EQA - International Journal of Environmental Quality
ISSN 2281-4485 - Vol. 41 (2021): 40-48
Journal homepage: https://eqa.unibo.it/
published by

Toxic elements contamination in surface sediments of major tanks in Anuradhapura district; A CKDu endemic district in Sri Lanka

Ruwan T. Perera[1]*, Nalika Dayananda[1], Shermila Botheju[1], Janitha A. Liyanage[1], Asanga Ranasinghe[2], Ranamuka Henayalage Karunarathne[2], Gardiye W. G. P. Kumara[2]

1 Department of Chemistry, Faculty of Science, University of Kelaniya, Kelaniya, Sri Lanka
2 Renal disease prevention and Research unit, Ministry of Health, Colombo

Corresponding author e-mail: 2017_perera@kln.ac.lk

Article info
Received 18/5/2020; received in revised form 14/8/2020; accepted 4/9/2020.
DOI: 10.6092/issn.2281-4485/11001

Abstract
Farming occupants are the major victims of Chronic Kidney Disease of unknown etiology (CKDu) in North Central region, Sri Lanka. Tanks are the main source of water for farming and they act as sinks for agricultural run-offs. Environmental toxicants are adsorbed by bottom sediments and can be released into the adjacent water column due to environmental changes as those are not permanently bound. Therefore, this study attempts to determine the contamination situation of the selected toxic metals in sediments of the tanks in a CKDu prevalence distrct (Anuradhapura) in Sri Lanka and prediction of the risk. Sixteen tanks were selected and sediment samples were randomly collected from each tank from bank to center. Digested sediment samples were analyzed for heavy metals using Inductive Couple Plasma Mass Spectrometry and Calcium and Magnesium contents were analyzed using Atomic Absorption Spectrometry. According to the statistics, average values of some toxic metals such as As, Pb, and Cr in sediments were higher than severe effect levels (SEL) while most of the mean values of Cd, As, Pb, Cr, Zn, and Cu were beyond the Lowest effect levels (LEL). Apart from that, Geo Accumulation Indexes (I_{geo}) Indicate that almost all tanks in Anuradhapura district have moderately polluted with above mentioned pollutants. Hence, findings reveal about a risk generated on aquatic lives in the tanks as well as humans via food chain contamination with hazardous metals.

Keywords
heavy metals; contamination; sediments; CKDu

Introduction

Toxic elements such as heavy metals are entered into the surface water by various types of processes such as runoff, precipitation, atmospheric deposition, adsorption, point spills, etc and thereafter some of the toxic elements deposited in the sediments (Scherer et al., 2011) of different aquifers. Major reasons for the high levels of heavy metals in aquifers resulted by the economic development and growth of population (Dey et al., 2017; Hasan et al., 2007; Zhang et al., 2016). Moreover, agricultural activities may be the fundamental risk factor for the heavy metal contamination in agricultural areas. It has become a major problem, as water, soil and sediments are contaminated by various trace elements (Biswas et al., 2012; Uddin et al., 2018), which may lead to serious health impacts due to their toxicity, persistence and carcinogenic nature (Khalil et al., 2007; Naz et al., 2016; Zhu et al., 2017). Although trace elements with small quantities may help in normal

DOI: 10.6092/issn.2281-4485/11001

functioning of the human body, excessive amounts and long term exposure to these elements may badly affect to human health (Vetrimurugan et al., 2017). Soil and sediements are heavily contaminated by pollutants from different sources such as rivers, agricultural canals, and industrial exhausts (Khan et al., 2008). However, anthropogenic sources related to the metal rich sewage sludge in agriculture, combustion, livestock manures, application of pesticides (manufacture, use, and disposal) and agricultural activities increase the pollutants which deposit in the water resources (Liu et al., 2005). Therefore, toxic metal analysis has become a subject of concern as their high persistence in the environment, ecological risk and chemical toxicity.

Previous studies reveal that Cadmium (Cd) is a major human carcinogen and excessive uptake may lead to the kidney damage, respiratory disorder and damage to the skeletal system (Bernard 2008; Belabed and Soltani 2018; Dutta et al., 2018. Apart from m that Exposure to excess amounts of Copper (Cu) causes nausea, diarrhoea and tissue injury of liver (USNRC 2000; Doza et al., 2019). As mentioned in former studies, most of the public health issues such as hypertension, cancer, vascular disease, restrictive lung disease, gastrointestinal bleeding, neurological disorder and reproductive effects may appear due to the use of contaminated water with trace metals such as Arsenic (As), Chromium (Cr), Lead (Pb) and Zinc (Zn) (Lu et al., 2015; Noubissié et al., 2016; Zhang et al., 2016; Belabed and Soltani 2018; Singh et al., 2018) for a long time with excessive amounts. Due to the requirement of large scale production of foods, agricultural practices are getting expanded throughout the world. Therefore, massive usage of pesticides and fertilizers may lead to contamination of soil, sediments, surface water and ground water (Barakat et al., 2019; Gallagher et al., 1996; Fischer et al., 2003). Water resources and soil can be contaminated with different types of contaminants due to the usage of synthetic agrochemicals in large amounts for the cultivations. Most of the toxicants which carried by the runoff may released into the existing water columns. Owing to the increase of deterioration of soil and sediment quality, assessment of sediment quality in aquifers is an important approach to determine the suitability of water resources for different purposes (Khan et al., 2008). Therefore, the study was conducted with the aims of analysis of sediment quality in major irrigation tanks in Anuradhapura district where high prevelance of Chronic kidney disease of unknown etiology (CKDu) occurs in Sri Lanka and identify of the risk related to the toxic metal contamination. Toxic metal transport process is much important when demonstrating the heavy metal entering pathways to the human body. The transport of metals will result in increased levels of toxic metals in groundwater or surface water, thereby posing a significant environmental and health risk to the environment (Smith et al., 1996). Deposition of heavy metals occurs mainly at the bottom of areas such as streams, reservoirs and estuaries (Senesi et al, 1979). The fate of toxic metal contamination is critical because it appears to be reactive, mobile, and highly toxic.

Materials and Methods

Sample collection

The total of sixteen (16) tanks were selected from Anuradhapura district in Sri Lanka including Mahakanadarawa, Lindawewa, Halmillakulama, Iranamadu, Mahadiwulwewa, Kabithigollewa, Wahalkada, Padawiya, Sadamalgama, Yakawewa, Nachchadoowa, Rajanganaya, Karuwalagaswewa, Nelugollewa, Navodhagama and Mahawilachchiya (Fig. 1) to collect sediment samples.

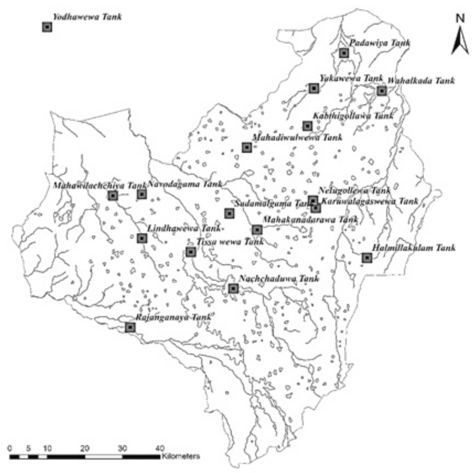

Figure 1. *Distribution of the selected tanks which obtained sediment samples in Anuradhapura district, Sri Lanka.*

All the locations were recorded according to the Global Positioning System (GPS) coordinates (Table 1).

Sediment samples were randomly collected from the bank to the center of the water body.

Sediment samples were obtained from Ten locations of each tank and composite samples were prepared by the combination of Five sediment samples from each location of the tank separately to ensure the sample representativeness.

DOI: 10.6092/issn.2281-4485/11001

Table 1. *GPS cordinations, volume (m^2), and located Grama Niladhari (GN) división (Anuradhapura district, Sri Lanka) of the selected tanks, (Source; Ministry of Health, Sri Lanka.)*

Name of Tank	GPS Location		Volume (m^2)	GN Division
	E	N		
Mahakanadharawa_Tank	080.54771	08.37022	5540870	Pothana
Lindhawewa_Tank	080.26437	08.36891	295340	Mahalindawewa
Halmillakulama_Tank	080.21412	08.25912	406403	Halmillakulama
Iranamadu_Tank	080.43731	09.34431	18905200	Mankulama
Mahadiwulwewa_tank	080.51721	08.58903	664973	Mahadiulwewa
Kebethigollewa_Tank	080.66364	08.63531	622079	Kebithigollewa
Wahalkada_Tank	080.83713	08.72772	14934500	Wahalkada D2
Padaviya_Tank	080.76233	08.81900	29188300	Padaviya
Sadhamalgama_Tank	080.47546	08.42320	106956	Sandamalgama
Yakawewa_Tank	080.39969	08.58124	No records	Yakawewa
Naachchadhuwa_Tank	080.47030	08.25433	19991280	Nachchaduwa
Rajanganaya_Tank	080.21471	08.13113	11909860	Rajanganaya
Karuwalagaswewa_Tank	080.68628	08.44380	695575	Kahatagasdigiliya
Nelugollewa_Tank	080.67986	08.48927	No records	Gonamuruwewa
Navodhagama_Tank	080.26332	08.47509	No records	Navodagama
Mahawilachchiya_Tank	080.19846	08.47775	4369221	Pemaduwa

There after, samples were stored in sterile polyethylene bags and kept at 4°C during transport. At the laboratory, the samples were dried at room temperature and subsequently sieved through a 60 µm mesh. Trace elemet analysis of the collected samples was done after 1 month from the sampling date. Triplicates from the composite sediment samples were used for the chemical analysis. All the chemical analysis was conducted in CKDu Information and Research Centre at University of kelaniya, Sri Lanka.

Sample analysis

Heavy metal analysis of the sediment samples 0.200 g of each soil sample was digested using microwave digester (ETHOS EASY) by adding 10.00 mL of concentrated Nitric acid and digested solutions were diluted up to 25.00mL with ultrapure water and 10.00mL of each digested soil solution was filtered through 0.45µm nylon syringe filters and determination of metal concentrations such as Cadmium(Cd), Lead(Pb), Arsenic(As), Chromium(Cr), Copper(Cu) and Zinc(Zn) in soil samples was done by ICP-MS technology (ICP-MS-8000-Agilent, Germany).

Statistical analysis

The obtained results of sediment samples were statistically analyzed by ANOVA using MINITAB software.

Geoaccumulation index (Igeo)

Geo Accumulation value was developed for the determination of the degree of metal concentrations and the pollution which is caused by the metals in soil. The Igeo values were determined as follows (Muller, 1969):

$$I_{geo} = \log_2(C_n/1.5*B_n) \quad [1]$$

where C_n is the measured concentration of the metal n in sediment, B_n is the geochemical background value of the metal n (Table 2).

In this study, the Natural Background Concentration (NBC) values were obtained from the reference table (Screening Quick Reference Table for Inorganics in Freshwater Sediment) established by the National Oceanic and Atmospheric Administration (NOAA) (Buchman 2008). Correction factor 1.5 allows to analyze natural fluctuations in the content of a given substance in the environment and to detect a very small anthropogenic influence (Espinosa et al., 2018).

DOI: 10.6092/issn.2281-4485/11001

Table 2. *Classes of Geo-accumulation index by Muller (1969).*

I_{geo}	I_{geo} class	Soil/Sediment Quality
0-0	0	Unpolluted
0-1	1	Unpolluted to moderately polluted
1-2	2	Moderately polluted
2-3	3	Moderately polluted to highly polluted
3-4	4	Highly polluted
4-5	5	Highly polluted to very highly polluted
5-6	>5	Very highly polluted

Results and Discussion

The obtained toxic element concentrations in sediment samples of the selected tanks in Anuradhapura district are listed in the Table 3. In order to evaluate the contamination due to the heavy metals and metallic elements of analyzed tank sediments, the Lowest Effect Level (LEL) and Severe Effect Level (SEL) were utilized (Pintilie et al., 2007). The LEL indicates that level of pollution has no effect on most of the species living in the reservior and the sediment or the water is proximate to slightly polluted. The SEL indicates sediment pollution stage is significant and it is likely to affect the health of sediment-dwelling species. If the level of pollution reaches the amount of severe effect then testing is required to determine whether sediment is extreamly toxic (Bala, et al., 2010).

Table 3. *Mean heavy metal and metallic element concentrations in the sediments of the selected tanks in Anuradhapura.*

Tank	Cd(mg/kg)		Pb (mg/kg)		As (mg/kg)		Cr (mg/kg)		Cu(mg/kg)		Zn(mg/kg)	
Mahakanadarawa	0		138	± 5	25.6	± 4.0	1842	± 43	744	± 32	1346	± 26
Lindhawewa	0		261	± 201	76.2	± 7.5	3594	± 533	1197	± 68	2119	± 138
Halmillakulama	0		261	± 20	64.9	± 9.0	7485	± 371	1197	± 48	1344	± 38
Iranamadu	0		221	± 24	27.3	± 4.0	355	± 38	169	± 14	758	±91
Mahadiwulwewa	26.3	± 5.8	231	±15	188	±15	1836	± 92	207	± 18	894	± 73
Kebithigollewa	7.26	± 2.15	168	±16	0		1210	± 67	258	± 49	927	± 51
Wahalkada	1.79	± 0.96	422	± 52	94.6	± 7.5	1641	± 79	530	±138	1946	± 57
Padawiya	4.62	± 1.23	338	± 37	25.0	± 4.3	4510	± 144	544	± 58	1129	± 72
Sadhamalgama	0		400	± 19	4.90	± 0.79	2299	± 158	659	± 75	1653	± 53
Yakawewa	0		280	± 36	31.5	± 4.2	3796	±284	639	± 29	2323	± 154
Naachchadhuwa	0		451	± 70	45.4	± 7.23	4529	± 203	748	± 80	1143	± 102
Rajanganaya	0		113	± 13	8.80	± 0.80	1337	± 455	171	± 12	656	± 76
Karuwalagaswewa	1.62	± 0.44	361	± 42	83.8	± 6.74	2944	± 125	742	± 47	2672	± 258
Nelugollawa	0		237	± 19	17.3	± 2.98	1545	± 85	225	± 57	456	± 17
Navodhagama	0		232	± 17	22.6	± 3.10	1267	± 162	142	± 22	1533	± 489
Mahawillachchiya	1.86	± 0.58	55.2	±3.8	0		593	± 91	180	± 30	851	± 35
LEL	0.60		35		6		37.3		35.7		123	
SEL	10		250		33		110		110		820	

LEL = the Lowest Effect Level - SEL = the Severe Effect Level – ND = Not Defined

As shown in the Table 3 mean Cd levels have not been exceeded the SEL (10 mg/kg) in all the demonstrated tanks except Mahadiwulwewa where the mean Cd concentration was 26.28(±5.77) mg/kg. In addition to that, Cd contents in Kabithigollewa, Wahalkada, Padaviya, Karuwalagaswewa and Mahawilachchiya reservoirs have reported as 7.26(±2.15) mg/kg, 1.79(±0.96) mg/kg, 4.62(± 1.23) mg/kg, 1.62(±0.44) mg/kg and 1.86(±0.58) mg/kg respectively and show Cd levels beyond the LEL level (0.596 mg/kg). Meanwhile, almost all the selected tank sediments have exceeded the LEL (35 mg/kg) of the Pb contents while

DOI: 10.6092/issn.2281-4485/11001

mean Pb contents of the sediments collected from Lindhawewa (260.6(± 20.01) mg/kg, Halmillakulama (260.67(±20.0) mg/kg, Wahalkada (421.5(± 51.73) mg/kg, Padawiya (337.52(± 37.4) mg/kg), Sadhamalgama (399.98(± 19.3 mg/kg, Yakawewa (279.88(±36.4) mg/kg, Naachchadhuwa (451.44(±69.7) mg/kg and, Karuwalagaswewa (361.2(± 41.88) mg/kg have exceeded the SEL (250 mg/kg).

Furthermore, mean As values of sediments of six tanks (Lindhawewa, Halmillakulama, Mahadiwulwewa, Wahalkada, Naachchadhuwa and Karuwalagaswewa) have exceeded the SEL (33 mg/kg) of As. The highest mean As content was shown by the Mahadiwulwewa tank (188.24(±15.27) mg/kg). As is one of the critical metallic elements that present in all the fertilizer types in larger quantities compared to any other trace element and Previous studies (Blaise 2013, Kim et al., 2016) reveal that the metallic elements such as As can also be accumulated in fish species in the water reservoirs. When water and the sediment metal Transfer Factor (TF) is grater than 1, bioaccumination of metals such as Arsenic can occur in fish via both water and sediments. Hence, Toxic metals can also be incorporated into the food chains. (Çevik et al., 2009). Further considering the results, the mean Cr, Cu, and Zn contents in the sediments obtained from all selected tanks have exceeded the SEL. Relatively high levels of toxic metal and metallic element concentrations were recorded in selected tanks of Anuradhapura District that may be due to the agricultural activities of paddy fields. On the other side and an excessive accumulation of heavy metals in agricultural soils which lead not only to soil contamination, but also to increased crop uptake of trace metals, thus affecting food quality and safety (Muchuweti et al., 2006).

Most of the agrochemicals such as fertilizers and pesticides used in agricultural fields contain excessive amounts of toxic metals. According to the studies of (Gimeno et al., 2016) Cd concentrations in different fertilizers namely copper sulphate, iron sulphate, urea and superphosphate were 0.21 mg/kg, 0.03 mg/kg, 0.01 mg/kg and 2.22 mg/kg respectively, while mean Pb concentrations have reported as 11.0 mg/kg and 10.0 mg/kg) in copper sulphate and iron sulphate fertilizers respectively. Furthermore, mean Cd concetrations in Antracol, Saturn-G and 205 Ordram has reported as 1.94 mg/kg, 1.48 mg/kg, and 1.38 mg/kg respectively, while mean Pb values of above pesticides were reported as 5.0 mg/kg, 10.0 mg/kg, and 7.5 mg/kg respectively. This study has conducted in rice farming areas in Spain (Gavrilescu, 2004). Therefore, usage of excessive amounts of fertilizers and pesticides may be a driving force to accumulation of toxic heavy metals in the sediments of tanks in the agricultural areas in Sri Lanka. Sediments serve as major sinks for heavy metals in aquatic environments, and are known as possible toxic metal sources. Furthermore, the findings of Gimeno et al., 2016 indicate that water sediment interactions in aquatic environments play an important role in the processes of bio-monitoring of accumulation of metals. According to the results of present study, some analyzed toxic metal contents of the sediments were reported in higher amounts in most of the selected tanks. Although living organisms require trace quantities of certain elements such as cobalt, copper, iron, manganese, molybdenum, vanadium, strontium, and zinc, excessive amounts of metals can be toxic to the organism. In addition, Cd, Cr, Hg, Pb, As, and Sb are non-essential heavy metals of special concern to surface water systems (Bala et al., 2010). Because of their long persistence and toxicity, toxic metals released into the aquirtic environment will harm both the diversity of fish species and the ecosystems (Persaud, 1993).

Assesement of transport and circulation of toxic metals is much significant for this study. Heavy metals can be carried by rivers that pass through of industrial and agricultural areas as soluble metals and adsorbed metals to suspended solids. Transported heavy metals can get accumulated at the bottom of the tank's sediments causing significant effects on aquatic lives and human (Monperrus et al., 2007). Apart from that Cd, Cr, Hg, Pb, As, and Sb are non-essential heavy metals of special concern to surface water systems (Khan et al., 2008). Due to the persistence of above-mentioned non-essential metals and metallic elements with elevated levels in the collected sediment samples of the tanks, a risk may be generated by transferring heavy metals in to the food chains (Zhu et al., 2017). Moreover, most of the demonstrated tanks are used for fishing industry and heavy metals can be ingested in to the body due to the consumtion of the fish.

Apart from that the geoaccumulation index (Igeo) is mainly used to assess the metal pollution in sediments to investigate the anthropogenic input to the soil or sediments (Genc and Yilmaz, 2018). In the present study, geo accumunation indexces have been calculated to evaluvate the contamination stage of the bottom sediment of the selected tanks in Anuradhapura District, Sri Lanka.

According to Muller (1969), Igeo is divided into

DOI: 10.6092/issn.2281-4485/11001

six categories, from uncontaminated to extremely contaminated. Obtained Igeo values (Table 4) depict that the sediments from all of the selected tanks are in the moderately contaminated stage or above the moderate level with the analyzed heavy metal and metallic elements. Considering the Igeo values obtained for Cd, Wahalkada tank and Rajanganaya tank show the highest value (1.69, 1.68) respectively.

Furthermore, Igeo values for Cr in Lindawewa, Padaviya, Yakawewa, Nachchaduwa and Karuwalagaswewa were reported Igeo values above 2.00, hence it is clear that sediments will be approaching heavier contamination with Cr, while Igeo values for As reported beyond 1 in most of the analyzed tanks except Lindawewa, Padawiya, Sadhamalgama, Yakawewa.

Studies of Espinosa 2018 reveal that the toxic metal concentrations in reservoirs mainly increase with the development activities, urbanization and industrialization. As well as these pollutants in different acquifers are associated with natural processes and human intervention in the bio geochemical cycles of metals and metallic elements (Saleem et al., 2015). The high concentrations of the anlyzed toxic metals in the selected tanks in Anuradhapura district possibly associated with the agricultural activities because Anuradhapura is an agriculture based district. Most of the agricultural activities in these areas include the direct addition of agrochemicals over a long period of time in excessive amounts. Some toxic metals such as Cd, Cr, As, Pb, and Zn are directly related to the fertilizers and pesticides. Erosion occurred due to rain drainages initiate the migration of different harmful chemical subtstances such as heavy metals. Therefore, tanks serve as major sinks for these heavy metals, metallic elements and other chemical substances which are harmful to the human health.

Table 4. *Geo accumulation indexes (Igeo) of the sediment of studied tanks*

	Tank	Cd	Pb	Cr	Zn	Cu	As
1	Mahakanadarawa	0	1.64	1.71	1.55	1.70	1.62
2	Lindhawewa	0	1.63	2.71	1.71	1.66	0.47
3	Halmillakulama	0	1.63	1.72	1.67	1.68	1.60
4	Iranamadu	0	1.66	1.65	1.70	1.71	1.55
5	Mahadiwulwewa	1.51	1.59	1.70	1.59	1.61	1.39
6	Kebithigollewa	1.67	1.67	1.71	1.67	1.64	1.74
7	Wahalkada	1.69	1.61	1.70	1.69	1.71	1.41
8	Padawiya	1.09	1.53	2.34	1.54	1.72	0.60
9	Sadhamalgama	0	1.54	1.71	1.64	1.71	0.95
10	Yakawewa	0	1.64	2.13	1.64	1.71	0.96
11	Naachchadhuwa	0	1.56	2.70	1.66	1.69	1.12
12	Rajanganaya	0	1.68	1.58	1.68	1.50	1.38
13	Karuwalagaswewa	1.17	1.57	2.69	1.63	1.68	1.66
14	Nelugollawa	0	1.59	1.63	1.66	1.53	1.52
15	Navodhagama	0	1.51	1.64	1.58	1.54	1.44
16	Mahawilachchiya	0	1.64	1.60	1.43	1.60	1.54

According the study, sediments of the selected tanks in Anuradhapura Distrit have shown the presence of toxic metals and metallic elemants. Moreover, the Geo accumilation Indexes of the tanks for selected heavy metals and metallic elements indicated that the sediments are moderately to strongly polluted as concentrations which were obtained from the present study were generally higher compared to the background values (Bn) established by the NOAA. Therefore, considering the importance of these major irrigatory tanks in Anuradapura District, it is recommended to carry out constant monitoring of heavy metals and take responsibility and actions to minimize the harm to the environmental, protect watersheds and preserve water quality and environment for current and future generations.

DOI: 10.6092/issn.2281-4485/11001

Conclusions

According to the novel environmental pollution assessments, it is clear to note that, anthropogenic sources readily augment the risk of toxic metal contamination in soil and sediments in both industrial and agricultural areas. Intence applications of the fertilizers and pesticides for the crops may be the leading process for the contamination of the water resourses in the agricultural areas. Due to the toxic metals accumulations, even food chains can be contaminated and enhance hazardous condition on aquatic life and human. Exceeded threshold values of some toxic metals (Cd, As, Pb, and Cr) in selected tank sediments reveal that a risk might be generated to toxic heavy metal circulation in the selected area. Further, heavy metal contents of the fertilizers and pesticides which are being applied in agricultural activities in Anuradhapura district should be analyzed to investigate the sources of the toxic metals.

Funding
This research was funded by the research project – PS/DSP/CKDU/06/3.5 titled "establish a CKDu Information and Research Center at University of Kelaniya, Sri Lanka"

Acknowledgments
Authors would like to acknowledge National Institute of Fundamental Studies (NIFS), Kandy, Sri Lanka.

Declaration of interests
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

BALA M., SHEHU R., LAWAL M. (2010) Determination of the level of some heavy metals in water collected from two pollution - prone irrigation areas around Kano Metropolis. Bayero Journal of Pure and Applied Sciences, 1(1). Doi: https://doi.org/10.4314/bajopas.v1i1.57511

BELABED S., SOLTANI N. (2018) Effects of cadmium concentrations on bioaccumulation and depuration in the marine bivalve Donax trunculus. Euro-Mediterr. Journal of Environment International. 3:19. Doi: https://doi.org/10.1007/s41207-018-0054-0

BERNARD A. (2008) Cadmium and its adverse effects on human health. Indian Journal of Medical Research. 128(4):557–564. PMID: 19106447

BIBAK A., BEHRENS A., ST¨URUP S., KNUDSEN L., GUNDERSEN V. (1998) Concentrations of 55 major and trace elements in Danish agricultural crops measured by inductively coupled plasma mass spectrometry. 2. Pea (Pisum sativum Ping Pong). Journal of Agricultural and Food Chemistry, 46:3146–3149. Doi: https://doi.org/10.1021/jf980191d

BISWAS, A., B. NATH, P. BHATTACHARYA, D. HALDER, A.K. KUNDU, U. MANDAL, A. MUKHERJEE, D. CHATTERJEE, C.M., MORTH, AND G. JACKS (2012) Hydrogeochemical contrast between brown and grey sand aquifers in shallow depth of Bengal Basin: consequences for sustainable drinking water supply. Science of the Total Environment, 431:402–412. Doi: https://doi.org/10.1016/j.scitotenv.2012.05.031

ENCYCLOPEDIA OF AQUATIC ECOTOXICOLOGY (2013). Doi: https://doi.org/10.1007/978-94-007-5704-2

ÇEVIK F., Gotzu M.Z.L., Derici O.B. (2009) An assessment of metal pollution in surface sediments of Seyhan dam by using enrichment factor, geoaccumulation index and statistical analyses. Environmental Monitoring and Assessment, 152(1–4):309–317. Doi: https://doi.org/10.1007/s10661-008-0317-3

COORAY T., YUANSONG W., ZHONG H., ZHENG L., WERAGODA S.K., WEERASOORIYA R. (2019) Assesment of ground water quality in CKDu affected areas of Sri Lanka: Implications for drinking water treatment. Environmental Research and Public Health. 16:1698. Doi: https://doi.org/10.3390/Fijerph16101698

DEY N.C., SAHA R., PARVEZ M., BALA S.K., ISLAM A.K.M.S., PAUL J.K., HOSSAIN M. (2017) Sustainability of groundwater use for irrigation of dry-season crops in northwest Bangladesh. Groundwater for Sustainable Development Journal, 4:66–77. Doi: https://doi.org/10.1016/j.gsd.2017.02.001

DUTTA P., KARMAKAR A., MAJUMDAR S., ROY S. (2018) Klebsiella pneumoniae (HR1) assisted alleviation of Cd(II) toxicity in Vigna mungo: a case study of biosorption of heavy metal by an endophytic bacterium coupled with plant growth promotion. Euro-Mediterranean Journal for Environmental Integration, 3:27. Doi: https://doi.org/10.1007/s41207-018-0069-6

DOI: 10.6092/issn.2281-4485/11001

ESPINOSA A.C.T., MER E.M., VALBUENE D.C., MARQUEZ L.C.G., BEJARANO F.T. (2018) Contamination level and spatial distribution of heavy metals in water and sediments of El Guajaro reservoir, Colombia. Bulletin of Environmental Contamination and Toxicology 101(1): 61-67. Doi: https://doi.org/10.1007/s00128-018-2365-x

GAVRILESCU M. (2004) Removal of heavy metals from the environment by biosorption', Engineering in Life Sciences, 4(3):219–232. Doi: https://doi.org/10.1002/elsc.200420026

GENC T.O., YILMAZ F. (2017) Heavy metals content in water, sediments, crab (Callinectus sapidus) and two fish species (Mugil cephalus and Anguilla anguilla) from koycegiz lagoon system in Turkey: An index analysis approch. Bulletin of environmental contamination and toxicology. (99) 173-181. Doi: https://doi.org/10.1007/s00128-017-2121-7

GIMENO-GARCÍA E., ANDREU V., BOLUDA R. (1996) Heavy metals incidence in the application of inorganic fertilizers and pesticides to rice farming soils. Environmental Pollution, 92(1):19–25. Doi: https://doi.org/10.1016/0269-7491(95)00090-9

HASAN M.A., AHMED M.K., SRACEK O., BHATTACHARYA P., BRÖMSSEN M.V., BROMS S., FOGELSTRÖM J., MAZUMDER M.L., JACKS D.G. (2007) Arsenic in shallow groundwater of Bangladesh: investigations from three different physiographic settings. Hydrogeology Journal. 15:1507–1522. Doi: https://doi.org/10.1007/s10040-007-0203-z

JI Y. (2008) Using geoaccumulation index to study source profiles of soil dust in China', Journal of Environmental Sciences, 20(5):571–578. Doi: https://doi.org/10.1016/S1001-0742(08)62096-3

KHALIL M.K.H., RADWAN A.M., EL-MOSELHY K.H.M. (2007) Distribution of phosphorus fractions and some of heavy metals in surface sediments of Burullus lagoon and adjacent Mediterranean Sea. Egyptian Journal of Aquatic Research. 33 (1):277–289. http://hdl.handle.net/1834/1888

KHAN S. (2008) Health risks of heavy metals in contaminated soils and food crops irrigated with wastewater in Beijing, China. Environmental Pollution, 152(3):686–692. Doi: https://doi.org/10.1016/j.envpol.2007.06.056

KIM D. Y. (2016) Cell-wall disruption and lipid/astaxanthin extraction from microalgae: Chlorella and Haematococcus', Bioresource Technology. Elsevier Ltd, 199:300–310. Doi: https://doi.org/10.1016/j.biortech.2015.08.107

LAWRENCE, D. R. AND SCOTT, G. I. (1982) Coastal and Estuarine Research Federation. Estuaries, 5(1):23–27. Doi: https://doi.org/10.2307/1352213

LIU W.H. (2005) Impacts of sewage irrigation on heavy metal distribution and contamination in Beijing, China. Environment International, 31(6):805–812. Doi: https://doi.org/10.1016/j.envint.2005.05.042

LU S.Y., ZHANG H.M., SOJINU S.O., LIU G.H., ZHANG J.Q., NI H.G. (2015) Trace elements contamination and human health risk assessment in drinking water from Shenzhen, China. Environmental Monitoting and Assessment. 187:4220. Doi: https://doi.org/10.1007/s10661-014-4220-9

MONPERRUS M. (2007) The biogeochemistry of mercury at the sediment-water interface in the Thau Lagoon. 2. Evaluation of mercury methylation potential in both surface sediment and the water column', Estuarine, Coastal and Shelf Science, 72(3):485–496. Doi: https://doi.org/10.1016/j.ecss.2006.11.014

MUCHUWETI M., BIRKETT J., CHINYANGA E., ZVAUYA R., SCRIMSHAW M.D., LESTER, J.N. (2006) Heavy Metal Content of Vegetables Irrigated With Mixtures of Wastewater and Sewage Sludge in Zimbabwe: Implications for Human Health. Agriculture, Ecosystems & Environment. 112:41-48. Doi: https://doi.org/10.1016/j.agee.2005.04.028

MULLER G. (1969) Index of geoaccumulation in sediments of the Rhine river. Geological Journal, 2(3):108-118. Doi: https://doi.org/10.4236/jep.2011.25059

NAZ A., CHOWDHURY A., MISHRA B.K., GUPTA S.K. (2016) Metal pollution in water environment and the associated human health risk from drinking water: a case study of Sukinda chromite mine, India. Human and Ecological Risk Assessment. 22(7):1433–1455. Doi: https://doi.org/10.1080/10807039.2016.1185355

NOUBISSIE E., NGASSOUM M.B., ALI A., CASTRO-GEORGI J., DONARD O.F.X. (2016) Contamination of market garden soils by metals (Hg, Sn, Pb) and risk for vegetable consumers of Ngaoundere (Cameroon). Euro-Mediterranean Journal for Environmental Integration, 1:9. Doi: https://doi.org/10.1007/s41207-016-0009-2

DOI: 10.6092/issn.2281-4485/11001

PERSAUD D. (1993) August 1993. Weatherwise, 46(5):47–52. Doi: https://doi.org/10.1080/00431672.1993.9930274

PINTILIE S. (2007) Modelling and simulation of heavy metals transport in water and sediments', Environmental Engineering and Management Journal, 6(2):153–161. Doi: https://doi.org/10.30638/eemj.2007.021

SALEEM M., IQBAL J., SHAH M. (2015) Geochemical speciation, anthropogenic contamination, risk assessment and source identification of selected metals in fresh water sediments - a case study from Mangla lake, Pakistan. Environmental Nanotechnology, Monitoring and Management. 4:27-36. Doi: https://doi.org/10.1016/j.enmm.2015.02.002

SENESI N., POLEMIO M., LORUSSO, L. (1979) Content and distribution of arsenic, bismuth, lithium and selenium in mineral and synthetic fertilizers and their contribution to soil', Communications in Soil Science and Plant Analysis, 10(8):1109–1126. Doi: https://doi.org/10.1080/00103627909366966

SCHERER U., SAGEMANN S., STEPHAN F. (2011) Emission via erosion and retention of heavy metals in river basins of Germany. Geophysical Research Letters 13:4769. Doi: https://doi.org/10.2166/wst.2003.069

SINGH A.K., SATHYA M., VERMA S., JAYAKUMAR S. (2018) Health risk assessment of heavy metals in crop grains grown on open soils of Kanwar wetland, India. Euro-Mediterranean Journal for Environmental Integration, 3:29. Doi: https://doi.org/10.1007/s41207-018-0073-x

SMITH S.L. (1996) A preliminary evaluation of sediment quality assessment values for freshwater ecosystems', Journal of Great Lakes Research. Elsevier, 22(3):624–638. Doi: https://doi.org/10.1016/S0380-1330(96)70985-1

TORREGROZA-ESPINOSA A.C. (2018) Contamination Level and Spatial Distribution of Heavy Metals in Water and Sediments of El Guájaro Reservoir, Colombia. Bulletin of Environmental Contamination and Toxicology. Springer US, 101(1):61–67. Doi: https://doi.org/10.1007/s00128-018-2365-x

UDDIN M.G., MONIRUZZAMAN M., QUADER M.A., HASAN M.A. (2018) Spatial variability in the distribution of trace metals in groundwater around the Rooppur nuclear power plant in Ishwardi, Bangladesh. Groundwater for Sustainable Development, 7:220–231. Doi: https://doi.org/10.1016/j.gds.2018.06.002

USNRC (2000) Copper in Drinking Water. Committee on Copper in Drinking Water, Board on Environmental Studies and Toxicology, Commission of Life Sciences. U.S. National Research Council, Washington, DC.

VETRIMURUGAN E., BRINDHA K., ELANGO L., NDWANDWE O.M. (2017) Human exposure risk to heavy metals through groundwater used for drinking in an intensively irrigated river delta. Applied of Water Science, 7:3267–3280. Doi: https://doi.org/10.1007/s13201-016-0472-6

YI Y., YANG Z., ZHANG S. (2011) Ecological risk assessment of heavy metals in sediment and human health risk assessment of heavy metals in fishes in the middle and lower reaches of the Yangtze River basin', Environmental Pollution, 159(10): 2575–2585. Doi: https://doi.org/10.1016/j.envpol.2011.06.011

ZHANG S., LIUA G., UNA R., WUA D. (2016) Health risk assessment of heavy metals in groundwater of coal mining area: a case study in Dingji coal mine, Huainan coalfield, China. Human and Ecological Risk Assessment. 22(7):1469–1479. Doi: https://doi.org/10.1080/ 10807039.2016.1185689

ZHU L., YANG M., CHEN X., LIU J. (2017) Health risk assessment and risk control: drinking groundwater in Yinchuan Plain, China. Exposure and Health, 11:59-72. Doi: https://doi.org/10.1007/s12403-017-0266-6

ZHANG L., SHI Z., ZHANG J., JIANG Z., WANG F., HUANG X. (2016) Toxic heavy metals in sediments, seawater, and molluscs in the eastern and western coastal waters of Guangdong Province, South China. Environmental Monitoring and Assessment. (188) 313. Doi: https://doi.org/10.1007/s10661-016-5314-3