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Temporal and spatial evaluation of the River Nile water quality between Qena and Sohag Cities, Egypt

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Abstract

Background: The River Nile became under stress in the last decades from the different human (anthropogenic) activities. The present work dealt with the River Nile water quality from Qena to Sohag districts, Egypt. Sixty water samples were collected during 2016 winter and summer and subjected to chemical analysis according to standard methods.

Results: The results indicated temporal and spatial variations in the chemical content of the collected water samples. The samples showed higher concentrations of Ca, Cl, Cd, Cu, Pb, Cr, and Zn during summer than winter, owing to intensive human activities during summer such as navigation and agricultural and industrial activities. The samples enriched with pH, TDS, Mg, Na, K, HCO_3, SO_4, and NO_3 during winter, due to the small water column and slow flow-rate.

Conclusion: The studied samples in winter and summer were unsuitable for drinking due to the recorded unacceptable concentrations of As, Cd, Cr, and Pb in the studied samples. The presence of As, Cd, Cr, and Pb may impact water consumer health because the used coagulation procedures in drinking water stations are not effective in the removal of these metals. The River Nile water is suitable for irrigation, except for some samples, which contain elevated concentrations of As and Cr. Finally, the River Nile protection laws must be strictly applied by national and international authorities to save its water quality.

Keywords: River Nile, Heavy metals, Drinking water, Irrigation water, Pollution, Spatial, Temporal, Evaluation, Egypt

Background

The River Nile is the main source of fresh water in Egypt. However, it has been reported that Egypt is one of the first 10 countries that will be suffering from water scarcity by the year 2025, due to the rapid population growth (Lawson 2011). The River Nile passes through 10 countries and gets its water from three Tributaries; the Blue Nile (68%), Atbara (22%) and the White Nile (10%) (Garzanti et al. 2015). The White Nile drains Archaean–Proterozoic rocks of the Congo Craton and extends through Precambrian rocks of the Saharan Metacraton (Abdelsalam et al. 2002). The Blue Nile and Atbara, together with its tributary the Tekeze, are sourced in the Ethiopian Highlands, where they drain the flood basalts (Garzanti et al. 2015).

One of the major environmental hazards worldwide is the pollution of water resources with heavy metals (HMs). HMs are present naturally in river water with very low concentrations safe for aquatic biota and come mainly from the weathering of rocks and soils. Meanwhile, the high concentrations come from the anthropogenic sources as domestic and industrial wastewater effluents and urban runoff (Reza and Singh 2010). The pollution of the aquatic environment with these metals can be poisonous and even killed the fish (Zeitoun and Mehana, 2014).

Human activities produce a huge amount of wastewater that can reach water bodies causing the deterioration of water quality and hence causing adverse human health impact (Melegy et al. 2014; Mohanta and Goel 2014). The River Nile receives a huge amount ($\approx 549 \times 10^6$ m^3 year^{-1}) of industrial effluents (El-Sheekh 2009). These effluents are loaded with different pollutant types, which can adversely impact the River Nile quality. The area contains many pollution point sources as agricultural drains, agro-industries, metallurgical (Aluminum) industries, navigation, and

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drinking water network washing station. Several authors (Ali et al., 2011; Melegy et al. 2014; Zaki et al. 2015, and Abu El Ella et al., 2017) pointed out the adverse impact of sugarcane industries on the River Nile water quality. Ipeaiyeda et al. (2012) concluded that the smelting activities in aluminum production led to the pollution of Essene Creek, Imo and Utaewa Rivers.

In the study area, coal is used in smelters that represent a major source of environmental pollution with HMs. On the other hand, the natural sources of pollution are the drains of the watersheds in the upstream and the Eastern Desert rocks during the seasonal flash floods. Also, the study area contains huge canal/drain networks. These networks facilitate the dispersal of pollutants into the river. The irrigation system in this region is by surface irrigation; therefore, the excess water containing these organic and/or inorganic chemical compounds migrates to the drains by infiltration or seepage. The aims of this work were the determination of the River Nile water quality and spatial as well as temporal variation in its inorganic chemical contents between Qena and Sohag districts.

Methods

Water samples were collected from 30 sampling points along the River Nile Trunk along a distance of about 150 km from Qena to Sohag districts (Fig. 1) in 1-L plastic bottles for physicochemical tests during winter 2016. The same sites were sampled again during summer 2016. A well-constrained Global Positioning System (GPS) was used for navigation to locate the sampling sites accurately. The samples were transferred to the Geological Sciences Department, National Research Centre (NRC), for analyses. The temperature, pH, and total dissolved solids (TDS) were determined in situ with digital HANNA pH meter (HI 991300), which was

Fig. 1 Location map of the study area and sampling Sites

calibrated prior to taking readings. In the laboratory, the samples were filtered and analyzed for chemical constituents by using standard procedures of APHA (1995). Calcium, magnesium, carbonate, bicarbonate and chloride were analyzed by volumetric methods. Sodium and potassium were determined by flame photometer. Nitrate and sulphate were determined by using HANNA Spectrophotometer instrument (model HI 83215). HMs were determined by using the atomic absorption spectroscopy (Perkin Elmer 400). The suitability of water for irrigation was determined by calculating the sodium absorption ratio (SAR) according to Richards (1954) equation (All values in meq/l):

$$SAR = Na^+ / \left[(Ca^{2+} + Mg^{2+})/2 \right]^{\frac{1}{2}}$$

Results

The measured parameters' descriptive statistics of the River Nile water for both winter and summer seasons are illustrated in Tables 1 and 2 and Figs. 2 and 3. Carbonate was not detected in the studied samples. Nearly all the collected samples contain acceptable levels of water major characteristics (Table 1) for drinking and irrigation purposes. It was observed that water samples contain higher concentrations of the studied parameters (except Ca and Cl) during winter over than summer. On contrary, samples collected during summer contained higher concentrations of Pb, Cr, Cu, Cd, As, and Zn than the samples collected during the winter season (Table 2).

Discussion

Water chemical characteristics

The recorded slightly alkaline pH is preferable in waters for the removal of heavy metals by precipitation as carbonate or bicarbonate (Ahipathy and Puttaiah 2006). The pH was relatively high in winter, because the water stays longer in contact with bottom sediment owing to the low flow rate and shallow water column. With respect to TDS, the water samples are considered good potable water with values < 500 ppm. A higher level of TDS during the winter season can be attributed to untreated agricultural and domestic wastes discharged into the river, as well as water longer contact with bottom sediment. Samples (23) and (24) were collected near agricultural drains while the sample (26) at Gerga Sugar factory. The water longer contact with bottom sediment was the main reason in the elevated concentrations of Mg, Na, K, HCO_3, SO_4, and NO_3 during winter than summer. The appearance of NO_3 in concentrations > 5 ppm is reflecting unsanitary conditions (Uqab et al. 2017) in the Nile water.

With respect to the studied HMs, Pb was the most dominant among all the metals studied in the collected water samples at different stations. The noticed low Pb
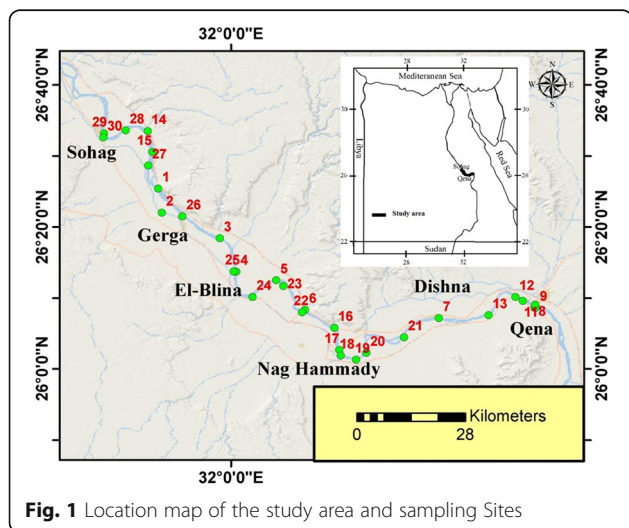
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Table 1 Descriptive statistics of the measured major characteristics of water sample

Parameter	Season	Min	Max	Mean	Q1	Q2	Q3	MAL	Passed %
pH	S	7.43	8.05	7.78 ± 0.19	7.6	7.84	7.97	6.5–8.5	100
	W	7.70	8.68	8.41 ± 0.23	8.39	8.45	8.54		96.6
TDS	S	130	270	148.7 ± 24.2	140	140	150	1000	100
	W	128.8	409.9	208.9 ± 53	187.4	199.1	207.9		100
Ca	S	24.9	45.7	31.1 ± 4.2	28.6	30.5	32.4	75	100
	W	18.4	59.6	28.6 ± 7.2	25.6	26.6	30.7		100
Mg	S	18.5	38.5	24.4 ± 4.1	21.6	23.1	26.3	100	100
	W	18.7	52.6	27.8 ± 7.7	22.1	27.5	31.6		100
Na	S	14.4	26.1	16 ± 2.1	15	15.6	15.6	250	100
	W	22.1	99.5	30.3 ± 13.8	25.4	27	29.4		100
K	S	1.4	6.22	3.7 ± 1	3.01	3.8	3.82	12	100
	W	3.5	6.9	4.4 ± 0.6	4.2	4.4	4.5		100
Cl	S	28	57.2	43.7 ± 7.1	40	44	47.9	250	100
	W	8.1	43.5	18.5 ± 8.9	12.1	16.2	23.2		100
HCO$_3$	S	122	274.5	157.7 ± 24.8	148.8	154.6	159.3	300*	100
	W	166.4	517.4	263.5 ± 77.2	215.9	256.9	285.5		87
SO$_4$	S	5	31.3	16.5 ± 7.3	10	15.6	20.6	250	100
	W	15	50	20.4 ± 6.4	18	20	20		100
NO$_3$	S	0	6.6	1.1 ± 1.5	0	0.5	1.5	50	100
	W	0.3	23.8	8.4 ± 5.7	3.9	6.3	12.9		100
SAR	S	0.45	0.69	0.52 ± 0.05	0.5	0.51	0.54	10**	100
	W	0.78	2.52	0.96 ± 0.31	0.84	0.9	0.94		100

W winter, *S* summer, *Min* minimum, *Max* Maximum, *MAL* maximum allowable concentration for drinking (WHO 2011)
Q1: 1st quartile (25% of samples); Q2: 2nd quartile (50% of samples); Q3: 3rd quartile (75% of samples). Passed %: the percent of samples acceptable for drinking
*HCO$_3$ acceptable value (in Zidi et al. 2017)
**SAR acceptable value (after Richards 1954)

Table 2 Descriptive statistics of the measured heavy metals (μg/l) in comparison with drinking and irrigation standards

Parameter	Season	Min	Max	Mean	Q1	Q2	Q3	MAL[1]	Pass[1]%	MAL[2]	Pass[2]%
Pb	W	163	202	183 ± 9.4	175	182	189	10	0	5000	100
	S	193	402	287.9 ± 57.3	239	289.5	332		0		100
Cr	W	1.7	62.9	23.1 ± 13.8	15.3	19.6	30.6	50	93.3	100	100
	S	63	467	288.2 ± 97	224.8	307.0	349		0		3.3
Cu	W	bdl	110	31.7 ± 34.1	0	25.0	50	2000	100	200	100
	S	bdl	170	40.7 ± 54.6	0	0	70		100		100
Cd	W	bdl	4	2.0 ± 1.1	1.3	2.0	3	3	93.3	10	100
	S	1	5	3.1 ± 1.0	2.3	3.0	4		70		100
As	W	bdl	3086	322.6 ± 698.3	0	0	228	10	63.3	100	70
	S	bdl	2380	375.4 ± 653.6	0	0	356		63.3		66.7
Zn	W	50	280	136.3 ± 48.4	102.5	130.0	160	3000	100	2000	100
	S	60	700	218 ± 149.5	140	170.0	220		100		100

bdl below detection limit, *MAL[1]* maximum allowable concentration for drinking, *Pass[1]%* the percent of samples acceptable for drinking, *MAL[2]* maximum allowable concentration for irrigation, *Pass[2]%* the percent of samples acceptable for irrigation

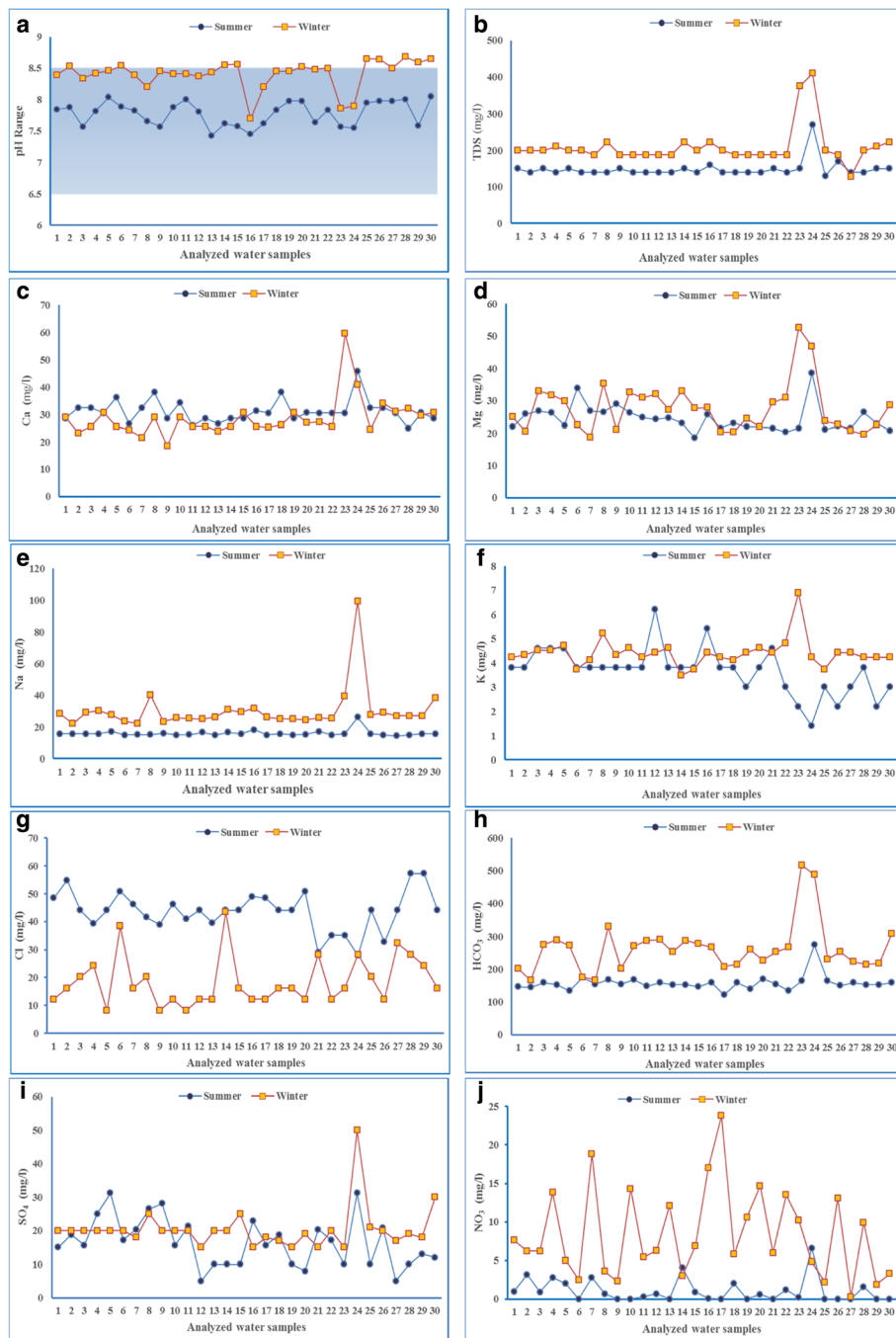Elnazer *et al. Bulletin of the National Research Centre* (2018) 42:3

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Fig. 2 Spatial and temporal variation in **a** pH, **b** TDS, **c** Ca, **d** Mg, **e** Na, **f** K, **g** Cl, **h** HCO₃, **i** SO₄, and **j** NO₃

concentration during the winter season compared to the summer season (Fig. 3a) may result from the human activities during summer such as navigation, traffic, wastewater effluents, and urban runoff. The spill of fuel and traffic exhaust can produce a considerable concentration of Pb (Elnazer et al. 2015). The Pb was detected as a pollutant for the River Nile from several decades, where 24 μg/l was recorded in 1987 (Lasheen 1987) and about

214.3 μg/l in 2009 (Toufeek 2011). Narrow ranges of Cd (bdl-4 and 1–5 μg/l in winter and summer, respectively) were recorded in the studied samples with noticed higher concentrations during summer than winter (Table 2, Fig. 3d). The higher concentration of Cd in the summer season might have resulted from the sediments of Lake Nasser, which contains about 0.175 μg/g of Cd (Goher et al. 2014). Also, navigation, agricultural runoff,
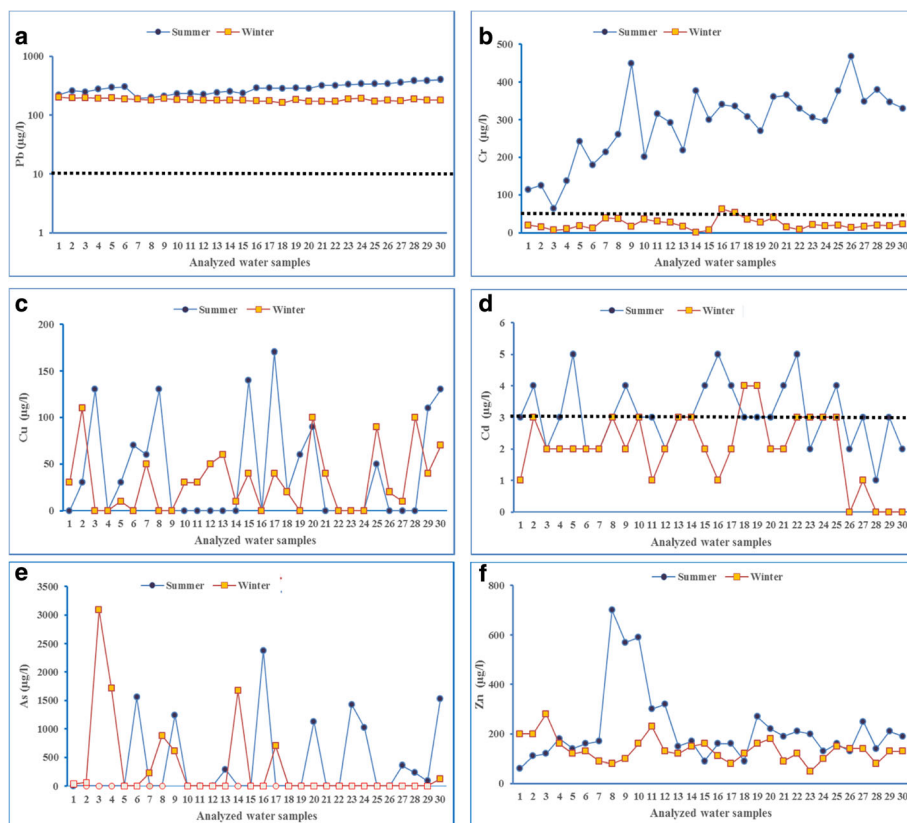
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Fig. 3 Spatial and temporal variation in **a** Pb, **b** Cr, **c** Cu, **d** Cd, **e** As, and **f** Zn concentrations (dashed line = allowable limits according to WHO 2011)

and sewage effluents discharge to the water courses contributed to the Cd load in this season.

Arsenic was detected only in about 36.7% of the studied samples. These results support the anthropogenic source of As in the study area water. The highest concentrations were recorded in Qena city (samples 8, 9, and 10), in agricultural drains (samples 14, 24, and 30), and at navigation sites (samples 4 and 20). The increase of As during summer than winter (Fig. 3e) might be due to the high and intensive activities during summer than winter such as navigation. The marked variation in As concentrations proposed intermixed sources in the study area including, to great extent, the role of human activities and to a limited extent the role of the natural process, especially the occasionally storms, which carry considerable amounts of sediments from the Eastern Desert mountains, where some rocks in the Eastern Desert contain up to 75 mg/kg of As (Sadek et al. 2015).

The mostly affected metal with seasonal variation was Cr; its concentration (Table 2) during summer (288.2 µg/l) was 12 times its concentration during winter (23.1 µg/l). The observed higher concentration of Cr during summer was mainly carried from the Ethiopian lands with water as a result of the dissolution of ferro-magnesian minerals by rains in the Ethiopian mafic/

ultramafic rocks (Omer, 1996). Copper was not detectable in > 50% of the samples collected during summer and 30% of the samples collected during winter. The reports show that sites with a low concentration of Cu had high Ca levels (Suresh 2008); this is supported by the negative correlation between Ca and Cu during the current study (Fig. 4) as a result of ion-exchange. The absence of Cu from about 50% of the studied samples during summer could be attributed to the high flow rate and volume of water, which led to the low interaction between sediments and water.
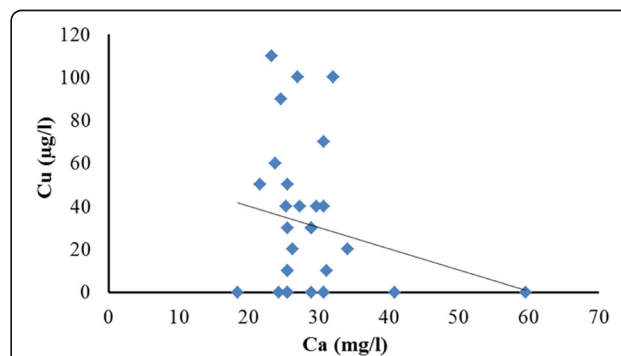

Fig. 4 Relationship between Ca and Cu during winter

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The recorded low concentrations of Zn can be attributed to its absorbance by bottom sediment (Singh 2005, Kabata-Pendias and Mukherjee 2007). The higher Zn concentration in summer than winter (Fig. 4f) might result from the small water column and slow flow-rate during winter, where Zn is mainly absorbed on the mineral grains. Also, lower pH values during summer than winter enhance the solubility of Zn (Singh 2005). Other sources of Zn into aquatic ecosystems include urban runoff, fertilizers, and municipal sewage (Kabata-Pendias and Mukherjee 2007, Damodharan 2013). Generally, the variation in the concentrations of the studied elements from site to another is mostly related to human activities (industrial, agricultural, urban runoff, traffic, etc.), which differentiate from location to another and also from winter to summer.

Evaluation of water for drinking

The results indicated the suitability of water for drinking purposes with respect to pH, TDS, Ca, Mg, Na, HCO_3, SO_4, Cl, NO_3, Cu, and Zn was within the permissible limits of WHO (2011) during the two seasons (Tables 1 and 2). Also, most of the studied samples contain acceptable levels of As (19 samples in winter and 19 samples in summer), Cd (28 samples in winter and 21 samples in summer), and Cr (28 samples in winter). On the other hand, the water samples contained unacceptable concentrations Pb (during winter and summer) and Cr (during summer).

The presence of the unacceptable concentrations of some metals in the River Nile water might cause health problems, because in Egypt, there are two types of water treatment plants (conventional and compact). The main step in the two types is the use of alum as a coagulant (Donia 2007). Unfortunately, the use of alum as coagulant had led to the appearance of high Al (the major component value in alum) concentrations in the domestic tap water (DWAF 1996). The presence of Al in water may cause Alzheimer's disease and carcinogenic effects. In addition, the percentage removal of the metals from raw water samples increased with mg/l dosage of coagulant. The efficiency of removal for As, Cd, Cr, Cu, Mn, Ni, and Zn was 3.7, 5.88, 85.42, 4.63, and 47.37%, respectively, at 10 mg/l dose of $Al_2(SO_4)_3$ (Fatoki and Ogunfowokan 2002). This indicates that till after treatment process toxic levels of metals may reach the end consumers of water causing many health problems. Therefore, more attention should be given to the presence and sources of these elements in drinking water by the governmental authorities.

Evaluation of water for irrigation

All the samples collected during this study had TDS < 500 ppm and considered excellent for irrigation without any detrimental effect according to Richards (1954). Also, all the samples collected during this study had SAR < 10 (Table 1) and can be used safely for all types of soil based on Richards (1954) classification of SAR. In addition, the studied water samples contain acceptable concentrations of the studied metals, except the recorded As (during winter and summer) and Cr (during summer only) in comparison with NAS-NAE (1972) allowable levels of HMs.

Conclusion

The River Nile water is fresh water with TDS < 500 ppm, with acceptable concentrations of the different ions. The main problem comes from the pollution of water mainly with Pb and to some extents with Cd, Cr, and As. The increased human activities during summer season had led to the increase of Ca, Cl, Cd, Cu, Pb, Cr, and Zn concentrations than the winter season. On the other hand, the slow flow rate and shallow water column during winter were caused the increase in the concentrations of pH, TDS, Mg, Na, K, HCO_3, SO_4, and NO_3.

Authors' contributions
All authors contributed equally in all article steps. All authors read and approved the final manuscript.

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