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Evaluation of human risks of surface water and groundwater contaminated with Cd and Pb in the southern El-Minya Governorate, Egypt

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Abstract. Water pollution with cadmium (Cd) and lead (Pb) is a worldwide concern because of their health impact. Determination of their concentrations and potential human health risks in surface water and groundwater in the southern El-Minya Governorate, Egypt, is the main aim of this study. Fifty-five samples were collected, 30 surface water samples and 25 groundwater samples. The samples were analyzed using atomic absorption spectrometry to determine Cd and Pb contents. Their levels in surface water and groundwater exceeded the maximum allowable level for drinking water set by the World Health Organization (WHO). The hazard quotient showed that the surface water and groundwater may pose a health risk to residents, especially to children.

1 Introduction

Water resource pollution is becoming a worldwide problem. To protect the environment and public health, it is important to have precise knowledge of the concentration and type of water pollutants, especially heavy metals. Cadmium (Cd) and lead (Pb) are among the most important chemical pollutants that threaten water quality for different uses. Monitoring their concentrations in water is critical for protecting ecological and human health because of their harmful effects and persistence (Nazar et al., 2012).

Cd is a major environmental concern and is ranked as the sixth most important toxic substance (ATSDR, 1997). It is released into the aqueous system from metal plating, smelting, mining, cadmium–nickel batteries, phosphate fertilizers, paint industries, pigments, and alloy industries, as well as from sewage (Kadirvalu and Namasivayam, 2003). The nervous system appears to be the most sensitive target of Cd toxicity. Cd exposure can produce a wide variety of acute and chronic effects in humans, such as renal failure, lung insufficiency, bone lesions, and hypertension (Sun and Li, 2011).

Pb is the most common environmental contaminant (Chiang et al., 2012). It does not undergo degradation or decomposition. Thus, its long persistence in the environment exacerbates its threat to human health. Pb is used in many industries, including lead smelting and processing, battery manufacturing, pigments, solder, plastics, cable sheathing, fuels, ammunition, and ceramics. Due to urbanization, Pb and other metals are regularly discharged into fields, water, and soils through sewage sludge, urban runoff, and automobile exhaust (Elnazer et al., 2015). Pb absorbed by the human body disturbs many processes and is harmful to organs such as the heart, bones, and nervous system (Bruce et al., 2012).

The application of a human health risk assessment model has many advantages in comparison with drinking water guidelines such as the WHO guidelines, because it takes into consideration the age, body weight, metal concentration, exposure duration, and daily intake (USEPA, 2011). So, quantifying human risk (carcinogenic and non-carcinogenic risks) of Cd and Pb to children and adults is important. The hazard quotient (HQ) is extensively used to characterize the carcinogenic and non-carcinogenic health effects of toxic metals by comparison of their exposure effects to a reference dose (RfD) (Qu et al., 2012). This was documented in several studies by taking into consideration exposure scenarios of metal intake through contaminated water (Muhammad et

Table 1. Surface water samples and localities.

Sample no.	Water stream name	Sample no.	Water stream name
S_3, S_6, S_{30}	River Nile	S_{28}	Al Nasriyah canal
S_1, S_5	Al Ibrahimayah canal	S_9	Branch from Ismail Siri canal
S_{11}, S_{20}, S_{24}	Bahr Youssef	S_{27}	Branch from Al Nasriyah canal
S_2	Al Sawahliyah canal	S_4	Al Sellic drain
S_7	Hafez canal	S_{14}	Jiris drain
S_8	Al ShiekhSharf canal	S_{15}	Al Moheet drain
S_{10}, S_{16}, S_{19}	Al Ashmoneen canal	S_{18}, S_{29}	Kabkab Drain
S_{12}, S_{17}	Ismail Siri canal	S_{21}	Al umomi drain
S_{13}	Al Mantutiyah canal	S_{22}	Al Sangrawi drain
S_{23}	Al Badraman canal	S_{26}	Tandah drain
S_{25}	Al Arosiyah canal		

Table 2. Cd and Pb concentrations in the surface water samples (µg L^{-1}).

Sample	Nile and canals		Drains		Sample	Nile and canals		Drains	
no.	Cd	Pb	Cd	Pb	no.	Cd	Pb	Cd	Pb
S_1	39	184	–	–	S_{18}	–	–	17	216
S_2	37	210	–	–	S_{19}	15	208	–	–
S_3	22	270	–	–	S_{20}	15	208	–	–
S_4	–	–	22	222	S_{21}	–	–	28	183
S_5	19	241	–	–	S_{22}	–	–	21	260
S_6	1	54	–	–	S_{23}	33	275	–	–
S_7	19	96	–	–	S_{24}	21	250	–	–
S_8	48	288	–	–	S_{25}	7	272	–	–
S_9	9	209	–	–	S_{26}	–	–	22	273
S_{10}	20	222	–	–	S_{27}	16	298	–	–
S_{11}	19	268	–	–	S_{28}	35	329	–	–
S_{12}	43	262	–	–	S_{29}	–	–	23	198
S_{13}	28	303	–	–	S_{30}	28	192	–	–
S_{14}	–	–	42	234	Mean	24	233	23	224
S_{15}	–	–	12	213	Median	21	245	22	219
S_{16}	32	225	–	–	Min.	1	54	12	183
S_{17}	22	261	–	–	Max.	48	329	42	273

al., 2011; Shah et al., 2012; Dou and Li, 2012). So, the objective of this study is the assessment of the potential human health risks for Cd and Pd in the surface water and groundwater systems in the western part of the River Nile between Abu Qurqas and Dyer Mawas districts, southern El-Minya Governorate, Egypt.

2 Materials and methods

2.1 Location

The study area occupied the middle part of the Nile Valley between longitudes 30°29′ and 30°54′ E and latitudes 27°37′ and 27°56′ N (Fig. 1). It is bounded by the River Nile from the east and the calcareous plateau in the west between Abu Qurqas northward and Dyer Mawas in the south. The water resources in the study area are represented by the River Nile, canals, drains, as well as groundwater (Fig. 1). The stratigraphic succession (Fig. 2) in the El-Minya area is represented by Tertiary and Quaternary sedimentary rocks (Said, 1981). The main aquifer in the study area is represented by Pleistocene sediments which are composed of sand and gravel of different sizes with some clay intercalation (Sadek, 2001). The aquifer is semi-confined in the old cultivated land (in the eastern part of the study area) and unconfined in the desert fringes (in the western part of the study area). The groundwater generally flows from the southern part to the northern part of the study area. The aquifer is recharged by Nile water, irrigation systems, drains, agricultural infiltration, and vertical upward from the deeper saline aquifers (Abdalla et al., 2009). The main sources of water for different purposes in the study area are the Nile, canals, drains, and groundwater. The study area contains many industrial zones, agricultural activities, and urban areas.

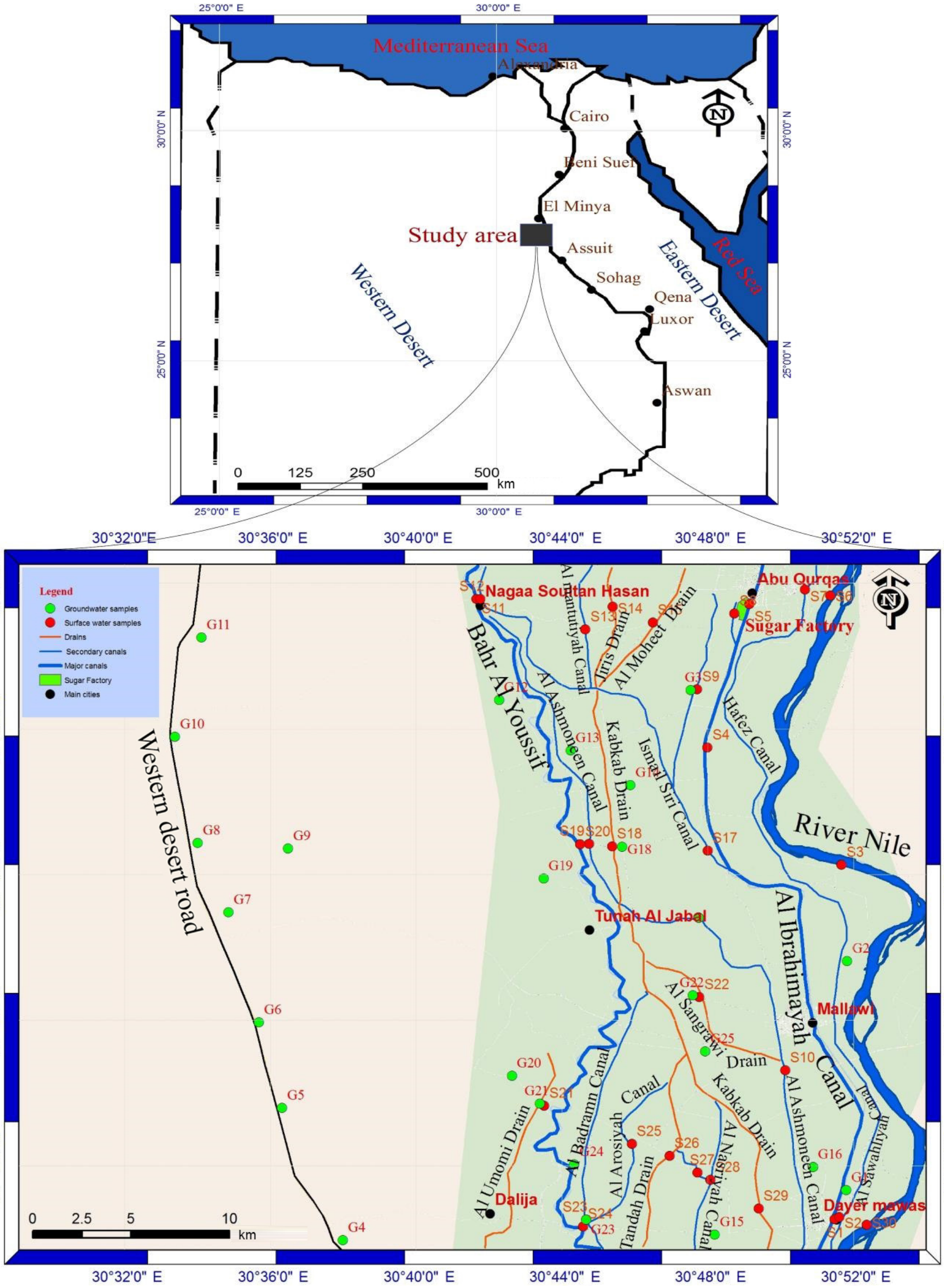

Figure 1. Location map of the study area.

2.2 Sampling and analyses

In November 2014, 30 water samples were collected from surface water resources in the study area (Fig. 1 and Table 1). In addition, 25 groundwater samples were collected from the Quaternary aquifer (Fig. 1). Pre-rinsed polypropylene bottles were filled with the samples, acidified ($pH < 2$) with nitric acid to prevent precipitation and microbial activity and sorption losses to container walls, and were sealed tightly. At the lab the samples were filtered through filter paper (Whatman no. 42) and digested with nitric acid (APHA, 1995). Samples were analyzed using an atomic absorption spectrometer instrument (model: Perkin Elmer 400) in the National Research Centre Laboratories.

For health risk assessment, non-carcinogenic (HQ_{nc}) and carcinogenic (HQ_c) hazard quotients for each contaminant were calculated according to the following equations (Kelepertzis, 2014):

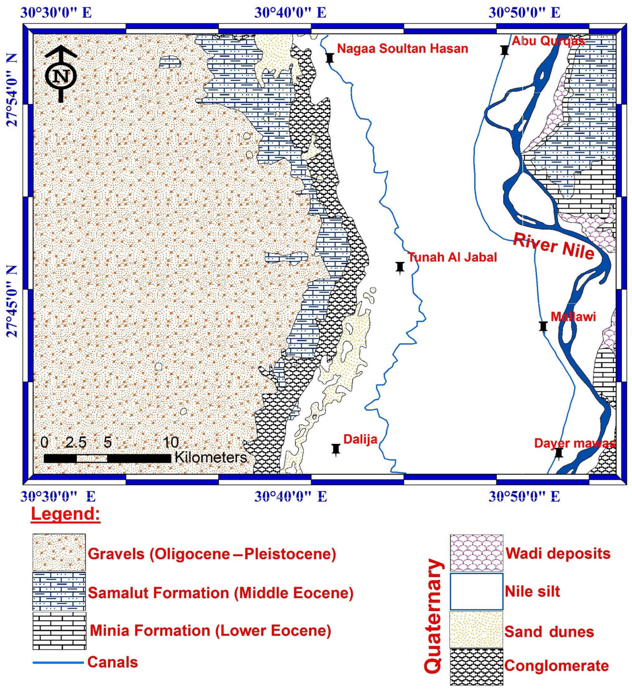

Figure 2. Geologic map of the study area.

$$HQ_{nc} = CDI/RfD, \tag{1}$$

$$HQ_{c} = CDI \cdot SF, \tag{2}$$

$$CDI = C \cdot IR \cdot ED \cdot EF/BW \cdot AT, \tag{3}$$

where CDI, C, IR, ED, EF, BW, AT, and RfD represent chronic daily intake ($mg\,kg^{-1}\,d^{-1}$), concentration of metal in water ($mg\,L^{-1}$), average daily intake rate ($2\,L\,d^{-1}$ for adults and $1.2\,L\,d^{-1}$ for children), exposure duration (15 years), exposure frequency (350 d), body weight (70 kg for adults and 28 kg for children), average time (ED*365 d for non-carcinogenic and lifetime*365 for carcinogenic risk) and toxicity reference dose. According to the USEPA (2011), the RfD for Cd and Pb are 0.0005 and $0.055\,mg\,kg^{-1}\,d^{-1}$, respectively, and the slope factor (SF) is 0.38 and $0.055\,mg\,kg^{-1}\,d^{-1}$, respectively. The average lifetime for an adult is 65, and 6.5 years for children.

3 Results and discussion

3.1 Surface water

The River Nile and its tributaries (canals and drains) are the main source of water in Egypt, especially for the governorates located on the river banks and on its branches. Cd concentrations (Table 2), ranging from 1 to $48\,\mu g\,L^{-1}$, exceeded the permissible limit ($3\,\mu g\,L^{-1}$) for drinking water according to the WHO (2011). Excess Cd could accumulate in the kidneys and remains for many years, causing irreversible kidney damage (Goyer, 1996). The number of kidney patients in the study area is presumed to have increased from 10 patients per million in 1974 to about 165 patients per million in 1995, and in 2005 it was 260 patients per million in El-Minya Governorate (El-Minshawy and Kamel, 2006). The highest concentration of Cd was recorded in sample number S_8, $48\,\mu g\,L^{-1}$, close to Abu Qurqas Sugar factory (Al-Shiekh Sharf canal). The lowest concentration was recorded in sample number S_6 ($1\,\mu g\,L^{-1}$), which was collected from the River Nile. These results are in line with those obtained by Toufeek (2011), who recorded an average Cd concentration of $12.5\,\mu g\,L^{-1}$ at Aswan (southern Egypt), while Melegy et al. (2014) found that the Cd levels in the collected samples from Sohag Governorate were around $16\,\mu g\,L^{-1}$. Osman and Kloas (2010) mentioned that the average Cd concentration in the River Nile at Assuit was $6\,\mu g\,L^{-1}$.

Table 3. Cd and Pb concentrations ($\mu g\,L^{-1}$) in the studied groundwater samples.

Sample no.	Cd	Pb	Sample no.	Cd	Pb
G_1	15	249	G_{15}	24	274
G_2	2	90	G_{16}	8	242
G_3	19	410	G_{17}	19	228
G_4	20	224	G_{18}	19	228
G_5	26	252	G_{19}	19	243
G_6	23	242	G_{20}	28	162
G_7	36	296	G_{21}	14	266
G_8	25	230	G_{22}	27	193
G_9	39	213	G_{23}	17	275
G_{10}	29	229	G_{24}	19	264
G_{11}	49	254	G_{25}	42	276
G_{12}	9	197	Mean	24	242
G_{13}	38	270	Minimum	2	90
G_{14}	23	242	Maximum	49	410

Pb concentration ranged from 54 to $329\,\mu g\,L^{-1}$ in the studied surface water samples (Table 2). The concentration of Pb passed the permissible limit ($10\,\mu g\,L^{-1}$) for drinking water according to the WHO (2011). Pb adsorbed by the human body disturbs many body processes and is harmful to many organs and tissues such as the heart, bones, and nervous system (Bruce et al., 2012). The highest concentration of Pb was recorded in sample number S_{28} ($329\,\mu g\,L^{-1}$) from Al-Nasriyah canal, while sample number S_6, which was collected from the River Nile in Abu Qurqas district, contained the lowest concentration ($54\,\mu g\,L^{-1}$). These results are in agreement with those obtained by Toufeek (2011), who reported about $214\,\mu g\,L^{-1}$ Pb in the River Nile at Aswan. In addition, Osman and Kloas (2010) proved that the average Pb concentration in the River Nile at Assuit was nearly $24\,\mu g\,L^{-1}$.

Agricultural activities are considered the most important source of Cd and Pb, where the used super-phosphate fertilizers in the study area contain about 8.5 and 16 ppm Cd

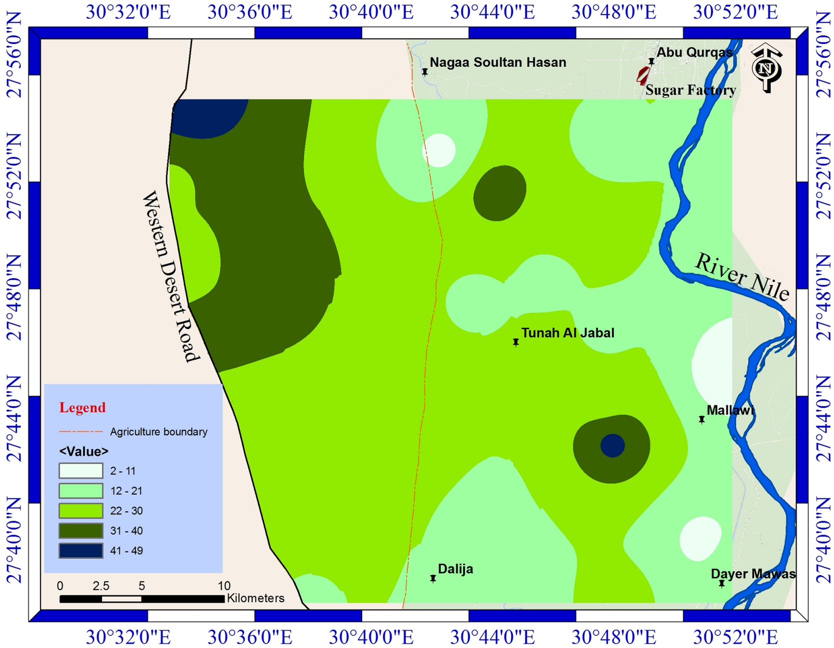

Figure 3. Spatial distribution map of Cd in the studied groundwater samples.

and Pb, respectively (Asmoay, 2017). In addition, vehicle exhaust, industrial activities, and urban runoff contribute to a great extent to the pollution of water with these metals (Elnazer et al., 2018).

3.2 Groundwater

Groundwater is the second important water resource in the study area, and it is used for irrigation as well as for domestic use and drinking in desert fringes and some villages which do not have access to drinking water. The groundwater samples exhibit a relatively wide range of the Cd level, varying from 2 to 49 $\mu g\, L^{-1}$ with a mean value of 24 $\mu g\, L^{-1}$ (Table 3). The groundwater Cd level decreased eastward (Fig. 3), probably due to mixing with the surface water from the River Nile and the role of the silty clay layer in the adsorption of Cd, which prevent it from reaching the aquifers (Asmoay, 2017). However, there were three hotspots of Cd identified, resulting from intensive human activities and fuel stations (Asmoay, 2017). The Cd hotspot in the northwestern part of the study area adjacent to the western desert road is vulnerable as a result of the unconfined condition of the aquifers (Asmoay, 2017).

Also, the measured Pb contents of the analyzed groundwater samples show a relatively wide range varying from 90 to 410 $\mu g\, L^{-1}$ with an average of 242 $\mu g\, L^{-1}$ (Table 3). The marked high level of Pb content implies that the anthropogenic activities (agricultural and urban runoff) are the main sources of Pb. The results are in agreement with Melegy et al. (2014), who mentioned that Cd and Pb concentrations in the groundwater of Sohag were around 21 and 383 $\mu g\, L^{-1}$, respectively. The Pb level in the groundwater of the study area was increased in Abu Qurqas district, resulting from the effect of the sugar factory, cesspits, and fuel stations (Asmoay, 2017) as shown in Fig. 4.

All the samples were unsuitable for drinking purposes where they possess Cd and Pb values above the permissible limit of 3 $\mu g\, L^{-1}$ for Cd and 10 $\mu g\, L^{-1}$ for Pb (WHO, 2011). On the other hand, surface water and groundwater were suitable for irrigation purposes according to NAS-NAE (1973), since they contain less than 10 and 5000 $mg\, L^{-1}$ of Cd and Pb, respectively.

3.3 Health risk assessment

Water from the River Nile and canals as well as groundwater are used for drinking and domestic purposes. The applied treatment techniques (flocculation and coagulation with alum) in drinking water stations (Donia, 2007) in the study area are effective for the removal of toxic metals bound to suspended solids (Fatoki and Ogunfowokan, 2002). However, it was observed that a great number of residents in rural areas use groundwater from hand pumps for drinking because they do not have access to the tap water. El-Minshawy and Kamel (2006) mentioned that the use of unsafe water for drinking contributes up to 71.8 % of the renal failure in the study area. Therefore, health risk assessments of surface water and groundwater were also carried out in this study. The results of HQ_{nc} and HQ_c due to metal exposure in surface water and groundwater samples are provided in Tables 4 and 5.

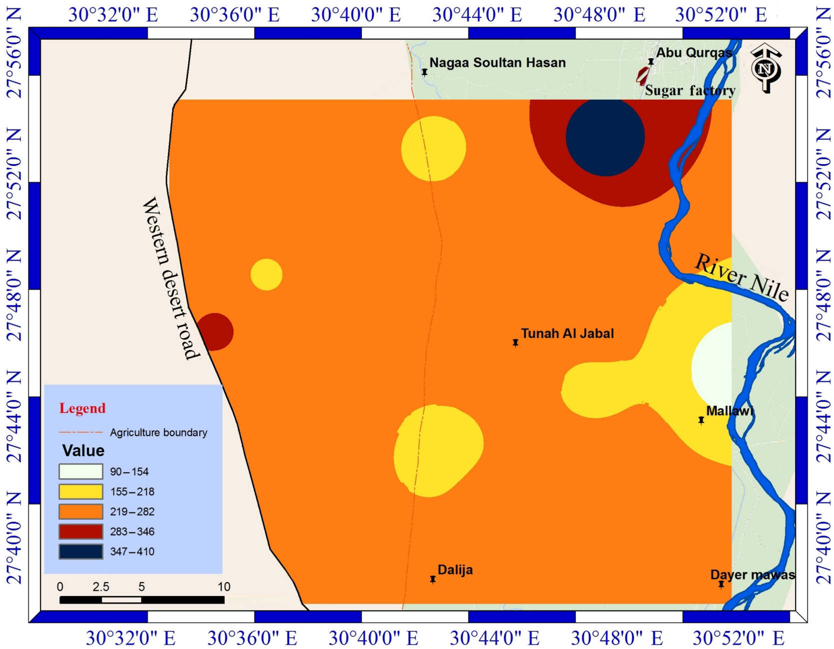

Figure 4. Spatial distribution map of Pb in the studied groundwater samples.

Table 4. Statistical parameters of non-carcinogenic and carcinogenic health risks for surface water samples.

Parameter	HQ_{nc} for adults		HQ_{nc} for children	
	Cd	Pb	Cd	Pb
Minimum	0.05	0.03	0.08	0.04
Maximum	2.06	0.16	3.95	0.25
Average	1.30	0.11	1.96	0.17
Parameter	HQ_c for adults		HQ_c for children	
	Cd	Pb	Cd	Pb
Minimum	0.17×10^{-4}	6.2×10^{-3}	0.1×10^{-5}	3.7×10^{-2}
Maximum	7.9×10^{-4}	37×10^{-3}	4.8×10^{-3}	22×10^{-2}
Average	3.9×10^{-4}	26×10^{-3}	2.3×10^{-3}	15×10^{-2}

Table 5. Statistical parameters of non-carcinogenic and carcinogenic health risks for groundwater samples.

Parameter	HQ_{nc} for adults		HQ_{nc} for children	
	Cd	Pb	Cd	Pb
Minimum	0.11	0.04	0.16	0.07
Maximum	2.68	0.20	4.03	0.31
Average	1.29	0.12	1.94	0.18
Parameter	HQ_c for adults		HQ_c for children	
	Cd	Pb	Cd	Pb
Minimum	4.8×10^{-6}	3.13×10^{-5}	2.9×10^{-5}	1.67×10^{-9}
Maximum	1.2×10^{-4}	14.3×10^{-5}	7.11×10^{-4}	86.1×10^{-5}
Average	5.66×10^{-5}	8.41×10^{-5}	3.42×10^{-4}	48.5×10^{-5}

The calculated HQ_{nc} average values for Cd in surface water for adults and children were 1.30 and 1.96, respectively, while HQ_{nc} average values for Pb were 0.11 and 0.17 (Table 4). On the other hand, the calculated HQ_{nc} average values for Cd in groundwater for adults and children were 1.29 and 1.94, respectively, while HQ_{nc} average values for Pb were 0.12 and 0.18 (Table 5). According to the USEPA (2011), Cd can cause non-carcinogenic health problems because its HQ_{nc} values were more than 1, while Pb presence in water had no adverse health impacts ($HQ_{nc} < 1$), although its concentration did exceed WHO (2011) guidelines.

The calculated HQ_c values for Cd in the surface water for adults ranged from 0.17×10^{-4} to 7.9×10^{-4} and for children from 0.1×10^{-5} to 4.8×10^{-3} (Table 4). The calculated HQ_c values for Pb varied from 6.2×10^{-3} to 37×10^{-3} for adults and varied from 3.7×10^{-2} to 22×10^{-2} for children (Table 4), while the calculated HQ_c values for Cd in the groundwater ranged from 4.8×10^{-6} to 1.2×10^{-4} for adults and from 2.9×10^{-5} to 7.11×10^{-4} for children (Table 5). The calculated HQ_c values for Pb varied between 3.13×10^{-5} and 14.3×10^{-5} for adults and varied from 1.67×10^{-9} to 86.1×10^{-5} for children (Table 5). According to USEPA (2011) recommended values ($HQ_c < 10^{-6}$), the studied surface water and groundwater consumption could cause carcinogenic health risks in adults and children.

4 Conclusions

Cd and Pb contents of the studied samples from the River Nile, canals, drains as well as groundwater exceeded the permissible limits for drinking water and could have adverse, carcinogenic, impacts.

Data availability. No data sets were used in this article.

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

Competing interests. The authors declare that they have no conflict of interest.

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