Evaluation of human risks of surface water and groundwater contaminated with Cd and Pb south of El-Minya Governorate, Egypt.

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Abstract:

Water pollution with cadmium (Cd) and lead (Pb) has worldwide concern because of their health impact. Evaluation of their concentrations and potential human health risks of surface and groundwater south El-Minya Governorate, Egypt is the main aim of the study. Fifty-five samples were collected; 30 samples surface water and 25 samples groundwater. The samples were analyzed using Atomic Absorption Spectrometry (AAS) to determine Cd and Pb contents. The heavy metals levels in both of surface and groundwater exceeded the maximum allowable level for drinking water which set by World Health Organization (WHO). The hazard quotient (HQ) showed that the surface water and the groundwater may pose a health risk to residents, especially the children, primarily due to the high Cd and Pb content. The pollution returns to human activities. The water can be recommended for irrigation, not for drinking.

1. Introduction

Water pollution resource has becoming a worldwide problem. To protect the environment and public health, it is important to have precise knowledge of concentrations and type of water pollutants, especially heavy metals. Because the heavy metals have long biological half-life, they are threating the human health in case of excessive concentrations

(Albji et al., 2013). Cadmium and lead are of the most chemical pollutants that threaten the water quality for different uses. Because of their harmful effects, persistence, identification and monitoring of their concentrations in water are of critical importance for protecting ecological and human health (Osei et. al., 2010; Nazar, et. al., 2012).

Cadmium has a major environmental concern and ranked as the sixth significant human health hazard toxic substances (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. Cadmium exposure can produce a wide variety of acute and chronic effects in humans such as renal failure, lung insufficiency, bone lesions and hypertension (Gupta and Bhattacharyya, 2007; Sun and Li, 2011).

Lead is used in many industries including lead smelting and processing, batteries manufacture, pigments, solder, plastics, cable sheathing, ammunition and ceramics. It was the most common environmental contaminant (Chiang et. al, 2012; Fischbein, 1998). Water and soil contaminated with lead pose serious human health risks with global dimensions (Tong et. al., 2000; Brooks et. al., 2010). Lead does not undergo degradation or decomposition. Thus, its long persistence in the environment exacerbates its threat to human health. Lead absorbed by human body disturbs many processes and is harmful to many organs and tissues such as heart, bones and nervous systems (Needleman, 2004; Bruce et. al., 2012). Fumes from lead-based paints, automobile exhaust, polluted air of industrial plants and cigarette smoke may all contain lead, therefore, products containing lead are now prohibited (Moreira and Moreira, 2004). Due to urbanization, lead and other metals are regularly discharged into fields, water and soils through sewage sludge (Abreu et al., 1998).

Depending on their concentration, heavy metals can result in a wide range of toxic effects on humans, plants, animals, and microbes (Caliza et al., 2012; Qu et al., 2012). Quantify both of carcinogenic risks for Cd and non-carcinogenic risk for Cd and Pb to children and adults is important. Human risk assessment methodologies are well developed and documented in lots of investigations by taking into consideration exposure scenarios of metal intake through contaminated water (Muhammad et al., 2011; Shah et al., 2012; Dou and Li, 2012). The hazard quotients (HQ) of the USEPA (1989) are extensively used to characterize the non-carcinogenic health effects of toxic metals by comparison of their exposure effects to a reference dose (R*f*D) (Qu et al., 2012).

The objective of the present study is to assess the health risk for cadmium and lead in the surface water and the groundwater systems in the western part of the River Nile between Abu Qurqas and Dyer Mawas districts, El-Minya Governorate, Egypt.

2. Material 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 at the west between Abu Qurqas northward and Dyer Mawas at the south. The water resources in the study area are represented by the River Nile, canals and drains as well as groundwater (Fig. 1). The River Nile passes through high eastern and western calcareous plateaus with a general slope from south to north about 0.1 m/km (Korany et al 2006). The stratigraphic succession in El-Minya area is represented by Tertiary and Quaternary sedimentary rocks (Fig. 2). The distribution of the different rock units was indicated in Said (1981). The stratigraphic sequence is built up from base to top as follow: Middle Eocene limestone intercalated with shale (Samalut Formation); Pliocene undifferentiated sands, clays, and conglomerates; Plio-Pleistocene sand and gravel with clay and shale lenses; Pleistocene sand and gravel with clay lenses and Holocene silt and clay. The main aquifer in the study area is represented by Pleistocene sediments which compose of sand and gravel of different sizes with some clay intercalation. The thickness of this aquifer ranged from 25 to 300 m from desert fringes to central Nile Valley (Sadek 2001). The aquifer is underlined by impermeable Pliocene clay layer and overlain by semi-permeable silty clay layer. The semi-confined bed (silty clay) is missed outside the floodplain and the aquifer becomes unconfined westward in the desert fringes. The groundwater flows generally from the southern part to the northern part of the study area. Locally, the groundwater flows from the center outwards in all directions; therefore, the River Nile is a recharge zone. The aquifer is recharged by Nile water, irrigation system, drains, agricultural infiltration and vertical upward from the deeper saline aquifers (Korany, 1984).

In November 2014, thirty water samples were collected from surface water resources at 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, sealed tightly. At lab, the samples were filtered through filter paper (Whatman No. 42) and digested with nitric acid (APHA, 1995). Samples were analyzed using atomic absorption spectrometer instrument (model: Perkin Elmer 400) in National Research Centre Laboratories.

For health risk assessment, chronic daily intake (CDI, mg/kg/day) and hazard quotient (HQ) for each contaminant was calculated according to the following equations (Eq. 1, 2, 3) adopted by Kelepertzis (2014):

$$CDI = C*IR*ED*EF/BW*AT \quad (1)$$

$$HQ_{non\text{-}carcinogenic} = CDI / RfD \quad (2)$$

$$HQ_{carcinogenic} = CDI * SF \quad (3)$$

where, C, IR, ED, EF, BW, AT and R*f*D represent the concentration of metal in water (mg/L), average daily intake rate (2 L/day for adult and 1.2 L/day for children), exposure duration (15 years), exposure frequency (350 days), body weight (70kg for adult and 28kg for children), average time (ED*365 days for non-carcinogenic and lifetime*365 for carcinogenic risk) and toxicity reference dose. According to USEPA (2011) the R*f*D for Cd and Pb are 0.0005 and 0.055 mg/kg/day respectively. Also, slope factor (SF) for Cd and Pb are 0.38 and 0.055 mg/kg/day respectively. The average lifetime for an adult is 65 years and 6.5 years for children (USEPA, 2011).

3. Results and Discussion

3.1. Surface water

River Nile and its tributaries (canals and drains) are the main source of water in Egypt especially for the governorates allocated on the river banks and on its branches. Therefore, the quality of water was evaluated by measuring of Cd and Pb concentrations in the south of El-Minya Governorate during 2014 (Table 2). Cadmium concentrations (Table 2), ranged from 1 to 48µg/l, exceed the permissible limit (3µg/l) for drinking water according to WHO (2011). Excess Cd could accumulate in the kidney and remains for many years causes irreversible kidney damage (Goyer, 1996). Patients with kidney failure patients in the study area are presumed to have increased from 10 patient/million in 1974 to about 165 patient/million in 1995 and in 2005 it was 260 patient/million in El-Minya Governorate (El Minshawy and

Kamel, 2006). Agricultural activities are considered as the most important sources for Cd, where the Egyptian marine phosphorite used for the manufacture of super-phosphate fertilizers contains up to 20 ppm Cd (El-Kammar, 1974). Pesticides also can lead to high Cd content in the study area (Bowen, 1966).

The highest concentration of Cd was recorded in sample number S_8 of 48µg/l close to Abu Qurqas Sugar factory due to the deposition of human wastes or garbage (Al-Shiekh Sharf canal). The lower concentration was recorded in sample number S_6 (1µg/l) which was collected from the River Nile. These results are in line with those obtained Toufeek (2011) who recorded average Cd concentration 12.5 µg/l at Aswan (southern Egypt), while Salman (2013) found that the Cd level in samples collected from Sohag Governorate was flocculated around 16µg/l. Therefore, Osman and Kloas (2010) mentioned that the average Cd concentration in the River Nile at Assuit was 6 µg/l.

Lead concentration ranged from 54 to 329µg/l in the studied surface water samples (Table. 2). The study samples content of Pb passes the permissible limit (10µg/l) for drinking water according to WHO (2011). Lead adsorbed by human body disturbs many body processes and is harmful to many organs and tissues such as heart, bones, nervous system (Needleman, 2004; Bruce et al., 2012). The highest concentration of Pb was recorded in sample number S_{28} (329µg/l) from Al-Nasriyah canal, while sample number $S_{6,}$ which was collected from the River Nile at Abu Qurqas district, contains the lowest concentration (54µg/l). These results are in agreement with those obtained by Toufeek (2011) who reported about 214µg/l 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 is nearly 24µg/l.

The Nile River and canals contain higher Cd and Pb concentrations than the drains indicating the role of the human activities as the main source of these metals because most of the canals penetrate settlements and adjacent to roads. In addition, most of the houses have not sewers and discharge their wastewater and solid waste into canals.

3.2. Groundwater

Groundwater is the second water resource in the study area and the only water resource in the desert fringes. It is used for irrigation and for domestic and drinking in some villages. The groundwater samples exhibit a relative wide range of the Cd level varying from 2 to 49µg/l with mean value 24µg/l (Table 3). The groundwater Cd level decreased eastward (Fig. 3) due to mixing with the surface water from River Nile and the role of the silty clay layer in the adsorption of Cd and prevent it to reach the aquifers. However, there are three hot spots of Cd resulted from the intensive human activities and fuel stations. Cd hot spot in the NW part of the study area adjacent to the western desert road is vulnerable as a result of the unconfined condition of the aquifers.

Also, the measured Pb content of the analyzed groundwater samples show a relative wide range varying from 90 to 410µg/l with an average of 242µg/l (Table. 3). The marked high level of Pb content implies that the anthropogenic activities are the main source of Pb. The results are in agreement with Melegy et al (2014) who mentioned that Cd and Pb concentration in the groundwater of Sohag were around 21 and 383 µg/l, respectively. In addition, Salman (2013) reported that the average of Cd and Pb concentrations are 21 and 383µg/l respectively in the Quaternary aquifer at Sohag. Pb level in the groundwater of the study area was increased at Abu Qurqas district resulting from the effect of the sugar factory, cesspits and fuel stations (Fig. 4).

All the samples are unsuitable for drinking purpose where they possess Cd and Pb values above the permissible limit of 3µg/l for Cd and 15 µg/l for Pb (WHO, 2011). On the other hand, surface water and groundwater are suitable for irrigation purposes according to

NAS- NAE (1973), where they contain less than 10000 and 5000000µg/l of Cd and Pb, respectively. But unfortunately, using the groundwater for drinking in some villages of the study area represents a serious health impact. 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.

3.3. Health risk assessment

It was observed that general population in the rural area is using surface water from the rivers or canals and groundwater from hand pumps for drinking and domestic purposes because they don't have access to the tap water from the tube wells. Therefore, health risk assessment (HQ) for surface water and groundwater was carried out in this study. The results of non-carcinogenic and carcinogenic health risks (HQ) due to metal exposure in surface water and groundwater samples are provided in Tables (4) and (5).

The non-carcinogenic health risk values for Cd in the drinking surface water for adults vary from 0.05 to 2.06 with an average of 1.30 and for children fluctuate between 0.08 and 3.95 with mean 1.96 (Table 4). The Pb values for adults range from 0.03 to 0.16 with mean 0.11 and for children extend between 0.04 and 0.25 with an average of 0.17 (Table 4). While, the values of the non-carcinogenic health risk of Cd in the drinking groundwater for adults range from 0.11 to 2.68 with an average of 1.29 and for children extend between 0.16 and 4.03 averaging 1.94 (Table 5). The Pb values for adults range from 0.04 to 0.20 with an average of 0.12 and for children vary from 0.07 to 0.31 averaging 0.18 (Table 5). According to USEPA (2011), Cd and Pb values of non-carcinogenic health risk should not exceed 1 to be considered as non-harmful drinking water.

The carcinogenic health risk values for Cd in the drinking surface water for adults range from $0.17*10^{-4}$ to $7.9*10^{-4}$ with an average of $3.9*10^{-4}$ and for children extend between $0.1*10^{-5}$ and $4.8*10^{-3}$ with mean $2.3*10^{-3}$ (Table 4). The Pb values for adults vary from

$6.2*10^{-3}$ to $37*10^{-3}$ with mean $26*10^{-3}$ and for children range from $3.7*10^{-2}$ to $22*10^{-2}$ with an average $15*10^{-2}$ (Table 4). As well, the Cd values of carcinogenic health risk for the drinking groundwater range from $4.8*10^{-6}$ to $1.2*10^{-4}$ averaging $5.66*10^{-5}$ for adults and from $2.9*10^{-5}$ to $7.11*10^{-4}$ with an average of $3.42*10^{-4}$ for children (Table 5). Pb values for adults fluctuate between $3.13*10^{-5}$ and $14.3*10^{-5}$ with an average of $8.41*10^{-5}$, also, the results for children vary from $1.67*10^{-9}$ to $86.1*10^{-5}$ averaging $48.5*10^{-5}$ (Tables 5). According to USEPA (2011), the values of Cd and Pb of carcinogenic health risk should not exceed 10^{-6} which it is the safe limit of the hazard quotient. More than this limit, the drinking water has very harmful effects on the inhabitants.

4. Conclusion

Cadmium and lead contents of the studied samples from Nile River, its tributaries (canals and drains) and groundwater exceed the permissible limits for drinking water and could be disturbing many body processes and are harmful to many organs and tissues such as the heart, bones, kidney and nervous system. The canals are higher in Cd and Pb concentrations than the drains indicating the role of the human activities as the main source of these metals because most of the canals penetrate settlements and adjacent to roads. The lowest concentrations of Cd and Pb were recorded in samples which were collected from the River Nile.

The non-carcinogenic health risk of Cd values exceeds 1 which is the safe limit of the hazard quotient indicating harmful drinking water while the Pb values do not pass that limit. The values of Cd and Pb of carcinogenic health risk exceed the safe limit of the hazard quotient and accordingly, the drinking water has very harmful effects on the inhabitants.

The water resources in the study area (surface water and groundwater) are suitable for irrigation purposes. Source of pollution in the investigated area was derived from anthropogenic activities such as industries, agriculture, mining and sewage. The water in the concerned area is suitable to use for irrigation purpose and unsuitable for drinking. The water needs to the treatment to be used for drinking purposes.

Recommendations

It is recommended to connect the houses in different rural parts of the study area with safe drinking water lines with regular monitoring of water resources and the end user water lines.

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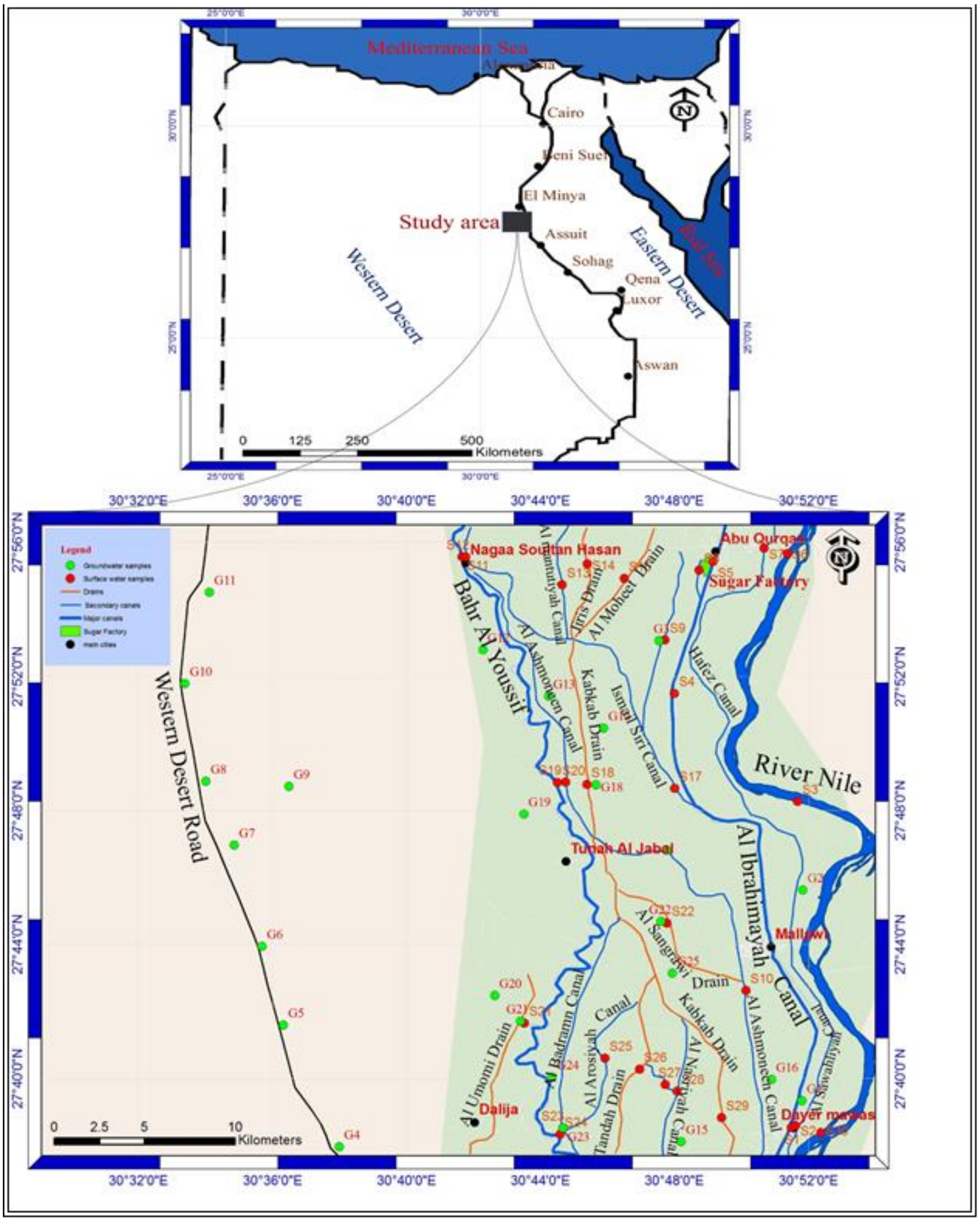

Figure 1: Location map of the study area.

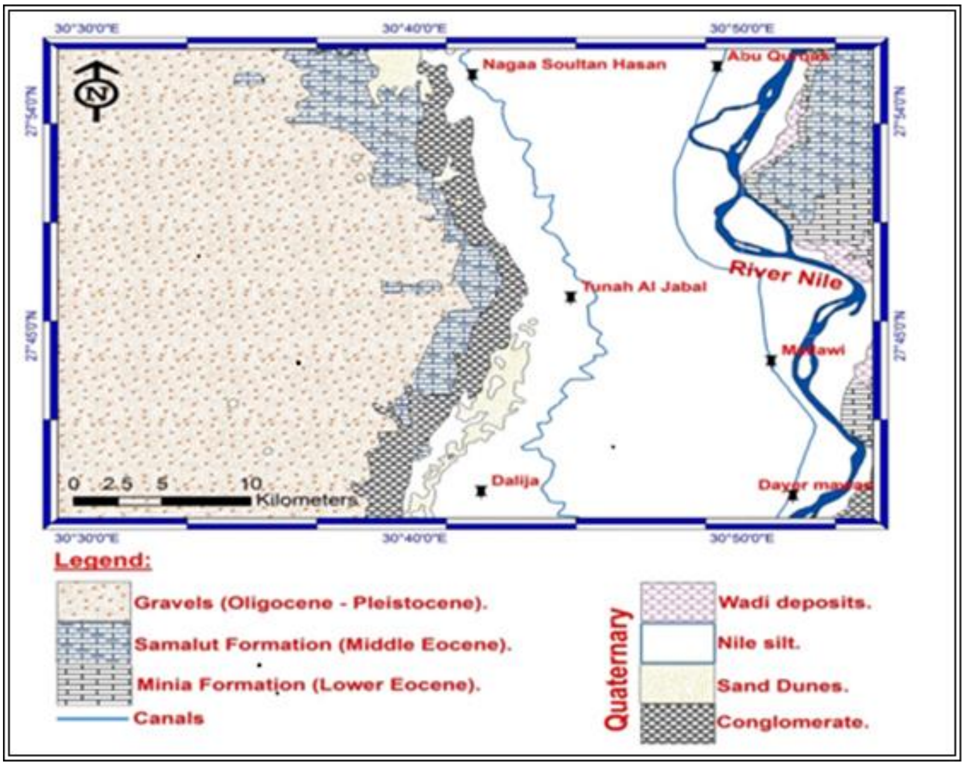

Figure 2: Geologic map of the study area.

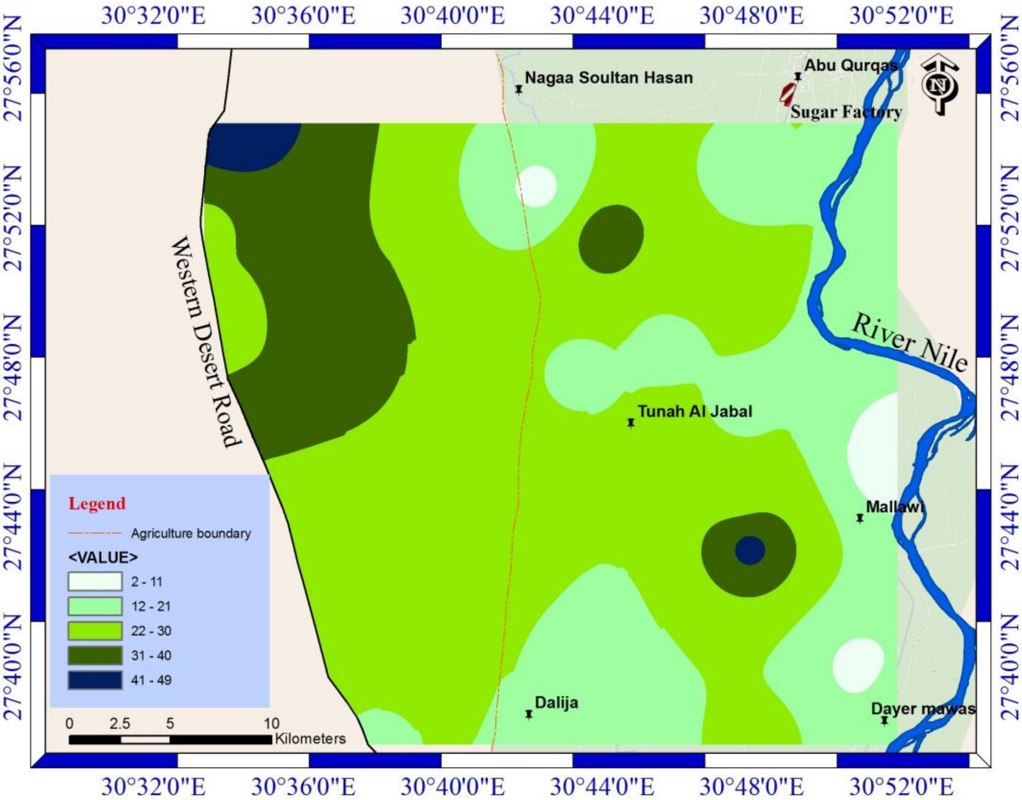

Figure 3: Spatial distribution map of Cd in the studied groundwater samples.

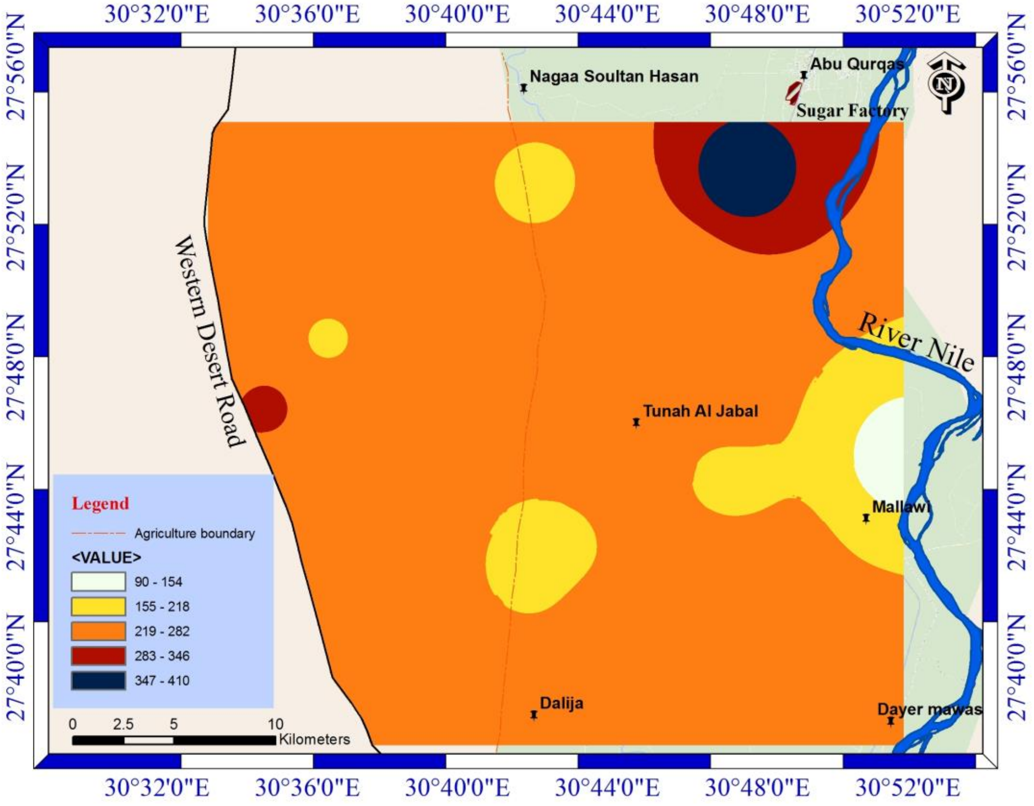

Figure 4: Spatial distribution map of Pb in the studied groundwater samples.

Table 1: Surface water samples and localities.

Sample No.	Canals	Sample No.	Canals & Drains
S_3, S_6, S_{30}	River Nile	S_{28}	Al Nasriyah canal
S_1, S_5	Al Ibrahimayah canals	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 canals	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).

Sample No.	Nile & Canals		Drains		Sample No.	Nile & Canals		Drains	
	Cd	Pb	Cd	Pb		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

Table 3: Cd and Pb concentrations (μg/l) in the study 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

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

Parameter	Non-carcinogenic for Adults		Non-carcinogenic for Children	
	HQ Cd	**HQ Pb**	**HQ Cd**	**HQ 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	**Carcinogenic for Adults**		**Carcinogenic for Children**	
	HQ Cd	**HQ Pb**	**HQ Cd**	**HQ 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	$3.9*10^{-4}$	$26*10^{-3}$	$2.3*10^{-3}$	$15*10^{-2}$

HQ = Hazard quotient; $HQ_{non\text{-}carcinogenic}$ = CDI / R*f*D; $HQ_{carcinogenic}$ = CDI / SF

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

Parameter	Non-carcinogenic for Adults		Non-carcinogenic for Children	
	HQ Cd	**HQ Pb**	**HQ Cd**	**HQ 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	**Carcinogenic for Adults**		**Carcinogenic for Children**	
	HQ Cd	**HQ Pb**	**HQ Cd**	**HQ 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	$5.66*10^{-5}$	$8.41*10^{-5}$	$3.42*10^{-4}$	$48.5*10^{-5}$

HQ = Hazard quotient; $HQ_{non\text{-}carcinogenic}$ = CDI / R*f*D; $HQ_{carcinogenic}$ = CDI / SF