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Environmental Impact of Wastewater Inflow on Groundwater Quality, West Girga, Sohag, Egypt

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Abstract

This research aims to determine the effects of wastewater irrigation on the groundwater quality west of Girga, Sohag, Egypt. Twenty-six groundwater and one sewage-treated effluent samples were analyzed using standard methods for a range of physio-chemical and microbiological parameters. Surrounding the wastewater plant, about 46% of collected samples were impacted by wastewater contamination, as indicated by positive detections of fecal coliform bacteria infiltrated into groundwater. The distribution of major ions in the groundwater is $Na^+>Ca^{2+}>Mg^{2+}>K^+$ and $Cl^->HCO_3^->SO_4^{2-}>NO_3^-$. The high salinity in the area may be due to the leaching of evaporites, chemical fertilizers, and irrigation return flow. The high sulfate concentration in the study area mainly from chemical fertilizers and wastewater. Cd, Pb, and Cu are enriched nearby the wastewater treatment plant suggesting contamination by wastewater disposal, while Fe, Mn, and Zn showed higher enrichment at the agricultural land, suggesting a mixing source from agrochemicals and atmospheric deposition of particles. Groundwater from the unconfined aquifer around the West Girga treatment plant is unsuitable for drinking purposes while suitable for irrigation with some restrictions in terms of heavy metals. To mitigate this, treatment of wastewater before irrigation and careful irrigation management is recommended.

Keywords: Wastewater, Groundwater Quality, West Girga, Sohag Governorate, Egypt.

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1. INTRODUCTION

The continuous use of wastewater produced by urban communities in agricultural activities worldwide poses potential health and environmental problems [1]. Over the past decade, the desalination and reuse of wastewaters have been practiced in most countries. In arid and semi-arid countries like Egypt, wastewaters have been utilized as a necessary component for irrigating crops and offering a low-cost water supply and higher agricultural yields [2]. The primary sewage treatment makes it safe for irrigation of non-food crops, such as forest trees, ornamental plants, and greenbelts [3].

In Sohag governorate, the wastewater plants service only the main cities where the villages are not equipped to treat their produced wastewater. They used the traditional septic tanks and cesspit system. These treatment units are placed in the desert fringes to the east and west of the cultivated areas.

In the west Girga region, the wastewater treatment plant and its attached farm are situated in the relatively high topographical zone adjacent to the old, cultivated lands. Surrounding the wastewater treatment plant, the newly reclaimed areas are widespread, depending on groundwater for irrigation. In the West-Girga treatment plant, secondary treatment was applied, including degradation of biological content derived from human waste. Treated water infiltrated from the farms and ponds that store treated water is likely to constitute a significant risk to public health as it seeps into the usable groundwater.

Different studies have focused on the new technologies and processes for wastewater treatment to reduce the cost of treatment in terms of reusing the wastewater for agriculture purposes [4-7]

The hydrochemical characteristics of the Quaternary aquifer in Sohag Governorate have been widely studied [8]–[12]. In contrast, the impact of municipal sewage effluent on groundwater has been studied surrounding the West Sohag treatment plant [13]. Moreover, different studies have considered the effect of sewage wastewater on groundwater quality in other areas [14], [15].

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This work aims to determine whether the polluted wastewater is infiltrated into groundwater and detect how far is the effect of the pollution and investigate the groundwater quality and its evaluation for drinking and irrigation purposes.

2. STUDY AREA CHARACTERISTICS

The city of Girga, in Sohag governorate, Egypt, is situated about 520 km south of Cairo and the West Girga area is one of the fastest-growing regions in agricultural activities depending on groundwater. The study area is a part of desert fringes west of Girga area, Sohag. It lies in Upper Egypt between latitudes 26º 14' 00" and 26 º 17' 00" N and Longitudes 31 º 46' 00" E and 32º 50' 00" E (Fig.1). The study area is characterized by newly cultivated land of desert areas, and it has elevations between 65 and 160 amsl. West Girga treatment plant is one of the main plants in Sohag Governorate that was launched for the first time in 2012 with capacity of 55000 m^3/day.

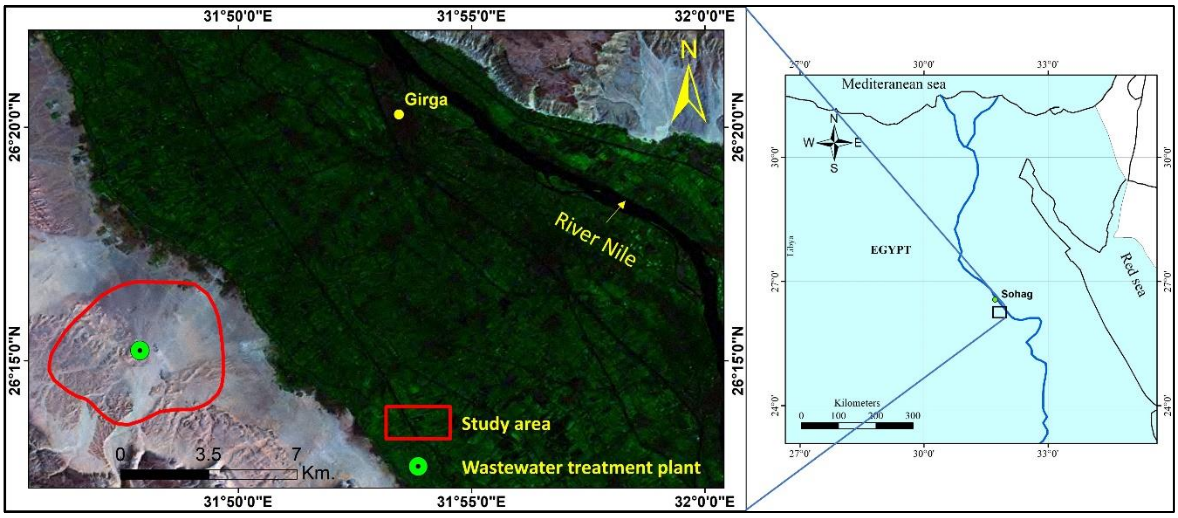

Fig. 1. Location map of the study area.

Geologically, the study area represents a part of Egypt's Nile valley geological system. The exposed sedimentary successions in the area are characterized by a wide range of sediments from older to younger starting from Lower Eocene to recent deposits (Fig. 2) [16].

The Lower Eocene Thebes Formation consists mainly of limestone with flint nodules exposed at the surface of the western plateau (Said 1960). Muneiha Formation (Early Pliocene) consists of fluvial sediments of clays with quartz grains [17] which form the base of the Quaternary aquifer (Fig. 3). Qena Formation of Early Pleistocene comprised coarse and medium-grained sand and gravel sediments, representing the main aquifer unit in the area. Kom Ombo, Ghawanim, and Dandara Formations are of the Pleistocene age of cross-bedded fluvial sediments that decrease in size to the lower deposits. It is represented by cross-bedded sand with gravel intercalation gradually down to medium and fine to very fine sands [18].

The Nile silt represents recent deposits at the surface of Nile Valley in addition to wadi deposits in the desert fringes formed from the transverse channels that accumulate the floods in the area.

3. HYDROGEOLOGICAL SETTING

Groundwater in the study area is drawn from the Quaternary and Plio-Pleistocene aquifer consisting of successive layers of fluvial sands and gravels with clay lenses [20]. In the Nile valley area, the Quaternary aquifer is semi-confined due to the silt-clay top layer that overlain the aquifer, while in the western fringes of Girga district, it is located under phreatic conditions (Fig. 3). This aquifer is composed mainly of sand with intercalation of clay lenses at different depths. At the foot slopes of the limestone plateau along the desert fringes, Plio–Pleistocene sediments are dominated. The aquifer is composed of gravely sand, clay, and limestone on the surface and is dominated by sand silty sand beds in the subsurface. Generally, the Quaternary aquifer is underlain by the Pliocene clay, representing the aquifer's base. The thickness of the aquifer varies between 20 m in the west below the plateau and 80 meters in the east beside the Nile Valley area.

The Quaternary aquifer is recharged by irrigation water infiltrated from cultivated lands and the subsurface flow from the surface canal system dominating the Nile Valley region. Locally, in the desert fringes, the groundwater flows towards the northwest, following the direction of the river Nile flow.

Samples were collected from some groundwater wells drilled in the desert fringes area, characterized by the absence of a cap silty clay layer. This may help stimulate treated wastewater filtration that negatively affects groundwater quality.

The groundwater level in the study area ranges from 55 m in (well no.16) to 59 m in (well no.9), resulting in groundwater flow toward the north and northwest (Fig. 5a), while the depths of groundwater range from 23 meters in (well no.2) to 92 meters in (well no.27) (Fig. 5b)

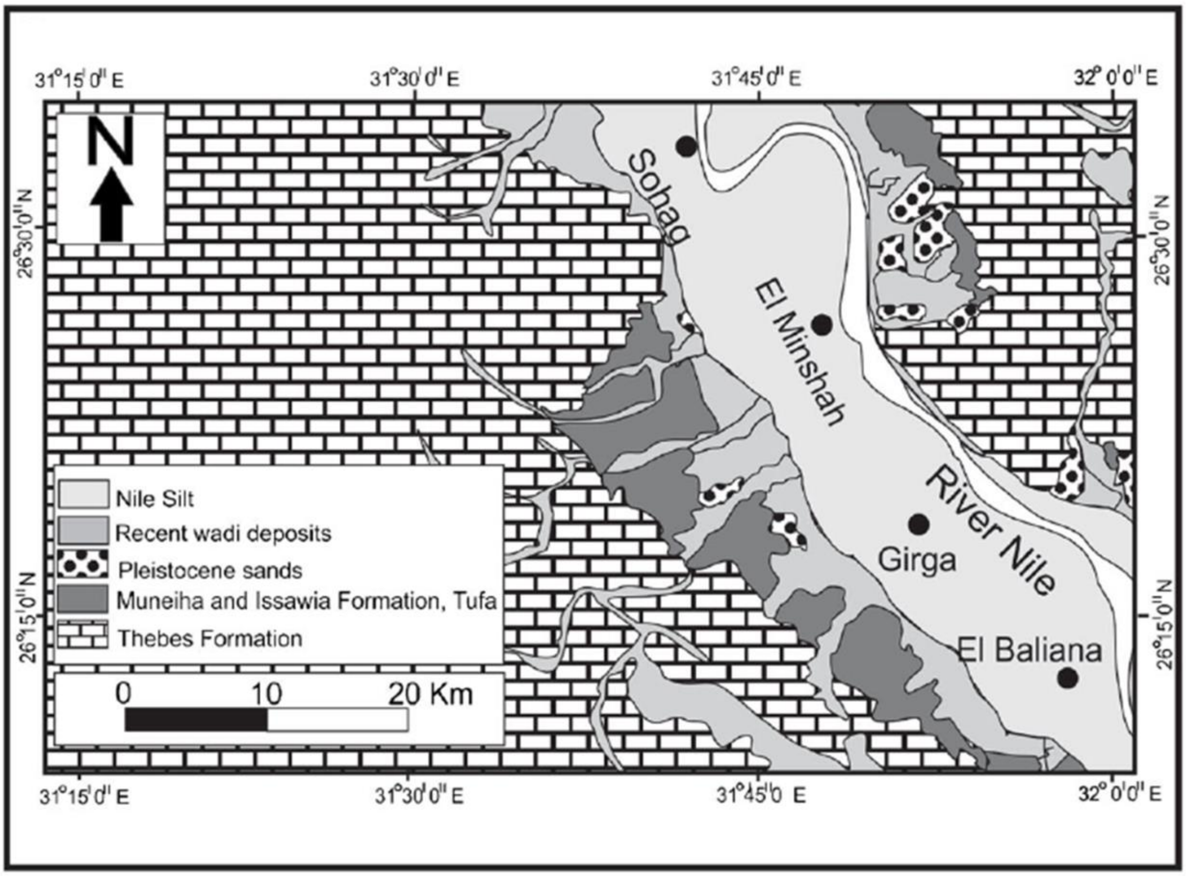

Fig. 2. Simplified geological map of west Sohag area [19].

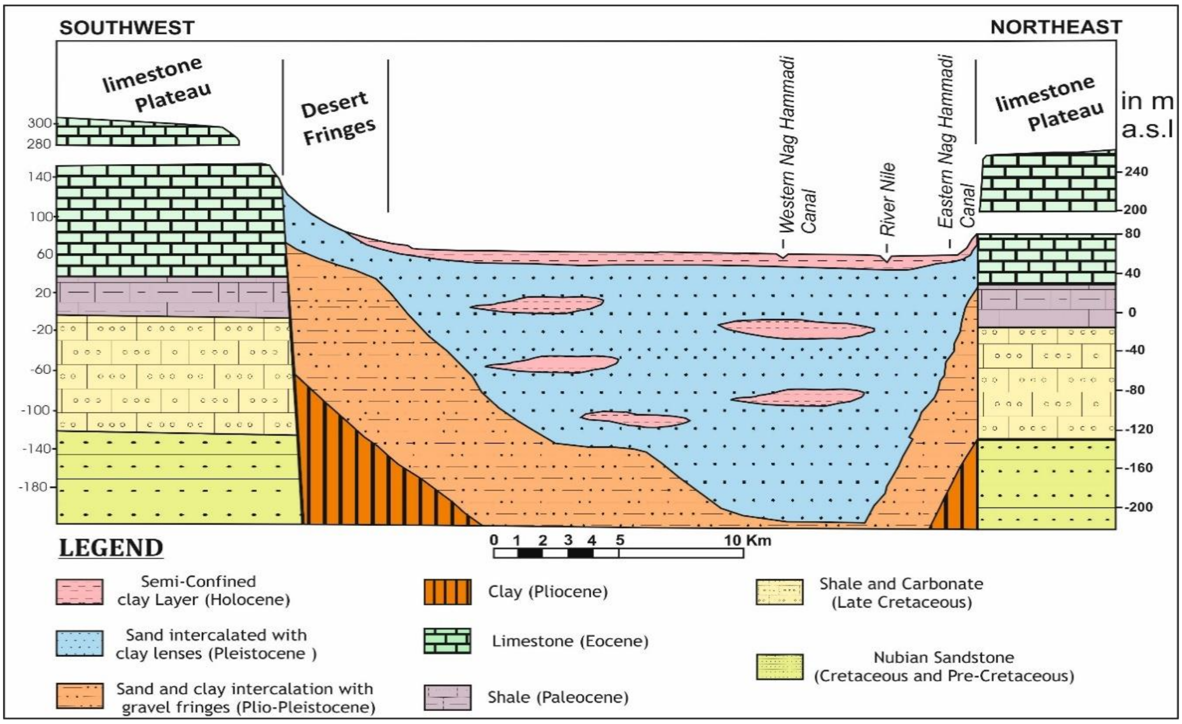

Fig. 3. The hydrogeologic cross section at Girga district, modified after [21].

4. MATERIALS AND METHODS

Twenty-six groundwater samples were collected from the available drilled wells in the study area, and one sample was collected from the treatment plant representing the treated sewage effluent (Fig. 4). The physio-chemical and bacterial analysis of the groundwater samples is used to evaluate the hydrochemical characteristics of the studied aquifer. AqQA (RockWare, Inc) and ArcGIS 10.5 were used to graphically represent the results of the chemical analyses of the collected groundwater samples.

The collected groundwater samples were analyzed at the wastewater Laboratory of the Sohag Water and Wastewater Company. The methods and techniques used in the chemical and bacteriological analyses include:

- A portable pH meter, EC-meter, and TDS-meter are used for measuring in situ parameters.
- Atomic Absorption Spectroscopy and Flame photometry: used to analyze of Cations such as Na^+, Ca^{2+}, Mg^{2+}, K^+., Pb, Zn, Cd, and Cu.
- Volumetric Analysis: titration used to estimate HCO_3^-, and Cl^-.
- Colorimetric and turbidimetric methods: used to estimate Sulfate SO_4^{2-}.
- Spectro photometric method: for NO_3^- and NH_4^+.

The multiple tube fermentation approach was used to conduct the bacteriological test.; MacConkey broth purple was used as a selective media, according to the standard methods for examining water and wastewater [22].

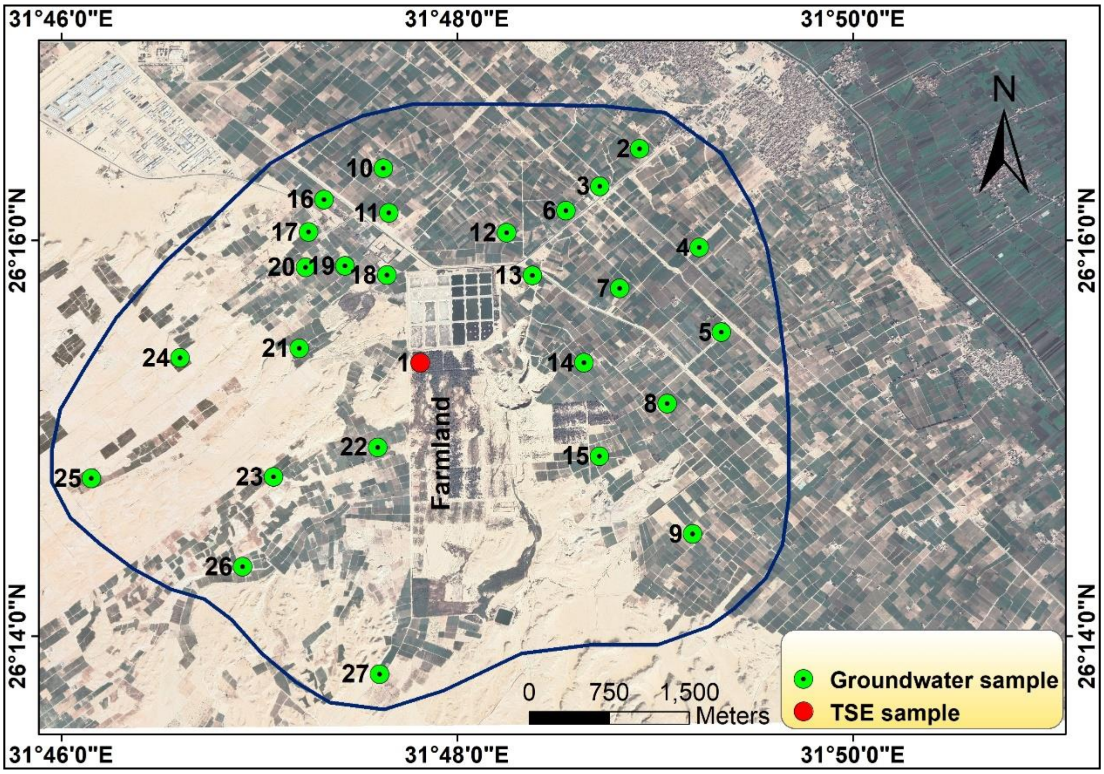

Fig. 4. Locations of the collected groundwater samples in the study area; TSE is a treated sewage effluent.

5. RESULTS AND DISCUSSIONS

5.1. Quality of treated sewage effluent

The results of the analysed sample for the treated sewage effluent were tabulated in (Table 1). The treated sewage effluent showed a positive indication of fecal coliform bacteria. The pH of the treated sewage effluent is 7.6. TDS value 1081 mg/L is out of the acceptable World Standards limit (< 1,000 mg/L). Except for Na^+ (265 ppm) and HCO_3^- (583 ppm), major cations and anions are within the permissible limits [23]. The sulfate value is 111 mg/L., nitrate is 0.74 mg/L. The maximum concentrations of heavy metals were Fe (0.181), Mn (0.131), Cu (0.016), Pb (0.033) and Zn (0.005 mg/L) in the treated wastewater lies within the permissible World limit but higher than in groundwater, except for Pb which exceeds the acceptable limits.

5.2. Geochemical characteristics of groundwater

Many groundwater samples showed positive indications of fecal coliform bacteria (46% of all groundwater samples) surrounding the disposal site and expanding northeast following the local topography and groundwater flow, reflecting the impact of wastewater on groundwater (Fig. 5c).

From the hydrogeological point of view, the depth of groundwater and the direction of groundwater flow significantly affect the deterioration of the groundwater quality near the water treatment plant. The pollution from sewage effluent increases in the shallow groundwater, as indicated in (well no. 11). In contrast, deep wells (e.g., well no. 23) are not polluted despite their relative proximity to the sewage discharge sites. Also, wells in the north and northwest of the treatment plant (e.g., well no. 24) are more susceptible to pollution than other wells. Wells located at a distance close to the treatment plant but in the opposite direction of groundwater flow (e.g., well no. 15) are not polluted from sewage effluent discharge.

The statistics for the measured physio-chemical parameters of the collected groundwater samples and the acceptable world limits for drinking [23] are shown in Table 1.

The groundwater samples were neutral to slightly alkaline, with pH values ranging from 7 to 7.8 in the groundwater samples. The study area is characterized by very high saline water (Fig. 5d) with a salinity of groundwater samples values varied from 833-2405 ppm in the analyzed samples (Fig. 6a). The major ions distribution in the groundwater is $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ and $Cl^- > HCO_3^- > SO_4^{2-} > NO_3$.

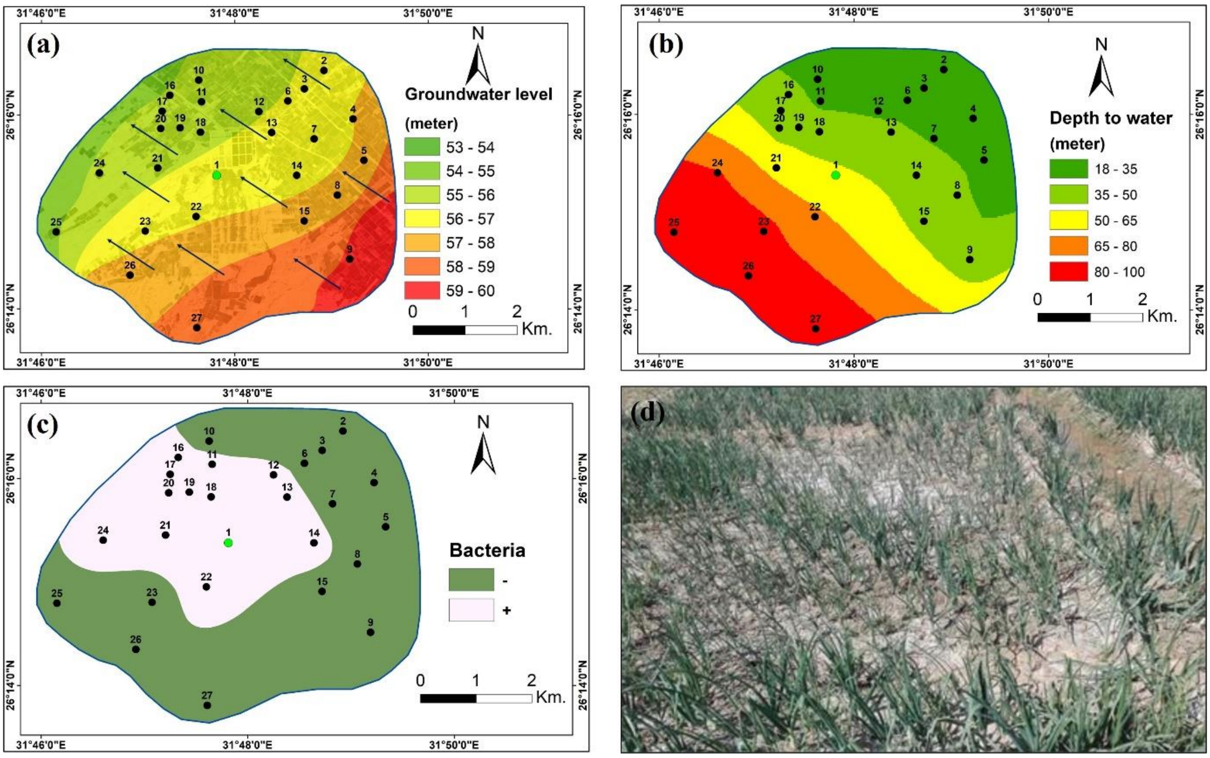

Fig. 5. (a) Water levels map with the common groundwater flow (b) Depth to water map, (c) Bacterial parameters with +/- signs refer to presence/non-presence of coliform bacteria, and (d) showing the high salinity with sulfate crystallization of irrigation water in the study area.

The treated sewage sample shows a high concentration of HCO_3^- which was reflected in the HCO_3^- concentration of groundwater as it ranges from 205-493.5 ppm in the study area (Fig. 6b). High sulfate concentration (Fig. 6c) indicates the impact of the addition of excessive sulfate fertilizer [24].

Wastewater disposal and leaching of evaporites and clays produce great Cl^- concentrations in the studied region. Evaporites, landfill leachate, chemical fertilizers, irrigation return flow, industrial discharge, brackish water from fish farms, and domestic wastewater may be the reason for the higher concentration of Cl^- [25]. The groundwater samples showed Cl^- concentrations from 148.5 to 722 mg/L (Figure 6d). The higher Cl^- concentration of the samples far from the disposal sites is due to the salinity of the sediments leached from the surface downward during irrigation.

Na^+, Ca^{2+}, $Mg^{2+,}$ and $K^{+,}$ concentrations show a large variation from 178.6-588, 32-216, 13.6-127.3, and 0.4-7.8 ppm, respectively (Fig. 7a-c). The potassium level in groundwater is usually low, and its elevated concentrations indicate the impact of wastewater and chemical fertilizers (Fig. 7d). In this study, K^+ concentrations in sewage effluent are low (0.2 ppm), whereas the normal average concentration in the sewage from domestic sources is 10.0–30.0 ppm [26]

TABLE 1. DESCRIPTIVE STATISTICS AND SUITABILITY OF DRINKING FOR GROUNDWATER PARAMETERS

	TSE-sample	Minimum	Maximum	Average	SD	WHO (2011)	Unsuitable samples (%)
pH	7.6	7	7.8	7.3	0.2	6.5 - 8.5	0
TDS	1081	833	2405	1399.6	495.3	1000	85
Ca^{2+}	74	32	216	105.2	50.5	75	78
Mg^{2+}	18.2	13.6	127.3	46.0	26.2	50	22
Na^{+}	265	178.6	588	302.2	131.5	200	81
K^{+}	0.2	0.4	7.8	3.5	2.1	12	0
HCO_3^-	583	205	493.5	309.4	70.3	500	0
Cl^-	120	148.5	722	343.1	172.1	250	63
SO_4^{2-}	111	143.6	413	251.7	82.5	250	33
NO_3^-	0.7	0	35.2	20.06	10.42	45	0
NH_4^+	7.2	0	3.2	0.88	0.90	0.5	48
Fe	0.181	0	0.2	0.103	0.059	0.3	0
Mn	0.131	0	0.1	0.057	0.035	0.4	0
Cu	0.016	0	0.008	0.002	0.002	2	0
Zn	0.005	0	0.012	0.003	0.004	3	0
Cd	0	0	0.0012	0.000	0.001	0.003	0
Pb	0.033	0	0.064	0.031	0.023	0.01	74

** TSE: Treated Sewage Effluent, Chemical composition in ppm*

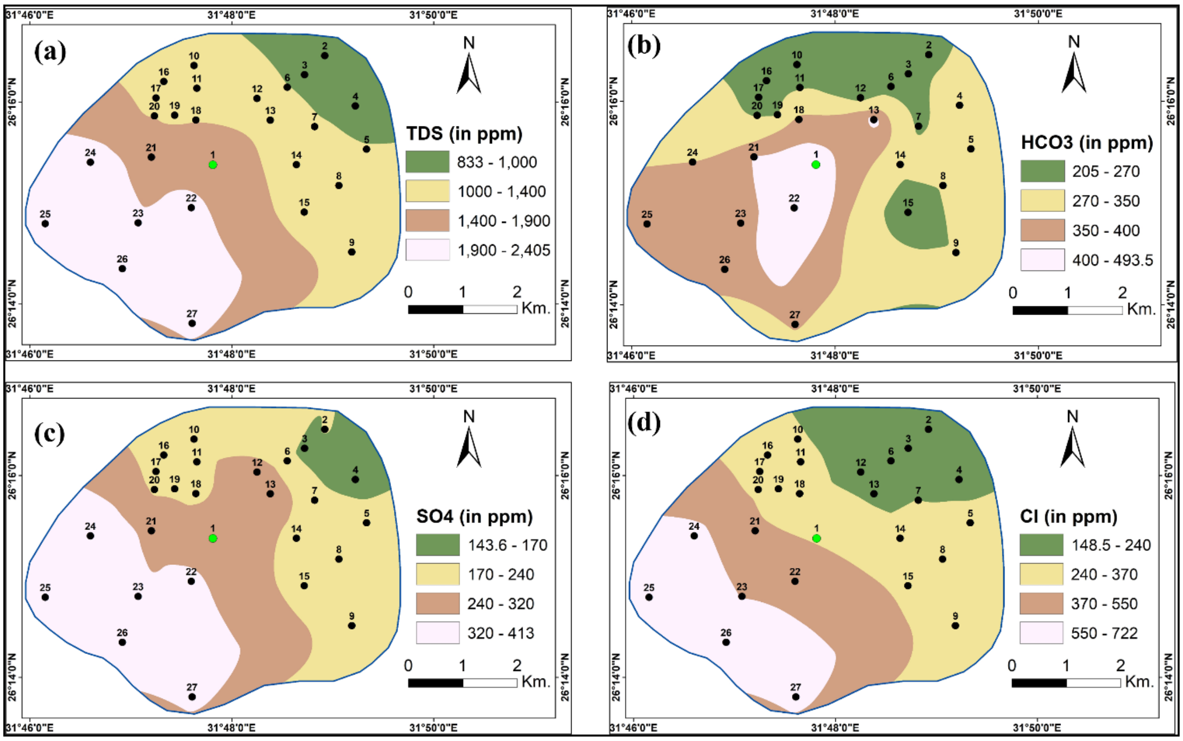

Fig. 6. TDS, HCO_3^-, SO_4^{2-} and Cl^- zones for groundwater samples in the study area.

Nitrate is very soluble in water and can be transported without interruption from the soil long distances to reach the water sources. Natural concentrations of NO3-, NH4+, and SO42- in rainfall are small [25]. Nitrification and denitrification are the main biochemical processes that influence the relative abundance of NO3- and NH4+. Soluble nitrogen derived from urine can be transferred to ammonium. Ammonium (NH4+) can be transferred to nitrite (NO2-) and then into nitrate (NO3-) during the nitrification process, and vice-versa depending on the redox condition. The natural anoxic groundwater has very low NO3- and NH4+, typically <0.1 mg/L of SO42-. The presence of NO3-, NH4+, and SO42- in amounts greater than expected from marine contributions (i.e., NO3-/Cl-, NH4+/ Cl-, and SO42-/Cl- mass ratios >0.0002 >0.07 and >0.14, respectively) is an indication of groundwater contamination by wastewater. However, the absence of NO3-, NH4+, or SO42- does not indicate that wastewater is absent because groundwater reducing conditions in aquifers remove SO42-, NO3-, and NH4+ from recharge [27].

NH_4^+ concentration of the samples ranges from 0 to 3.2 mg/L (Fig. 8). The lower values of NH_4^+ in some wells near the treatment plant are due to the transformation processes based on the aquifer conditions [27].

The distribution of heavy metals is not homogenous in the groundwater of the study area. The maximum concentration of Fe, Mn, Cu, Zn, and Pb in the groundwater of the study area are 0.2, 0.1, 0.008, 0.012, and 0.064 ppm, respectively. Cd, Pb, and Cu are enriched around the treatment plant suggesting contamination by wastewater disposal [28]. Fe, Mn, and Zn showed higher enrichment in the agricultural land, suggesting a common source (Figs. 8 and 9). According to [29], [30], the origins of Zn, Fe, and Mn in bed sediments are agrochemicals and residential wastes.

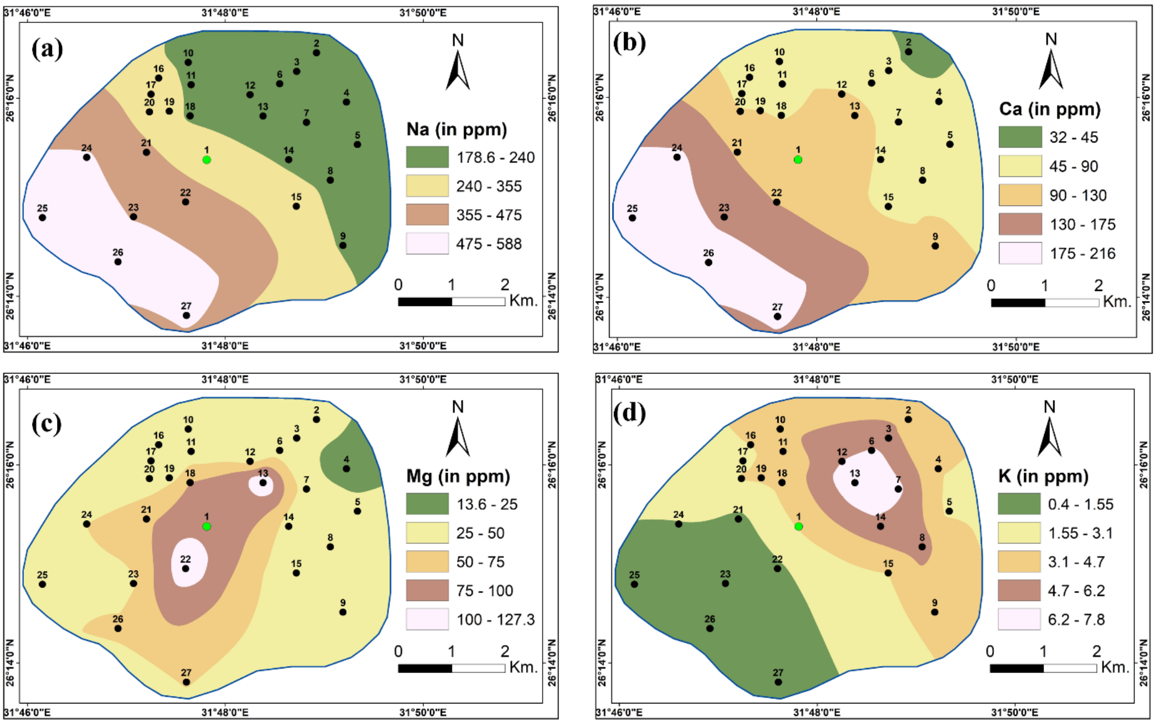

Fig. 7. Na^+, Ca^{2+}, Mg^{2+} and K^+ zones for groundwater samples in the study area.

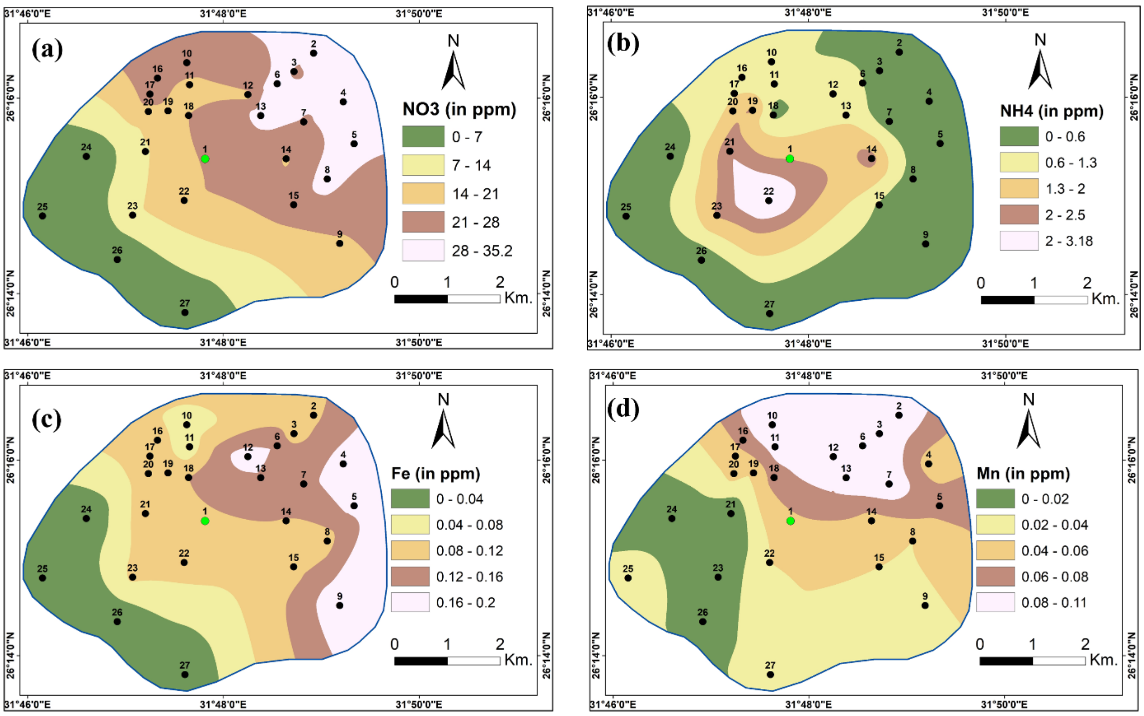

Fig. 8. NO_3^-, NH_4^+, Fe and Mn zones for groundwater samples in the study area.

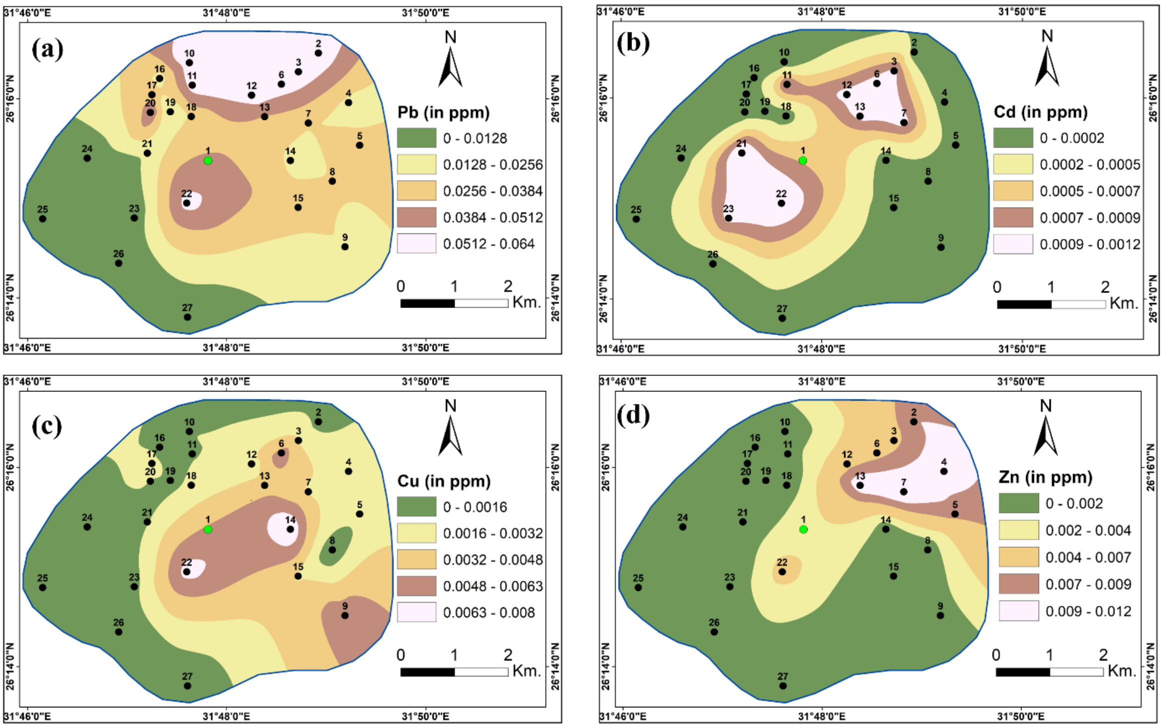

Fig. 9. Pb, Cd, Cu, and Zn zones for groundwater samples in the study area.

5.3. Groundwater evaluation for domestic uses

Water should be free from color, odor, and turbidity, while harmful microorganisms and radioactivity components or elements must be absent. The chemical analysis was compared with the Guidelines for Drinking-Water Quality [23].

TDS of the groundwater samples vary between 833 and 2405 ppm. In comparison, the maximum desirable limit is 500 ppm, and the absolute maximum limit is 1000 ppm, which appears in wells no. (2, 3, and 4), which are suitable for domestic uses according to salinity, while 78% of groundwater are not suitable for drinking purposes. A higher TDS value decreases palatability and causes digestive problems. Also, increased salinity in the water can cause the formation of salt stones in the urinary system and kidneys [31].

The Ca^{2+} is an essential element to develop proper bone growth. Ca^{2+} concentrations vary between 32 and 216 ppm. The maximum desirable limit of Ca^{2+} is 75 ppm. Therefore, most wells (78%) are not suitable for domestic uses. Mg^{2+} concentrations vary between 13.6 and 127.3 ppm. The maximum desirable limit of Mg^{2+} is 50 ppm. Na^{+} concentrations vary between 178.6 and 588 ppm. The absolute maximum limit of Na^{+} is 200 ppm. Therefore, all the wells, except wells nos. (3, 5,12, and 13) are not suitable for domestic uses. Na^{+} causes severe health problems like hypertension. K^{+} concentrations vary between 0.4 and 7.8 ppm. The absolute maximum limit of K^{+} is 12 ppm; all the groundwater samples are suitable.

Generally, the Cl^{-} and SO_4^{2-} are essential inorganic ions that deteriorate drinking water quality. Cl^{-} concentration varies between 148.5 and 722 ppm. The maximum desirable limit of Cl^{-} is 250 ppm. Therefore, only 34% of wells (2, 3, 4, 6, 7, 8, 10, 12, and 13) are suitable for domestic uses, while all the remnant groundwater samples are not suitable. Excessive drinking water containing sodium chloride can cause hypertension and congestive heart failure. Uncontrolled observations implicate sulfate in drinking water cause of dehydration from diarrhoea, and Cathartic effects [32]. SO_4^{2-} concentration varies between 143.6 and 413 ppm. The desirable maximum limit of SO_4^{2-} is 250. Therefore, (33%) of the collected samples are not suitable for domestic use. Bicarbonate is necessary for digestion and reduces the acidity of food ingredients. HCO_3^{-} concentration varies between 205 and 493.5 ppm. The absolute maximum limit of HCO_3^{-} is 500 ppm. Therefore, all wells are suitable for domestic uses.

Although nitrate is considered of low toxicity, its transformation into other forms as nitrite (NO_2^{-}) and N-nitroso compounds is responsible for many adverse health effects. These include methemoglobinemia, hypertension, nervous system diseases, birth defects, and even cancer via the bacterial production of N-nitroso compounds [33]. NO_3^{-} concentration varies between 0 and 35.2 ppm. The maximum desirable limit of NO_3^{-} is 50 ppm. Groundwater sample No. 6 showed high NO_3^{-} concentration (35.2 ppm).

5.4. Evaluation of irrigation water using residual sodium carbonate (RSC)

Excessive dissolved ions concentrations in the irrigation water affect plants and agricultural soil physically and chemically by lowering osmotic pressure in the plant structural cells. This inhibits water from reaching the branches and leaves, thus reducing agricultural productivity.

Carbonate ions ($HCO_3^- + CO_3^{2-}$) are among the most important elements that must be measured before using water in agriculture because they affect the soil as well as plant growth. When the irrigation water has ($HCO_3^- + CO_3^{2-}$) concentration over the alkaline earth elements, the excess react with Na^+ to form $NaHCO_3$, which has harmful effects on the soil structure [34].

As a result, the RSC parameter can be used to explain the water validity for irrigation. It can be calculated through the following equation:

$$RSC = (CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+}) \qquad \text{values in epm}$$

where RSC value of more than 2.5 is considered a high hazard and unsuitable for irrigation, while a value less than zero is excellent water quality for irrigation [34]. Moreover, the high concentration of Bicarbonate in water leads to an increase in its toxicity and affects the minerals nutrition of plants. From the results of the analysed samples, all samples have a value < 0 epm, and therefore are excellent and suitable for irrigation in terms of RSC.

6. CONCLUSION

- Surrounding the West Girga wastewater plant, about 46% of collected samples were influenced by wastewater drainage as indicated by coliform bacteria.
- Depth to water and direction of groundwater flow significantly affect the degradation of groundwater quality.
- Groundwater from the unconfined aquifer around the West Girga treatment plant is unsuitable for drinking and would be used for irrigation purposes with some restrictions in terms of heavy metals.
- The distribution of major ions in the groundwater is $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ and $Cl^- > HCO_3^- > SO_4^{2-} > NO_3^-$. Higher salinity in the area may be due to fertilizers, irrigation water, and domestic wastewater. Higher sulfate concentration is from chemical fertilizers and wastewater.
- Pb, Cu and Cd showed high enrichment nearby the treatment plant suggesting contamination by wastewater disposal. In contrast, Fe, Mn, and Zn showed higher enrichment at the agricultural land, suggesting a mixing source from agrochemicals and atmospheric deposition of particles.
- Due to the high salinity, chloride, sulfate, and sodium concentrations of groundwater in the west Girga area, regulation, monitoring, and remediation methods are recommended.
- The public groundwater wells should be at deeper depths to minimize its contamination from anthropogenic sources (wastewater and agricultural inflow).
- Tertiary-process treatments using low-cost technologies of treated sewage water are pre-requisite in order to reuse it in irrigation purposes.
- Periodic monitoring of groundwater quality and heavy metals distribution in the area are required for future remediation aspects.

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