	32.78633	113	32	81
13	26.18139	32.78878	111	32	79
14	26.17511	32.79083	116	41	75
15	26.17697	32.79331	119	45	74
16	26.19208	32.78542	130	53	77
17	26.17742	32.78711	104	23	81
18	26.17675	32.78819	105	28	77
19	26.17767	32.79517	116	35	81
20	26.17036	32.79333	120	40	80
21	26.14506	32.78183	81	9	72
22	26.15575	32.77308	85	10	75
23	26.13031	32.78739	83	10	73
24	26.13286	32.7875	79	9	70
25	26.15325	32.78289	84	10	74

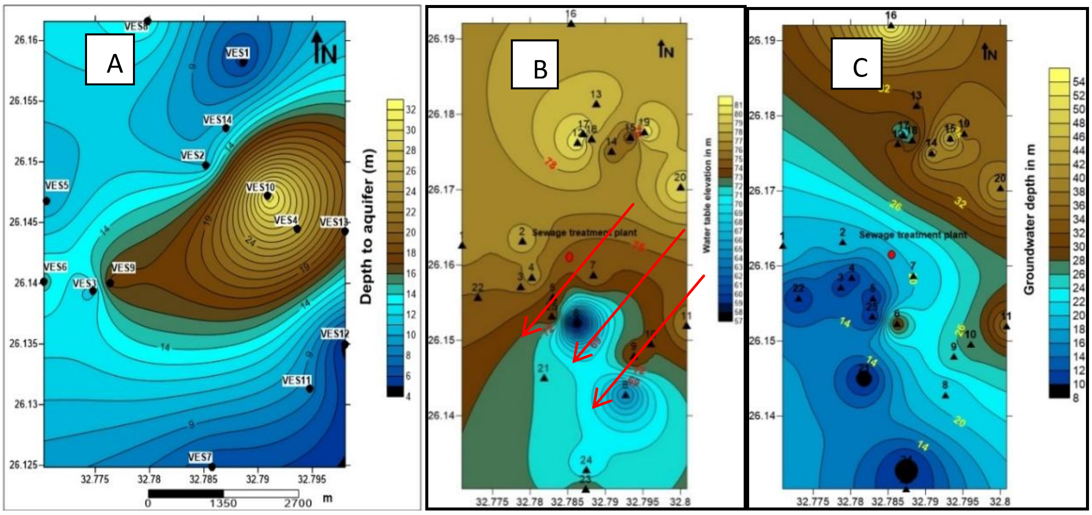

Fig. (6): (A) Aquifer depth contour map using VES, (B) Groundwater table elevation contour map and arrows show the groundwater flow direction, (C): Hydrological Field groundwater depth contour map.

Hydro chemical results

During the sampling process, immediate measurements of the physiochemical parameters were made immediately such as temperature, EC, TDS, and pH, while the alkalinity was measured in the laboratory (Table 2). Short notice was taken about the sampling site environment that may assist with data interpretation.

Table (2): The physical parameters of EL-Salhiya sewage water treatment plant and the groundwater samples around EL-Salhiya sewage water treatment plant.

Sample No.	T (C^0)	EC(µS/cm)	TDS (mg/L)	pH	Alkalinity (mg/L)
inflow wastewater	28	653	470	7.6	275
Outflow wastewater	28.9	783	472	8.1	340
1	27	1625	970	7.15	208.6
2	30	1232	742	7.47	224.2
3	26	796	476	6.8	269.8
4	28	764	458	6.75	367.2
5	26	882	527	6.77	349
6	29	2200	1325	7.37	368
7	29	2220	1335	7.32	306
8	29	2160	1297	7.25	374
9	27	2840	1707	7.23	304
10	28	3080	1847	7.2	218
11	29	3600	2210	7.18	178
12	30	1700	1018	7.5	104.8
13	27	583	349	7.52	109
14	27	4010	2400	7.2	187.4
15	28	2870	1722	7.3	135
16	28	3640	2180	7.25	1100
17	28	2160	1297	7.3	445.8
18	29	2620	1574	7.2	335.4
19	30	1940	1166	7.3	279
20	30	943	565	7.6	50.6
21	26	2210	1327	7.12	205.4
22	26	628	978	7.04	209.4
23	28	2240	1351	7.15	306.8
24	30	2210	1333	7.12	397
25	29	966	577	7.03	495
26	28	783	470	7.58	340
Max.	30	4010	2400	8.1	1100
Min.	26	583	349	6.75	50.6

The EC value in the inflow wastewater sample in El-Salhiya sewage plant is 653 µS / cm while in the outflow wastewater sample is 783 µS / cm. For the surrounding groundwater wells EC values showed that EC increase towards the sewage water treatment plant, the treated sewage storage, desert, and reclaimed lands. This may be due to filtration processes for fertilizers and natural minerals already found in desert soils (e.g. $CaSO_4$and halite NaCl gypsum) and sand gravel covers mainly new reclamation areas. .

The concentration of dissolved solids in the effluent wastewater sample at the Salhiya wastewater plant is 470 mg/L and increased to 472 mg /L. From the results, it is obvious that the values of TDS in outflow wastewater are less than the acceptable limit for TDS (2000 mg/L) in the Egyptian standard for reusing treated sewage water. TDS result shows that, about 42.31% of groundwater samples is of freshwater type (TDS <1000), and 57.69% of groundwater samples are saline water types (1000-10000) according to Todd (1980)[35] water classification.

pH results showed that groundwater in most wells were in a slightly alkaline state (6.75 as in sample No. 4 to7.6 as in sample No. 20). This alkaline state may be due to the high concentration of base compounds, for example, bicarbonate as alkalinity ranges from 275 mg/L in inflow sewage sample to 340 mg/L in outflow sample.

Finally the alkalinity ranges from 275 mg/L in inflow sewage sample to 340 mg/L in outflow sample. While in groundwater samples it ranges between 50.6 mg/L and 1100 mg/L.

Major cations and anions

The chemical properties of wastewater differ with the source of drinking water supply, the sewage system, and the season of the industrial discharge in the system. Of course, groundwater has a variety of dissolved compounds, many of which are beneficial to humans, but if they exceed the permissible level, they may pose a danger to humans and animals. The chemical properties which were measured of groundwater and wastewater in Salhiya are major (cations and anions), COD & DOD, and heavy metals (Table 3, 4, and 5).

Table (3): Major cations and anions concentrations of sewage water samples in EL-Salhiya sewage treatment plant and groundwater samples around EL-Salhiya sewage treatment plant.

Sample No.	Unit	HCO_3^-	Cl^-	NO_3^-	SO_4^{2-}	Total anion epm	K^+	Na^+	Ca^{2+}	Mg^{2+}	Total cation epm	Error %
Inflow wastewater	-	340	64	22	48	-	4.2	101	39.5	13.1	-	-
Outflow wastewater	-	371	73	21	21	-	5.6	125	37	12.2	-	-
1	ppm	208.6	342	49.29	171.5	17.4	6.1	250	75.22	15.26	16.00	4.12
	epm	3.42	9.63	0.80	3.57		0.16	10.87	3.76	1.25		
2	ppm	224.2	131	42.6	115.64	10.5	7.4	104	70.13	30.77	10.76	1.35
	epm	3.68	3.69	0.69	2.41		0.19	4.52	3.51	2.52		
3	ppm	269.8	88	1.02	44.61	7.85	5.2	52	74.53	20.45	7.80	0.318
	epm	4.42	2.48	0.02	0.93		0.13	2.26	3.73	1.68		
4	ppm	367.2	67	0.56	22.26	8.38	7	34	101.01	28.14	9.02	3.66
	epm	6.02	1.89	0.01	0.46		0.18	1.48	5.05	2.31		
5	ppm	349	69	0.72	99.8	9.77	9.1	50	90.51	37.33	10	1.16
	epm	5.72	1.94	0.01	2.08		0.23	2.17	4.53	3.06		
6	ppm	368	560	77.52	238.9	28	3.5	400	95.23	41.31	25.65	4.65
	epm	6.03	15.77	1.25	4.98		0.09	17.39	4.76	3.39		
7	ppm	306	489	162.5	175.25	25.1	7	354	70.59	19.2	22.3	5.73
	epm	5.02	13.8	2.62	3.64		0.18	15.4	5.81	0.99		
8	ppm	374	522	114.1	158.88	26	9.4	422	84.38	39.41	26	0.123
	epm	6.13	14.70	1.84	3.31		0.24	18.35	4.23	3.22		
9	ppm	304	716	254	374.7	37	8	563	73.64	61.21	33.41	5.17
	epm	4.98	20.17	4.10	7.81		0.21	24.48	3.68	5.02		
10	ppm	218	995	444.6	324.8	45.5	5	781	60.59	42.15	40.6	5.75
	epm	3.75	28.03	7.17	6.77		0.13	33.96	3.03	3.45		
11	ppm	178	1540	430.9	580.9	65.35	10	1004	391.41	11.34	64.41	0.734
	epm	2.92	43.4	6.95	12.10		0.26	43.65	19.57	0.93		
12	ppm	104.8	155	50.6	212.9	11.3	7.2	112	69.82	25.22	10.62	3.49
	epm	1.72	4.37	0.82	4.43		0.18	4.87	3.43	2.08		
13	ppm	109	241	503.1	199.6	20.8	8.5	195	78.54	75.21	18.81	5.13
	epm	1.79	6.79	8.11	4.16		0.22	8.48	3.93	6.16		
14	ppm	187.4	1870	444.95	330.4	69.8	9	1541	89.94	65.15	77.1	4.96
	epm	3.07	52.7	7.18	6.87		0.23	67	4.50	5.36		
15	ppm	135	10.22	179.85	258.5	10.8	6.2	5	70.37	69.71	9.62	5.64
	epm	2.21	0.29	2.90	5.39		0.16	0.22	3.52	5.71		
16	ppm	1100	1740	151.4	330.4	76.4	7.6	1421	295.09	125.38	87.08	6.53
	epm	18	49.01	2.44	6.88		0.19	61.78	14.75	10.28		
17	ppm	445.8	412	49.95	290.1	25.8	6.6	311	165.31	35.44	24.9	1.77
	epm	7.31	11.61	0.81	6.03		0.17	13.52	8.25	2.92		
18	ppm	335.4	602	110.55	321.1	30.9	5.9	421	97.37	56.21	27.96	5.04
	epm	5.50	16.96	1.78	6.69		0.15	18.30	4.87	4.61		
19	ppm	279	305	102.75	29.4	15.4	7.3	213	77.46	45.43	17.0	4.95
	epm	4.57	8.59	1.66	0.61		0.19	9.26	3.87	3.73		
20	ppm	50.6	74	18.33	199.6	7.36	6	45	60.25	17.56	6.57	5.73
	epm	0.83	2.08	0.30	4.16		0.15	1.96	3.01	1.44		
21	ppm	205.4	368	105.5	293.5	21.5	8.8	254	85.39	47.73	19.46	5.07
	epm	3.37	10.37	1.70	6.11		0.23	11.4	4.27	3.91		
22	ppm	209.4	247	13.02	208.4	14.9	8.3	198	69.31	21.22	14.00	3.13
	epm	3.43	6.96	0.21	4.34		0.21	8.61	3.47	1.74		
23	ppm	306.8	582	90.6	284.8	28.8	7.9	422	104.25	70.21	29.54	-1.24
	epm	5.03	16.39	1.46	5.92		0.20	18.3	5.20	5.78		
24	ppm	397	526	92.25	279.2	28.6	8	415	99.36	46.45	27.0	-2.85
	epm	6.51	14.82	1.49	5.80		0.21	18.04	4.96	3.82		
25	ppm	495	94	9.78	181.02	14.7	7	95	110.37	77.67	16.22	4.94
	epm	8.11	2.65	0.16	3.77		0.18	4.13	5.52	6.37		
26	ppm	340	64	0.22	48.88	8.40	5	125	35	11	8.21	-1.09
	epm	5.57	1.80	0.0036	1.02		0.13	5.43	1.75	0.905		

The accuracy degree of the processed data was checked according to Hem (1970)[36] as illustrated in the following equation and previous table:

$$\text{Percentage error} = \frac{\sum Cations - \sum Anions}{\sum \text{cations} + \sum \text{Anions}} \times 100 \cong \pm 5\%$$

Where,

Percentage error = the error factor which should not prevail at 5%.
$\sum A$= the summation of anions.
$\sum C = the summation of cations.$

The results indicated that the sodium concentration in the inflow sewage water sample in El-Salhiya sewage plant is 101 mg/L but it becomes high to125 mg/L in the outflow sample. Moreover, that sodium concentrations increase towards desert edges; higher concentrations of sodium may be owing to dissolution and leaching of sodium salts like halite through the movement of groundwater over Quaternary aquifer deposits. Sodium has been found in higher concentrations than the permissible limits for drinking (200mg/L; WHO 1998 & Egypt 2007) in about 57.7% of the groundwater samples.

The calcium concentration in the inflow sewage water sample in El-Salhiya is 39.5 mg/L and 37 mg/L in the outflow sample. Also, the results revealed that Ca^{2+} concentrations in groundwater samples increase towards desert borders; higher calcium concentrations may be owing to discharge processes of carbonate materials to the aquifer. All the groundwater samples indicated that Ca^{2+} content was less than the permissible limits for drinking water except samples No. 11 and 16, which exceed the permissible limits (200 mg/L; WHO 1998).

Magnesium concentration in the inflow sewage water sample is 13.1 mg/L and 12.2 mg/L in the outflow sample. The values of Mg^{2+} concentrations in groundwater samples increase towards desert borders; higher concentrations of magnesium may be owing to the dolomite dissolution or infiltrations from clay-rich deposits. All the groundwater samples displayed that magnesium content was less than the permissible limits for drinking water except sample No. 16, which exceed the permissible limits (125 mg/L; WHO 1998).

For potassium, the measurements showed that its concentration in the inflow sewage water sample is 4.2 mg/L While in outflow is 5.6 mg/L. Potassium concentrations in groundwater samples increase towards desert fringes; higher concentrations of potassium may be owing to intensive use of fertilizers in newly cultivated regions. All the groundwater samples revealed that K^+ content was less than the permissible limits for drinking water (12 mg/L; WHO 1998)

Sulfates results showed that the concentration in the effluent wastewater sample was 48 mg/L but it decreased to 21 mg/L in the outflow sample. This may be owing to the sulfur-oxidizing bacteria (Thiobacillus Tiooxidance) in the secondary treatment process (Biological treatment) which oxidize reducing sulfur compounds like thiosulfuric $(S_2O_3)^{2-}$ via consuming oxygen in the air[37]. For groundwater samples, the results showed that about 42.31% of the groundwater samples have SO_4 values higher than the permissible limits for drinking water (250 mg/L; WHO 2011 & Egypt 2007).

Chloride in the sewage water has concentration within the limit allowed in the Egyptian standard for reusing treated wastewater (Cl 300 mg/L). But in the surrounding groundwater samples, chloride has been found in higher concentrations than the permissible limits for drinking water (250mg/L; WHO 1998 & Egypt 2007) in about 57.7% of the groundwater samples. Chloride concentrations in groundwater samples increase towards desert borders; the higher concentrations of chloride are related to Pliocene deposits which have marine salts like halite. Additionally, the heaviest application of fertilizer perhaps accounts for the higher concentrations of chloride in the samples in the newly cultivated ground[31].

The HCO_3 concentration in groundwater samples increase towards the southwest direction in El-Salhiya sewage water plant which might be due to the dissolution of carbonate minerals. The measured HCO_3 in the groundwater samples is less than the permissible limits for drinking water (350 mg/L; WHO 2003) except for samples No. 4, 6, 8, 16, 17, 24, and 25. The results also showed that the concentration of bicarbonate in the wastewater sample included in the Salhiya wastewater treatment plant is 340 mg/L, but it rose to 371 mg/L in the external flow sample

The Nitrate concentration is used to evaluate the contamination, created GIS map of nitrate distribution (Fig. 7) shows the nitrate values increase towards the reclaimed land and the treated sewage storage, where a large part of the farmlands in the areas and excessive use of nitrogen fertilizers, and the sewage water discharge processes. About 61.5% of the groundwater samples (Fig. 8-A) indicated that the nitrate concentrations were over the permissible limits for drinking water (45 mg/L; Egypt 2007 & 50 mg/L; WHO1996 and 1998) Nitrate in drinking water has been related to blue-baby syndrome and many types of cancer[38, 39, 40]. The comparison of nitrate concentrations between effluent sewage water and groundwater samples round El-Salhiya sewage plant (Fig. 8-B) displays that the infiltrating sewage water, which fed the groundwater, has been naturally treated via soil aquifer. About 30.8% of the groundwater samples contain lower levels of nitrate than effluent sewage water owing to the denitrification process via aerobic and anaerobic bacteria[41, 42]. While 69.2% of the groundwater samples contain nitrate higher than effluent sewage water owing to NH_3 nitrification, and the use of nitrogen fertilizers in the new cultivated regions nearby the sewage treatment plant[43].

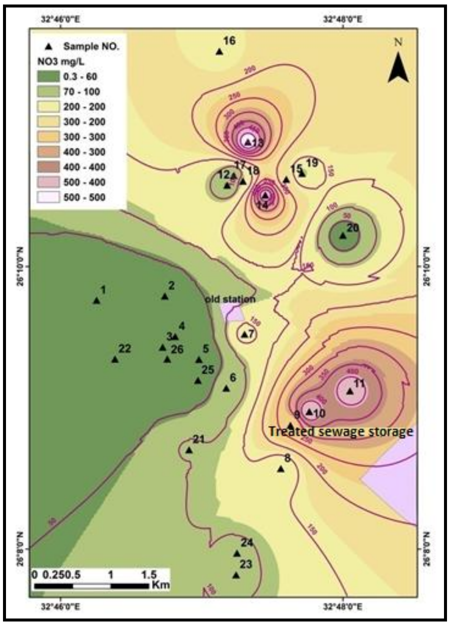

Fig. (7): GIS map shows Nitrate distribution of groundwater samples around El-Salhiya plant.

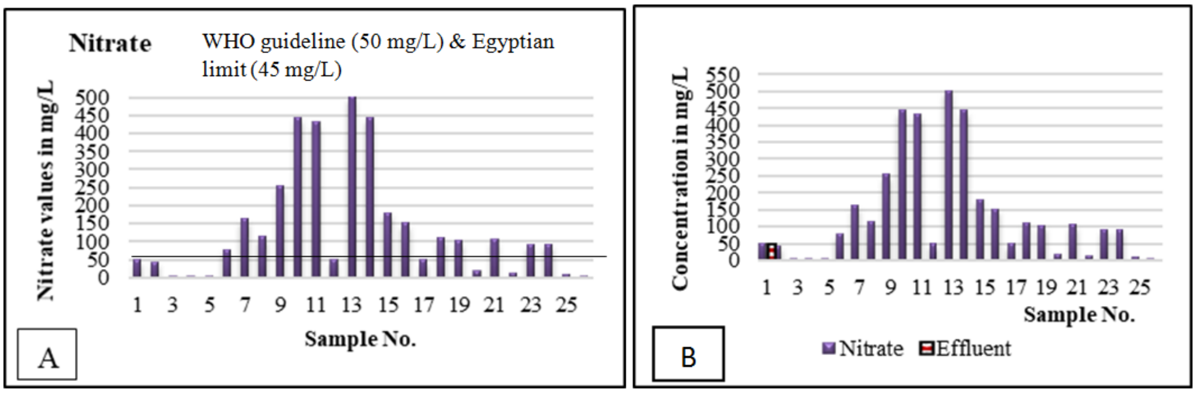

Fig. (8): (A): Histogram shows Nitrate concentrations of groundwater samples around El-Salhiya plant, (B): Histogram shows the Nitrate comparison of concentrations between effluent sewage water and groundwater around El-Salhiya sewage plant.

Chemical Oxygen Demand (COD) & Biological Oxygen Demand (BOD)

COD and BOD consider the most important indicator for sewage contamination around El-Salhiya sewage plant.

The result of BOD and COD (table 4) show that entire BOD values of groundwater samples are inside permitted limits for drinking water except for samples No. 1, 3, 4, 5, 21, 24, 25, and 26 which exceeded the permissible limits (3 mg/L, Egypt 2007). The produced GIS distribution map of BOD in groundwater (Fig. 9-A) clears that values of BOD increase in wells close to El-Salhiya sewage water plant, signifying sewage water infiltration into the aquifer, while they decrease in wells far from the sewage water plant. Figure (10-A) displays a comparison of the BOD values between the wastewater sample in the Salhiya wastewater treatment plant and the samples of groundwater around this plant. This figure indicates that the infiltration of wastewater flowing into the groundwater has been treated naturally by the soil groundwater layer. BOD has been reduced by 98.5%, which reveals the main role of natural treatment and its effectiveness, and this is consistent with previous work done in other locations[41, 42].

For COD, the created GIS map of COD (Fig. 9-B) shows that the COD values distribution of groundwater samples increase in wells close to El-Salhiya sewage treatment plant and the treated sewage storage signifying sewage water infiltration into the groundwater while the values decrease in wells distant from the sewage water plant. Approximately most of the COD values in groundwater samples (Fig. 10-B) are less than permissible limits for drinking water (10 mg/L; Egypt 2007). This figure shows the comparison of COD values between effluent sewage water samples of El-Salhiya plant and groundwater samples round the region of this plant. The figure indicated that infiltrating the sewage water into groundwater, this proof that the sewage water has been in nature treated via soil aquifer. COD has been reduced by 98%, which reveals the main role of soil natural treatment (SNT) processes. These are in agreement with the previous work made at other sites[44, 42].

Table (4): COD & BOD values of EL-Salhiya sewage treatment plant and groundwater samples around EL-Salhiya sewage treatment plant.

Sample No.	Inflow	1	2	3	4	5	6	7	8	9	10	11	12	13
COD	212	6	4	8	8	7	1	1	1	2	3	1	3	3
BOD	193	3.9	2.6	5.2	5.2	4.55	0.65	0.65	0.65	1.3	1.95	0.65	1.95	1.95
Sample No.	Outflow	14	15	16	17	18	19	20	21	22	23	24	25	26
COD	58	1	3	4	2	3	1	4	6	5	3	7	12	46
BOD	39	0.65	1.95	2.6	1.3	1.95	0.65	2.6	3.9	3.25	1.95	4.55	7.8	29.9

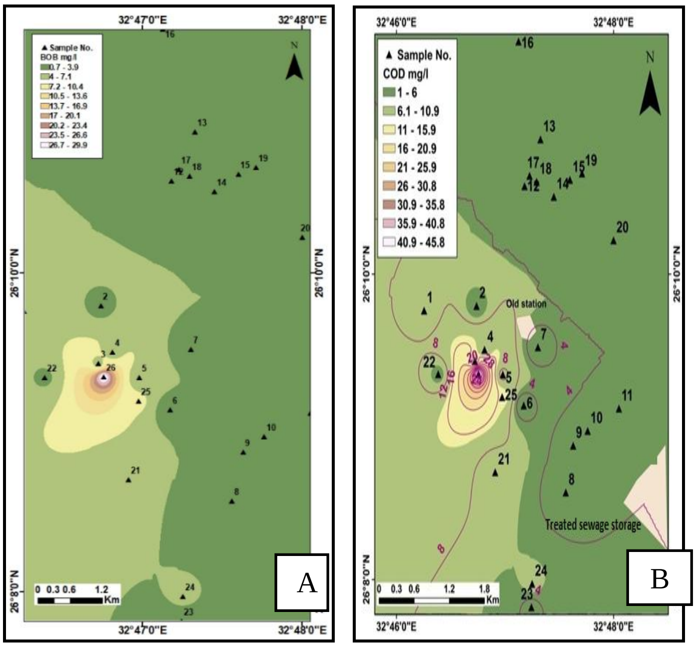

Fig. (9-A): GIS map shows the BOD distribution in groundwater samples around El-Salhiya sewage treatment plant,
(B): GIS map shows the COD distribution in groundwater samples around El-Salhiya sewage treatment plant.

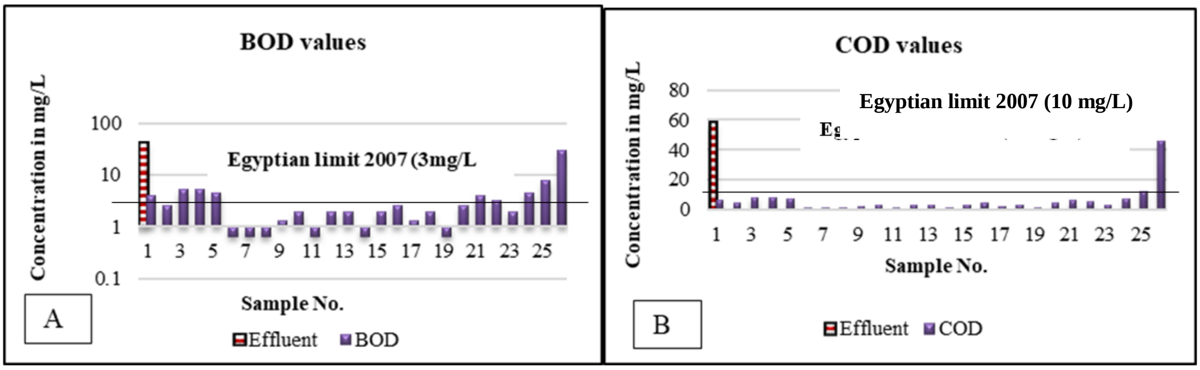

Fig. (10): (A): Histogram shows the BOD value comparison between effluent sewage water and groundwater samples around El-Salhiya sewage treatment plant, (B): Histogram shows the comparison of COD concentrations between effluent sewage water and groundwater around El-Salhiya treatment plant.

Heavy metal

The groundwater pollution with heavy metals is an issue of large concern. The studied heavy metals in our research are cadmium, iron, manganese, lead, and copper (Table 5). Trace elements in raw sewage water are successfully removed into the sludge generated by primary sedimentation and secondary clarification[45].

Table (5): Heavy metal concentrations of El-Salhiya sewage water treatment plant and groundwater around El-Salhiya sewage water plant.

sample No.	Fe^{2+}	Mn^{2+}	Cd^{2+}	Cu^{2+}	Pb^2+
Inflow wastewater	1.6	0.09	0.06	0.02	0.03
Outflow wastewater	0.62	0. 08	0.035	$4*10^{-3}$	$6*10^{-5}$
1	0.02	0.13	0.01	ND	ND
2	0.3	0.02	0.007	ND	ND
3	0.05	0.003	0.04	ND	ND
4	0.05	0.004	0.009	ND	ND
5	0.03	0.09	0.011	ND	ND
6	0.2	0.1	0.033	ND	ND
7	0.04	0.002	0.008	ND	ND
8	0.01	0.01	0.021	ND	ND
9	0.05	0.1	0.019	ND	ND
10	0.01	0.005	0.04	ND	ND
11	0.06	0.001	0.049	ND	ND
12	0.04	0.1	0.037	ND	ND
13	0.05	0.13	0.029	ND	ND
14	0.01	0.002	0.049	ND	ND
15	0.03	0.12	0.017	ND	ND
16	0.85	0.001	0.03	ND	ND
17	0.04	0.1	0.04	ND	ND
18	0.3	0.1	0.019	ND	ND
19	0.2	0.002	0.01	ND	ND
20	0.1	0.1	0.036	ND	ND
21	0.03	0.2	0.031	ND	ND
22	0.01	0.3	0.041	ND	ND
23	0.2	0.2	0.032	ND	ND
24	0.1	0.1	0.019	ND	ND
25	0.3	0.001	0.026	ND	ND
26	0.77	0.009	0.035	$6*10^{-4}$	$6*10^{-4}$

ND: below detection limits

The results indicated that the iron concentration in the inflow sewage water sample in El-Salhiya sewage plant is 1.6 mg/L although it dropped to 0.62 mg/L in the outflow sample (Fig. 11), this may perhaps be owing to the oxidation of ferrous compounds Fe^{2+} to ferric compounds Fe^{3+}. The concentration of iron in inflow and outflow sewage water samples is within the acceptable limit in the Egyptian standard limit for reusing treated sewage water (5 mg/L). Iron contents in all groundwater samples are within the permissible limits for drinking water except samples No. 16 and 26 (0.3 mg/L; Egypt 2007 & WHO 2003).

The value of cadmium in inflow and outflow sewage water samples is higher than the allowed limit the in Egyptian standard for reusing treated sewage water (0.01 mg/L). But the groundwater samples revealed that Cd^{2+} content was less than the permissible limits for drinking water (5 mg/L; WHO 1998).

The value of copper and lead in inflow and outflow sewage water samples is less than the permitted limit in the Egyptian standard for reusing treated sewage water (5 and 0.2 mg/L respectively). While the chemical analysis results illustrated that lead and copper are not detected in groundwater samples round El-Salhiya sewage water plant which may be owing to the natural treatment processes effect by soil particles through the unsaturated zone.

The manganese value in inflow and outflow sewage water samples is within the permitted limit in the Egyptian standard for reusing treated sewage water (0.2 mg/L). Its content in all the groundwater samples was within the permissible limits for drinking water (0.4 mg/L; Egypt 2007 & WHO 2003).

The results indicated that infiltrating effluent sewage water has been naturally treated by soil particles where Cd, Fe, Mn, Cu, and Pb were removed during soil percolation by about 80%, 98.3%, 98.8%, 100%, and 100% respectively, this may due to that Cd are mainly associated with carbonate fraction while Pb and Cu are more present in the residual fraction. The relative amounts of easily dissolved phase of heavy metals in the soils are in the order of Cd > Pb > Cu[46].

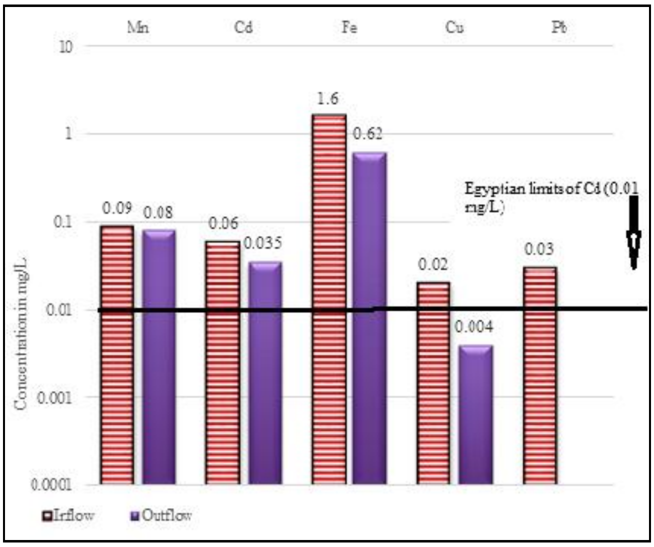

Fig. (11): Histogram shows heavy metal concentrations in El-Salhiya sewage water plant.

IV. Discussion

Groundwater wells in the area of study used to irrigate the reclaimed land are partially recharged by overflow treated or untreated wastewater. Within the aim of the study, all available data were used to evaluate the effect of natural wastewater treatment in the area of study. The pH of groundwater is slightly alkaline and flocculated around 7.22 while TDS varies widely from 349 to 2400 mg/L. The groundwater samples lie in two classes 10 freshwater samples and 16 brackish water samples. The majority of samples (69%) have nitrate concentrations extremely above the WHO guide limit of 45 mg/L, especially near the sanitation waste dumping sites, and decrease westward coinciding with the groundwater movement direction due to anthropogenic activities such as on-site sanitation, waste dumpsites, and agricultural chemicals. The predominant cation was Na^+ and the predominant anion was NO^-_3 and Cl-, this reflects the role of dissolving marine deposits in the study area in water chemistry and the use of nitrogen fertilizers in the new cultivated regions nearby the sewage treatment plant. The groundwater in the study area is unsuitable for human drinking purposes, wherein the case of suitable one element, another element is not suitable especially the pollution of water with nitrate. The studied heavy metals were within the permissible limit for human drinking purposes except for iron.

The qualitative and quantitative interpretation of the obtained results indicated that the subsurface section in the area are represented by mainly four units except in some parts where the seven units are appeared. The true resistivities of these layers range between less than 1 Ω.m to more than 4200 Ω.m. The first layer is the surface cover which consists of alluvial deposits of sands with gravels and clay. The isopach map is constructed to reflect the lateral variations in the thickness of the saturated zone of this quaternary aquifer all over the area which reflect that the average of the Quaternary aquifer thickness (saturation zone) ranging between 47.5 m and 85.5m. The aquifer potentiality increases toward the southwest. Also, a depth contour map is established to detect the depth to the saturated zone of this quaternary aquifer at any point in the study area. The geophysical interpretations proved that the depth of groundwater in the Quaternary aquifer varies from few meters to about 30 m below ground level. The groundwater flow in the aquifer increases gradually towards the Nile.

V. Conclusion

The results of chemical analysis of groundwater samples indicated that the removal percentage by the soil particles through the vadose zone were 98.5% and 98% for BOD and COD. The results also indicated that infiltrating effluent sewage water has been naturally treated by soil particles (SNT) where Cd, Fe, Mn, Cu, and Pb were removed during soil percolation by about 80%, 98.3%, 98.8%, 100% and 100% respectively due to chemical precipitation and adsorption mechanisms. The effectiveness of the natural treatment process in the removal/reduction of the most problematic substances throughout infiltration and percolation of sewage water into the aquifer through the unsaturated zone was studied via physical and chemical indicators. The total results of the study demonstrated the effectiveness of this method, where the majority of problematic substances were significantly reduced. This method significantly reduces the concentrations of total solids, and trace elements through soil filtration through the vadose zone. The study suggests that the possible removal mechanisms in the vadose zone are primarily filtrations, absorption, and biodegradations, which are the most commonly referenced. From the water table and water depths within the three wells and also the slope and dip direction, it is clear that the groundwater flows to the SW towards the Nile Valley. The leakage of sewage water in the area of study in the Qena water station is an additional source of nutrition for the aquifer. Treated/untreated sewage here is directly discharged to the ground to form some ponds, and sewage from the plant is used to irrigate a woody forest in El-Salhiya. Discharge components comprise groundwater pumping from wells and upward capillary flow from the shallow water table due to evapotranspiration. Based on the topographic map of the study area, the general direction of groundwater flow is from northeast to southwest coinciding with the regional slope of the Nile Valley, where groundwater level drops gently towards the southwest. From the qualitative interpretations, the changes in resistivity values with depth may show that the water flow direction maybe towards the southwest. Aquifer depth contour map interpretation points that the depth of the aquifer is decreasing towards the south west parts of the study area, towards the Nile Valley. (Increasing towards the eastern north part of the study area, away from the Nile Valley), reaching more than 32 m. Integrations of hydrochemistry and geophysical modeling agreed that the low resistivity values at the surface of study area is owing to irrigation water, and infiltration of sewage water.

References

[1]. Huang, G.; Sun, J.; Zhang, Y.; Chen, Z.; Liu, F. Impact of anthropogenic and natural processes on the evolution of groundwater chemistry in a rapidly urbanized coastal area, South China. Sci. Total Environ. 2013, 463–464, 209–221.

[2]. Zhang, F.; Huang, G.; Hou, Q.; Liu, C.; Zhang, Y.; Zhang, Q. Groundwater quality in the Pearl River Delta after the rapid expansion of industrialization and urbanization: Distributions, main impact indicators, and driving forces. J. Hydrol. 2019, 577, 124004.

[3]. Barba, C., Folch, A., Gaju, N., Sanchez-Vila, X., Carrasquilla, M., Grau-Martínez, A., Martínez-Alonso, M. (2019): Microbial community changes induced by Managed Aquifer Recharge activities: linking hydrogeological and biological processes. – Hydrology and Earth system sciences 23(1): 139-154. https://doi.org/10.5194/hess-23-139-2019

[4]. El-Rawy, M., Al-Maktoumi, A., Zekri, S., Abdalla, O., Al-Abri, R. (2019): Hydrological and economic feasibility of mitigating a stressed coastal aquifer using managed aquifer recharge: a case study of Jamma aquifer, Oman. – Journal of Arid Land 11(1): 148-159.

[5]. Al-Maktoumi, A., Zekri, S., El-Rawy, M., Abdalla, O., Al-Abri, R., Triki, C., Bazargan-Lari, M. R. (2020): Aquifer storage and recovery, and managed aquifer recharge of reclaimed water for management of coastal aquifers. – Desalination and Water Treatment176: 67-77

[6]. El-Rawy, M., Zlotnik, V. A., Al-Raggad, M., Al-Maktoumi, A., Kacimov, A., Abdalla, O. (2016): Conjunctive use of groundwater and surface water resources with aquifer recharge by treated wastewater: evaluation of management scenarios in the Zarqa River Basin, Jordan. – Environmental Earth Sciences 75(15): 1146

[7]. Salameh, E., Abdallat, G., van der Valk, M. (2019): Planning considerations of managed aquifer recharge (MAR) projects in Jordan. – Water 11: 182.

[8]. Siebe, C., Prado Pano, B. L., and Alcantara-Hernandez, R. J. (2019): Impacts of long-term wastewater irrigation on soil-aquifer interactions: evidences from the Critical Zone Observatory Valle del Mezquital, Central Mexico. – American Geophysical Union, Fall Meeting

[9]. Elkayam, R., Michail, M., Mienis, O., Kraitzer, T., Tal, N., Lev, O. (2015): Soil Aquifer Treatment as Disinfection Unit. – Journal of Environmental Engineering 141(12): 1-7.

[10]. Page, D., Bekele, E., Vanderzalm, J., Sidhu, J. (2018): Managed Aquifer Recharge (MAR) in Sustainable Urban Water Management. – Water 10: 239. Doi: 10.3390/w10030239.

[11]. Fichtner, T., Goersmeyer, N., Stefan, C. (2019): Influence of Soil Pore System Properties on the Degradation Rates of Organic Substances during Soil Aquifer Treatment (SAT). –Applied Sciences 9(3): 496.

[12]. Amy, G., and Drewes, J. (2007): Soil aquifer treatment (SAT) as a natural and sustainable wastewater reclamation/reuse technology: fate of wastewater effluent organic matter (EfOM) and trace organic compounds. – Environ. Monit. Assess. 129(1-3): 19-26.

[13]. Nadav, I., Arye, G., Tarchitzky, J., and Chen, Y. (2012): Enhanced infiltration regime for treated-wastewater purification in soil aquifer treatment (SAT). – Journal Hydrol. 420: 275-283.

[14]. Donn, M., Reed, D., Vanderzalm, J., Page, D. (2020): Assessment of E. coli Attenuation during Infiltration of Treated Wastewater: A Pathway to Future Managed Aquifer Recharge. – Water 12(1): 173.

[15]. He, K., Asada, Y., Echigo, S., Itoh, S. (2020): Biodegradation of pharmaceuticals and personal care products in the sequential combination of activated sludge treatment and soil aquifer treatment. – Environmental Technology 41(3): 378-388. DOI:10.1080/09593330.2018.1499810.

[16]. Bancolé, A., Brissaud, F., Gnagne, T. (2003): Oxidation processes and clogging in intermittent unsaturated infiltration. – Water Sci. Technol. 48(11): 139-146.

[17]. Reemtsma, T., Miehe, U., Duennbier, U., Jekel, M. (2010): Polar pollutants in municipal wastewater and the water cycle: occurrence and removal of benzotriazoles. – Water Res. 44(2): 596-604.

[18]. Cha, W., Kim, J., Choi, H. (2006): Evaluation of steel slag for organic and inorganic removals in soil aquifer treatment. – Water Research 40(5): 1034-1042.

[19]. Kopchynski, T., Fox, P., Alsmadi, B., Berner, M. (1996): The effects of soil type and effluent pre-treatment on soil aquifer treatment. – Water Science Technology 34(11): 235-242.

[20]. Drewes, J. E., Fox, P. (2000): Effect of Drinking Water Sources on Reclaimed Water Quality in Water Reuse Systems. – Water Environment Research 72(3): 353-362.

[21]. Leenheer, J. A., Rostad, C. E., Barber, L. B., Schroeder, R., Anders, R., Davisson, M. L. (2001): Nature and chlorine reactivity of organic constituents from reclaimed water in groundwater, Los Angeles County, California. – Environmental Science Technology 35: 3869-3876.

[22]. Drewes, J. E., Hoppe, C., Jennings, T. (2006): Fate and transport of N-nitrosamines under conditions simulating full-scale groundwater recharge operations. – Water Environment Research 78(13): 2466-2473.

[23]. Tchobanoglous, G., Burton, F. L., Metcalf, L., Eddy, H. P. (1999): Wastewater Engineering: Treatment, Disposal and Reuse. – Third ed. Tata McGraw-Hill Publishing Company Limited, New Delhi.

[24]. Essandoh, H. M. K., Tizaouib, C., Mohameda, M. H. A. (2013): Removal of dissolved organic carbon and nitrogen during simulated soil aquifer treatment. – Water Research 47(11): 3559-3572.

[25]. Friedman, L., Mamane, H., Avisar, D., and Chandran, K. (2018): The role of influent organic carbon-to-nitrogen (COD/N) ratio in removal rates and shaping microbial ecology in soil aquifer treatment (SAT). – Water Research 146: 197-205. Doi: 10.1016/j.watres.2018.09.014.

[26]. Mienis, O., Arye, G. (2018): Long-term nitrogen behavior under treated wastewater infiltration basins in a soil aquifer treatment (SAT) system. – Water Research 134: 192-199. https://doi.org/10.1016/j.watres.

[27]. Takabe, Y., Kameda, I., Suzuki, R., Nishimura, F., Kusuda, Y., Phattarapattamawong, S.S. (2019): Evaluation of dissolved organic matter removals through WWT and SAT using pilot-scale and lab-scale reactors. – Water Air Soil Pollution 230: 127.

[28]. Elewa, S.A., (2004): Effect of the construction of Aswan High Dam on the ground water in the area between Qena and Sohag, Nile Valley, Egypt, Ph. D. Thesis, Fac. Sci. Assuit Univ., Egypt.

[29]. Faure MG. Enforcement issues for environmental legislation in developing countries. [Internet]. 1995. Available online: http://archive.unu.edu/hq/library/Collection/PDF_ files/INTECH/INTECHwp19.pdf [Accessed 2015/8/19].

[30]. Hago, A.H, 2000. "Application of electric resistivity method in quantitative assessment of groundwater reserve of unconfined aquifer." M.Sc. Thesis, Environmental studies dept. Faculty of Science, Putra University Malaysia, 215p.

[31]. Abd El-Moneim AA (1988): Hydrogeology of the Nile Basin in Sohag Province. MSc. Thesis. Sohag Fac. of Sci., Assuit Uni., 165 pp.

[32]. Ahmed AA (2007): Using lithological modeling techniques for aquifer characterization and groundwater flow modeling of Sohag area, Egypt. Second International Conference on GeoResources in the Middle East and North Africa, 24–28 Feb, 2007, Cairo University, Egypt.

[33]. RIGW "Research Institute of Groundwater" (1994): Hydrogeological maps of Egypt, scale 1:100,000. Water Research Center, Ministry of Public Works and Water Resources, Egypt.

[34]. Hamdan, A.M., (2013): Hydrogeological and Hydrochemical Assessment of the Quaternary Aquifer South Qena City, Upper Egypt. Earth Science Research, 2. No. 2, ISSN 1927-0542.

[35]. Todd, D. K. (1980): Ground-water hydrology (Second Edition): John Wiley and Sons or New York, 535.

[36]. Hem, J. D., (1992): Study and interpretation of the chemical characteristics of natural water, (3d ed.): U.S. Geological Survey Water.

[37]. Fujii, M. (2009): Treatment technology of industrial wastewater and sewage, the textbook of Jica - Kita.

[38]. Comly, H., (1987): landmark article Sept. 8. 1945: Cyanosis in infants caused by nitrate in well water. JAMA 257 (20): 2788-2792.

[39]. Drury, C.F., McKenney, D.J., Findlay, W.., and Gaynor, J.D., (1993): Influence of tillage on nitrate loss in surface water runoff and tile drainage Soil Scissor Am J 57:797-802.

[40]. Levallois, P., and Phaneuf, D., (1994): Contamination of drinking water by nitrate: analysis of health risks. Con J Public Health 85 (3): 192-196.

[41]. Idelovitch, E., Icekson-Tal, N., Avraham, O., and Michail, M., (2003): The long term performance of Soil Aquifer Treatment (SAT) for effluent reuse. Water Science and Technology: Water Supply, 3 (4), 239-246.

[42]. Akber, A., Mukhopadhyay, A., Al-Senafy, M., Al-Haddad, A., Al-Awadi, E., & AlOallaf, H., (2008): Feasibility of long-term irrigation as a treatment method for municipal wastewater using natural soil in Kuwait. Agricultural Water Management 95, 233-242.

[43]. Divya, J., and Belagali, S.L., (2012): Impact of chemical fertilizers on water quality in selected agricultural areas of Mysore district, Karnataka, India. International J, of Environmental Sciences, 2, No.3.

[44]. Sato, K., Masunaga, T., and Wakatsuki, T., (2005): Characterization of, Ikeatment Processes and Mechanisms of COD, Phosphorus and Nitrogen Removal in a Multi Soil Layering System. Soil Sci. Plant Nutr, 51 (2), 213-221.

[45]. Feigin, A.; Ravina, I.; Shalhevet, J., (1991): Irrigation with treated sewage effluent management for environmental protection. Berlin: Springer-Verlag, 224.

[46]. Bi, P., Pei, L., Huang, G., Han, D, and Song, J (2021): Identification of Groundwater Contamination in a Rapidly Urbanized Area on a Regional Scale: A New Approach of Multi-Hydrochemical Evidences. J. Environ. Res. Public Health 2021, 18, 12143. https://doi.org/10.3390/ ijerph182212143

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