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Concentration of heavy metals in surface water and sediments of Chah Nimeh water reservoir in Sistan and Baluchestan province, Iran

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ABSTRACT

Heavy metals, which may result from chemical leaching of bedrock, water drainage, and runoff from banks, the discharge of urban industrial and rural agricultural wastewaters, are widely present in water and sediments. Metal concentrations in aquatic ecosystems are usually monitored by determining their concentrations in water and sediment samples. The main purpose of this study was to examine the levels of eight heavy metals (Cr, Cd, Cu, Mn, Fe, Pb, Zn, and Ni) in surface water and sediments in the Chah Nimeh reservoir. Seven sampling sites were predefined in different locations of the reservoir. The concentrations of heavy metals were measured in the surface water and sediments of Chah Nimeh reservoir. A preliminary study of heavy metals in the surface water and sediments was determined. The obtained results showed that, in general, the heavy metal concentrations in water and sediments did not exceed WHO guidelines (except Cd). The concentrations of heavy metals in sediments were found to be considerably higher than those obtained in reservoir water. Generally, heavy metal concentrations of the sediments were found to decrease in the sequence of Fe > Mn > Zn > Ni > Pb > Cr > Cd > Cu. The findings of this study indicated a general absence of serious pollution in the Chah Nimeh reservoir.

Keywords: Heavy metals; Major elements; Water; Sediments

1. Introduction

With the rapid industrialization and economic development in coastal regions, heavy metals are continuing to be introduced to water resources and aquatic environment through rivers, runoff, and land-based point sources where metals are produced as a result of metal refinishing by-products. Therefore, heavy metal contamination is still an environmental problem today in both developing and developed

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countries throughout the world [1,2]. Under certain environmental conditions, metals may accumulate to toxic concentration and they cause ecological damage [3,4].

On the other hand, heavy metals are among the most common environmental pollutants, and their occurrence in waters and biota indicate the presence of natural or anthropogenic sources. The main natural sources of metals into the aquatic system are the weathering of soils and rocks and by anthropogenic activities, whereby industrial and urban wastes are discharged into water bodies [5–8]. The metals can be either adsorbed onto sediments or accumulated in benthic organism, sometimes to toxic levels. Therefore, the bioavailability and subsequent toxicity of metals have been a major research area [8–14].

In aquatic systems, metals are present as dissolved ions and complexes, suspended and colloids ions, and solid in sediments. Concentrations of these metals ions are strongly dependent on biological processes, redox potential, ionic strength, pH, activities of organic and inorganic chelators, and scavenging processes [15].

The pollution of water resources due to indiscriminate disposal of heavy metals has been causing worldwide concern for the last few decades. Unlike organic pollutants, the majority of which are susceptible to bio-degradation, heavy metals are non-degradable to harmless end products. They are toxic to aquatic flora and fauna even in relatively low concentrations. Metals, which are significantly toxic to human beings and ecological environments, include arsenic (As), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), manganese (Mn), cadmium (Cd), nickel (Ni), zinc (Zn), iron (Fe), etc. Some of these are capable of being assimilated, stored, and concentrated by human body, causing erythrocyte destruction, nausea, salivation, diarrhea, muscular cramps, renal degradation, chronic pulmonary problems, and skeletal deformity [16].

The mobility and immobility and thus toxicity of heavy metals in sediments depend to a large extent on their type of binding forms. Thus, heavy metals adsorbed onto clays and sand can easily—through ion exchange—be released, in contrast to the much stronger metal–sulfide bindings and heavy metals incorporated in the lithogenic phase of the sediment. These different heavy metal binding forms may show large variations under the influence of varying environmental conditions. For example, a lowering of sediment pH may give rise to mobilization of heavy metals bound to carbonates [17,18].

Heavy metals are inert in sediment environment and are often considered as the conservative pollutants [19]. However, they can be released to water column in response to certain disturbances [20] and threat the ecosystems [21,22]. Zheng et al. has reported that the distribution of heavy metals in sediments adjacent to populated areas could be used to investigate the anthropogenic impacts on ecosystems and benefit assessing the risks posed by human waste discharges [23]. Systematic sampling of the river bed sediments at predefined locations of Kabini River in India revealed that the heavy metal accumulation is very close to normal and also beyond threshold limits [24].

Chah Nimeh water reservoirs are Sistan's only water resources at present. On the other hand, these resources, because of drought and also Hamun international wetland going dry, are the last biological resort in the region. Also, the main water supply for Chah Nimeh reservoirs is Helmand River, which flows in Afghanistan, and there is no reliable information on its health and the route in which it flows regarding the issue of contamination with heavy metals. Thus, studying the concentration of heavy metals in these water resources is important.

The main aim of this study is to investigate current metal distributions and concentrations in the surface water and sediments of Chah Nimeh reservoir and its adjacent areas, examine the environmental status, and update the information for effective environmental management in the region.

2. Materials and methods

2.1. Site description

Zabol is a city in and the capital of Zabol County in Sistan and Baluchistan Province, Iran. Zabol lies on the border with both Afghanistan and Pakistan. Zabol area is well known for its "'120 d wind"', a highly persistent dust storm in the summer, which blows from north to south. It is situated at a latitude of 31˚01´ N and longitude of 60˚30´ E and about 1,350 m above sea level. The climate of the city is semi-arid and arid with cold winter and approximately eight months of dry season (from middle of April to December).

Its mean annual precipitation is 94 mm and it is unequally distributed throughout the year. The mean annual temperature is 22.7℃ with the warmest month in July (average 35.2℃) and the coldest in January (average 8.9℃). The sunlight of the year is 263 d.

Chah Nimeh reservoirs of Zabol are four natural and big cavities in the south of Sistan Plain in south-eastern Iran and cover an area of 47 km^2. The precipitation and water flow into the Chah Nimeh reservoirs has decreased in recent years, causing continuous shrink of the area and volume of this lake. The water stored in these cavities is used to irrigate the Sistan Plain and to provide the drinking water of Zabol and Zahedan city. The studied reservoir (Chah Nimeh no 3 with water surface area equal 9 km^2) is located in the Zabol city, northeastern Sistan and Baluchistan province, Iran (30˚44´´–30˚48´´ N, 61˚39´–61˚41´ E) (Fig. 1).

2.2. Sampling and chemical analysis

Sampling stations were chosen to provide good area coverage of the background and anthropogenic input values. Totally, seven sites have been selected in Chah Nimeh reservoir. Water sampling (25 cm in depth) was performed in 2012. Collected samples were stored in polyethylene bottles (2 L) for subsequent preparation and analyses. Polyethylene bottles were rinsed at least three times with double-distilled water and 1:1 HNO_3:H_2O. Water samples were passed through Whatman glass microfiber filters (GF/C). The samples were acidified with (0.2 v/v) ultra pure (E. Merch, Darmstadt, Germany) nitric acid to pH <2 as acidification minimizes to absorption of metals into the wall of the containers and stored approximately at 4˚C. After sediment sampling, samples were put into a polyethylene bag and stored at 4˚C during its transportation to the laboratory. In the laboratory, sediment samples were dried at 40˚C up to a constant weight, ground, and homogenized in a mortar to a fine powder. Total metals (Cd, Cr, Cu, Mn, Ni, Pb, Fe, and Zn) were determined by atomic absorption spectrophotometer technique (Shimadzo AA7000) after acid digestion. For digestion, 2 g of dried sample was put into a PTFE vessel with 4 ml of nitric acid, 2 ml of hydrochloric acid, and 2 ml of hydrofluoric acid. For each digestion program, a blank was prepared with the same amount of acids. After digestion and cooling below extractor hood, samples were filtered and diluted to 100 ml with distilled water and analyzed [25]. Physicochemical characteristics including pH and electrical conductivity and also Ca, Mg, Na, and K were analyzed according to standard methods [26].

2.3. Statistical analysis

Pearson correlation analysis was implemented to determine the relationship between the heavy metals. The rotation of principal component was carried out by Varimax method. Data were analyzed by SPSS ver. 19.0 software and *P* values of 0.05 were considered indicative of a statistically significant difference. For interpolation and for mapping the spatial distribution of heavy metals, the ordinary Kriging method and Surfer software were used.

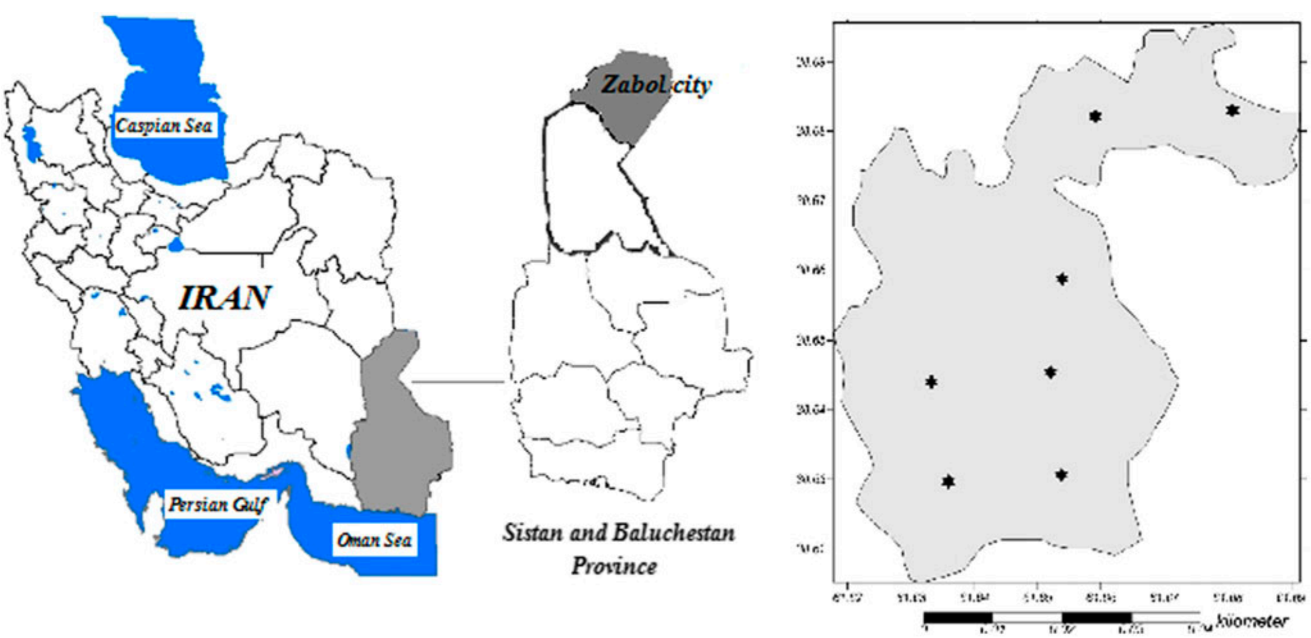


Fig. 1. The area of study and points of sampling. (Source: Department of Geography, University of Birjand, Birjand, Iran.)

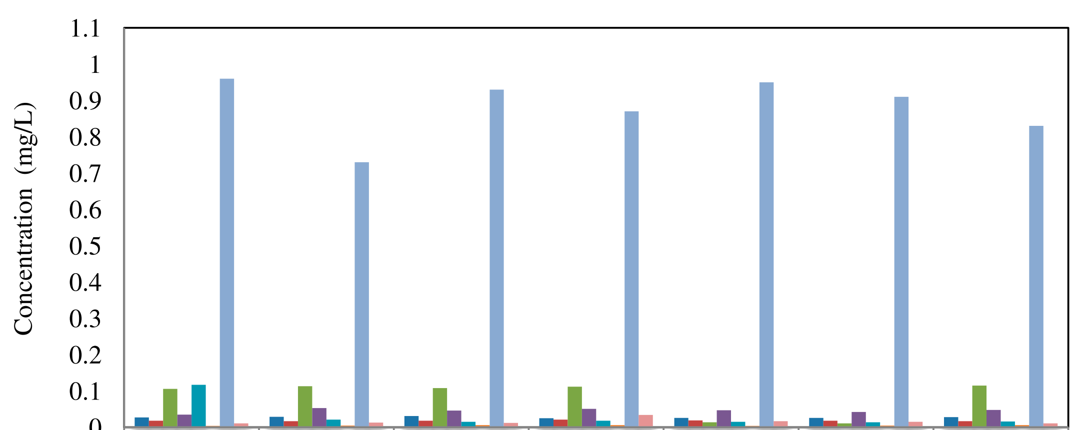
3. Results and discussion

3.1. Heavy metal concentrations in surface water and sediments

As shown in Figs. 2 and 3, mean concentrations of all metals, except Cd, were lower than the acceptable limits of the WHO guidelines in drinking water [27]. In addition, the concentrations of heavy metals in surface sediments of the Chah Nimeh reservoir are summarized in Figs. 4 and 5. The total heavy metal contents in the Chah Nimeh reservoir sediments in spring season ranged from 10.0 to 13.0 mg/kg Cr (11.72 ± 1.11), 5.0 to 7.98 mg/kg Cd (7.20 ± 1.08), 3.0 to 5.0 mg/kg Cu (3.84 ± 0.74), 104.0 to 114.0 mg/kg Mn (110.29 ± 0.74), 222.0 to 251.0 mg/kg Fe (235.0 ± 8.72), 19.9 to 28.0 mg/kg Pb (23.57 ± 3.31), 87.0 to 99.0 mg/kg Zn (92.14 ± 4.45), and 28.0 to 37.0 mg/kg Ni (33.29 ± 3.04). Also, the total heavy metal contents in the Chah Nimeh reservoir sediments in summer ranged from 12.0 to 13.96 mg/kg Cr (13.05 ± 0.69), 6.0 to 8.82 mg/kg Cd (7.73 ± 0.93), 3.4 to 5.18 mg/kg Cu (4.09 ± 0.57), 108.0 to 116.0 mg/kg Mn (114.43 ± 3.16), 223.0 to 326.0 mg/kg Fe (250.43 ± 38.70), 21.0 to 29.0 mg/kg Pb (25.29 ± 2.93), 88.0 to 99.0 mg/kg Zn (93.14 ± 3.98) and, 32.0 to 38.0 mg/kg Ni (34.57 ± 2.44).

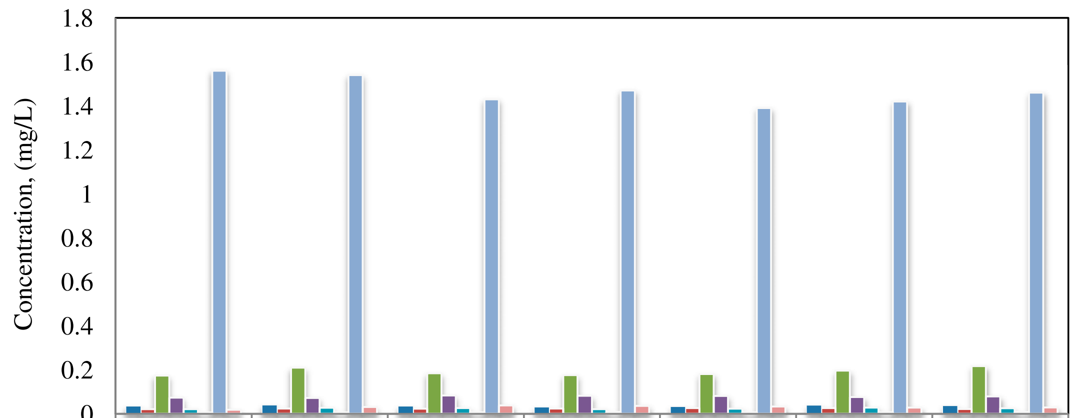
3.1.1. Cadmium

Cadmium (Cd) is one of the most toxic heavy metals and is considered non-essential for living organisms. The metal is of special concern because it is non-degradable and therefore persistent. The harmful effects of cadmium include a number of acute and chronic disorders, such as "itai-itai" disease, renal damage, emphysema, hypertension, and testicular atrophy. According to WHO's recommendation, Cd limit in drinking water is 0.003 mg/L [27]. As shown in Figs. 2 and 3, the maximum concentration of Cd in surface water at summer was observed in stations 5 and 6 (0.026 mg/L) that is higher than standard value of Cd in drinking water (0.003 mg/L) and also, minimum concentration of Cd was observed in surface water at spring in stations 2 and 7 (0.017 mg/L). Furthermore, as it can be seen from Figs. 2 and 3, Cd concentration in surface water for all stations in spring and summer seasons is higher than the standard value. Additionally, as presented in Figs. 4 and 5, maximum concentration of Cd in surface sediments was observed in station 3 (8.82 mg/kg) at summer and minimum concentration was observed at spring in station 1 (5 mg/kg).



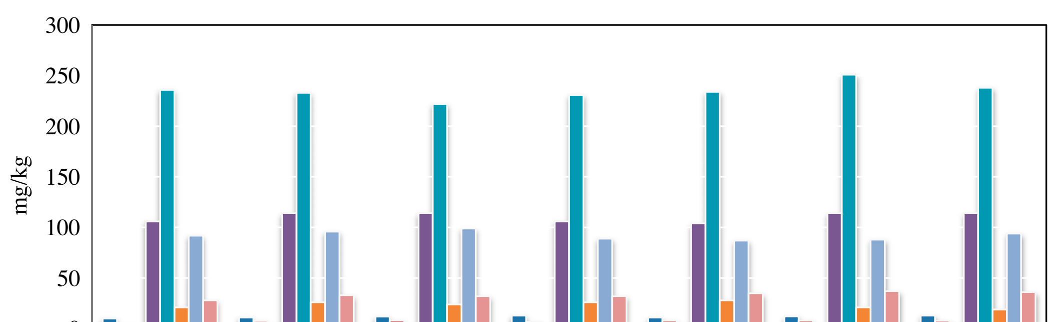
	1	2	3	4	5	6	7
Cr	0.027	0.029	0.031	0.025	0.026	0.026	0.028
Cd	0.018	0.017	0.018	0.021	0.019	0.018	0.017
Cu	0.106	0.113	0.108	0.112	0.014	0.011	0.115
Mn	0.035	0.053	0.046	0.051	0.047	0.042	0.048
Fe	0.117	0.021	0.015	0.018	0.015	0.014	0.016
Pb	0.004	0.005	0.006	0.006	0.004	0.005	0.006
Zn	0.96	0.73	0.93	0.87	0.95	0.91	0.83
Ni	0.011	0.013	0.012	0.034	0.017	0.015	0.011

Fig. 2. The concentration of heavy metals in surface water at seven sampling points in spring.



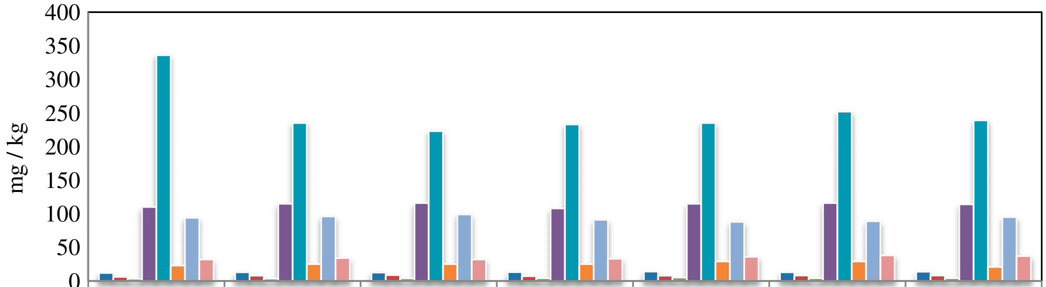
	1	2	3	4	5	6	7
Cr	0.033	0.038	0.033	0.029	0.031	0.037	0.035
Cd	0.021	0.024	0.023	0.024	0.026	0.026	0.022
Cu	0.174	0.21	0.184	0.176	0.181	0.196	0.217
Mn	0.073	0.072	0.083	0.082	0.081	0.076	0.079
Fe	0.021	0.027	0.026	0.021	0.023	0.028	0.025
Pb	0.006	0.007	0.007	0.008	0.007	0.007	0.008
Zn	1.56	1.54	1.43	1.47	1.39	1.42	1.46
Ni	0.018	0.031	0.038	0.036	0.033	0.028	0.029

Fig. 3. The concentration of heavy metals in surface water at seven sampling points in summer.



	1	2	3	4	5	6	7
Cr	10	11	12	12.98	11	12.09	13
Cd	5	7.6	7.98	6.54	7.86	7.8	7.65
Cu	3	3.05	4.03	4.46	5	3.45	3.86
Mn	106	114	114	106	104	114	114
Fe	236	233	222	231	234	251	238
pb	21	26	24	26	28	21	19
Zn	92	96	99	89	87	88	94
Ni	28	33	32	32	35	37	36

Fig. 4. The concentration of heavy metals in sediments of seven sampling points in spring.



	1	2	3	4	5	6	7
Cr	12	12.85	12.58	13.22	13.96	12.88	13.86
Cd	6	8	8.82	7	8	8.08	8.2
Cu	3.4	3.62	3.92	4.26	5.18	4.1	4.15
Mn	110	115	116	108	115	116	114
Fe	336	235	223	233	235	252	239
pb	23	25	25	25	29	29	21
Zn	94	96	99	91	88	89	95
Ni	32	34	32	33	36	38	37

Fig. 5. The concentration of heavy metals in sediments of seven sampling points in summer.

According to the findings of this study, the Cd concentration is found to be high in all of the samples as they exceeded the WHO guideline value of 0.003 mg/L. Compared to the reported data from other parts of Iran, the Cd concentrations in the surface water of Chah Nimeh reservoir were high.

The mean concentration of Cd in sediment from Anzali Wetland in Iran was determined as 0.157 mg/kg [28], which is very lower than that of Cd concentration presented in this study. Yang et al. also reported that Cd was a serious pollutant in sediments of the Baiyangdian Lake [29]. Cd is released to the environment in wastewater, and diffuse pollution is caused by contamination from fertilizers [27]. Surface water contamination due to consumption of various fertilizers by farmers and surface runoff from agricultural lands are the major reasons for high levels of Cd. On the other hand, because of rapid agricultural development around the Chah Nimeh reservoirs, heavy applications of agrochemicals and fertilizers contributed to a large increase in heavy metal concentrations in the water and surface sediments. Nevertheless, geology is also an important factor influencing the concentration of heavy metals in water resources. According to findings of this study on Cd concentration in surface water of Chah Nimeh reservoir, continuous monitoring of this pollutant is very critical and its removal by different methods including coagulation or precipitation softening at water treatment plants must be mentioned.

3.1.2. Chromium (Cr)

Chromium is carcinogenic and mutagenic to living organisms. In addition, it leads to lung cancer, skin, liver and kidney damage. Maximum allowable concentration of chromium (hexavalent) in drinking water based on health concerns is 0.05 mg/L [27]. Chromium enters aquatic systems through aerial deposition or surface runoff, and subsequently, its association with particulate matter results in its deposition in bed sediments [30]. According to the results presented in Figs. 2 and 3, maximum concentration of Cr was observed in surface water at summer in station 2 (0.038 mg/L) and minimum concentration was detected at spring (0.025 mg/L). It is clear that concentration of Cr in surface water is at the standard range. Additionally, as presented in Figs. 4 and 5, the concentration of Cr at station 5 was the highest with value of 13.96 mg/kg at summer and the lowest Cr concentration was at station 1 with a value of 10 mg/kg, value ranging from 10 to 13.96 mg/kg. Results of a study that was performed by Gao et al. on heavy metal concentrations in wetland soils of a typical shallow freshwater lake, China, showed that the mean concentration of Cr is 0.22 times higher than the background value [31].

3.1.3. Copper (Cu)

Copper and zinc are the two micronutrients for aquatic life in all natural waters and sediments. Although both of them are minor nutrients at low concentrations, they can become toxic to aquatic life at higher concentrations than the threshold required concentrations [32]. The concentration of Cu in surface water of the study area, respectively, ranges from 0.011 to 0.155 and 0.174 to 0.217 mg/L at spring and summer, which is within the permissible limit of WHO (2 mg/L). Station 7 showed higher concentration of copper in surface water at summer (0.217 mg/L) compared to that of other stations. The lowest concentration of copper was observed at station 6 at spring (0.011 mg/L).

Also, station 5 showed higher concentration of copper in surface sediments at summer (5.18 mg/kg) compared to that of other stations. The lowest concentration of copper was observed at station 3 at spring (3.0 mg/kg). As is known, the concentration of Cu for all sampling stations is lower than standard values. The mean concentration of Zn and Cu in the sediments of Ataturk lake was 60.79 and 14.57 mg/kg, respectively [33]. In addition, the mean concentration of Cu in sediment from Anzali wetland was determined as 44.45 mg/kg [28], which is very higher than Cu concentration at current study. Moreover, Cu concentration in sediments of a stream in southwestern Turkey of 13 mg/kg was reported [34]. Differences between our findings and the mentioned data by other researchers are probably due to dissimilarities in geological mining history of cites.

3.1.4. Lead (Pb)

Owing to the decreasing use of lead-containing additives in petrol and of lead-containing solder in the food processing industry, concentrations in air and food are declining, and intake from drinking water constitutes a greater proportion of total intake. Lead is a general toxicant that accumulates in the skeleton and is toxic to both the central and peripheral nervous systems, inducing subencephalopathic neurological and behavioral effects [27]. As shown in Figs. 2 and 3, the maximum value of Pb concentration in surface water at summer was observed in station 7 (0.008 mg/L) which is lower than the standard value of Pb in drinking water (0.01 mg/L) and also, minimum concentration of Pb was observed in surface water at spring in stations 1 and 5 (0.004 mg/L). Furthermore, as it can be seen from Figs. 4 and 5, maximum concentration of Pb in surface sediments was observed in stations 5 and 6 (29 mg/kg) at summer and minimum concentration was observed at spring in station 7 (19 mg/kg). The mean concentration of Pb in sediment from Anzali wetland was determined as 0.0036 mg/kg [28], which is much lower than Pb concentration in the current study. Sadiq et al. reported that low concentrations of lead still might pose a threat to life in a marine environment in comparison with other heavy metals [35]. Pb might originate from domestic and industrial effluents and the heavy applications of agricultural chemicals in the adjacent arable fields, as they are contained in different manufactured goods (e.g., paints, cosmetics, automobile tyres, and batteries) and in agricultural fertilizers [36]. Nevertheless, it seems that geology is the main factor influencing the concentration of Pb in surface water and sediments of the studied reservoir in this study.

3.1.5. Nickel (Ni), iron (Fe), manganese (Mn), and zinc (Zn)

Nickel is used mainly in the production of stainless steel and nickel alloys. Food is the dominant source of Ni exposure in the non-smoking, non-occupationally exposed population; water is generally a minor contributor to the total daily oral intake. However, where there is heavy pollution, where the areas in which Ni naturally occur in groundwater is mobilized, or where there is use of certain types of kettles, of non-resistant material in wells or of water that has come into contact with Ni- or Cr-plated taps, the Ni contribution from water may be significant. Metallic Ni is possibly carcinogenic (Group 2B). However, there is a lack of evidence of a carcinogenic risk from oral exposure to Ni [27]. The lowest concentration of Ni is at stations 1 and 7 at spring (0.011 mg/L). As is known, the concentration of Ni for all sampling stations is lower than maximum contaminant level of Ni in drinking water recommended by WHO (0.07 mg/L). Also, station 6 showed highest concentration of Ni in surface sediments at summer (38 mg/kg) compared to that of other stations. The lowest concentration of Ni is at station 1 at spring (28 mg/kg). As is known, the concentration of Ni for all sampling stations is lower than standard values.

Kishe and Machiwa investigated concentrations of heavy metals in sediments of Mwanza Gulf of Lake Victoria (Tanzania) and found the following highest concentrations (in mg/kg) 45.4 ± 13.1 Zn, 26.1 ± 4.8 Cu at approximately 25 m from the shoreline [37]. Additionally, according to Bowman and Harlock, typical ranges of heavy metals in surface sediment considered to be European background values are (mg/kg): Pb 2–80, Zn 10–200, Cu 2–100, Cd 0.1–1.0, and Ni 0.5–100 [38].

As shown in Figs. 2–5, similar trends were observed for other heavy metals including Fe, Zn, and Mn in surface water and sediments. The similar spatial distribution patterns of these heavy metals in the water and sediments of this water reservoir might be closely related to the similar geological enrichment characteristics, which also showed that they might come from the same input sources.

It is clear that the values for all the trace metals assessed were higher in dry seasons for water samples than the wet season. Similarly, the trace metal concentrations in the sediment samples were higher in dry season (summer) compared to those of wet season (spring). This may be as a result of slow current of water in dry season giving room for the particles to settle down. Also, the trace metal concentrations in the sediment samples were higher compared to those of the water samples. This is because water sediments are metal reservoirs. Research has revealed that nearly all metal content in aquatic environment reside in water sediments [39]. Sediments have a high absorption capacity with regard to trace elements, and in fact, it is the sediment that is one of the main factors of water body self-purification from heavy metal compounds. Similar findings were reported by Maitera et al. on trace metal levels in water and sediments of River Benue in Adamawa state, Nigeria [25]. Findings of Xiao et al. indicated that the total contents of the six metals (Cd, Cr, Cu, Ni, Pb, and Zn) in all sediment samples exceeded the soil background value in Guangdong province, China, and also according to the sediment quality guidelines of the US EPA, all samples were moderately to heavily polluted by Cr, Cu, Ni, Pb, and Zn [40].

Furthermore, heavy metal concentrations of the sediments were found to decrease in the sequence of Fe > Mn > Zn > Ni > Pb >Cr > Cd > Cu. According to results of Doong et al., the concentration levels of heavy metals in sediment samples were in the order as follows: Zn > Pb > Cr > Cu > Cd [41]. Also, the concentration levels of heavy metals in three sites of Anzali Wetland were in the order as follows: Zn > Cu > Hg > Cd > Pb [28]. In another study, Varol reported that the accumulation order of heavy metals in the sediment samples was Fe > Mn > Cu > Pb > Zn > Ni > Cr > Co > As > Cd [42].

According to results of Gao et al., levels of trace elements in wetland soils of a typical shallow freshwater lake, China, showed that the mean contents of As, Cd, Cr, Cu, Ni, Pb, and Zn all exceeded their environmental background values of Hebei Province and had various degrees of spatial variations [31].

3.2. Statistics of heavy metal concentrations in surface sediments

As presented at Table 1, the mean concentrations of Cr, Cu, Pb, and Zn were lower than the threshold effect levels (TELs), except for Cd and Ni which was higher than TELs. However, they were lower than the potential effect levels (PELs) except for Cd. Also, it is clear from Table 1, which values of all studied metals are lower than ERMs. Pb, Cd, Cu, and Zn concentrations were lower in the Yilong Lake sediments compared to heavily polluted Qilu and Dianchi Lakes on the Yunnan Plateau [44]. In addition, systematic sampling of the river bed sediments at predefined locations of Kabini River in India has revealed that the heavy metals accumulation (Cd, Cr, Cu, Fe, Mn, Ni, Pb, and Zn) is very close to normal and also beyond threshold limits. Compared with the maximum background values in Kabini river sediment, Pb was the highest in terms of contamination level, especially at the point of influx of paper mill effluents, followed by Zn and Cu [24]. Furthermore, findings of Bai et al. on spatial distribution of heavy metals in surface sediments from a typical plateau lake wetland in China showed that the mean concentrations of As, Cd, Cr, Ni, and Pb were higher than the TELs, while lower for Cu and Zn. However, they were lower than the PELs [45]. Findings of Gao et al. [31] showed that almost all trace elements (As, Ni, Cr, Zn, Pb, Cu, Cd) exceeded TELs except for Pb. Ni and Cr pollution were also serious in this region, as contents of Ni and Cr exceeded TEL values at all sampling sites, and even exceeded PEL values at some sampling sites. Contents of Cd and Cu also exceeded TELs in about 80% of soil samples, whereas they were lower than PELs. Pb and Zn pollution levels were low in this region, as more than 60–90% of soil samples showed lower contents of them than TELs [31].

In order to make a quantitative analysis of the relationship among trace element contents in the sediment samples, Pearson's correlation analysis was applied to the data. The Pearson's linear correlation indexes from the obtained data are in Tables 2 and 3, from which it can be seen that strong positive correlations ($\tau > 0.70$) are those exhibited between Cd and Ni (0.807), Cr and Cu (0.827), and Cd and Mn (0.835) which indicate the same or similar source input. In addition, based on correlation analysis, a significant negative correlation was found between Cd and Fe (−0.825) in summer season. As can be seen from Tables 2 and 3, in most cases, however, there are no significant correlations among most of these heavy metals, suggesting that these metals are not associated with each other. Furthermore, these metals might have different

Table 1
Summary statistics of heavy metal concentrations in surface sediments of seven sampling points and guide values. All concentrations are in mg/kg dry weight [43]

	Cr	Cd	Cu	Mn	Fe	Pb	Zn	Ni
Minimum	10	5	3	104	222	19	87	28
Maximum	13.96	8.82	5.18	116	336	29	99	38
Average	12.387	7.466	3.963	111.857	242.714	24.429	92.643	33.929
S.D.	1.126	1.008	0.646	4.167	28.116	3.131	4.088	2.731
CV (%)	9.093	13.500	16.295	3.725	11.584	12.816	4.412	8.048
TEL[a]	37.3	0.596	35.7	–	–	35	123	18
PEL[a]	90	3.53	197	–	–	36	315	91.3
ERL[a]	80	5	70	–	–	35	120	30
ERM[a]	145	9	390	–	–	110	270	50

Note: S.D.: Standard deviation; CV: coefficients of variation; TEL: threshold effect level. PEL: Probable effect level; ERL: effects range low; ERM: effects range median.
[a]Threshold effect level or probable effect level for freshwater ecosystem [43].

anthropogenic and natural sources in sediments of reservoir. These patterns may also reflect the main anthropogenic discharges that constitute sources for several heavy metals.

In a study that was performed by Bai et al. on heavy metal pollution in wetland soils from tidal freshwater and salt marshes in the Yellow River Delta, China, no significant differences in heavy metal concentrations

Table 2
Pearson correlation matrix between heavy metal concentrations in the sediments of area of study (spring)

Spring	Cr	Cd	Cu	Mn	Fe	Pb	Zn	Ni
Cr	1.000							
Cd	0.443	1.000						
Cu	0.385	0.379	1.000					
Mn	0.352	0.539	−0.482	1.000				
Fe	0.026	−0.004	−0.300	0.139	1.000			
pb	−0.187	0.218	0.539	−0.464	−0.474	1.000		
Zn	−0.001	0.146	−0.401	0.622	−0.601	−0.176	1.000	
Ni	0.538	0.807*	0.314	0.415	0.522	−0.085	−0.299	1.000

*Significant correlation at the 0.05 level (two-tailed).

Table 3
Pearson correlation matrix between heavy metal concentrations in the sediments of area of study (summer)

Metal	Cr	Cd	Cu	Mn	Fe	Pb	Zn	Ni
Cr	1.000							
Cd	0.435	1.000						
Cu	0.827*	0.340	1.000					
Mn	0.198	0.835*	0.189	1.000				
Fe	−0.621	−0.825*	−0.511	−0.437	1.000			
Pb	0.149	0.248	0.554	0.382	−0.266	1.000		
Zn	−0.425	0.237	−0.650	0.140	−0.046	−0.663	1.000	
Ni	0.632	0.632	0.474	0.483	−0.278	0.347	−0.560	1.000

*Significant correlation at the 0.05 level (two-tailed).

were observed between freshwater and salt marsh soils, either before or after the regulation [46].

4. Conclusions

Heavy metals have been widely used as environmental monitoring factors, and their toxicity in humans, animals, and plants is receiving increased attention. Heavy metals, which may result from chemical leaching of bedrock, water drainage, and runoff from banks, the discharge of urban industrial and rural agricultural wastewaters, are widely present in water and sediments. According to results of this study, all the values of heavy metal concentrations except Cd were within the acceptable limits of the WHO values in water samples. The concentrations of heavy metals in sediments were found to be considerably higher than those obtained in reservoir water. The mean concentrations of Cr, Cu, Pb, and Zn in surface sediments were lower than the TELs, except for Cd and Ni which was higher than TELs. However, they were lower than the PELs except for Cd. The values for all the heavy metals assessed were high in dry seasons for sediment samples than the wet season. However, the trace metal concentrations in the water samples were higher in dry season compared to those of wet season (except for Fe). Heavy metal concentrations of the sediments were found to decrease in the sequence of Fe > Mn > Zn > Ni > Pb > Cr > Cd >Cu. The occurrence of heavy metals in surface water and sediments is due to the discharge of municipal effluents and agrochemical and fertilizer runoff from nearby villages directly or indirectly into the reservoir.

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