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Groundwater potentiality and evaluation in the Egyptian Nile Valley: case study from Assiut Governorate using hydrochemical, bacteriological approach, and GIS techniques

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Abstract

Background: The expected deficit of the Egyptian share of the River Nile budget with the construction of the Renaissance Dam in Ethiopia necessitates a proper utilization of the water resources in the Nile Valley. The present study aims at characterizing the chemical and bacteriological compositions of the groundwater in the Quaternary and Eocene fractured limestone aquifers in Assuit Governorate as a suggested scheme for the groundwater quality evaluation in the Egyptian River Nile basin.

Results: We analyzed 92 samples collected from shallow boreholes within 15 km on both sides of the River Nile for major, minor, and trace ions and compared the results to the national and international standards for drinking water. Some chemical data were collected from Assiut Drinking Water Station while some other samples were analyzed chemically and bacteriological in the Laboratories of Science and agriculture faculties and the laboratories of Assiut Drinking & sanitation Company. The groundwater composition is seasonally variable depending on the variation in the local surface water (level composition). The results of bacteriological examination show that the highest most probable number of total coliform was found 5.9 MPN/100 ml and the minimum value of MPN of total coliform was found 1.1 MPN/100 ml. Groundwater potentiality and evaluation for drinking and domestic uses depend on several parameters which must be taken into consideration.

Conclusions: The current research concluded that the GIS-based water potentiality spatial model (WPSM) indicated that the northwest part and southeast part represented the highest and lowest potentiality respectively for drinking water purposes. The suggested scheme in this study could be a valid tool to evaluate the water quality in the River Nile basin and similar settings worldwide.

Keywords: Hydrochemical analysis, Bacteriological analysis, River Nile, Groundwater quality, GIS

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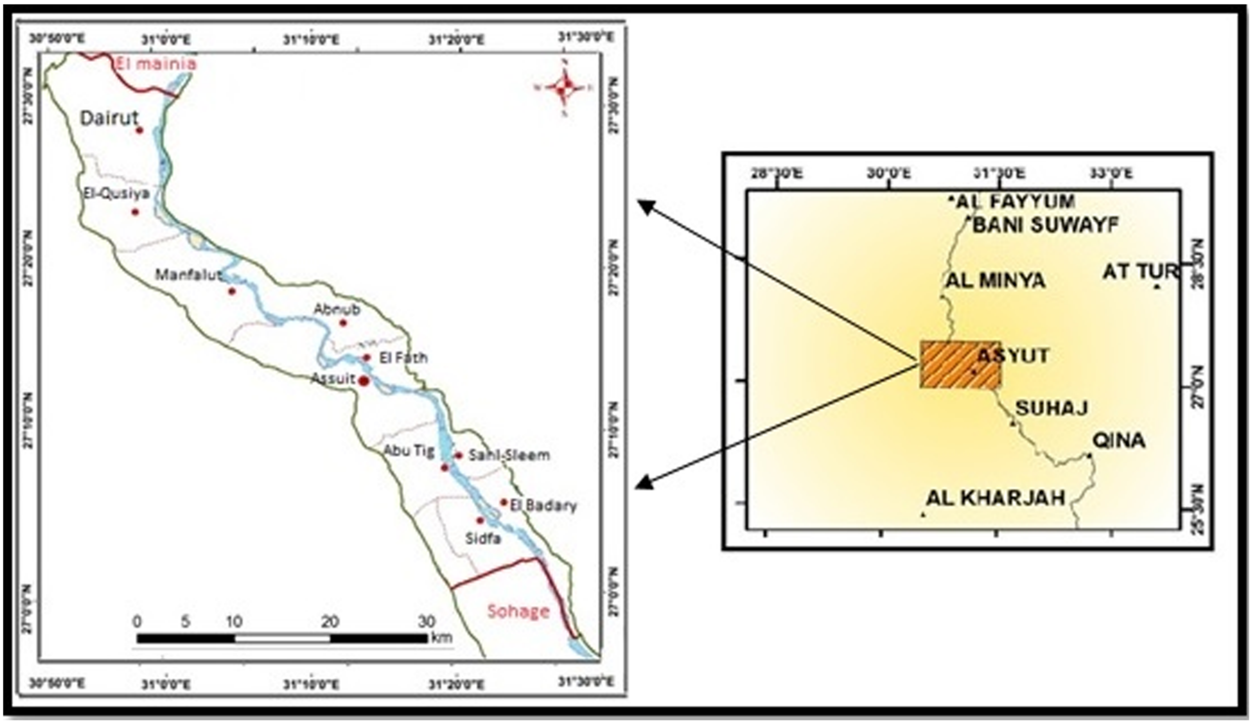

Fig. 1 Location map of Assiut Governorate

Background

Groundwater is an important source of water supply in many parts of the world in particular in desert environments such as in Egypt. The expected storage in the Nile water in the near future, as upstream countries proceed with building dams on the main course of the river, encourage the government and research institutions to look for the optimum solutions for sustainable use of drinking water. The quality of portable groundwater in the Nile Valley such

Table 1 Some climatic data averages (Assiut Meteorological Station. 2010–2017)

Assiut Meteorological Station (2010–2016)						
Month	Temperature		Wind velocity m/s	Evaporation (mm/day)	Rainfall	
	Min. temp. ℃	Max. temp. ℃			Rainfall (mm/month)	Max rainfall in 1 day/mm
January	5.5	18	5.6	6.39	0.4	0
February	6.5	21.6	6.4	8.52	0.18	2.5
March	10.1	25.6	8.6	11.83	0.07	1
April	14.9	31.6	8	16.14	0.07	2.5
May	18.9	35.3	6.4	19.92	0.1	0
June	21.4	37.4	7.2	21.84	0	0
July	22.2	36.8	7	19.47	0	0
August	21.9	36.3	6	17.74	0	0
September	19.6	34.2	7.2	16.01	0	0
October	16.8	31.3	5.6	12.44	0.01	0
November	11.4	25.5	4.4	8.23	0.01	0
December	7.2	21	4.4	5.99	0.12	0.1

as in Assuit Governorate is currently threatened by the chemical and microbiological contamination. Domestic sewage water from septic tanks is one of the main sources contributing to the groundwater pollution in these areas. For example, infiltration of surface water carrying animal waste or sewage to the water horizons in the Central part of the Nile Valley lead to gastrointestinal illnesses, as fecal material may contain various pathogenic microbes (Schijven et al. 2010). According to the World Health Organization, up to 50% of the population in developing countries suffers from health problems associated with lack of clean drinking water (World Health Organization 1992). The quality of groundwater in terms of microbiological and chemical contents is crucial to determining its suitability for drinking use. Detection of bacterial indicators in water samples is an evidence for the presence of pathogenic organisms that are likely the source of water-related fatal diseases (Macler and Merkel 2000). In this study, we aim at providing an integrated hydrochemical and bacteriological analyses in a geographic information system (GIS) environment to evaluate the water quality in the central part of the Nile Valley, Egypt. We use the analysis of major, minor and trace ions, and concentration of coliform bacteria in the study area; we then use GIS interpolation methods to represent the spatial distribution of the analysis results. We compare the results relative to the international and national standards for drinking water purposes and finally we develop a GIS-based water potentiality spatial model to assess the various classes of water quality in the study area.

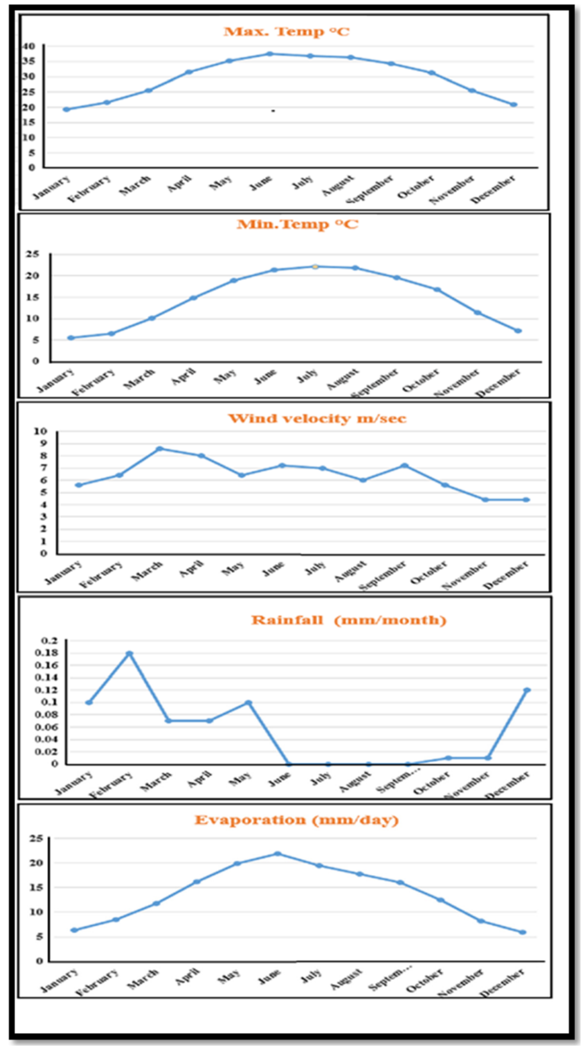

Fig. 2 Climatic data diagrams of the study area

Location and description of the study area

Assiut Governorate is located between latitudes 26° 50′ and 27° 40′ North and longitudes 30° 40′ and 31° 32′ 13.5″ East and bordering the River Nile on both its eastern and western sides (Fig. 1).

Climate

Assiut Governorate belongs to the arid belt of Egypt which is characterized by long and hot summer, cold winter, low rainfall, and high evaporation rates. According to Assiut Meteorological Station, the average daily air temperature is about 22.7 °C in the area. The summer seasons are dry and very hot with mean temperature reaching up to 37 °C. December to February periods is the coldest months where the mean temperature falls to 18 °C (Table 1 and Fig. 2).

Geological and hydrogeological situation

Many studies were carried out concerning the geological and hydrogeological situations concerning Assiut Governorate. A brief idea about these studies is given in the following part. The Nile Valley in the Assuit area is bounded from the east and the west by the Eocene Limestone plateau. The cultivated area is wider in the western part than it is in the eastern one of the River Nile.

The area is generally slopes from the south to the north. The elevation of the western and eastern limestone plateaux ranges from + 120 to + 220 m, whereas the elevation of the floor of the studied area varies from + 50 to + 60 m above sea level. It is underlain by clays, salt, sand, and gravel (Fig. 3).

Both the surface water and the groundwater are used for drinking and domestic uses. More than 700 groundwater wells were pumped for these purposes. These wells are located at 220 water pumping stations sites. Most of the used wells are penetrating

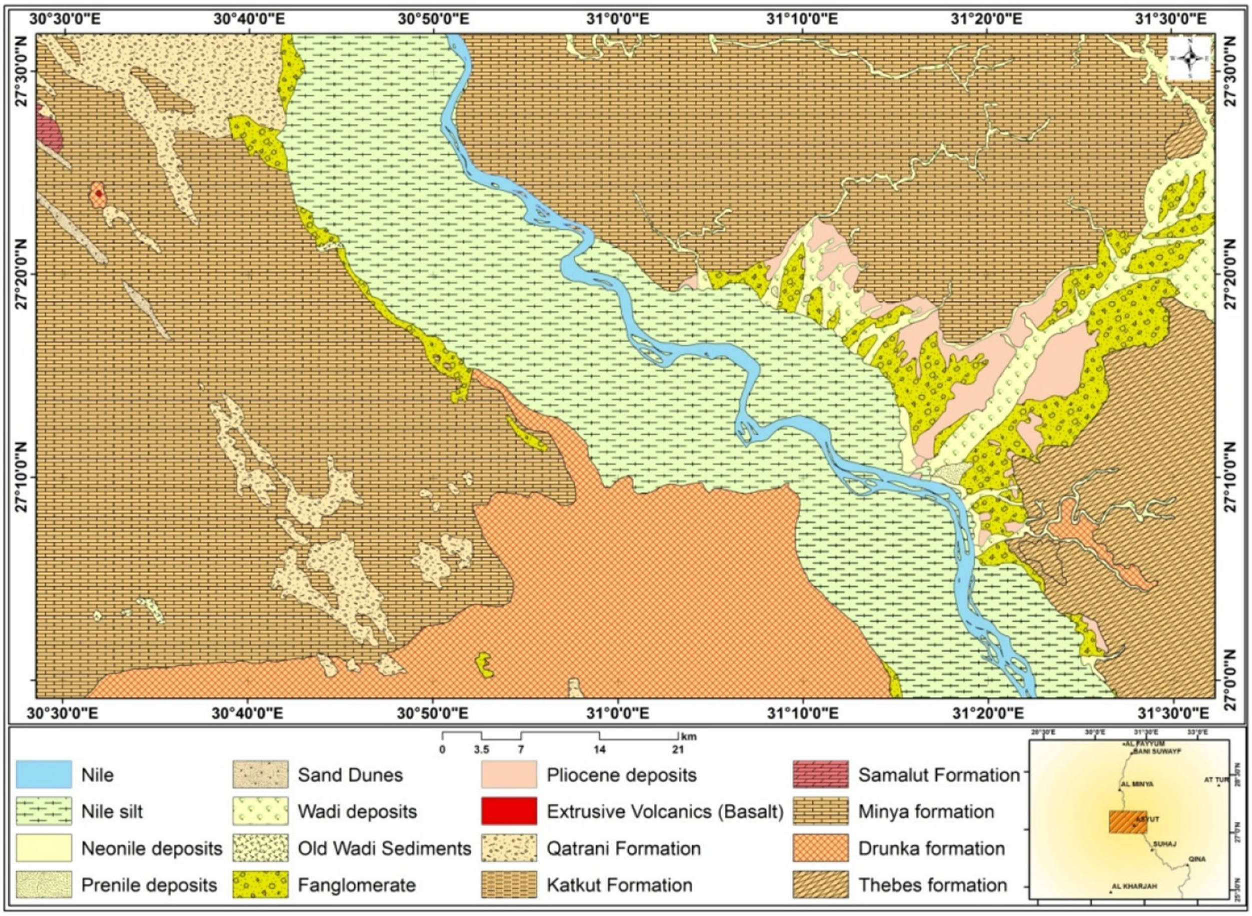

Fig. 3 Geological map of Assiut Governorate, Egypt (Mansour and Philobbos 1983)

the Quaternary water bearing sediments which are mainly recharged from the local surface water system. Other groundwater aquifers are present in and around the area. (Farrage 1982, 1991) concluded that the groundwater level of the aquifer descends gradually from the south to the north. He also concluded that the groundwater in the area is influenced by evaporation where the depth to the water table lies within the range of 3 to 4.5 m, and the surface water plays an important role in recharging the groundwater. The surface water in the area is represented by the River Nile, El-Ibrahymia, El Sohagia, and Nag Hammadi Eastern canals. The Quaternary aquifer is the important aquifer in the area. It is formed from alluvial deposits of the Nile which consists of graded sand and gravel with thin interbeds of clay. The thickness of this aquifer as well as its width differs from one locality to another and the groundwater in this aquifer is present under semi-confined conditions (Farrage 1982). It is present under unconfined condition underneath the desert fringes where the Nile silt is absent. The sand and gravel of the Pleistocene age cover the surface of the old alluvial plains bordering the valley which are subject to the new reclamation activities.

Methods

Hydrochemical analysis

Some field and laboratory measurements and analysis were carried out on 92 groundwater samples collected from many parts of the study area during February 2017 (Fig. 4). The samples were collected in polyethylene bottles (1 L) after 10 min of pumping to avoid any local contamination or evaporation. The physical and chemical parameters were estimated and measured including turbidity, total dissolved solids (TDS), hydrogen ion concentrations (pH), and the concentrations of the major ions (sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), sulfate (SO_4^{2-}), bicarbonate (HCO_3^-), and chloride (Cl^-)) in addition to the trace ions (iron (Fe^+), manganese (Mn^+), and ammonia (NH_3^-). The chemical analyses were carried out in the Laboratory of the Faculty of Agriculture, Assuit University. Electrical conductivity

Fig. 4 Location map of groundwater wells, in Assiut Governorate

meter was used to estimate the total dissolved solids (TDS). Ca and Mg were determined using the titration with standard versenate (EDTA) solution, using Eriochrome Black T (EBT) as indicator. Na and K were determined using flamphotometry method. Carbonate and bicarbonate were determined by the titration with standard solution of hydrochloric acid. Chlorides were determined using standard solution of silver nitrate and sulfates were spectrophotometery measured using the turbidimetry method.

Bacteriological analysis

The water samples were collected using sterile 750 ml containers. Before collection, the mouth and the outer parts of the borehole taps were sterilized with the direct flame of a cigarette lighter, and allowed to cool by running the water for about 1 min. Thereafter, the sample bottles were rinsed with the sample water before filling them. The bottles were held at the bottom while filling, to avoid contamination from the hands or fingers. After recording the time of collection, the samples were labeled with code names before going to the laboratory for analysis.

In the lab, the samples were stored in cold room (4 °C). The analysis was started without delay, based on the priority to analyze parameters as prescribed by APHA (American Public Health Association)-AWWA (American Water Works Association)

Table 2 Standard most probable number (MPN) table for ten tubes

MPN per 100 ml	Number of positive tubes
< 1.1	0
1.1	1
2.2	2
3.2	3
5.1	4
6.9	5
9.2	6
12.0	7
16	8
23.0	9
> 23	10

Table 3 Groundwater data compared with the maximum permissible concentration for drinking water according to the (WHO Guidelines 2004) and Egyptian limits (Egyptian Higher Committee for Water 2007)

Constituent	Unit	World Health Organization (2004)	Egyptian maximum permissible limits (EHCW 2007	Average concentration range for the studied water samples
pH		6.5–8.5	6.5–8.5	7.55
TDS	ppm	500	1000	950
Na^{+}	ppm	200	200	203.5
Ca^{++}	ppm	200	–	250
Mg^{++}	ppm	150	–	170
K^{+}	ppm	30	–	9.25
Cl^{-}	ppm	250	250	300
SO_4^{--}	ppm	250	–	40
HCO^{-}_3	ppm	200	250	226
Fe^{++}	ppm	0.3	0.3	0.85
Mn^{++}	ppm	0.4	0.4	0.55

1994 methods. All the samples were analyzed for total coliform (TC) according to internationally accepted procedures and standard methods (APHA-AWWA1994).

All media, chemicals, and reagents used were prepared according to manufacturer's specifications. The culture media used were sterilized using an autoclave at 121 °C for 15 min, while Petri-dishes, pipettes, and other glass wares were sterilized in a hot air oven at 160 °C for 1 h. The composition of the lauryl tryptose broth medium used was as follows. The procedure below is for estimation of coliforms by multiple-tube fermentation technique (MTF), also called most probable number (MPN) procedure in 96 h, or less, in water samples on the basis of the production of gas and acid from fermentation of lactose. This procedure can be applied for non-potable water. The technique of enumerating coliforms by means of multiple tube fermentation (MTF) has been used for over 80 years as a water quality monitoring method. The method consists of inoculating a series of tubes with appropriate decimal dilutions of the water sample. Production of gas, acid formation, or abundant growth in the test tubes after 48 h of incubation at 35 °C constitutes a positive presumptive reaction.

Count the number of tubes that contain gas in the inner vial. Find the MPN of the sample (total coliform bacteria per 100 ml sample) from the MPN table for ten tubes (Table 2). Both lactose and lauryl tryptose broths

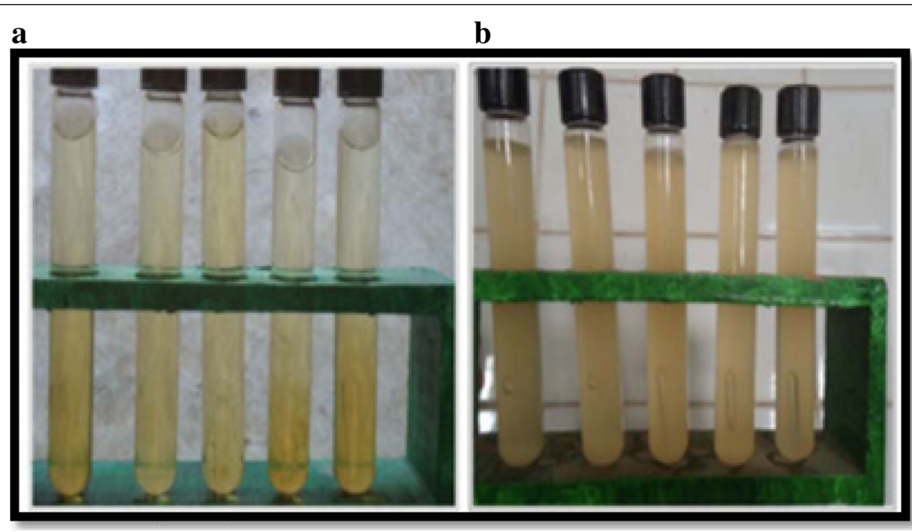

Fig. 5 a Negative lauryl tryptose broth tubes for coliform. **b** Positive presumptive test can be used as presumptive media, but Seidler et al. (1981) and Evans et al. (1981) have obtained interference, with high numbers of non-coliform bacteria, using lactose broth. All tubes with a positive presumptive reaction are subsequently subjected to a confirmation test. The formation of gas in a brilliant green lactose bile broth fermentation tube at any time within 48 h at 35 °C constitutes a positive confirmation test (Fig. 5a, b).

Results

Water that can be used for domestic or drinking purposes should be physically colorless, odorless, transparent, and free from turbidity and microorganism. Chemically, the water should preferably be of low dissolved solid content, soft, and free from poisonous constituents.

Several parameters were established to determine the suitability of groundwater in the area for human drinking and domestic purposes. The fitness of this water was determined by comparing its chemical characteristics with the standards given by the Egyptian Higher Committee for Water (Egyptian Higher Committee for Water 2007) and World Health Organization (WHO Guidelines 2004). Other classification of the suitability of groundwater according to the TDS, major and trace elements are listed in (Table 3).

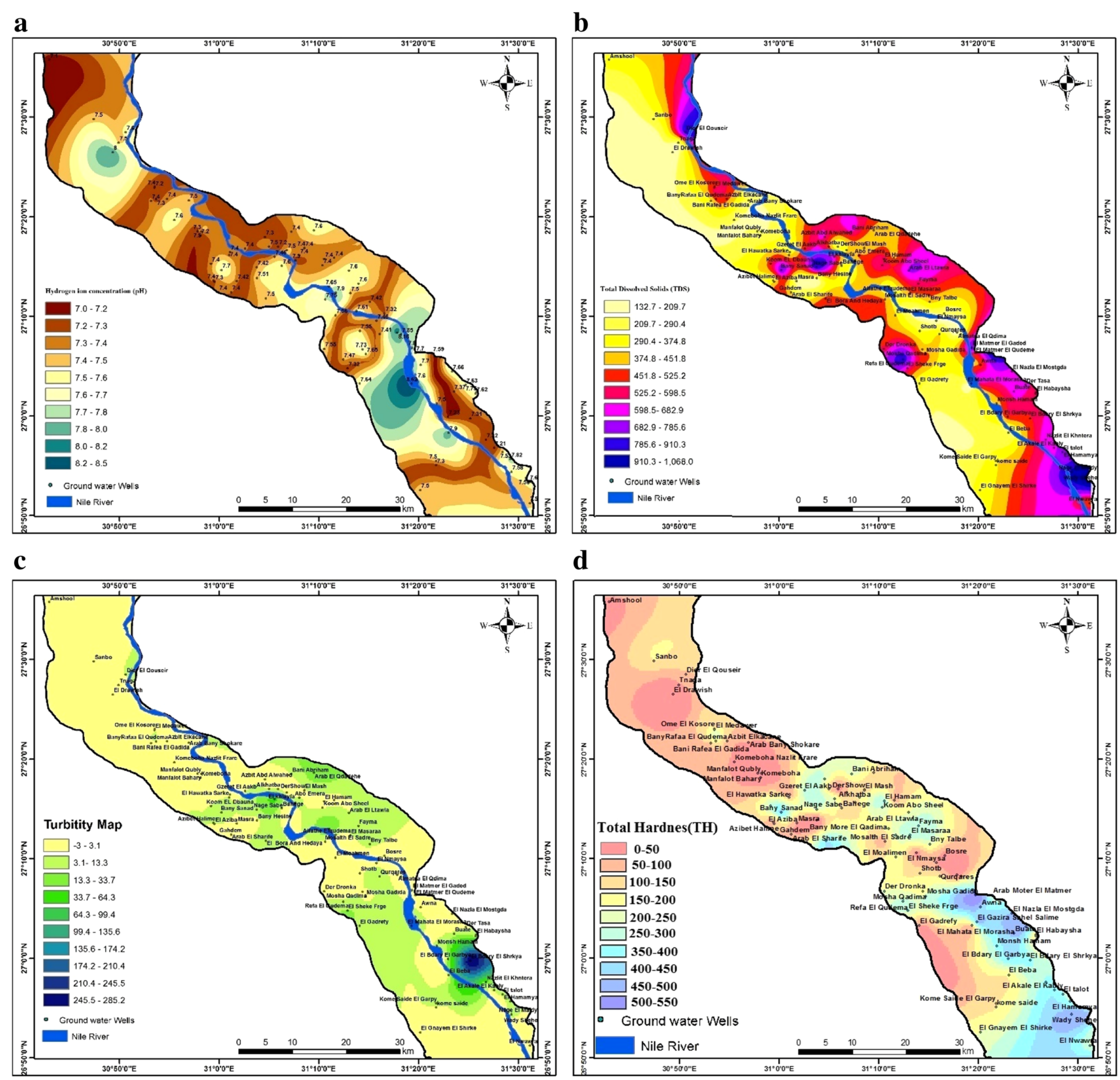

Fig. 6 Iso-concentration maps showing spatial variation in **a** pH, **b** TDS, **c** turbidity, and **d** TH in the study area

Hydrogen ion concentration (pH) is a measure of the acidity or alkalinity conditions of a solution. The pH values of the analyzed samples in the investigated area varied from 7 to 8.1. Accordingly, the groundwater in the studied area is classified as slightly acidic to light alkaline water (Fig. 6a). The accepted limits of pH value for drinking water ranging between 6.5 and 8.5 according to Egyptian standards while it is ranging between 6.5 and 8 according to WHO Standards, so the groundwater in the area has no problem regarding to its pH values (Fig. 7a).

The TDS are the measure of the total amount of minerals dissolved in water. It is a very useful parameter for evaluation water quality. Different methods are used for water classification according to its total dissolved salts content. Hem (1985) classified water according to TDS value into four classes: fresh, moderately saline, very saline, and brine water. The values of TDS in the groundwater in the area ranged from 200 to 1700 ppm. Figure 6b and Table 4 show local increase in TDS value at the eastern parts of study area between Abnoub and Al Fath. A local TDS increase west of Manfalout and west of Assiut while it decreases near the River Nile and EL-Ibrahimiya Canal. It is observed that TDS values increase during January and February and decrease during July and August. The accepted limit of TDS value for drinking water according to the Egyptian standards is 1000 ppm while it is only 600 ppm according to WHO Standards. Accordingly, most the groundwater in the area is acceptable for drinking purposes regarding to the TDS parameter except for the northwest Assiut and East Abnoub parts (Fig. 7b).

The turbidity values in groundwater in the area ranged from 0 to 10 NTU. Figure 6c and Table 4 show an increase in the turbidity values between Dayrout, Qusiya, and at the western parts of study area between Assiut and Abu Tieg. The accepted limit of turbidity value for drinking water according to Egyptian standards is 1 NTU, which mean that the groundwater in most of the area has no turbidity problem except for the mentioned localities.

The values of TH in groundwater in the area ranged from 150 to 550 ppm. Figure 6d shows an increasing in TH value between Manfalout and Assiut. TH decreases near the Nile River and EL-Ibrahimiya Canal. The accepted limit of TH value for drinking water according to Egyptian standards is 500 ppm while it is 200 ppm according to WHO Standards. Accordingly, the groundwater is accepted for drinking purposes regarding to Egyptian limits.

Calcium content in groundwater ranged from 100 to 400 ppm. Figure 8a and Table 4 show general

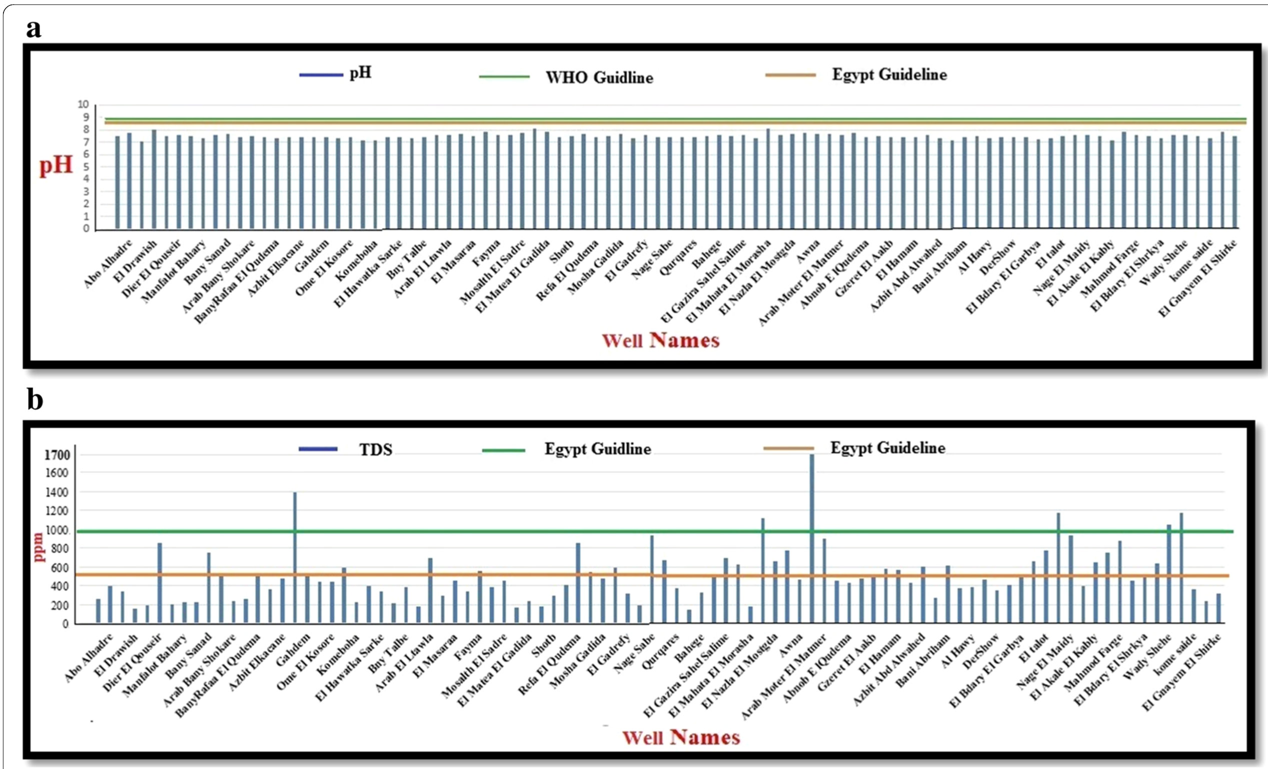

Fig. 7 **a** Hydrogen ion concentration and **b** total dissolved solids concentration in the groundwater samples compared with WHO Guidelines (2004) and Egyptian Higher Committee for Water (2007) guidelines for drinking water

Table 4 Results of chemical analyses of studied groundwater samples in Assuit Governorate

N	Location	pH	Turb	TDS	Major cation				Major anion			Trace Elements		
					Na^+	K^+	Ca^{+2}	Mg^+	SO_4^{-2}	Cl–	HCO_3	Fe+	Mn+	NH_3^-
1	Sanbo	7.50	0.70	260	150	4.69	160.00	110.00	45	50	170	0.50	0.40	0.10
2	Abo Alhadre	7.80	0.60	400	146	3.91	136	44.00	32	442	120	0.30	0.10	0.20
3	Amshool	7.10	1.60	340	100	4.52	196	244.00	20	325	110	0.40	0.20	0.10
4	El Drawish	8.00	0.50	156	70	29.33	160	66.00	15	114	58	0.50	0.20	0.10
5	Tnaga	7.50	1.50	185	110	4.60	100	140.00	30	225	90	0.30	0.40	0.20
6	Dier El Qouseir	7.60	3.20	855	142	3.91	130	75.00	35	336	120	0.50	0.50	0.30
7	Manfalot Qubly	7.50	1.60	205	88	3.91	180	50.00	45	440	110	0.30	0.20	0.14
8	Manfalot Bahary	7.30	0.98	223	90	2.74	188	44.00	45	540	130	0.40	0.10	0.15
9	Komeboha Nazlit Frare	7.60	1.54	220	160	14.86	100	289	10	313	140	0.30	0.20	0.03
10	Bany Sanad	7.70	5.30	751	225	11.73	286	100.00	40	335	320	0.40	0.30	0.28
11	Koom EL Dbauna	7.40	3.10	513	210	7.04	224	106.00	50	525	256	0.30	0.40	0.18
12	Arab Bany Shokare	7.50	2.70	234	108	6.26	106	46.00	15	110	140	0.20	0.20	1.50
13	Azibet Halime	7.40	5.05	263	125	29.33	106	94.00	17	312	154	0.20	0.20	0.38
14	BanyRafaa El Qudema	7.30	3.10	499	180	7.04	174	126.00	30	535	220	0.40	0.30	0.69
15	Bani Rafea El Gadida	7.40	2.90	357	192	13.29	140	300	22	320	260	0.40	0.20	0.71
16	Azbit Elkacane	7.40	1.40	480	130	8.99	124	164.00	20	524	280	0.30	0.20	0.54
17	Arab El Sharife	7.40	0.51	1386	200	10.56	720	410.00	40	550	150	0.20	0.20	1.51
18	Gahdem	7.40	0.79	511	134	8.21	134	96.00	65	270	248	0.30	0.20	1.69
19	El Aziba	7.30	1.49	438	180	7.04	138	88.00	50	152	232	0.30	0.30	1.52
20	Ome El Kosore	7.40	1.18	441	110	7.82	118	82.00	40	241	250	0.30	0.30	0.12
21	El Medawer	7.20	2.69	592	230	7.82	232	108.00	40	245	310	0.20	0.40	0.55
22	Komeboha	7.20	0.55	227	90	11.73	180	36.00	12	218	140	0.10	0.20	0.12
23	El Hawatka Garbe	7.40	3.16	397	145	8.55	140	80.00	20	229	208	0.20	0.40	0.47
24	El Hawatka Sarke	7.40	1.89	342	112	12.51	110	64.00	21	122	216	0.30	0.40	0.41
25	Bosre	7.32	0.40	216	90	7.04	184	58	24	323	226	0.10	0.50	0.38
26	Bny Talbe	7.42	4.12	381	205	8.21	206	60	47	150	390	0.45	0.15	0.06
27	Jazirat Elwasta	7.61	1.23	182	109	8.21	100	200	20	322	210	0.18	0.30	0.16
28	Arab El Ltawla	7.60	3.67	691	192	9.78	190	170.00	38	267	264	0.30	0.20	0.20
29	Bany More ElQadima	7.65	28.10	294	180	10.90	180	68.00	50	149	260	1.50	0.30	0.56
30	El Masaraa	7.50	1.45	448	155	5.08	228	152.00	30	235	506	0.20	0.20	0.50
31	Alfathe Elqudema	7.90	1.04	338	280	15	208	132.00	15	217	352	0.15	0.10	0.60
32	Fayma	7.60	10.20	552	233	10.95	240	140.00	12	120	448	1.00	0.10	0.30
33	El Moalimen	7.56	2.16	385	156	8.99	190	235	70	272	370	0.35	0.40	0.70
34	Mosalth El Sadre	7.75	0.54	447	150	14	130	198	35	130	230	0.02	0.60	1.00
35	Almatea El Qdima	8.1	0.72	161	78	7.82	186	166.00	10	312	170	0.45	0.30	0.70
36	El Matea El Gadida	7.85	1.93	233	110	9.78	110	96.00	20	119	306	0.08	0.23	0.18
37	El Nmaysa	7.46	2.22	175	120	20.72	110	94.00	32	230	230	0.50	0.20	0.06
38	Shotb	7.55	2.29	289	192	14.90	158	112.00	44	145	296	0.30	1.00	0.50
39	Mosha Qadima	7.73	2.73	408	130	10.95	172	168.00	50	90	360	0.42	0.20	0.80
40	Refa El Qudema	7.47	4.73	851	200	9.38	400	194.00	45	190	394	0.50	0.27	0.40
41	Der Dronka	7.55	0.34	546	134	5.17	190	356	52	81	280	0.08	0.30	0.10
42	Mosha Gadida	7.65	1.81	474	180	3.74	230	122	60	95	330	0.40	0.05	0.66
43	El Sheke Frge	7.32	14.80	590	110	3.91	224	180	63	104	306	1.00	0.15	0.30

Table 4 Results of chemical analyses of studied groundwater samples in Assuit Governorate *(Continued)*

N	Location	pH	Turb	TDS	Major cation				Major anion			Trace Elements		
					Na^+	K^+	Ca^{+2}	Mg^+	SO_4^{-2}	Cl–	HCO_3	Fe+	Mn+	NH_3^-
44	El Gadrefy	7.64	11.10	318	230	10.35	100	350	30	120	276	0.95	0.10	0.14
45	Masra	7.42	1.45	194	90	11.17	112	55	19	317	230	0.05	0.13	0.10
46	Nage Sabe	7.42	8.23	935	145	3.91	202	160	42	243	390	0.58	0.10	0.54
47	Nage AbdEl Rasule	7.46	4.10	671	112	4.74	196	260	30	234	344	0.10	0.15	0.04
48	Qurqares	7.41	6.10	376	90	3.91	156	280	58	158	396	0.58	0.20	0.34
49	Bany Hesine	7.51	1.41	140	205	5.35	270	40	14	214	160	0.18	0.60	0.16
50	Bahege	7.60	3.56	327	109	12.69	148	60	25	225	364	0.35	0.15	0.50
51	El Boraand Hedaya	7.50	7.07	484	192	13.69	274	56.00	26	487	324	0.42	0.20	0.02
52	El Gazira Sahel Salime	7.60	6.80	694	180	3.91	315	135.00	29	170	390	1.70	0.24	0.49
53	Buate	7.37	6.56	621	155	3.91	315	135.00	36	140	610	0.77	0.25	0.72
54	El Mahata El Morasha	8.62	10	180	280	12.74	119	51.00	16	116	150	0.77	0.10	0.59
55	Der Tasa	7.63	1.53	1111	233	14.86	336	144.00	44	490	400	1.20	0.21	0.10
56	El Nazla El Mostgda	7.66	1.41	659	156	11.73	308	132.00	32	333	420	1.27	0.16	0.10
57	El Matmer El Gaded	7.80	1.07	768	150	12.04	238	102.00	63	195	174	1.30	0.10	0.10
58	Awna	7.70	1.38	467	78	6.26	287	123.00	11	227	300	2.10	0.40	0.35
59	El Matmer El Qudeme	7.70	0.38	1700	110	10.33	494	211.00	10	542	240	1.76	0.10	0.10
60	Arab Moter El Matmer	7.59	0.52	900	120	7.04	224	96.00	22	270	280	0.72	0.20	0.46
61	El Habaysha	7.75	2.52	457	116	13.29	116	49.00	30	103	250	1.10	0.10	0.22
62	Abnob E lQudema	7.40	0.98	433	110	8.99	110	102.00	38	50	260	0.10	0.20	0.36
63	Bani Mohammadeyat	7.50	2.63	472	148	10.56	148	84.00	45	75	180	0.30	0.30	1.95
64	Gzeret El Aakb	7.40	2.76	513	203	8.02	236	168.00	50	245	370	0.40	0.30	1.55
65	Koom Abo Sheel	7.40	2.39	583	220	7.04	218	162.00	38	220	394	0.10	0.40	0.46
66	El Hamam	7.40	0.82	565	255	7.82	248	192.00	10	60	344	0.10	0.30	0.33
67	Arab El Qdadehe	7.60	22.60	431	142	7.82	156	150.00	15	221	256	0.60	0.30	0.39
68	Azbit Abd Alwahed	7.30	1.14	604	200	11.73	210	120.00	35	435	324	0.30	0.00	1.68
69	Alkhatba	7.20	1.01	270	95	5.50	390	138.00	28	220	180	0.30	0.00	0.88
70	Bani Abriham	7.40	3.10	610	200	12.51	200	160.00	38	128	330	0.40	0.40	0.77
71	El khlayfa	7.50	1.20	374	350	7.04	136	100.00	15	118	240	0.50	0.30	1.12
72	Al Hawy	7.30	5.00	380	142	8.21	140	60.00	25	228	170	0.40	0.20	0.28
73	Abo Emera	7.40	3.62	461	156	8.21	164	96.00	60	324	280	0.40	0.20	0.01
74	DerShow	7.40	3.60	345	133	9.78	128	86.00	30	125	230	0.40	0.20	0.05
75	El Mash	7.40	1.30	411	166	10.80	160	70.00	25	130	260	0.30	0.30	0.60
76	El Bdary El Garbya	7.23	3.65	507	280	5.08	281	120.00	51	51	242	1.59	1.00	0.05
77	Nazlit El Khntera	7.32	2.31	652	225	15.00	250	108.00	57	55	265	1.62	0.67	1.72
78	El talot	7.53	4.76	767	255	10.95	250	106.00	36	130	369	1.30	0.51	0.53
79	El Atmanya	7.58	0.90	1177	320	8.99	315	135.00	48	390	275	1.26	0.10	0.31
80	Nage El Maidy	7.58	3.59	928	329	10.55	329	141.00	65	250	270	1.64	0.83	0.41
81	Monsh Hamam	7.50	4.40	396	250	7.82	254	109.00	30	130	389	2.02	0.49	0.10
82	El Akale El Kably	7.21	4.92	645	280	9.78	273	117.00	16	110	140	2.35	0.56	0.10
83	El Hamamya	7.82	5.24	754	248	12.72	245	105.00	12	110	110	2.00	0.68	0.24
84	Mahmod Farge	7.64	1.21	880	296	13.80	299	128.00	23	230	250	2.00	0.10	0.10
85	El Nwawra	7.50	0.38	448	210	10.95	215	92.00	51	77	264	2.00	0.10	0.10
86	El Bdary El Shrkya	7.31	303.00	517	230	9.38	252	108.00	50	50	224	1.80	0.49	0.30

Table 4 Results of chemical analyses of studied groundwater samples in Assuit Governorate *(Continued)*

N	Location	pH	Turb	TDS	Major cation				Major anion			Trace Elements		
					Na^+	K^+	Ca^{+2}	Mg^+	SO_4^{-2}	Cl–	HCO_3	Fe+	Mn+	NH_3^-
87	El Kome El Ahmer	7.62	0.66	636	188	11.17	172	73.00	22	184	258	0.34	0.10	0.66
88	Wady Shehe	7.60	0.70	1051	270	12.74	260	111.00	25	350	260	1.50	0.10	0.28
89	Kome Saide El Garpy	7.50	6.98	1170	310	13.91	500	294.00	29	240	340	0.60	0.60	0.05
90	kome saide	7.30	1.11	365	150	12.35	160	120.00	45	60	314	0.05	0.30	0.10
91	El Beba	7.90	1.20	233	160	11.17	170	70.00	45	236	254	0.30	0.05	0.10
92	El Gnayem El Shirke	7.50	2.20	312	180	13.91	190	40	24	124	362	0.40	0.25	0.05

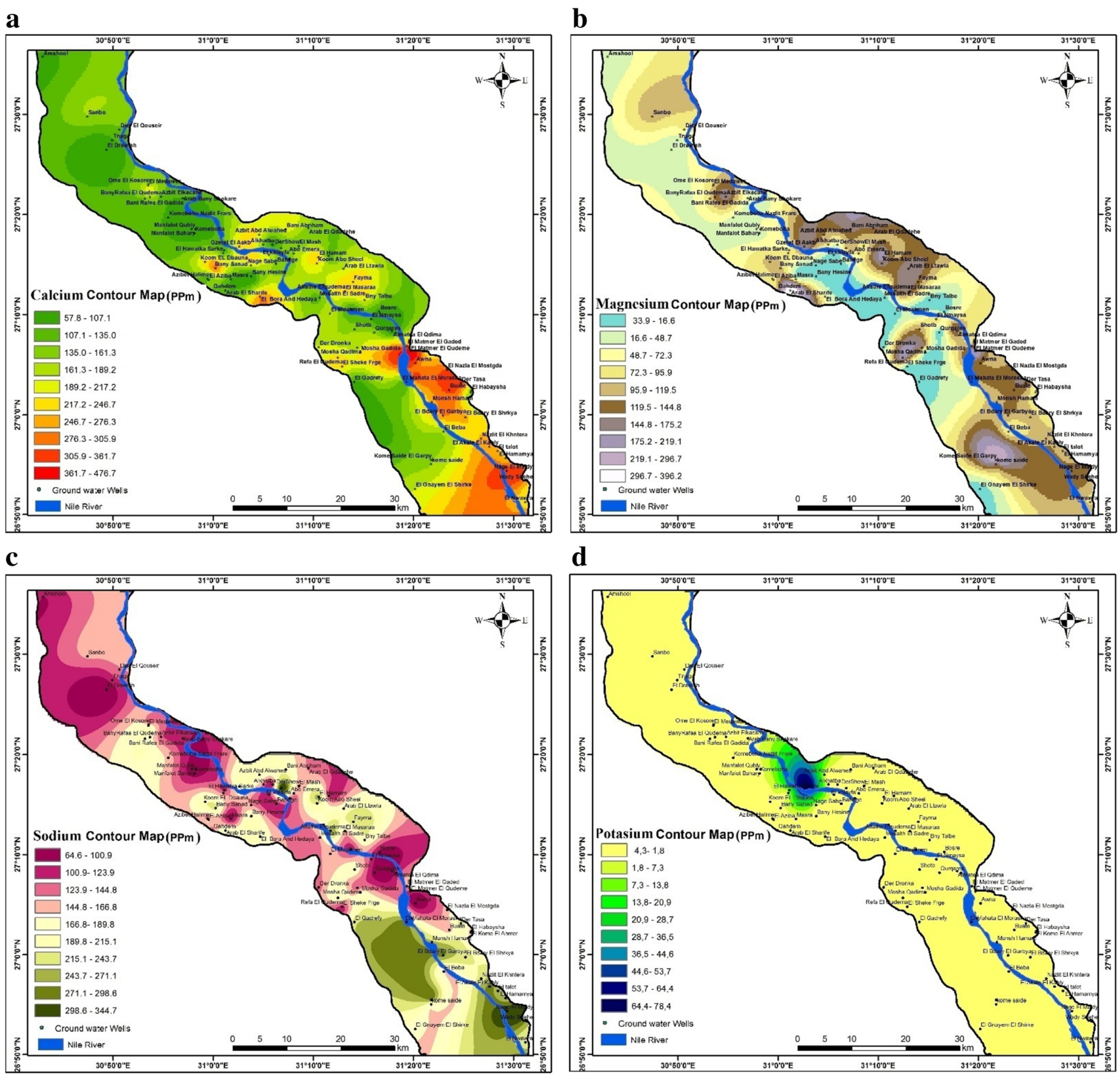

Fig. 8 Iso-concentration maps showing spatial variation in **a** Ca, **b** Mg, **c** Na, and **d** K in the study area (values in milligrams per liter)

increase in the calcium at the southwest parts of study area. Calcium concentration decrease near the Nile River. The accepted limit of calcium value for drinking water according to Egyptian standards is 200 ppm. Which means that the calcium concentration in the groundwater in the area is acceptable for western Sedfa and southwest of Assiut areas (Fig. 9a).

The sodium content in the groundwater samples range from 78 to 329 ppm. The maximum recommended World Health Organization limit for Na concentration in drinking water is 200 ppm. More lower Na concentration is recorded (3.5 to 15 ppm) in all of the analyzed samples (Fig. 8b). This result indicates that all the wells in the studied area contain water having Na content acceptable according to the World Health Organization limit (200 mg/L) for domestic use (Fig. 9b).

The values of magnesium in groundwater samples ranged from 40 to 300 ppm. Figure 8c and Table 4 show an increase in magnesium east of Abnoub. Magnesium concentration generally decreases in the southern parts of study area. It decreases near the River Nile and EL-Ibrahimiya Canal. The accepted limit of magnesium value in drinking water according to Egyptian standards

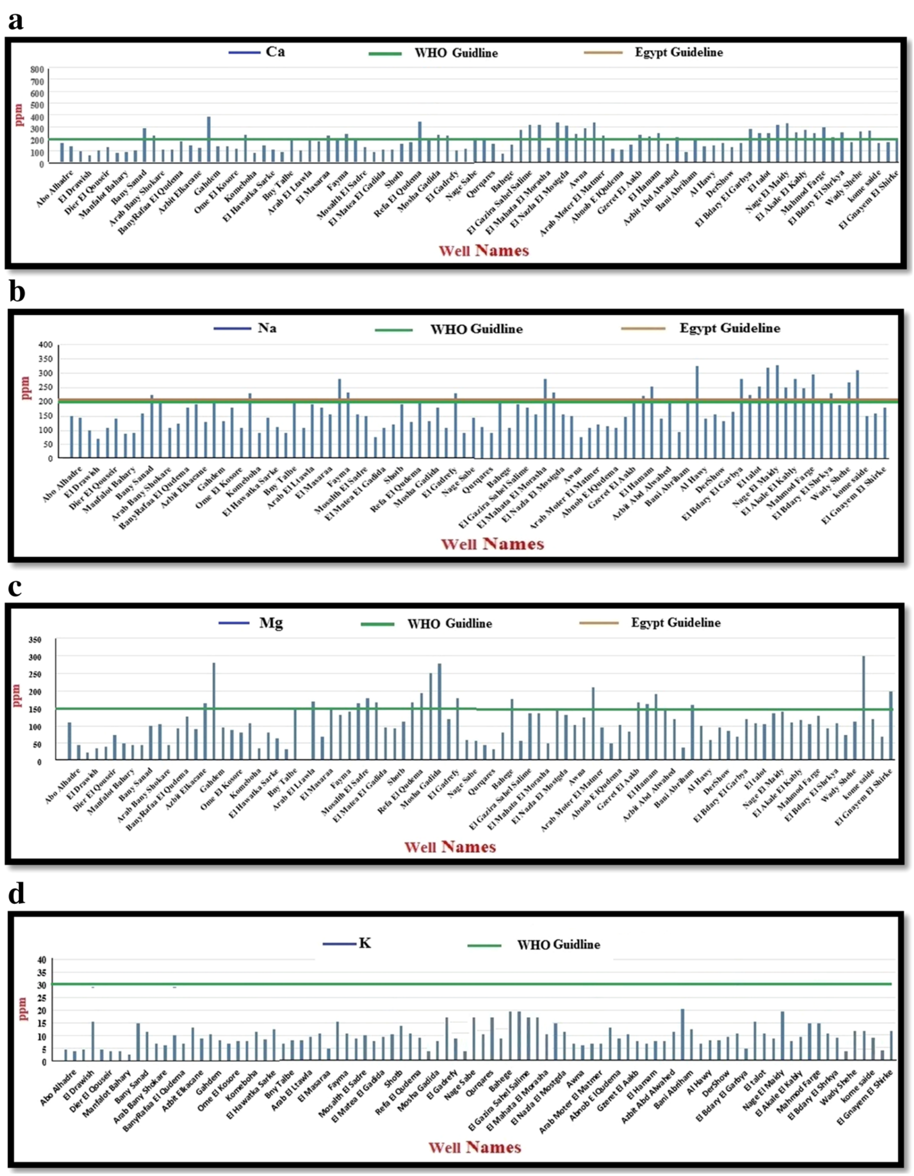

Fig. 9 **a** Ca, **b** Mg, **c** Na, and **d** K concentration of groundwater samples compared with WHO Guidelines (2004) and Egyptian Higher Committee for Water (2007) guidelines for drinking water

is 150 ppm. So, the groundwater in the area is acceptable for drinking purposes except for that in northwestern part of Assiut city and north Abnoub (Fig. 9c).

The chloride content in groundwater samples ranged from 50 to 550 ppm. Figure 10a and Table 4 shows an increase in the chloride content between the western part of Manfalout and Assiut. The maximum acceptable limit of chloride value for drinking water according to the Egyptian and WHO Standards is 250 ppm. So the groundwater in the area is acceptable for drinking purposes except for the western part between Manfalout and Assiut City (Fig. 11a).

Few local areas show relatively high bicarbonate content (Fig. 10b), especially in the northern zone and at the desert fringes because of the dissolution of the carbonates from the adjacent carbonate rocks (Fig. 11b).

Sulfate content ranges from 10 to 70 ppm in the study area (Fig. 10c). The sulfate content is also locally high at the western part because of the extension of the Miocene sediments containing gypseous limestone. Low content of sulfate ions is observed in the northern and eastern parts of the area. This may be due to seepage of freshwater from the River Nile and El-Ibrahimyya canal (Fig. 11c).

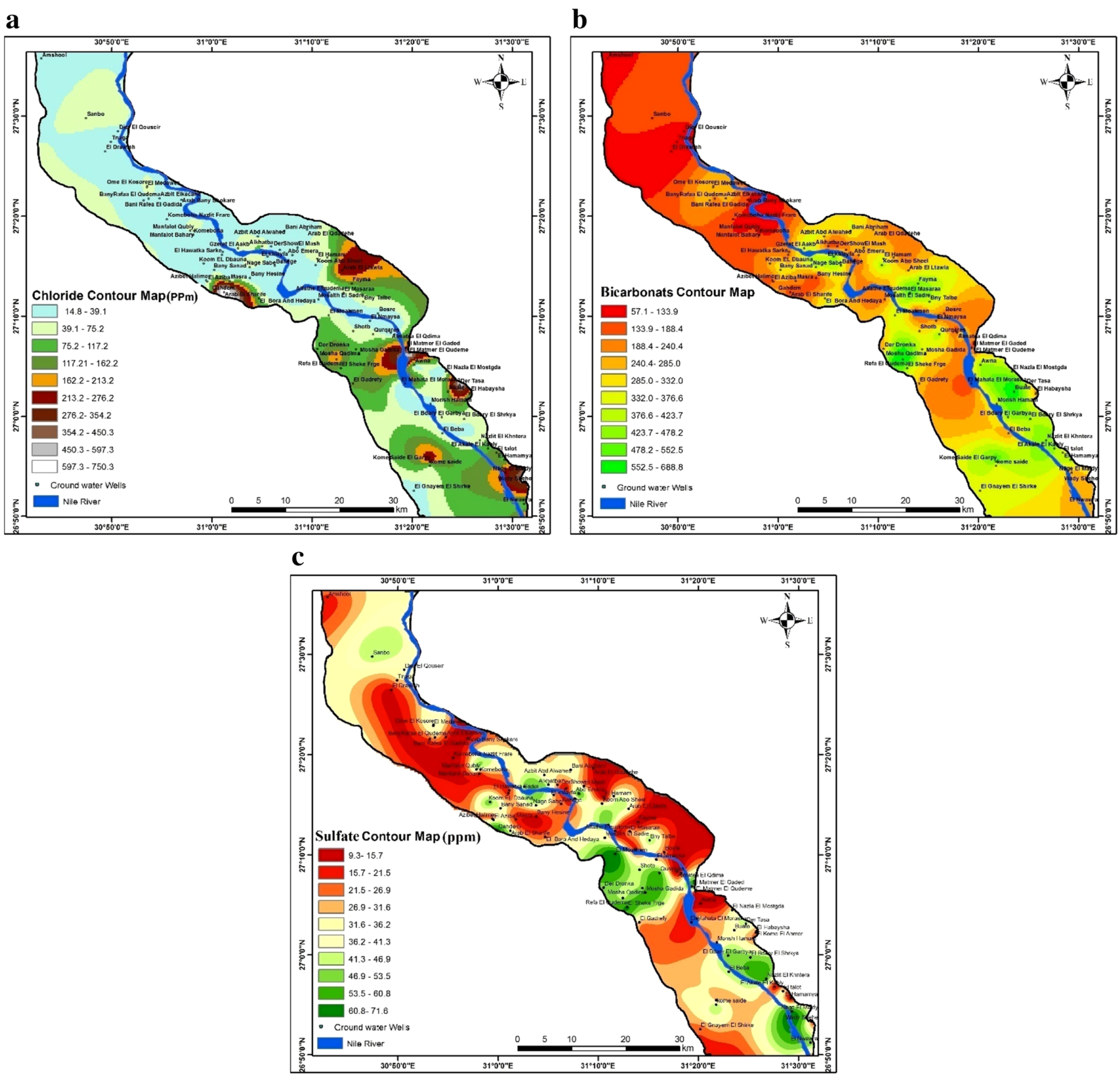

Fig. 10 Iso-concentration maps showing spatial variation in **a** Cl, **b** HCO_3, and **c** SO_4 in the study area (values in milligrams per liter)

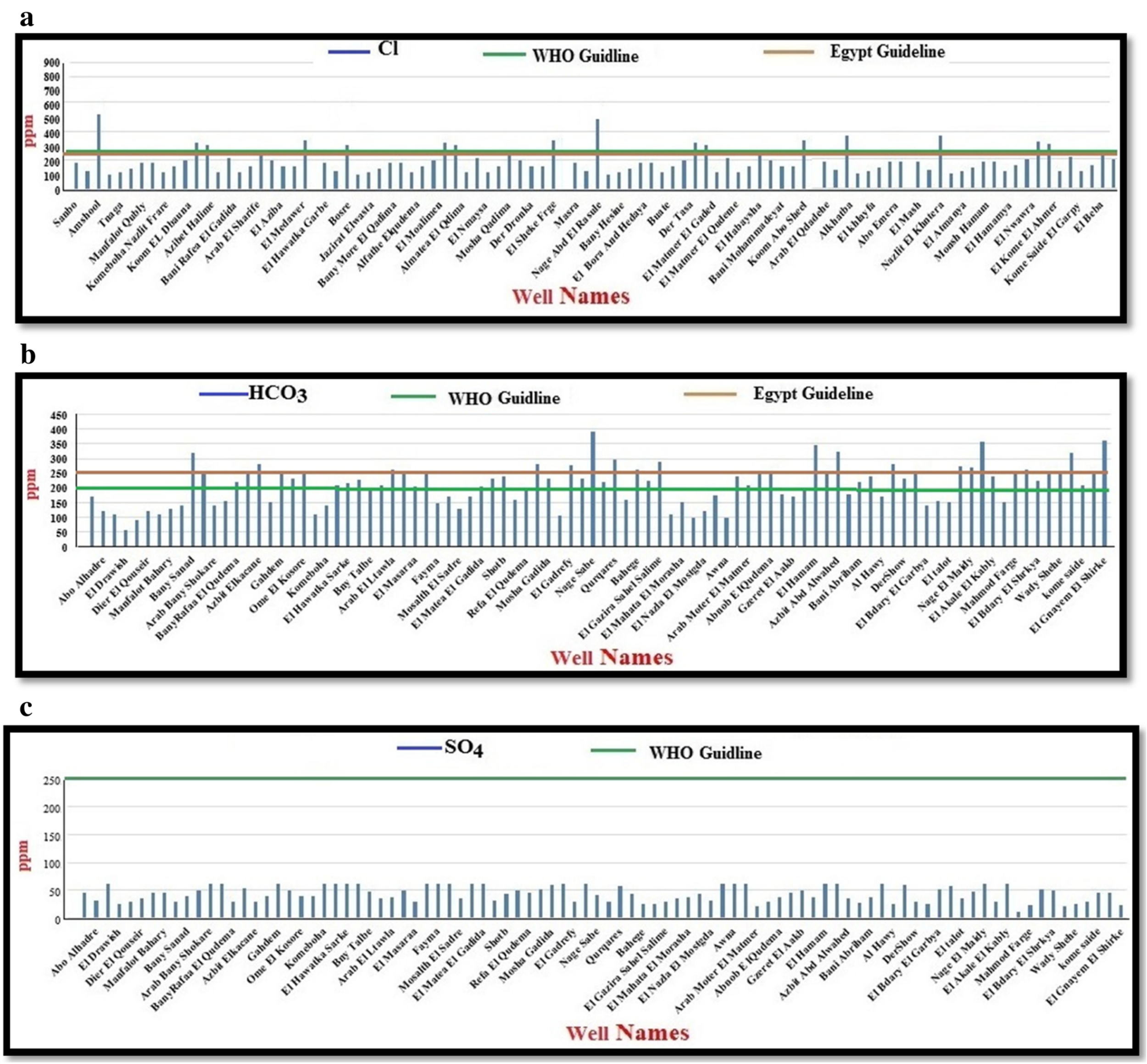

Fig. 11 **a** Cl, **b** HCO_3, and **c** SO_4 concentration of groundwater samples compared with WHO Guidelines (2004) and Egyptian Higher Committee for Water (2007) guidelines for drinking water

Iron concentration in the groundwater in the area ranged from 0.1 to 1.6 ppm. Figure 12a and Table 4 show increases in iron content at southwestern parts of the area. The accepted limit of iron for drinking water according to the Egyptian standards is 0.3 ppm (Fig. 13a).

The values of manganese in groundwater in the area ranged from 0.1 to 1 ppm. Figure 12b shows a slightly increase in the manganese concentration in the area at the southern part of the area, especially between Assuit and Abo Tieg. The accepted limit of manganese value for drinking water according to the Egyptian and WHO is 0.4 ppm. Only in Sedfa area and in south Assiut localities more manganese content then the recommended limits (Fig. 13b).

The values of ammonia content in groundwater ranged from 0 to 1.4 ppm. Local increase in the ammonia values at the eastern parts of study area between Qusiya and Manfalout are observed (Fig. 12a). The accepted limit of ammonia value for drinking water according to Egyptian standards is 0.5 ppm, so the groundwater in the area can be accepted for drinking purposes except for that of Dayrout and in the area between Qusiya and Manfalout.

Bacteriological analysis results

A total of 2189 groundwater samples were collected from 92 groundwater wells distributed in Assiut

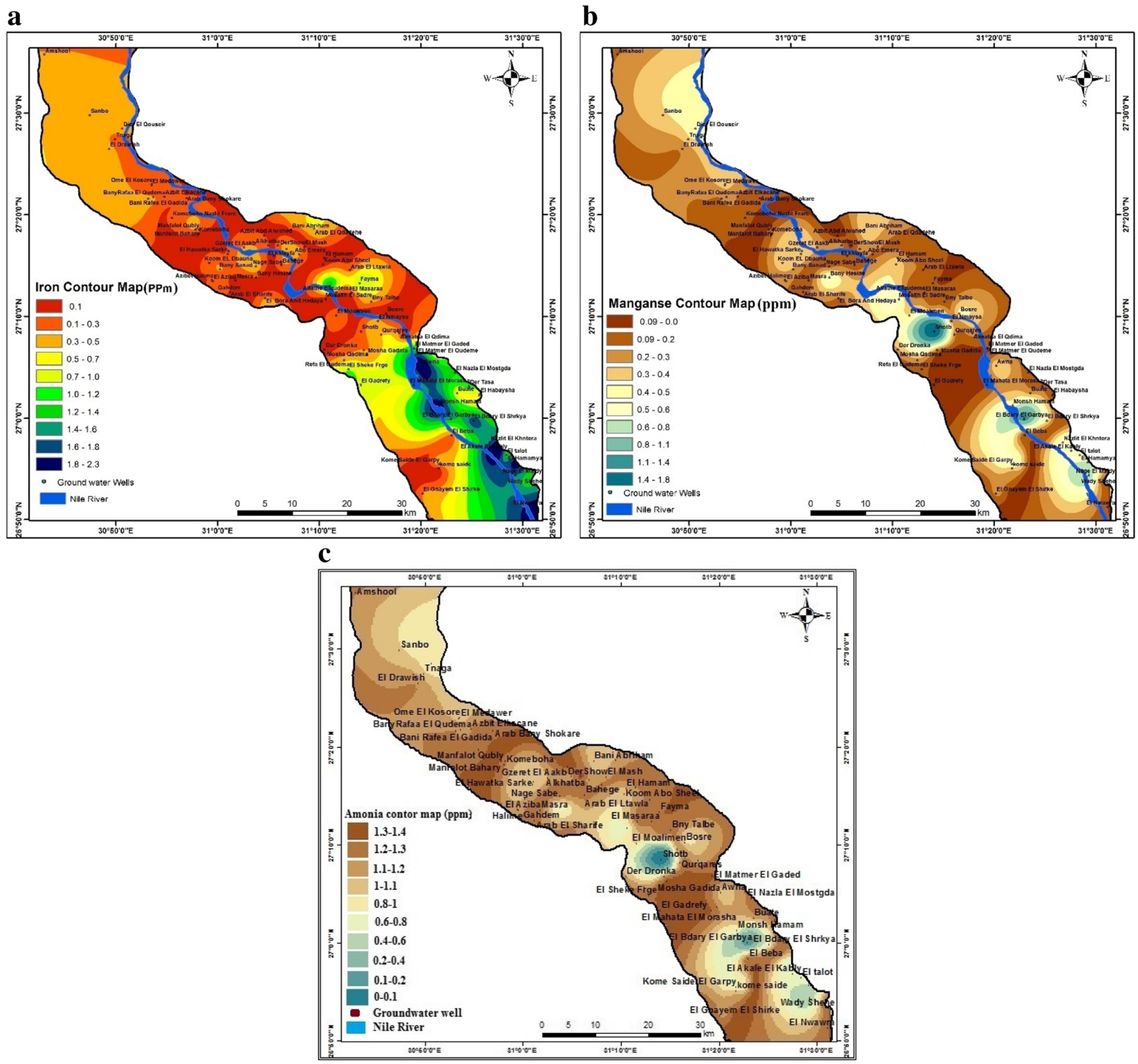

Fig. 12 Iso-concentration maps showing spatial variation in **a** Fe, **b** Mn, and **c** NH_3 in the study area (value in milligrams per liter)

Governorate during the period between January and November 2017 (Table 5). The samples were examined for total coliform and analyzed in the laboratories of the applied Bacteriology, Botany and Microbiology Department, Faculty of Science, Assiut University and in the Holding company for drinking and waste water, (Assiut Drinking and Sanitation Company).

The results of bacteriological examination are shown in Fig. 14. Data show that the highest probable number of total coliform was found to be 5.9 MPN/100 ml and the minimum value of MPN of total coliform was found to be 1.1 MPN/100 ml.

The distribution of the total coliform in the groundwater in the area during the winter season is shown in Table 6 and Fig. 15a. The highest mean value of MPN/100 ml was founded in Abnob district followed by Assiut and Manfalut districts then El Badary and Sidfa, whereas the lowest mean values was found in Dayrout city followed by El Qusiya and Sahel Salime district.

In the spring period, the distribution of the total coliform is shown in (Table 6 and Fig. 15b). The highest mean value of MPN/100 ml was found in Abo Tegi and Abnob cities followed by El fath and Assiut district then Manfalut and El Badary, whereas the lowest mean values were found in El Qusiya and Sahel Salime district.

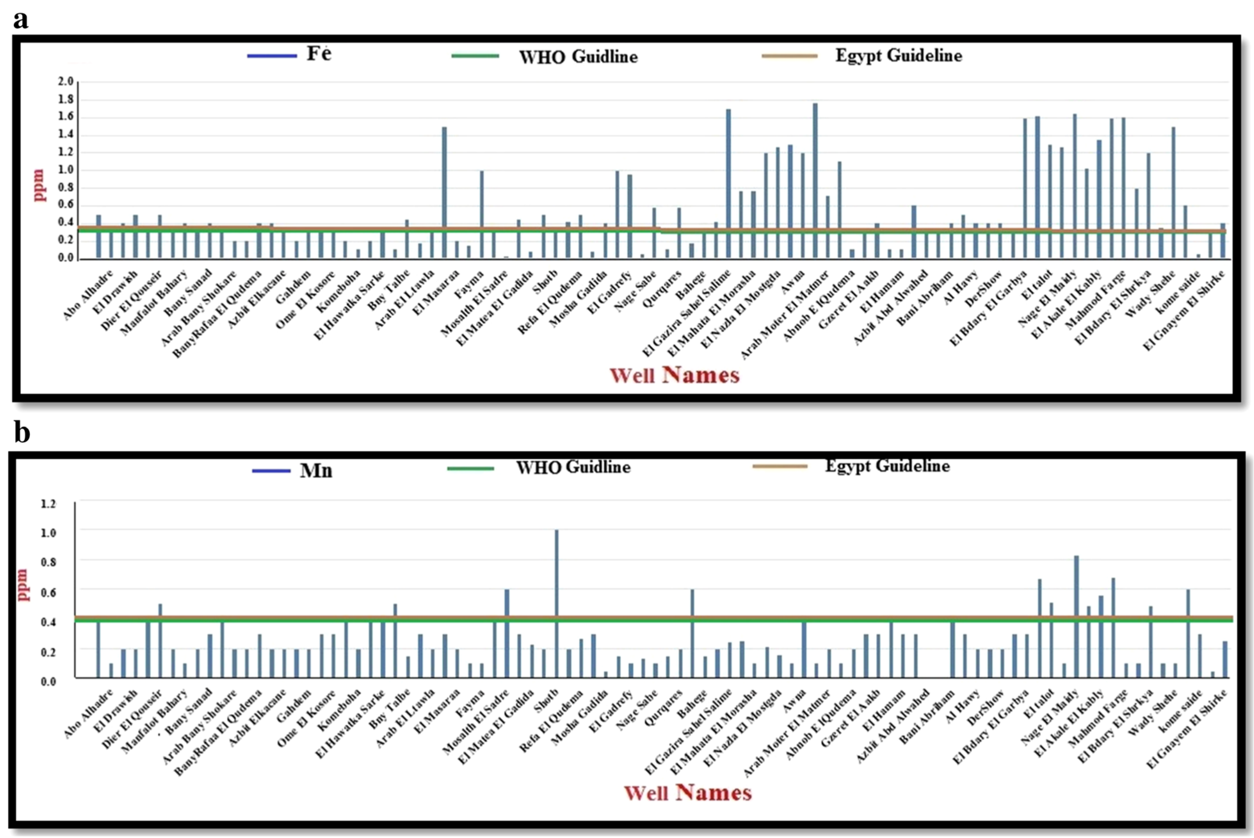

Fig. 13 a Fe and **b** Mn concentration of groundwater samples compared with WHO Guidelines (2004) and Egyptian Higher Committee for Water (2007) guidelines for drinking water

In the summer period, the distribution of the mean value of total coliform is shown in Table 6 and Fig. 15c. The highest mean values of MPN/100 ml was found in El Badary, Assiut, El fath, and Abnob district then Manfalut and El Gnayem, whereas the lowest mean values of MPN/100 ml was found in El Qusiya and Dayrout district.

In the autumn period, the distribution of the mean value of total coliform in the study area is shown in Table 6 and Fig. 15d. The highest mean values of were

Table 5 Total coliform averages (MPN/100 ml) (2017)

	Dayrout	Qusiya	Manfalot	Abnob	Elfathe	Asuit City	Asuit	Abo Tegi	Sahel Salime	Bdary	Sidfa	Ghanayem
January	1.89478	1.2426	1.7032	3.9525	2.859	1.7	2.7682	1.95833	1.1	3.3808	1.6996	1.5976
February	1.1	1.1068	3.32745	3.325	1.4106	1.1	2.3128	1.7121	1.1	1.4521	3.0867	2.2428
March	1.7604	1.4374	1.8533	4.07962	1.909	1.1	2.5608	3.4347	1.3075	1.2557	3.0958	2.5583
April	2.0933	1.9636	2.4032	3.3226	2.9166	1.1	1.20138	3.7255	1.13666	1.5173	1.1	1.1
May	1.8256	1.47272	2.1071	4.29561	2.3635	1.1	2.8578	5.2666	3.29	3.25166	1.1	1.1
June	1.3428	1.5955	2.35478	2.2488	2.271	2.795	2.18333	4.85	1.7866	4.1555	2.8888	3.8828
July	1.1	1.40982	2.1906	3.4755	4.5054	1.1	5.065	1.1	1.333	5.7653	1.1	1.1
August	1.5674	1.5242	1.43206	4.1566	2.9826	1.775	2.5931	1.12036	1.465	1.3	1.1	1.1
September	1.4222	1.3152	2.5032	2.9523	1.4625	3.8375	5.478	1.2885	1.3	1.1	1.75	1.1
October	1.4611	1.18888	2.56	1.1	1.1	1.1	1.1	1.1	1.1	3.8375	1.1	1.1
November	1.5264	1.187	1.1	1.1	1.1	1.1	1.1	1.1	1.2466	2.5166	1.1	1.1

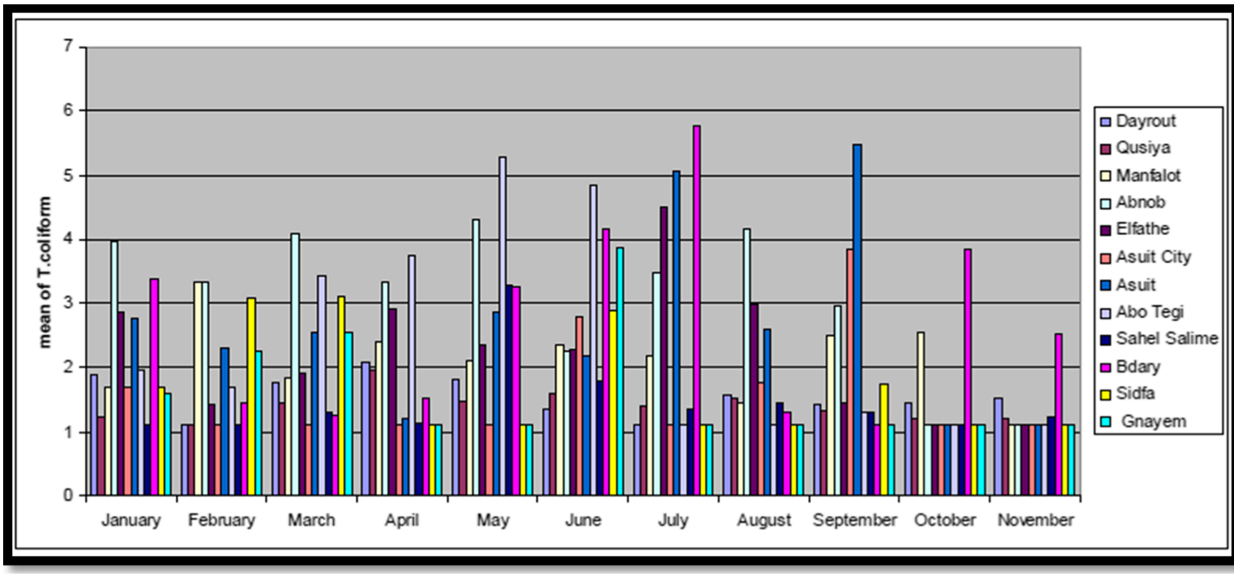

Fig. 14 Mean values of total coliform in the study area from Jan 2017 to Nov 2017

founded in El Badary, Assiut, El fath, and Abnob district then Manfalut and Gnayem, whereas the lowest values were found in Qusiya and Dayrout district.

Discussion

Water resource potentiality model for drinking uses

Water potentiality spatial model

The study developed water potentiality spatial model to identify the most appropriate area for drinking uses planning based on the bacteriological and chemical analysis; the model input included nine variables, i.e., water salinity, wells depth, and chemical and physical analysis of minor and major of groundwater wells. The results of the model are classified into five potentiality classes, such as high, moderately high, moderate, moderately low, and low. Figure 16 shows the model structure. Inspection of the model output (Fig. 17) indicates that the high quality of the groundwater of the quaternary aquifer is located in north of the Manfalut city, and two local lenses in south in ElFath and Abo Tig area. While low quality of groundwater is concentrated in the southern part of Assuit Governorate.

Conclusions

The study revealed that most of the groundwater in the area is suitable for drinking purposes according to

Table 6 Total seasonal coliform (MPN/100 ml) (2017)

	Winter	Spring	Summer	Autumn
Dayrout	1.49739	1.8931	1.336733	1.4699
Qusiya	1.1747	1.62457	1.50984	1.4636
Manfalot	2.515325	2.1212	1.99248	2.5316
Abnob	3.63875	3.89927	3.293633	2.02615
Elfathe	2.1348	2.396366	3.253	1.28125
Asuit City	1.4	1.1	1.89	2.46875
Asuit	2.5405	2.20666	3.28047	3.289
Abo Tegi	1.835215	4.142266	2.98518	1.19425
Sahel Salime	1.1	1.91138	1.5272	1.215533
Bdary	2.41645	2.0082	3.74026	2.4847
Sidfa	2.39315	1.765266	1.696	1.425
Gnayem	1.9202	1.5861	2.0276	1.1

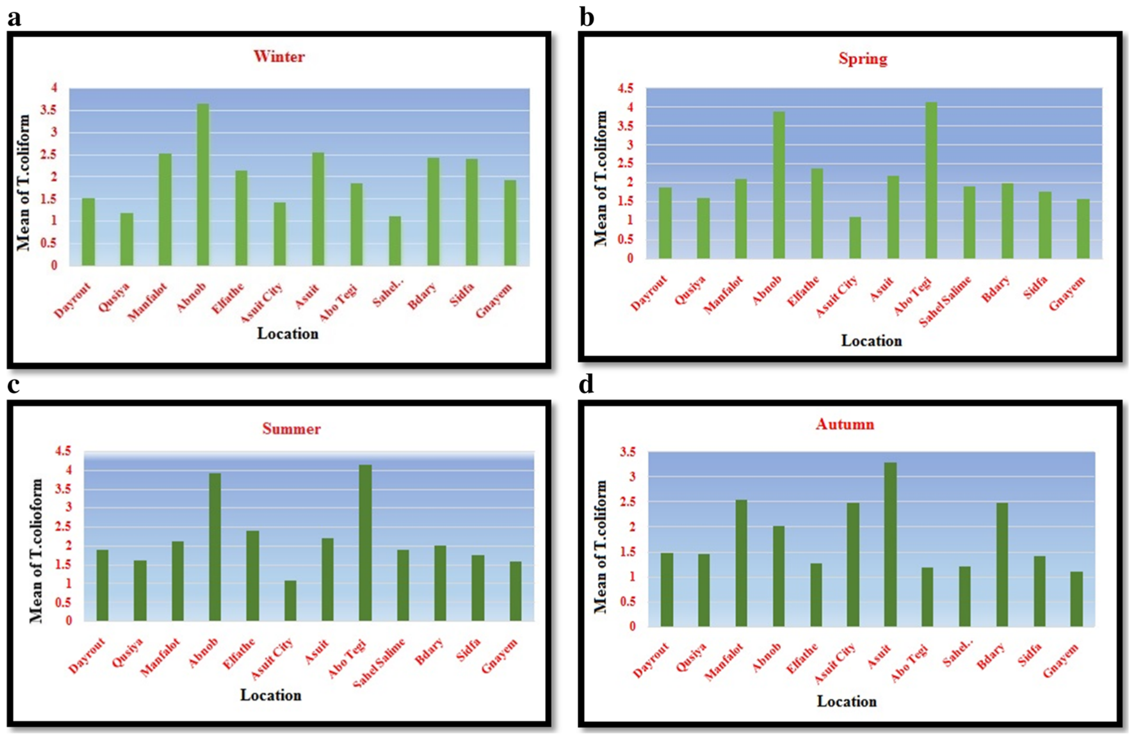

Fig. 15 Mean values of total coliform in the study area in **a** winter, **b** spring, **c** summer, and **d** autumn season from Jan 2017 to Nov 2017

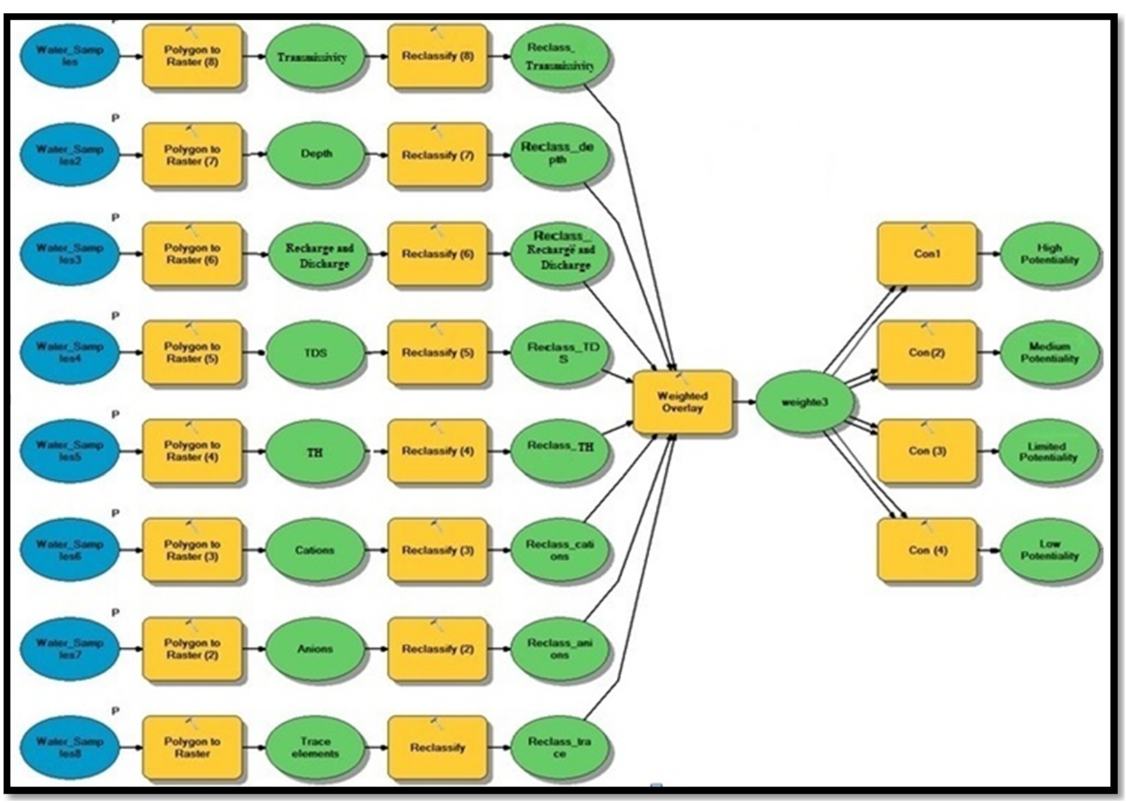

Fig. 16 Water recourses potentiality model flow chart for drinking uses

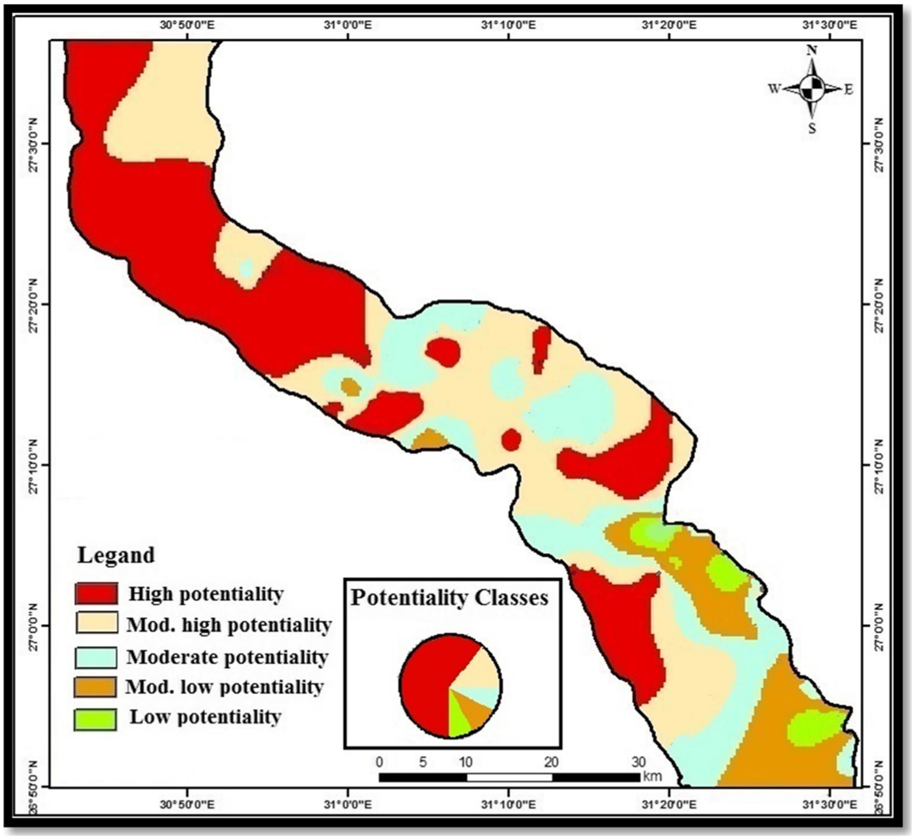

Fig. 17 Groundwater potentiality map of the study area for drinking uses

the chemical composition and the bacteriological analysis. The water quality is better close to the River Nile and El Ibrahymia Canal. Low water quality was detected close to the bounding of the Nile Valley either because of the effect of the adjacent Limestone plateau or the effect the Pliocene deposits.

Abbreviations

Ca^{2+}: Calcium; Cl^-: Chloride; EBT: Eriochrome Black T; Fe^+: Iron; GIS: Geographic information system; HCO_3^-: Bicarbonate; K^+: Potassium; Mg^{2+}: Magnesium; Mn^+: Manganese; MPN/100 ml: Most probable number per 100 ml; MTF: Multiple tube fermentation; MTF: Multiple-tube fermentation technique; Na^+: Sodium; NH_3^-: Ammonia; pH: Hydrogen ion concentrations; SO_4^{2-}: Sulfate; TC: Total coliform; TDS: Total dissolved solids; WHO: World Health Organization; WPSM: Water potentiality spatial model

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Availability of data and materials

All data generated or analyzed during this study are included in this manuscript.

Authors' contributions

HAM collected the groundwater samples and performed the chemical analyses of these samples and studied the geology and climate of the study area. AE-HAF build up the water potentiality spatial model to identify the most appropriate area for drinking uses planning based on the bacteriological and chemical analysis. Both authors read and approved the final manuscript.

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Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Competing interests

The authors declare that they have no competing interests.

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