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Heavy metals contamination and its health risk assessment in the sediments of water reservoir dams at Al-Baha region, KSA

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ABSTRACT

The objective was to determine the contamination status of heavy metals in the sediments of some water dams reservoir at Al-Baha region, KSA and to assess their human health risk as a contribution to the knowledge and management of the water dams and the region around them. The concentrations of heavy metals in sediments of four water dams reservoir were investigated. More than 130 samples of the sediments were collected under wet and dry weather conditions and analyzed for heavy metal contents by Atomic Absorption Spectrophotometry. The results indicate that the concentrations of the tested metals in the sediment samples are significantly high in most samples. This indicates a clear pattern of geogenic sources and anthropogenic impact on these dams. In general, the order of concentration was Ba >Sr> Cr > Cu > Ni >Co >Pb. Exposure through ingestion was the scenario proposed for this study. The non-carcinogenic risk estimations reveal that HQ values for most of the metals much exceeds one, indicating a concern for chronic non-cancer effects on oral exposure to the sediments from these dams. The highest HQ values were for Co followed by Cr and Sr.

KEYWORDS

Risk assessment;
Heavy metals;
Sediments;
Contamination.

INTRODUCTION

Risk to human health associated with chemical exposure falls into a category of involuntary risk due to human activity. Coping with risk in a broad sense involves two basic processes: risk assessment and risk management. The need for chemical risk assessment, and management is necessary because it would be futile to try to eliminate completely such a risk from human life.

Increased urbanization and industrialization worldwide has resulted an increase in the levels of chemicals pollution of soils and water. The degree of anthropogenic impact in the environment can be evaluated in terms of metal contamination of soils[1-2].

Among various effective pollutants associated with sediment contamination are heavy metals which are paid attention in this study because they may have toxic impact to human being and animals and tend to bio-accumulate in the food chain, and their distribution in the environment is strongly affected by diffuse of anthropogenic sources[3-5].

Sediments are loose particles of sand, clay, silt, and other substances that settle at the bottom of a water body. They come from eroding soil and from decomposing plants and animals. Sediment can be contaminated by different pollutants which enter the water every day. Some flow directly from industrial and municipal waste dischargers, while others come from polluted runoff in urban and agricultural areas. And other contaminants are carried through the air. In cases like this, the sediments may serve as a contaminant reservoir or source of contamination. We believe that contaminated sediments are serious problem because it directly influences human health,since they have excellent ecological transference potential[5-6]. When contaminants bioaccumulate in food sources pose a threat to human health, and possible long-term effects of eating contaminated food include cancer and neurological defects[7].

Dams reservoir's sediments represent the ultimate sinks for heavy metals and are normally the final pathway of both natural and anthropogenic components produced or derived to the environment[8-9]. As important sinks and sources for various heavy metals, sediments constitute a reservoir of bioavailable trace metals and play a significant role in contamination mobilization in aquatic systems under favorable conditions. Studies on heavy metals in sediments of rivers, lakes and dams have been a major environmental focus in the last two decades[9-11].

The present study focuses on the sediments of some water reservoir dams at Al-Baha region,which is situated in the southwestern part of Saudi Arabia with an area around 11000 Km^2 and of about half million population. In Al-Bahaprovince there are around 28 water dams distributed at different locations in the region. The dam-reservoirs play an important role in supporting water supply for agriculture and non-potable water supply for households and daily use in Al-Baha region. There are no known background levels of metals in the sediments and water of dams in the area, and according to our knowledge there are no studies have been done before regarding heavy metal contamination in these dams. The Al-Baha residents have expressed concerns regarding contamination of the water they use from the dams with heavy metals.

Therefore, it is of importance to establish the degree of heavy metal contamination, that may be present in the sediments of the dams at Al-Baha region and evaluate whether these levels may pose any health effects.

MATERIALS AND METHODS

Sampling area

This study was carried out at Al-Baha province which is located in the south-west part of the Kingdom of Saudi Arabia with very limited water resources as compared to its population needs. The area of Al-Baha province is around 11000 Km^2 and of about half million population. Due to its location with an elevation of 2155 meters above sea level, Al Baha's climate is moderate in summer and cold in winter. The probability that precipitation will be observed at this location varies throughout the year. the most common forms of precipitation are thunderstorms (85%), moderate rain (7%), and light rain (6%). The average rainfall throughout the whole region is 100–250 mm annually.

Therefore, some dam-reservoirs (*nearly 28*) were constructed in Al-Baha region which constitute a vital source of water. Water from these dams is used for irrigation and for household purposes and daily use. Different anthropogenic sources around the dams which may contribute in metal contamination of the sediments of the different dams.

Four dams namely : Alkharar (Hadwah) (*total restoration of water=150000 m^3*), Beedah (*total restoration of water=200000 m^3*), Alsadr (*total restoration of water=50000 m^3*) and Midhas (*total restoration of water=15000 m^3*) are chosen in this study as they are one of the major water sources in the Al-Baha region.

Sampling and analytical methods

Sediment samples were collected from each dam (n = 16) from the mouth of the dam and (n = 16) from the dam's basinduring low level of waterat two stages. for measuring heavy metals residues in the sediments. Soil samples were taken by regular augersampler at depth of about 5-15 cm from the surface. The samples (about 1 kg each) at each station were taken in a plastic bag and transferred to the laboratory for analysis. In the laboratory, the samples were dried in the oven at

70 °C for 24 hrs, then grinded and sieved.

The sediment samples were analyzed for heavy metal contents at King Abdulaziz University on Perkin Elmer -3100 Model Atomic Absorption Spectrophotometer. A fraction of each most dried grains of each sample (1.0 gm) was digested using H_2O_2 (45%), HNO3 (45%) and HF (10%) solutionmixture. The solution of the digested samples was filtered and diluted and analyzed by using atomic absorption spectrometer for heavy metals[12]. All analysis were carried out twice for each sample.

Health risk assessment

Exposure scenario

Potential exposure pathways to heavy metals in sediments may result from ingestion exposures (include drinking water and using water for cooking or eating small amounts of sediments on the surface of unwashed vegetables). Children, in particular, may ingest significant quantities of sediments due to their tendency to play on the sediments and their tendency to mouth objects or their hands. Other pathway of exposure is dermal exposure (when people come in touch with the sediments either when swimming, walking in the water, bathing and showering and general washing). Dermal uptake of pollutants in contact with the contaminated sediments is an exposure pathway with small amount from the total exposure. The skin has an outer layer that protects humans against different external metals and other pollutants having a low probability to pass through. Accordingly, we take into consideration that the dermal uptake for metals is zero.

Sediment inhalation has a high contribution to the total exposure of humans to pollutants. sediment inhalation depends on wind velocity, sediment texture, sediment humidity and not only.

So in this study, the direct contact pathway for sediments is ingestion (*worst case exposure*) and considered the potential source of exposure to heavy metals in sediments.

Non-cancer risks quantification

For potential non-carcinogenic toxic effects of heavy metals, a hazard quotient (HQ) was calculated, comparing the expected exposure to the agent (i.e. chronic daily intake (CDI)) to an exposure that was assumed not to be associated with toxic effects (i.e Reference Dose (RfD) or Minimal Risk Level (MRL)). An HQ <1 was considered to be safe for a life time of exposure[4,13].

For calculating HQ we used the following equation:

$$\mathbf{HQ = CDI / RfD}$$

{*Where: CDI = Chronic Daily Intake ; RfD = Reference Dose*}

The CDI was estimatedfor ingestion of sediment route by default and site-specificconditions. The default equation, and exposure factors were derived from database. The default equation used for calculating CDI[4]is:

$$\mathbf{CDI = (C_s \times IR_{soil} \times EF \times ED) / (BW \times AT)}$$

{*Where: C_s = Concentration of metal in sediment (mg. Kg^{-1}); IR_{soil} = Ingestion rate of sediment (Kg. day^{-1}); EF = Exposure frequency (days $year^{-1}$);p ED = Exposure duration (years); BW = Body weight (kg); AT = Average time (days)*}

The CDI of sediment ingestion was calculated separately for adults (men,women) and children, because of differences in bodyweight and ingestion rate of sediment. Estimates are made using the following default values[14-15] (TABLE 1).

TABLE 1 : Default values used for calculations (Ingestion pathway)

Variable	Adults		children
	Male	female	
IR_{soil}	(0.1gm/d)	(0.1gm/d)	(0.2g/d)
EF	350	350	350
ED	30	30	6
BW	70	65	15
AT	10950	10950	2190

To assess the overall potential for non-carcinogenic effects posed by all the chemicals, the HQ estimated for each metal are summed up (assuming additive effect) and expressed as Hazard Index (HI):

$$\mathbf{HI = HQ_1 + HQ_2 + HQ_3 \ldots\ldots\ldots + HQ_n}$$

If the HI is greater than unity, then a chronic noncancer effect is likely to occur[16].

RESULTS AND DISCUSSION

This study was designed to find out the distribution

TABLE 2 : Average concentration (mg/kg) of heavy metals in the sediments of the dams

Metals	Average concentration of the metals in (mg/kg)							
	Alsadr		Beedah		Medhas		Alkharar	
	At the mouth	At the basin	At the mouth	At the basin	At the mouth	At the basin	At the mouth	At the basin
Sr	219.1	255	250.28	302.05	239.37	290.4	426.66	344.08
Ba	747.5	788.45	770.15	1011.85	1137.07	900.4	7215.14	4991.38
Cr	380.83	411.55	221.75	216.15	261.87	265.55	228.63	246.14
Co	21.79	22.42	21.675	20.86	22.3	22.05	21.68	26.73
Ni	73.24	84.36	42	37.7	54.22	49.6	42.26	54.12
Cu	61.9	81.23	75.52	65.53	57.55	49.9	63	62.29
Pb	2.04	4.98	4.91	8.01	3.03	3.6	6.73	3.5

of heavy metals and evaluate exposure to these metals from sediments of water dams reservoir. The study covered four water dams reservoir ((*Alsadr, Beedah, Medhas and Alkharar*)) in Al-Baha province, Saudi Arabia from which most of population having access to public water supplies. According to our knowledge no studies on the distribution and human health risk assessment of heavy metals in sediments have been carried out in Al-Baha region. We have carried out one study before on the risk assessment of heavy metals in water-wells at Al-Baha region[4].

Nearly 130 sediment samples were collected from the four dams sites during the wet and dry seasons and analyzed for the heavy metals content. Heavy metal analysis in the sediments from the four dams (*Alsadr, Beedah, Medhas and Alkharar*) are shown in TABLE (2). TABLE 2 showed that the metal elements detected in the analyzed samples from the mouth and basin of the dams were: Sr, Ba, Cr, Co, Ni, Cu and Pb.

Results (TABLES 2) show that the average concentration of the heavy metals detected in the sediments were as summarized in the following points :

1 The concentration of the detected metal elements in general are significantly high except for lead. And on comparing with EPA sediment quality guidelines, we observe that all sites fall in the criteria of moderately to heavily polluted range for all metals examined except for Pb is not polluted[11].

2 The concentrations of the heavy metals in the sediments at the basin of the dams at all sites are relatively higher than that at the dams' mouth.

3 Of all the metals examined, barium was found to be the most abundant metal in all samples at both the mouth and basin of the dams. While lead was with lowest concentration.

4 In general the order of concentration was:

i. for *Hadwah&Beedah*: Ba>Sr> Cr > Cu > Ni >Co >Pb in both the mouth and the basin

ii. For *Medhas*: Ba> Cr >Sr> Cu > Ni >Co >Pb at the mouth and Ba>Sr> Cr > Cu > Ni >Co >Pb in the basin.

iii. For *Alsadr* : Ba> Cr >Sr> Cu > Ni >Co >Pb in both the mouth and the basin.

5 On comparing the concentration of all detected metals at the basin of *Alsadr*dam were higher than that at the mouth of the dam

6 At *Beedah*dam the concentration of Cr, Co, Ni and Cu, were higher at the mouth of the dam, while Sr, Ba and Pb were higher in the basin.

7 At *Medhas*dam the concentration of Ba, Co, Ni, and Cu were higher at the mouth of the dam, while Sr, Cr and Pb were higher in the basin.

8 At *Alkharar*dam the concentration of Sr, Ba, Cu and Pb were higher at the mouth of the dam, while Cr, Co, and Ni were higher in the basin.

9 The concentration of Co in the samples from both the mouth and the basin of the dams was nearly equal.

It can be seen that the sediments at the dams are seriously contaminated by heavy metals, the contamination of heavy metals probably relates togeogenic sources and the discharging of municipality wastes and wastes from the people (tourists and sightseers) activities near these sites.

From the results obtained it could be observed that the metal concentration varies from one dam to another, this could be attributed to the volume of anthropogenic activities near these sites and the geological distribution of minerals that varies from one location to the other. Moreover, the variance in concentration is probably related to differences in sedimentary and particle size characteristics[17].

Health risks associated with chemicals found in the sediments are estimated on the basis of assumed long-term exposure and the dose-response relationships for chronic toxic effects of the contaminants. In the present analysis, however, health risks are assessed for lifetime exposure to conditions defined by fixed contaminant levels in the sediments. People living in the region of concern may come in contact daily with the sediments of the dams through different means. The individuals might ingest, inhale or get on their skin on continuing (daily average) basis.

For the human health risk assessment, ingestion of sediments is the only potential exposure pathway was selected in this study due to the site-specific uses and the feature of metals. The inhalation and dermal exposure routes were neglected in accordance with other studies[18-22].

The results of human health risk assessment are shown in TABLE 3 and TABLE 4. TABLE 3 summarizes the estimated CDIs and HQ values with default data for children and adults exposed to contaminants in the sediments at the mouth of the dams. While TABLE 4 summarizes the estimated CDIs and HQ values with default data for children and adults exposed to contaminants in the sediments at the basin of the dams.

For comparison the ingestionRfD values or MRL values (mg/g/day) used in this study were: Sr = 6.00E-01[23], Ba = 2.00E-01[24], Cr (VI) = 3.00E-03[25], Co = 3.0E-04[26], Ni = 2.0E-02[27],Cu = 4.00E-02[28], andPb= 3.50E-02[29-30].

Non-cancer risk quantification

The potential non-carcinogenic risks for exposure to the detected heavy metals at the contaminated sediments were quantified for the selected scenario (i.e. ingestion route of exposure). The CDIs were estimated for each exposure to single heavy metal and compared with the RfD or MRL to produce HQs.

Calculated HQ values for the most sensitive population (Child) is much higher than 1 for all metals except Pb, in all dams which indicates that there is a concern for increased risk of chronic non-cancer effects for humans from ingestion of the sediments from these dams, similarly HQ values for Ba, Cr, Co, Ni and Cu in all sites were much higher than 1 for adults population.

The highest HQ values were for Co ((9.90E+01)–(1.10E+2)) nearly in all dams' sediments followed by Cr and Sr. The least was for lead and it was below one for adult population while HQs values exceeded one for the sensitive population (i.e. child) at the sites of Beedah, Al Kharar and medhas dams.

Moreover on calculating the Hazard Index (HI)for all the metals examined we find that it was be very much higher than one which supports the concern for chronic human health risk.

CONCLUSION

This study provides an overview of the heavy metals content in sediments of the selected four water dams reservoir and the extent of human exposure to different levels of these heavy metals. Our investigation on the sediments status of the selected water dams at Al-Baha region indicate that sediments are seriously contaminated with heavy metals. The critical points with concentrations of the heavy metals in the sediment samples exceeding the permissible level concentrations were located and the sites fall within highly polluted criteria. The non-carcinogenic risks estimations reveal that there is a concern for increased risk of chronic effects on humans. The type of the received results could be taken into account in supporting experts in developing strategies and planning of durable monitoring plan and management of sustainable dam reservoir uses. In addition, public awareness campaigns plan should be implemented to develop effective solution.

RECOMMENDATIONS

- Increasing public awareness of the problem is crucial to developing effective solution. People should be informed and educated about the potential health risk.
- There is a need for continuous monitoring of pollution levels in the sediments of these dams.
- The results obtained in this study would serve as baseline data for the present and future metal pollution status in sediments of dams at Al-baha province, KSA.
- Further research must be carried out to study the relationship between concentration of heavy metals in the sediments and the contribution of anthropogenic contamination or natural weathering of rocks and soils.
- Some steps must be taken to reduce heavy metal concentration by dilution by addition of uncontaminated soil or distributing sediments to other places like garden plots or others.

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