World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(RESEARCH ARTICLE)

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Accumulation of Heavy Metals in Dam Sediments Effects on Plankton Productivities of the Arabian Gulf

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World Journal of Advanced Research and Reviews, 2022, 14(01), 116–124

Publication history: Received on 25 January 2022; revised on 01 March 2022; accepted on 03 March 2022

Article DOI: https://doi.org/10.30574/wjarr.2022.14.1.0194

Abstract

Purpose: Metal accumulation in sediments threatens adjacent ecosystems due to the potential of metal mobilization and the subsequent uptake into food webs. Dams produce important changes in flow regime and sediment deposition. When inundation starts with the building of dams, water surface area increases, flow rate decreases, and sediment carried by the valleys is deposited in the dams. However, there is a lack of research on the chemical properties of deposited sediment in dams.

Method: We aimed to fill this gap in the literature by providing valuable data on the particle size and heavy metal of sediment in different dams. Therefore, the aim of this study conducted within the Northern emirates of United Arab Emirates dams, to estimate heavy metal concentration of sediment, including particle size distribution. A total of eight sediment samples from each dams were collected and analyzed for heavy metals. The concentrations of Iron (Fe), Nickle (Ni), Copper (Cu), Zinc (Zn), Lead (Pb), Cadmium (Cd), Chromium (Cr), and Cobalt (Co) in sediment samples were determined using Atomic Absorption Spectrophotometer (AAS).

Results: The concentrations of the heavy metals studied in the sediment samples were accumulated as Fe> Ni> Cr> Zn> Co> Pb> Cu. The concentrations of Ni and Cr have exceeded the threshold in the sediments of in line with W.H.O standards. Cadmium was not detected in soil, while other elements detected were in trace amount below the allowable limits in soil. The consideration of environmental factors is required to develop pollution managements and assess environmental risks for dam sediments.

Conclusion: The studies conducted provide background to a discussion on the extent of anthropogenic pressure on the natural environment in the Arabian Gulf, further underlining the relationship between retention of sediments in the dam and the increase in heavy metal contamination of bottom sediments and to the marine environment which effects possible to plankton productivity.

Keywords: Dam reservoir; Deposited sediment; Particle size; Heavy metals

1. Introduction

Heavy metal distribution has been one of the critical concerns in natural environments due to their toxicity and biomagnification attributes. Many regulations have been established to avoid heavy metal concentrations in waters, sediments, and soils exceed quality criteria for environmental protection. Anthropogenic activities have discharged significant amounts of heavy metals into water. By accumulated in sediments, heavy metals could enter the food chain

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as bottom sediments in reservoirs serve as habitats and food sources for benthic fauna. Subsequently, heavy metals may directly or indirectly threaten the aquatic flora and fauna. Thereby, metal contamination in sediments has been an ongoing issue worldwide [1] as sediment-bound metals may be of great significance for water quality and ecosystem health [2]. Most importantly, the relative abundance of heavy metals in sediments is mainly dependent on the waste discharged from industrial and other anthropogenic activities [3].

Studies concerning the heavy metal content of bottom sediments are of practical importance, particularly with respect to reservoirs impounded by dams since such reservoirs are used for various purposes and metals may be released from sediments to the water in certain conditions, causing secondary pollution [4]. The bottom sediment layer in reservoirs impounded by dams is mostly formed by sedimentation and to a much smaller extent by sedentation [5] Bottom sediments are polygenetic materials, but in reservoirs impounded by dams, the primary source of the material accumulated is the waters of the rivers that feed them [6]. However, that both heavy metals and other trace elements find their way into surface waters mainly as a result of anthropogenic pressure [7]. Heavy metals interact with aquatic ecosystems by means of natural events, such as the abrasion of soil and rock, erosion and volcanic destruction, and non-natural, such as agricultural as well as domestic and industrial waste [8]. As they do not undergo biodegradation, they are accumulated in the environment and reach high concentrations; then they can be carried to the top steps of the food chain [9]. Toxic effects of heavy metals, such as a decrease in chlorophyll content, decrease in rate of growth, generation of reactive oxygen types and accordingly oxidative damage in biomolecules were determined in earlier studies [10]. Aquatic ecosystems, which have high primary productivity and produce oxygen, are also used for fishing, irrigation, and recreation purposes; however, they are regarded as a receiving environment for pollution. Heavy metals that are transported to these environments can easily accumulate in the sediment, under certain conditions, permeate to the water layer [11]. The detection of heavy metal concentrations in the sediment is an important parameter that shows the level of pollution in aquatic ecosystems [12]. In recent years' metal concentrations were found to be increased in coastal and marine eco-systems as a result, aquatic organisms are exposed to elevated levels of heavy metals. The distribution and behavior of heavy metals in the marine environment, as well as their impact upon marine organisms and human health, are of great concern due to their persistent, non-biodegradable and toxic properties. In addition, heavy metals show harmful effects even at very low concentration on the aquatic organisms including plankton, aquatic plants, invertebrates and vertebrates [13].

Dam construction decreases velocity of the water flow, causing a sedimentation increase upstream of the dam. Thus negatively influencing other benefits of dams, such as water supply, power production, and flood control [14]. Sedimentation can change geomorphological conditions upstream of reservoir areas. For example, sediments deposited reduced flow, while the accumulated sediments can change the terrain of the bottom of the reservoir [15, 16]. When analyzing properties of sediments, physical properties such as particle size distribution and chemical properties are taken into account [17]. Previous studies reported significant levels of variation in particle size distribution related to precipitation, human activities source material, and physiographic factors [18].

The purpose of the studies described in this paper was to determine the level of heavy metal pollution of bottom sediments of the dams are situated in the northern part of United Arab Emirates. The objectives of this study were to determine the differences in particle size distribution, of eight dams; to determine variation in metal concentration. The data gathered from this research, the first study on the deposited sediments in these Bayyah, Gadaah, Galeelah, Shasm, Al Ghail, Baiah, Aiam and Siji Dams, can be considered a pioneer addition of information on the deposited sediments accumulated in dam reservoirs. The studies conducted provide background to a discussion on the extent of anthropogenic pressure on the natural environment in the Arabian Gulf. This discussion providing information on natural content of heavy metals in the dam sediments, further underlining the relationship between retention of sediments in the dam and the increase in heavy metal contamination of bottom sediments and to the marine environment which effects possible to plankton productivity.

2. Material and methods

2.1. Study areas with coordinates

Ba'ayya Dam: N 25° 19' 13.38" E 56° 1' 23.35", Al Gada'ah Dam: N 25° 46' 23.34" E 56° 2' 36.93", Ghaleelah Dam: N 25° 58' 57.94" E 56° 8' 46.62", Sha'am Dam: N 26° 1' 58.46" E 56° 6' 53.89", Al Ghail Dam: N 25° 27' 11.67", E 56° 1' 57.77", Al Biah Dam: N 25° 47' 52.30" E 56° 4' 35.51, Al Aiam Dam: N 25° 26' 42.53" E 56° 2' 53.59", Siji Dam: N 25° 16' 26.97" E 56° 2' 1.51"

Figure 1 Location of the study area

2.2. Samples Collection

The sediment samples were collected from all eight dams. In Each dam eight sediment samples were collected, four samples from upper dam and four samples from lower dam. Using a core sampler. After the sediments had been collected, from sub surface 10 to 20 cm sediment layers in order to determine sediment properties they were placed in tightly sealed plastic containers.

2.3. Sediment sample drying and sieving

Samples kept in suitable dry container e.g. porcelain dish, beaker etc. First weigh the empty container followed by weighing with sample, so as weight of sample can be calculated. Kept this container to the oven at 70^0 C for 2-3 hours or more till the sample get dried. When the sample appears to be dried raise the temperature maintaining 110 ± 5°C till constant weight. Sediment sampling and drying procedure according to Mudroch and Azcue [19].

2.4. Grain size analysis

According to Mudroch et al [20], a known amount of soil is sieve by placing largest size of sieve upon the top of the sieve group. (Top sieve should be of the largest screen openings followed by decrease in size to the bottom with collector). All the sieves should be shaken mechanically by sieve shaker for a specified period of time. After shaking the shaking is over the material retained on each sieves are weighed either with sieve or taken in any other container. For this purpose, each sieve should be weight in the beginning (known as the tare weight) and at the end of sieving. This process is repeated for all the sieves and the bottom pan. Cumulative should be exactly same as the starting material weight but it be less because of some losses during sieving and transferring.

2.5. Digestion methods

Microwave digestion were performed in a close microwave oven system method note followed CEM MARS Microwave digestion and extraction system USA.

2.6. Metal determination procedure using AAS

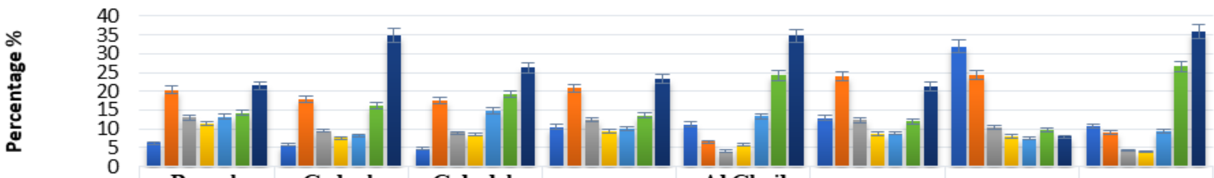
Heavy metal concentrations in the fraction <63-micron size. Concentration of Iron (Fe), Nickle (Ni), Copper (Cu), Zinc (Zn), Lead (Pb), Cadmium (Cd), Chromium (Cr), and Cobalt (Co) in sediment were measured with Atomic Absorption Spectrophotometer- AA-7000 Shimadzu and the stability of the device was checked by reading a standard every tenth sample. A blank solution was used to determine the analytical solution and probable contamination. All of the analysis were repeated three times.

2.7. Data Analysis

For comparing and maintaining the uniformity and homogeneity, all the data were transformed into the same units and the results were expressed as mean ± SE. Mean, standard deviation, minimum and maximum were determined for all properties measured.

3. Results and discussion

In United Arab Emirates no existing studies on sediment properties have focused on sediments being deposited in dam. The sediment deposition areas in this study shows that, this sedimentation process is much clearer and visible at the upper section of the dams and creates sediment deposition areas, especially when the level of water flow decreases. This, in turn, provides an opportunity to sample and study selected properties of recently deposited sediments. When the particle size distribution was evaluated in terms of mean values, it was found that the deposited material mainly consisted with less fractions. The sediment collected from eight dams each dams with eight samples. The particle size distribution of the dam sediment samples was studied at Bayyah, Gadaah, Galeelah, Shasm, Al Ghail, Baiah, Aiam and Siji Dams. The average particle results indicate that less the 63 micron the average percentage showed high in all the dams sediments except Aiam Dam showed less with 7.94 % [Fig 2], and the fine-grained sediments (< 63 m in particle diameter) are transported and deposited toward the dam. Other studies have observed that suspended materials, are trapped and deposited in the dams due to slower flow regime and decreased sediment carrying capacity and thus form sediment deposits with high silt and clay fractions [21]. Morris and Fan [15] reported that sediments depositions tend to show a loose matrix with a large volume of small water-field voids during their initial settlement. Later on with the weight of the overlaying sediment, this causes vertical compression of the layers. However, the sediment deposition areas in our study have been recently deposited and not enough time has passed for these sediments to be compacted.



	Bayyah Dam	Gadaah Dam	Galeelah Dam	Shaam Dam	Al Ghail Dam	Baiah Dam	Aiam Dam	Siji Dam
>1.25 mm	6.24	5.81	4.78	10.56	11.23	12.89	31.98	10.76
1.25 mm	20.33	17.8	17.63	20.78	6.54	23.88	24.23	9.08
1.0 mm	13.05	9.52	8.88	12.46	4.11	12.38	10.52	4.39
500 um	11.4	7.55	8.45	9.3	5.78	8.66	8.06	3.96
250 um	13.27	8.22	14.77	10.12	13.31	8.84	7.46	9.35
125 um	14.19	16.19	19.19	13.55	24.18	12.01	9.77	26.57
63 um	21.48	34.86	26.27	23.19	34.83	21.31	7.941	35.86

Figure 2 Average particle size in percentage % in eight different dam's sediments, the data is shown as mean ± standard deviation (n=8)

3.1. Heavy Metal Concentration in Sediment Samples

In sediment samples the effect of particle size distribution on the metal concentration in dam's bottom sediments were also studied, because of preferentially pollutants attaching to the finest particles (fractions < 63 μm). The metal analysis results of the samples are given in graphically in Figures 3-9. As sediment has a high absorption capacity, the heavy metals dissolved in the water accumulate in the sediment. The concentrations of the heavy metals studied in the sediment samples were accumulated as Fe> Ni> Cr> Zn> Co> Pb> Cu. The results of the study revealed that Fe, Ni, and Cr present in the soil sample are in higher concentrations than Zn and Cd, that are in trace amount and were in the following order of abundance Fe> Ni> Cr> Zn> Co> Pb> Cu.

Fe is present in concentration higher than other metals investigated because of geographical origin of the soil. The higher Fe, Ni and Cr concentrations showed that there is heavy metals pollution at the sampling site where anthropogenic activities. Concentration of Zn and Cd showed that anthropogenic activities are lower. In general, the results obtained showed that, the heavy metals concentration in the sediments sample can be attributed to leaching of the top soil and unproductive nature at the time of sampling. The distribution pattern of the metals in the soil sample were similar to those reported by many researchers [23, 24]. The concentrations of, Ni and Cr have exceeded the permissible limit prescribed by WHO [25] in Bayyah, Al Aiam and Siji Dams [Figures 5 & 6]. This means that the inhabitants of this area are susceptible to heavy metal toxicity.

Cadmium (Cd) was not detected in quantities, which does not mean that it was absent, however. Cadmium is a metal closely related to anthropogenic pollution and poses a problem for the health of the aquatic environments [25]. It easily finds its way into water where it is absorbed by living organisms and accumulates in their tissues. It is also bound in sediments, inter alia owing to bacterial activity that leads to its precipitation as sulphides [26].

Cobalt (Co) was found high in the sediments of the Bayyah Dam, Aiam Dam, Siji Dam, Al Ghail, Ghalial Dam, Al Biah Dam and Gadah Dam [Fig:3]. These are concentrations referring to the presence of cobalt in the sediments of all. As opposed to other heavy metals, the presence of this metal in aquatic ecosystems may be caused to a large extent by the denudation of the natural rock and soil environment [27].

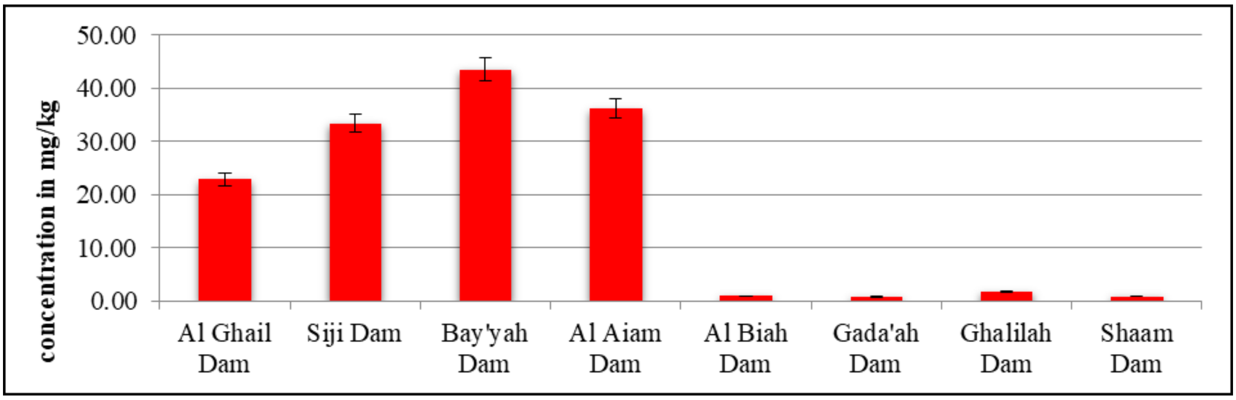


Figure 3 Variation of Cobalt Concentration in eight different Dams. Data are mean values of replicate analyses, error bars indicate SD (n=8), Average Concentration of metals in mg/kg

Copper (Cu) is readily adsorbed onto suspended matter. Its concentration in the bottom sediments of the dams may be considered low in the light of the data quoted by [28], which suggests that water concentrations are low as well. Nevertheless, it has been found that copper concentrations in the sediments analyzed not exceeded the levels considered standards. This is important from the point of view of vegetation, for which copper is highly toxic [Fig: 4]. the amount of copper in the samples examined is probably linked to the fact that it is strongly immobilized in the soil and this prevents its migration to the aquatic environment. Just as in the case of chromium, significantly higher concentrations were found in the Bayyah Dam in comparison with the lower Al Biah dam [Fig: 5]. Concentration values, which exceed the soil environment, point to anthropogenic pressure as a factor contributing to the accumulation of this element.

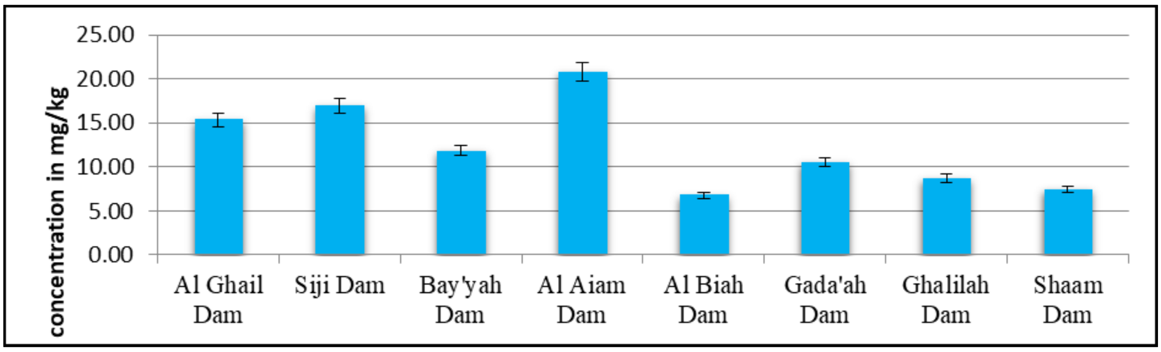


Figure 4 Variation of Copper Concentration in eight different Dams. Data are mean values of replicate analyses, error bars indicate SD (n=8), Average Concentration of metals in mg/kg

Nickel (Ni) concentrations in sediments varied spatially. The contribution nickel pollution of the Bayyah dam, Aiam dam, Siji dam and Al Ghail dam confirmed revealed that the concentration of nickel in this dams almost fivefold increased level, the trend is worrying owing to the possible carcinogenic effect of this metal [Fig: 6]. Lead (Pb) concentrations in all the dams did not vary spatially [Fig: 7]. Lead is relatively immobile in the soil, and in the aquatic environment it is often completely adsorbed by sediments. Lead concentrations in the environment are linked to industrial pollution and road usage. Since this metal is highly toxic to living organisms [29]. The threat of lead poisoning to human results from its accumulation in the food chain. Zinc (Zn) concentrations in the bottom sediments examined range described as low. Generally, zinc toxicity in water is limited but its presence increases the toxic effects of copper, nickel and cadmium [27]. It is estimated that zinc is toxic to fish at higher concentrations, however Zinc has estimated with in the WHO concentration in all the dam's sediments [Fig: 8].

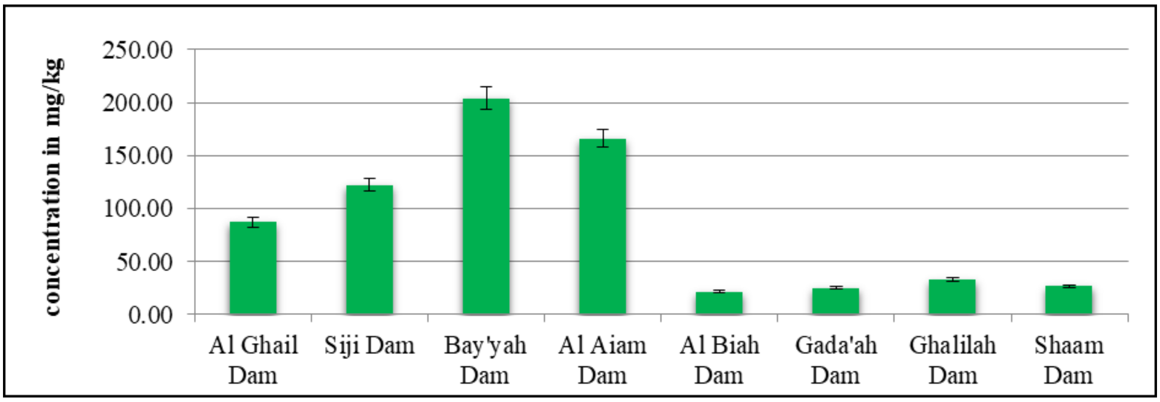


Figure 5 Variation of Chromium Concentration in eight different Dams. Data are mean values of replicate analyses, error bars indicate SD (n=8), Average Concentration of metals in mg/kg

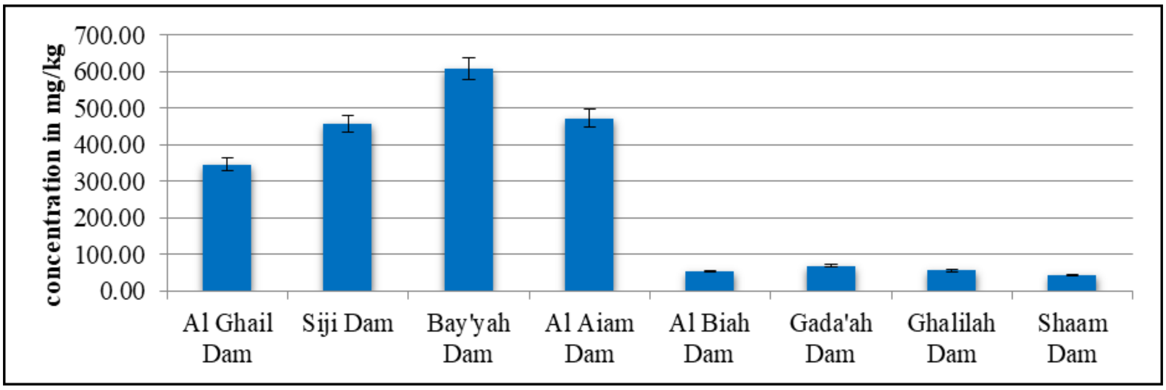


Figure 6 Variation of Nickel Concentration in eight different Dams. Data are mean values of replicate analyses, error bars indicate SD (n=8), Average Concentration of metals in mg/kg

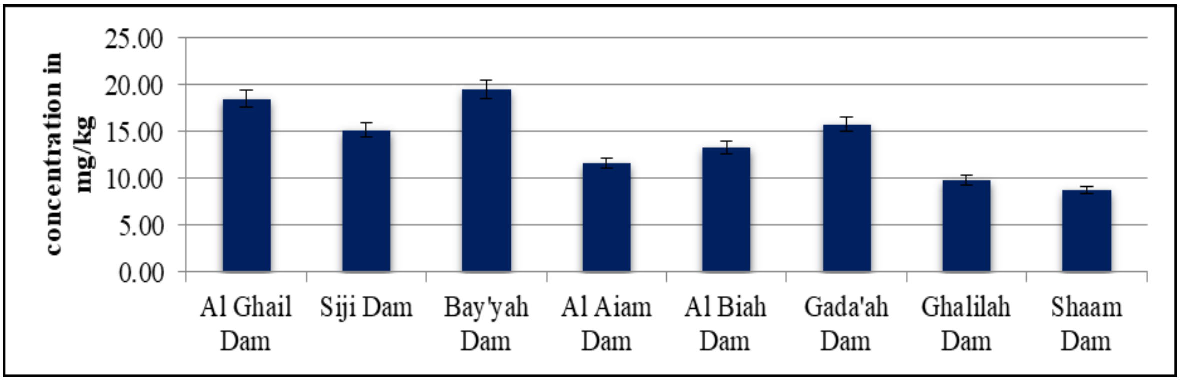


Figure 7 Variation of lead Concentration in eight different Dams. Data are mean values of replicate analyses, error bars indicate SD (n=8), Average Concentration of metals in mg/kg

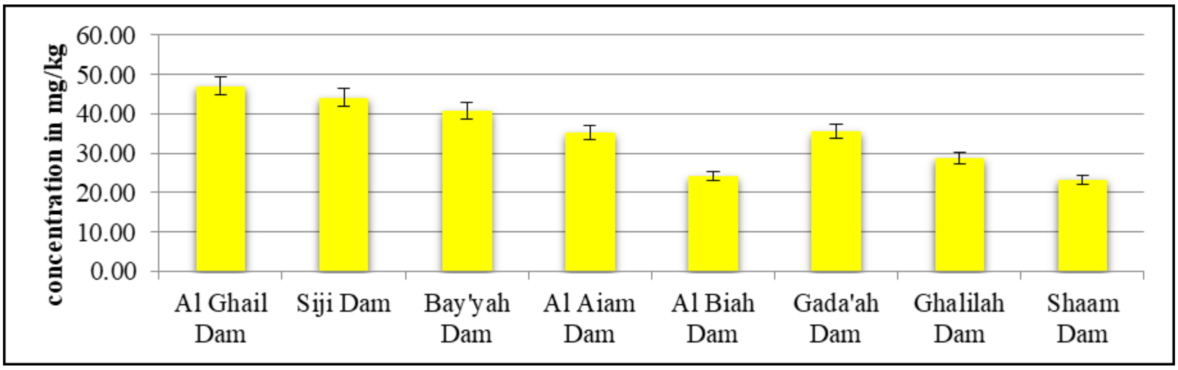


Figure 8 Variation of Zinc Concentration in eight different Dams. Data are mean values of replicate analyses, error bars indicate SD (n=8), Average Concentration of metals in mg/kg

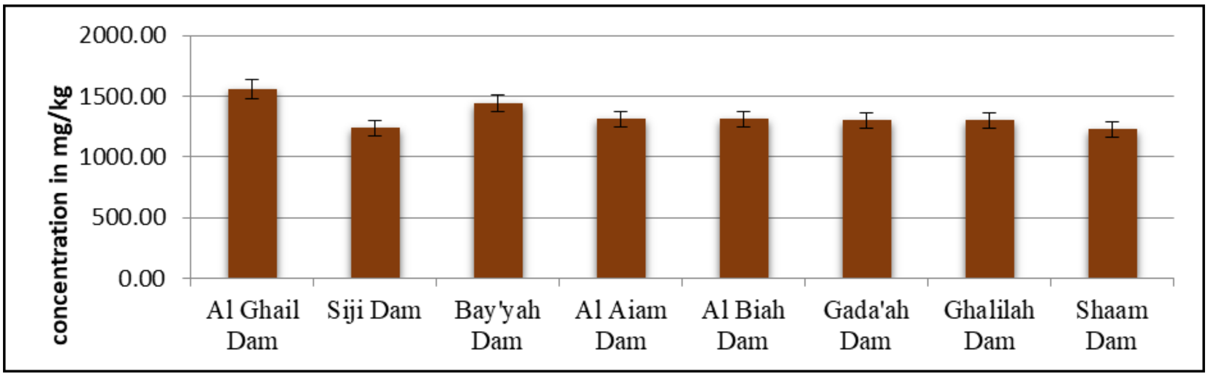


Figure 9 Variation of Iron Concentration in eight different Dams. Data are mean values of replicate analyses, error bars indicate SD (n=8), Average Concentration of metals in mg/kg

One of the major environmental impacts for the metal accumulation in sediments was the metal uptake by primary producers and the subsequent access into the food webs of aquatic ecosystems. In this study, the accumulation of heavy metals in relational to environmental factors in the dams was determined by AAS. The results pointed out the discrepancy in metal distributions between the different dam sediment samples. Collectively, our results clearly suggest that these dams are be taken into account to assess the metal behavior in sediments. Recognition of the roles of environmental factors in metal distribution could lead to a better quantification in dynamics and mass balances for metals in contaminated ecosystems.

4. Conclusion

The results obtained from particle size distribution analysis confirmed, that the fine-grained sediments (< 63 μm) sampled from dams are deposited in all the dams. The results of metal analyses proved the dependence between the metal concentrations in sediments and their particle size. The highest metal contents in dam sediments have been determined in Bayyah dam. It can be related to the high proportion of fine-grained eroded particles which have more surface area, and therefore contaminants adsorb preferentially to them. The deposition of sediments in dams, their size distribution and metal composition can contribute to marine environment. One of the major environmental impacts for the metal accumulation in sediments was the metal uptake by primary producers and the subsequent access into the food webs of aquatic ecosystems. In this study, the distribution and accumulation of heavy metals in relational to environmental factors in the dams. The results pointed out the difference in metal distributions between different dam sediment samples. In spite of other factors such as sediment deposits directly influenced the metal distribution in dams, such properties in environments may control the species transformation for metals and further change their mobility, bioavailability, and toxicity. This is of environmental concern could bioaccumulate in organisms and thus incorporate into food webs. Recognition of the roles of environmental factors in metal distribution could lead to a better quantification for metals in contaminated ecosystems. Particular that bed sediments serve as a sink and source of metals, the prediction of relative abundance of metals in sediments could improve strategies for the management and remediation of metal contamination. Further long term investigations are needed on heavy metals accumulations in plankton species in precise to have clear picture on biomagnification rate of heavy metals to higher trophic levels.

Compliance with ethical standards

Acknowledgments

The authors immensely thank the Authority for their constant support to carry out the research work.

Disclosure of conflict of interest

The authors declare that they have no conflict of interest.

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