Article

Potential ecological risk assessment of heavy metals in sediments of water reservoir case study: Chah Nimeh of Sistan

O. Rashki Ghaleno[1], **M.H. Sayadi**[2], **M.R. Rezaei**[2]

[1]Student of Department of Environmental Sciences, University of Birjand, Birjand, Iran

[2]Department of Environmental Sciences, University of Birjand, Birjand, Iran

E-mail: mh_sayadi@yahoo.com, Mh_sayadi@birjand.ac.ir

Received 9 April 2015; Accepted 15 May 2015; Published online 1 September 2015

Abstract

The distributions of heavy metal concentrations in the surface sediments of Chah Nimeh of Sistan water reservoir were assessed. Sediment samples collected at 6 sites in the Chah Nimeh of Sistan water reservoir in connection with field surveys and the total concentrations were determined using atomic absorption spectrophotometry. The average contents of the metals studied were: Cd, 0.58 mg/kg; Pb, 4.76 mg/kg; and Cu, 42.41 mg/kg and arrangement of the metals from higher to lower mean content in this area are: Cu > Pb > Cd. The Igeo values were ranged from -2.7 to 1.8 with an average of -0.65. The pollution load index (PLI) ranged from 0.6 to 1.4, and the average index of PLI was 1.0, the Chah Nimeh of Sistan was moderately polluted. The index range of potential ecological risk was from 45.3 to 165.2, and the average index of potential ecological risk factors (RI) was 111.2.

Keywords heavy metal; surface sediment; ecological risk assessment; concentration factor.

Proceedings of the International Academy of Ecology and Environmental Sciences
ISSN 2220-8860
URL: http://www.iaees.org/publications/journals/piaees/online-version.asp
RSS: http://www.iaees.org/publications/journals/piaees/rss.xml
E-mail: piaees@iaees.org
Editor-in-Chief: WenJun Zhang
Publisher: International Academy of Ecology and Environmental Sciences

1 Introduction

Heavy metal pollution in the aquatic environment is one of the critical issues due to the toxic and persistent characters (Zhan et al., 2010; Varol and Sen, 2012). Heavy metal pollutants pose potential threats to ecosystems because they could be concentrated or accumulated in organisms and biomagnified at higher tropic levels (Gao and Chen, 2012). Heavy metals in water reservoir originate from both natural processes and anthropogenic sources. Natural processes like atmospheric inputs and geological weathering of rocks and soil, directly to surface waters, is usually the largest natural source. Comparatively, anthropogenic sources are mainly from industrial processing, urban sewage and agricultural run-off (Rezaei and Sayadi, 2015). After being introduced into the aquatic environment, heavy metals from the aqueous phase eventually become deposited to sediment through physical, chemical or biological mechanisms (Yuan et al., 2012; Zhan et al., 2010) . Sediments play an important role in elemental cycling in the aquatic environment. Sediments can be sensitive indicators for monitoring contaminants in aquatic environments. They can also act as a nonpoint source and other pollutions to overlying waters, and in turn adversely affect aquatic organisms (Sayadi et al., 2014). Many researchers have used sediment to study the behavior of metals (Sayadi et al. 2010; Sayadi et al., 2015; Sayadi et al., 2008). Since Chah Nimeh of Sistan is as one of important the water reservoir of Zabol city, and used in different purpose such as drinking water, agriculture, industry and livestock therefore the study and evaluation of heavy metals in the sediments is necessary. The main objective of the present study is to determine the distribution of the heavy metals (Cd, Pb and Cu) concentrations in surface sediments of Chah Nimeh of Sistan, and to assess the pollution status of this area with the geo-accumulation index (Igeo), contamination factor (CF), pollution load index (PLI) and potential ecological risk index (PERI).

2 Study Area and Methodology

Chah Nimeh is three semi-natural wells along the Helmand River, which is dug in the Quaternary terraces. The water reservoirs are located along the border between in the southeastern Sistan, Iran and Afghanistan. For storage and better control of the water reaching to the Sistan irrigated plain, the Chah Nimeh reservoirs in three units with 630 volume million m3 were constructed where the Helmand River separates into the Sistan and Baluchistan Province while making Chah Nimeh the second most important water storage reservoir in the Helmand basin. The forth unit with 900million m3 is under construction (UNDP, 2006). Surface sediment samples were collected as shown in figure 1 using a polypropylene coring device with 1m long and 10 cm internal diameter. Typically, cores were comprised of a 10 cm sediment surface layer for each sample, and 3 subsamples were taken at randomly chosen locations within an area of about 10 m2 surrounding each site. These samples were thoroughly mixed to create composite samples for each site.

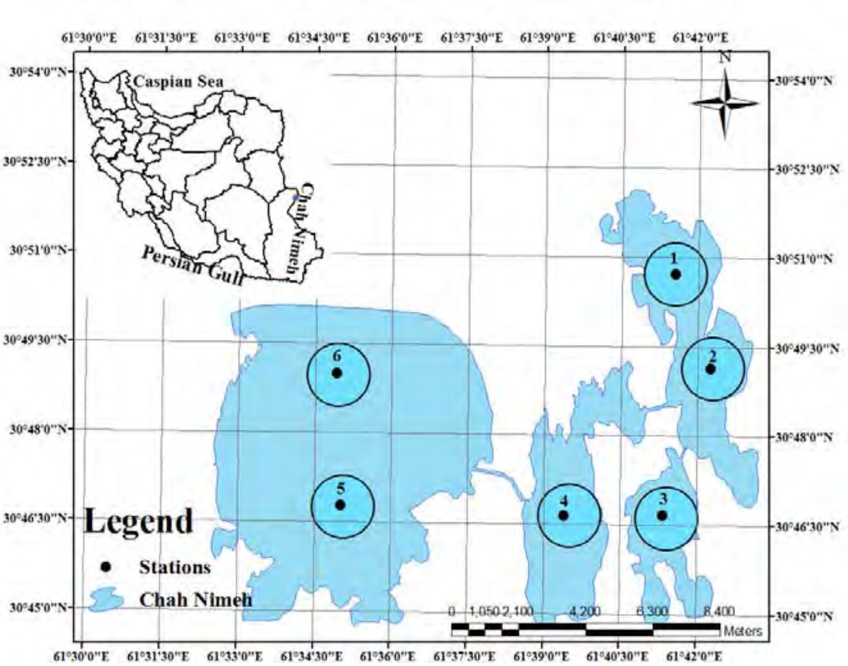

Fig. 1 Map of sampling stations.

A total of 6 composite samples was obtained and transported to the laboratory at -4 ºC, air-dried prior to screening using a 63 µm nylon sieve. Then, subsamples of the sediments were oven dried at 105 ºC to constant weight and were grinded using mortar and pestle. For metal analysis, total sediment digestion was performed on Teflon vessels following the classical open digestion procedures (SEPA, 2002). About 1 g air-dried sediment sample was weighed into Teflon beakers, in which a mixture of concentrated HCl-HNO_3-$HClO_4$ (i.e., 12 ml HCl, 4 ml HNO_3 and 4 ml $HClO_4$) was added, a Teflon watch cover was put in place, and the sample was left at room temperature overnight. On the following day the sample was heated to a temperature of about 100 ºC on a hot plate (El-Rjoob et al., 2008). Diagnosis distilled water was added and the digested material was filtered, then the residue was washed several times with deionized distilled water and complete with 50 ml volumetric flask. Cd, Pb and Cu were analyzed by atomic absorption model Contra AA 700 flame atomic absorption spectrophotometer with detection limits (mg/l).

In this study, four methods of pollution assessment of metals are conducted, the geoaccumulation index (I_{geo}) (Müller, 1969), contamination factor (CF), pollution load index (PLI) and Hakanson potential ecological risk index (Hakanson 1980). The Background values of Cd, Pb and Cu were 0.17, 19 and 33 mg/kg, respectively (Salomons and Forstner 1984).

The geo-accumulation index (I_{geo}) is defined by the following equation:

$$I_{geo} = \log_2 (C_n / K \times B_n) \quad (1)$$

where C_n is the concentration of metal n and B_n is the background concentration of the metal (n). The factor K is the background matrix correction factor due to lithospheric effects, which is usually defined as 1.5 (Müller, 1969). The classification of geo-accumulation index is presented in Table 1.

Table 1 Muller classification for geo-acumulation index.

I_{geo}	Class	Pollution status
> 5	6	Extremely contaminated
4-5	5	Heavy to extremely contaminated
3-4	4	Heavily contaminated
2-3	3	Moderately to heavily contaminated
1-2	2	Moderately polluted
0-1	1	uncontaminated to moderately contaminated
0	0	practically uncontaminated

The pollution load index (PLI) is defined as the n^{th} root of the multiplications of the concentrations (CF_{metals}):

$$PLI = (CF_1 \times CF_2 \times CF_3 \times \ldots\ldots\ldots CF_n)^{1/n} \quad (2)$$

values of PLI > 1 imply that heavy metal pollution exists. Otherwise, if PLI < 1, there is no heavy metal pollution (Tomlinson et al., 1980).

The Hankanson potential ecological risk index (RI) is defined as follows:

$$C_f^i = \frac{C_i}{C_n^i} \quad (3) \qquad E_r^i = T_r^i . C_f^i \quad (4) \qquad RI = \sum_i^m E_r^i \quad (5)$$

here C_i and C^i_n are the concentrations of metals examined in sediment samples and the geochemical background values of metals, respectively. C^i_f is the monomial contamination factors. T^i_r is the toxic-response factor for a given substance, e.g. Cd= 30, Pb and Cu = 5 (Hakanson, 1980). RI is the sum of all risk factors for heavy metals in sediments. The relation between evaluation indices and the pollution degree and potential ecological risk are shown in Table 2.

Table 2 Corresponding relationships between evaluation indices pollution degree and potential ecological risks.

C_f^i	Monomial contamination factor	E_r^i	Monomial potential ecological risk factor	RI	Sum of all risk factors
< 1	Low	< 40	Low	< 150	Low
1-3	Moderate	40-80	Moderate	150-300	Moderate
3-6	High	80-160	Moderate to high	300-600	High
≥ 6	Very high	160-320	High	≥ 600	Very high
		≥ 320	Very high		

3 Results and Discussion

The mean metal concentrations in the sediments are shown in Table 3. Metal contents were ranging over the following intervals: Cd, 0.22-0.89 mg/kg; Pb, 2.41-6.45 mg/kg; and Cu, 33.2-62.3 mg/kg. The average contents of the metals studied were: Cd, 0.58; Pb, 4.76; and Cu, 42.41, and arrangement of the metals from higher to lower mean content in this area are: Cu > Pb > Cd.

Table 3 the concentrations of heavy metals in surface sediments in Chah Nimeh of Sistan.

Station	Cd	Pb	Cu
1	0.89	6.45	49.7
2	0.71	5.89	36.8
3	0.28	3.96	33.2
4	0.22	2.41	35.7
5	0.78	5.33	62.3
6	0.64	4.52	36.8
Average	0.58	4.76	42.41
SD	0.27	1.46	11.32

The correlations between heavy metals were shown in Fig. 2. The Cu has poor correlation with the Cd and Pb, but relatively positive correlations with the Cd and Pb (coefficient of correlation r = 0.44 and 0.25, respectively). The metal Pb, show a higher correlation with the Cd (r = 0.85). Zahra et al (2014) indicated a strong positive correlation between Cd and Pb in sediments of the Kurang Nallah-feeding tributary of the Rawal Lake.

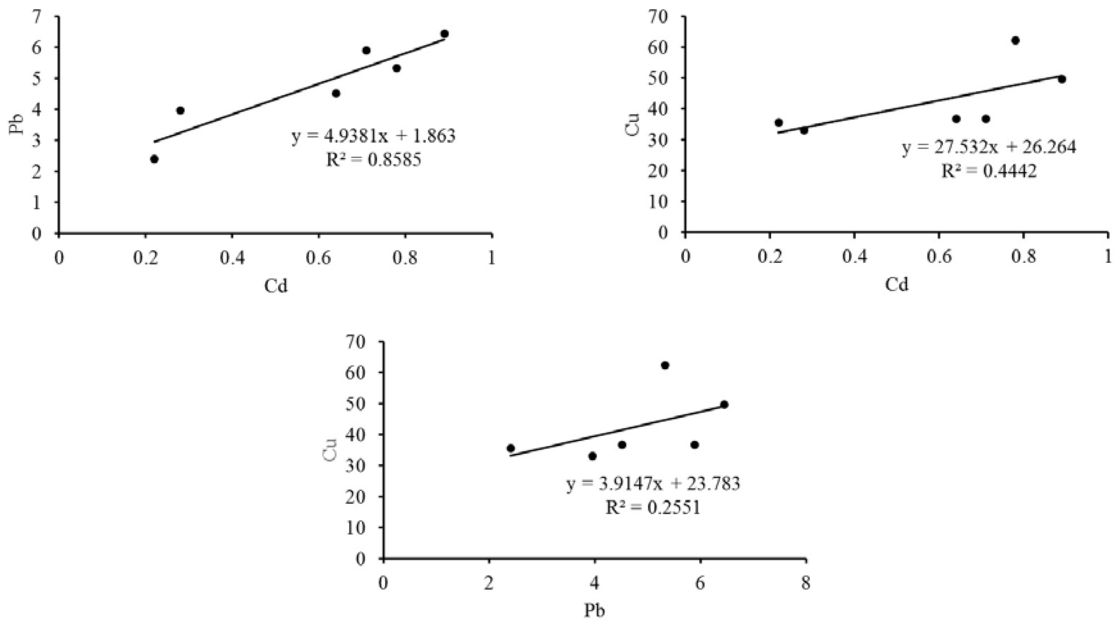

Fig. 2 Scatter plots showing the correlations between the heavy metals.

The results of CF and PLI are presented in Table 4. In this study, Cd had the highest and Pb had the lowest CF values among the three metals studied. The CF value for metal Cd had the highest CF values among the three metals studied at all sites except sites 3 and 4. The Pb had the lowest CF values among the three metals studied at all sites. Total contamination factors followed the order of site-1 > site-5 > site-2 > site-6 > site-3 > site-4.

PLI ranged from 0.6 to 1.4 (Table 4). According to the mean PLI value (1.0), the Chah Nimeh of Sistan was moderately polluted. Sites 1, 2, 5 and 6 had the highest PLI (1.4), (1.1), (1.3) and (1) within the study area, indicating that the sediments of site-1, 2, 5, and 6 were polluted by investigated heavy metals, where sites 3 and 4, PLI were > 1. The PLI followed the order of site-1 > site-5 > site-2 > site-6 > site-3 = site-4.

Table 4 the Contamination Factor and Pollution Load Index of heavy metals in surface sediments in Chah Nimeh of Sistan.

Station	Contamination factor			PLI
	Cd	Pb	Cu	
1	5.2	0.34	1.5	1.4
2	4.2	0.31	1.1	1.1
3	1.6	0.21	1	0.7
4	1.3	0.13	1.1	0.6
5	4.6	0.28	1.9	1.3
6	3.8	0.24	1.1	1

3.1 Geo-accumulation index (Igeo)

The results of the calculation of the Geo - accumulation index (I_{geo}) in sediment were shown in Fig. 3. Muller (1969) distinguished seven classes of geoaccumulation index, as shown in Table 1. The I_{geo} values were ranged from -2.7 to 1.8 with an average of -0.65. The Cd I_{geo} values varied, mostly, ranging from -0.4–1.8, most of the stations in the range of 1-2 (means moderately contaminated), except stations 3-4 (were <0, unpolluted). For the Pb and Cu metals, while the all stations (Cu except station 5) were fell in unpolluted. The Cd is a relatively rare metal, it has no essential biological functions and is highly toxic to plants and animals, and the major hazard to human health from Cd is its chronic accumulation in the kidneys. On the basis of the mean values of I_{geo}, the degree of heavy metal pollution in the surface sediments yielded the following ranking: Cd > Cu > Pb.

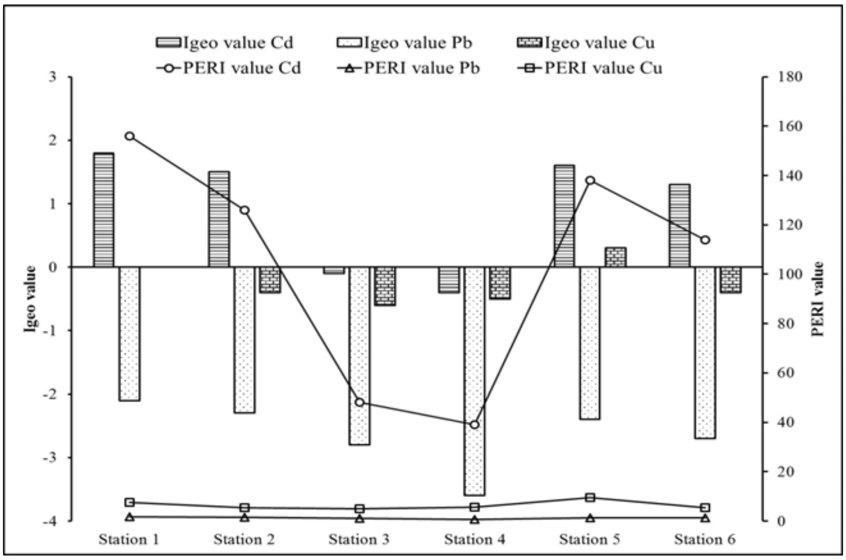

Fig. 3 The distributions of geo-accumulation index (Igeo) and potential ecological risk index in the sediment.

3.2 Risk assessment of heavy metals in Chah Nimeh of Sistan

The potential ecological hazard index was built by Hakanson (1980), which integrated the concentration of heavy metals with ecological effect, environmental effect, toxicology, and used to assess the heavy metals pollution and ecological hazard for sedimentology. Spatial distribution of single risk indices (E_r^i) is shown in Table 5; it was found that the single risk indices of heavy metals were ranked in the order of Cd > Cu > Pb. The result was consistent with that based on geoaccumulation index. The average ecological risk of Cd in the studied area was 103.5, indicating that Cd posed a very high risk to the local ecosystem. Generally, nonferrous metal mining and refining, manufacture and application of phosphate fertilizers are the main anthropogenic sources of Cd in the environment (Sayadi et al., 2015b). Preliminary studies have shown that the distribution of Cd is closely related to the intensive use of phosphate fertilizers, as phosphate fertilizers contain significant amount of metals, particulate Cd, as impurities (Zhang and Shan 2008; Xia et al. 2011). Similar findings were found in this study. The agricultural and other anthropogenic sources of Cd may cause the relative enrichment of these metals in the study area. Metal processing lots of agriculture lands and living residents are the source of Cd in the present sediments. The minimal ecological risk of Pb and Cu denoted low risk to the environment. The very high risk to environments posed by Cd should be widely concerned.

Table 5 Evaluations results of bio-available heavy metal, ecological risk index.

Station	E_r^i Cd	E_r^i Pb	E_r^i Cu	PERI
1	156	1.7	7.5	165.2
2	126	1.6	5.5	133.1
3	48	1.1	5	54.1
4	39	0.7	5.6	45.3
5	138	1.4	9.5	148.9
6	114	1.2	5.4	120.6

In order to quantify the overall potential ecological risk of heavy metals in sediments, the values of PERI were shown in Table 2. The values in six sampling stations ranged from 45.3 to 165.2, with an average of 111.2. The higher and the lower PERI values were observed at Stations 1 and 4, respectively. Higher this value may be due to the presence of higher heavy metal contents. The three heavy metals in 24% of the sampling stations posed moderate risk, 76% for low risk. The heavy metals pollution was obvious in sites of station 1, 2, 5 and 6 of the studied area, where the E_r^i reaches maximum value 165.2, attributing to moderate potential ecological risk level.

The risks of each heavy metal based on Igeo and PERI were different, especially for Cd. The possible reason may be the higher values of the toxic factor for Cd. Comparisons of total risks of heavy metals in sediments of Chah Nimeh of Sistan calculated by methods of Igeo and PERI are presented in Fig. 2. It was shown that the risk of metal Cd in sites of station 1, 2, 5 and 6 was high, which should be of particular concern. Cd is typical anthropogenic metal affected by human activities (Zhang and Shan, 2008; Sayadi and Sayyed, 2011; Sayadi et al., 2015a; Sayadi et al., 2015c) and showed severe Contamination Factor. Cd has been associated to a greater extent with colloidal materials in surface runoff that can easily be transported in river flow (Wakida et al. 2008). According to PERI, heavy metals in suspended sediments collected from sites (1, 2, 5, and 6) cause a moderate risk to the aquatic ecosystem while sampling sites (3 and 4) areas show low ecological risk cause by heavy metal contents in suspended sediments. Bed sediments collected from throughout the study area show low ecological risk from heavy metals.

4 Conclusions

The contents of Cd, Pb, and Cu in the sediments of the Chah Nimeh of Sistan were analyzed, and four methods of pollution assessment of metals are conducted, the geoaccumulation index (Igeo), contamination factor (CF), pollution load index (PLI) and Hakanson potential ecological risk index method in this study. Igeo, CF, PLI and PERI values indicated widespread pollution by Cd, Pb and Cu in the sediments. Pb and Cu in all the sampling stations are unpolluted polluted. The higher values of Igeo, CF, PLI and PERI of Cd in the Chah Nimeh of Sistan are attributed principally to anthropogenic sources, such as agricultural fertilizers. In the future, biological and ecological studies will need to be carried out to elucidate the influence of factors to the ecosystems.

Acknowledgement

The authors are appreciated the authorities of Research Council and Faculty of Natural Resources and Environment, University of Birjand, due to their sincere cooperation.

References

El-Rjoob AO, Mzsszdeh AM, Omari MN. 2008. Evaluation of Pb, Cu, Zn, Cd, Ni and Fe levels in Rosmarinus officinalis labaiatae (Rosemary) Medical plants and soils in selected zones in Jordan. Environmental Monitoring and Assessment, 140: 61-68

Gao X, Chen CTA. 2012. Heavy metal pollution status in surface sediments of the coastal Bohai Bay. Water Resources, 46: 1901-1911

Hakanson L. 1980. An ecological risk index for aquatic pollution-control- a sediment logical approach. Water Resources, 14: 975-1001

Müller G.1969. Index of geo-accumulation in sediments of the Rhine River. Geo Journal, 2: 108-118

Rezaei A, Sayadi MH. 2015. Long-term evolution of the composition of surface water from the River Gharasoo, Iran: a case study using multivariate statistical techniques. Environmental Geochemistry and Health, 37(2): 251-261

Salomons W, Forstner U. 1984. Metals in the Hydrocycle. Springer-Verlag, Berlin Heidelberg, Germany

Sayadi MH, Sayyed MRG. 2011. Comparative assessment of baseline concentration of the heavy metals in the soils of Chitgar Industrial Area Tehran (Iran) with the comprisable reference data. Environmental Earth Sciences, 63: 1179-1188

Sayadi MH, Shabani M, Ahmadpoor N. 2015a. Pollution index and ecological risk of heavy metals in the surface soils of Amir-Abad Area in Birjand City, Iran. Health Scope, 4(1): e21137

Sayadi MH, Rezaie A, Rezaei MR, Nourozi K. 2014. Multivariate statistical analysis of surface water chemistry: Acase study of Gharasoo River, Iran. Proceedings of the International Academy of Ecology and Environmental Sciences, 4: 114-122

Sayadi MH, Rezaei MR, Rezaei A. 2015b. Fraction distribution and bioavilability of sediment heavy metals in the environmental surrounding MSW landfill: case study. Environmental Monitoring and Assessment, 187(1): 4110

Sayadi MH, Rezaei MR, Rezaei A. 2015c. Sediment Toxicity and ecological risk of trace metals from streams surrounding a municipal solid waste landfill. Bulletin of environmental contamination and toxicology, 1-5

Sayadi MH, Sayyed MRG, Saptarshi PG. 2008. An assessment of the Chitgar River sediments for the short-term accumulation of the heavy metals from Tehran, Iran. Pollution Research, 27: 627-634

Sayadi MH, Sayyed MRG, Suyash Kumar .2010. Short-term accumulative signatures' of heavy metal in river bed sediments, Tehran Iran. Environmental Monitoring and Assessment, 162: 465-473

Tomlinson D, Wilson JG, Harris CR, Jeffrey DW. 1980. Problems in the assessment of heavy-metal levels in estuaries and the formation of a pollution index. Helgoländer Meeresuntersuchungen, 33: 566-575

UNDP. 2006. History of Environmental Change in the Sistan Basin, Based on Satellite Image Analysis: 1976 – 2005. UNEP Post-Conflict Branch, Geneva, Switzerland

Varol M, Sen B. 2012. Assessment of nutrient and heavy metal contamination in surface water and sediments of the Upper Tigris River, Turkey. Catena, 92: 1-10

Wakida F, Lara-Ruiz D, Temores-Pena J, Rodriguez-Ventura J, Diaz C, Garcia-Flores E. 2008. Heavy metals in sediments of the Tecate River, Mexico. Environmental Geology, 546: 37-42

Xia P, Meng XW, Yin P, Cao ZM, Wang XQ. 2011, Eighty-year sedimentary record of heavy metal inputs in the intertidal sediments from the Nanliu River estuary, Beibu Gulf of South China Sea. Environmental Pollution, 159: 92-99

Yuan H, Song J, Li X, Li N, Duan L .2012. Distribution and contamination of heavy metals in surface sediments of the South Yellow Sea. Marine Pollution Bulletin, 64: 2151-2159

Zahra A, Hashmi MZ, Malik RN, Ahmed Z. 2014. Enrichment and geo-accumulation of heavy metals and risk assessment of sediments of the Kurang Nallah-Feeding tributary of the Rawal Lake. Science of the Total Environment, 470: 925-933

Zhan S, Peng S, Liu C, Chang Q, Xu J. 2010. Spatial and temporal variations of heavy metals in surface sediments in Bohai Bay, North China. Bulletin of Environmental Contamination and Toxicology, 84: 482-487

Zhang H, Shan BQ. 2008. Historical records of heavy metal accumulation in sediments and the relationship with agricultural intensification in the Yangtze- Huaihe region, China. Science of the Total Environment, 399: 113-120