Measurement and ecological risk assessment of heavy metals accumulated in sediment and water collected from Gomishan international wetland, Iran

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ABSTRACT

This study aimed to measure and ecologically assess heavy metals, including As, Cr, Pb, Cd, and Ni in water and sediment samples taken from Gomishan, an international wetland located in Golestan, Iran. Four sampling stations were selected to cover all parts of the wetland. The analyses of the heavy metals were performed by ICP-MS. Based on the content of the heavy metals in the sediments, the values of risks for individual heavy metals, as Er, and for total heavy metals, as IR, were estimated. Igeo and EF also presented the soil quality in terms of accumulated contamination. The average content of the heavy metals in water was 23.12, 4.14, 10.04, 6.71, and 94.48 μg/L for As, Cd, Cr, Ni, and Pb, respectively. The heavy metal concentrations in sediments were decreased in the following order: Pb (2130 ppb) > As (655 ppb) > Cr (295 ppb) > Ni (148.8 ppb) > Cd (148.8 ppb). The potential risk values for individual heavy metals were in the low range, Er < 40, except for Cd, which mostly posed a moderate ecological risk. The values of EF and Igeo showed that the sediments sampled from the Gomishan wetland were minimally enriched and contaminated. As the Gomishan wetland has a moderate risk of heavy metal contamination, conservative and monitoring activities should be performed.

Key words: ecological risk assessment, heavy metals, sediments, wetland

HIGHLIGHTS

• The content of heavy metals in both water and sediments were measured.
• Pb had the highest concentration on water and sediments.
• The risk attributed to the heavy metals in the majority of samples was in an acceptable range.
• It is more likely that the sediments were naturally contaminated by the heavy metals.

INTRODUCTION

Due to the fast-changing development of industries and cities as the main consequence of population growth, ecosystems have been affected by a heavy load of human-made industrial and domestic pollutants such as heavy metals (AKOTO et al. 2014; Shi et al. 2018; Sevik et al. 2020). The presence of heavy metals in the environment is a substantial concern which could pose a huge risk to all creatures, including animals, plants, and humans (Liu et al. 2019; Neckel et al. 2021; Silva et al. 2021). Heavy metals including As, Cr, Pb, Cu, Cd, and Ni originate from both natural sources, usually in low concentrations, and anthropogenic ones by higher concentrations, and have severe environmental, ecological, and health effects (Chen & Lu 2018; Zwolak et al. 2019). Heavy metals are known as prioritized pollutants with specific properties including toxicity, non-biodegradability, and bioaccumulation in different media (Yin et al. 2019; Hu et al. 2020; Liu et al. 2020).

Marine ecosystems have been vulnerable due to the decreased self-cleaning capacity (Rajeshkumar et al. 2018). Pollutants such as heavy metals can accumulate in water bodies; higher concentrations of these contaminants can threaten the health of different organisms such as humans and fish (Zolfaghari 2018; Huang et al. 2020). During the past decades, a great amount of heavy metals stemming from agricultural run-off, waste leachate, mining, other metal-centered industries, irregular wastewater discharges, and other human activities have been released into water bodies and eventually accumulated in bedrock sediments (Kanmani & Gandhimathi 2013; Ke et al. 2017; Strzebońska et al. 2017). A high amount of heavy metals in...
water and sediments has several ecological impacts. It can reduce the fertility and productivity of the corresponding soil (Raklami et al. 2021) and transfer into the food chain, exposing consumers to health risks (Volpe et al. 2009).

Sediments play a key role in exchanging heavy metals in water bodies. Heavy metals can be transferred between the water body and sedimentary formation depending on their concentration gradient (Volpe et al. 2009). The deposition of heavy metals in sediments occurs by different biological and physiochemical processes, including adsorption, hydrolysis, and precipitation (Xia et al. 2020).

Wetlands greatly contribute to decreasing the level of pollutants receiving other water bodies; in other words, they act as a buffer reducing the concentration of pollutants moving toward seas. Additionally, they are a host for a wide variety of animals and plants and, therefore, have a great ecological and environmental protecting role (Weng et al. 2003; Lovell & Sullivan 2006).

Gomishan is an international wetland located in the southeast of the Caspian Sea. It is a substantial water body located between Iran and Turkmenistan (Basatnia et al. 2018). The hydrological properties of Gomishan depend on the Caspian Sea. Due to human activities and the lack of strict environmental regulations, this wetland has been highly contaminated by different types of pollutants (Sievers et al. 2018; Solgi & Mohammadi Galangashi 2018). There is ample evidence suggesting that the contents of heavy metals in Gomishan have been increasing in recent years, but information regarding the ecological and health risk assessment of heavy metals is very limited.

As the identification of potential risks, characterization of pollutants, and indication of the sources are essential steps for controlling pollutants such as heavy metals (Chen et al. 2016; Ke et al. 2017), the present study aimed to fill in the gap by measuring the level of some important heavy metals (Ni, Pb, Cd, Cr, As) and assess the health and ecological risk of human exposure to these heavy metals.

**MATERIALS AND METHODS**

**Study area**

The Gomishan wetland is located in a semi-arid climate in the Northern area of Golestan Province, Iran (Figure 1). It is an international wetland placed between Iran and Turkmenistan and the southeastern coastal strip of the Caspian Sea (37°09'09" to 37°20'02" N, 53°54'34" to 53°58'54" E). Its surface area is about 20,000 hectares, of which 14000 hectares is protected as a no-hunting area. The main hydrological properties of the wetland mostly depend on those of the Caspian Sea. For example, the water height in the wetland ranges from 1 to 2.5 m, varying based on the height of the water column in the Caspian Sea. The material constituting the bedrock of the wetland is mostly silt and sand originating from the Caspian Sea.

To cover the physicochemical and biological differences in the entire wetland, we selected four sampling stations based on field visits and the topography of the wetland. Station No. 1 is located in the southernmost part of the wetland and outside the hunting area, approximately in front of the Gomishan fishing ground. The main sampling location in this station is near the

![Figure 1](https://example.com/figure1.png)  | Study location and the sampling stations.
entrance of the sewage canal of Gomishan city into the wetland. Station No. 2 is positioned in the southeastern part of Gomishan wetland and within the protected hunting area. Station No. 3 is located in the northwestern part of the wetland, where the Caspian Sea water is connected to the wetland through a canal. The position of Station No. 4 is in the northernmost of the wetland near the Makhtumkuli checkpoint on the Turkmen border. The depth of water in this station is higher compared to other parts of the wetland and, due to its great connection with the sea, it is mostly considered as the control station. The sampling stations are illustrated in Figure 1. Since the hydrologic characteristics of the wetland change throughout the year, sampling was performed in spring and summer.

**Sampling and preparation of water and sediment samples**

To measure the content of heavy metals, including Ni, Pb, Cd, Cr, and As, samples were collected from sampling stations in polyethylene bottles cleaned and acid-washed by chromic acid. The water samples were filtered using a 45-μm glass fiber Whatman filter. Nitric acid was added to the samples to reach pH = 2 to avoid precipitation in the bottles. The samples were carefully handled to avoid possible contamination and stored at 4 °C until metal analysis.

We used the Van Veen grab device to gather the sediments from all the stations by three repetitions. All the sediment samples were collected in cleaned plastic bags. The digestion of the sediment samples for chemical analysis was performed using method 3050 B (USEPA- SW-846) (USEPA 1996). Briefly, 1 g of wet sediments was digested using nitric acid (HNO₃) and hydrogen peroxide (H₂O₂). The digested resultant was heated and then diluted by ultrapure water to reach a 100-ml volume. Following the preparation process of water samples and digestion of sediment samples, the content of the given heavy metals was analyzed using Graphite Furnace Atomic absorption model GTA120 and inductively coupled plasma mass spectrometry (ICP-MS) model 710, both devices made by VARIAN Inc.

**Quality assurance and control (QA/QC)**

Regarding quality control and assurance, the digestion of heavy metals was accomplished using a certified reference material. All reagents and chemical components were Sigma-Aldrich grades. An eight-point calibration curve was prepared using the standard solutions for each metal. The average recovery extent for the given heavy metals ranged from 83 to 108%. We used blank measurement accompanied by standard samples for quality control. The preparation procedure of the blank samples was exactly similar to that of the analyzed samples. The blank samples were metal-free. The triplicated measurement of the standard samples was performed and, eventually, the average content of the heavy metals was reported. The limits of detection (LOD) for Pb, Cr, Cd, As, and Ni were 0.1, 0.07, 0.05, 0.07, and 0.07 μg/l, respectively; however, those of LOQ (limits of quantity) were 0.3, 0.2, 0.015, 0.2, and 0.2 μg/l, respectively.

**Potential ecological risk index**

To assess the potential ecological risk attributed to heavy metals, the risk index (IR) introduced by Hakanson (1980) was used (Hakanson 1980). The following equations and parameters were applied to estimate IR:

\[
C_i^j = \frac{C_i}{B_i}
\]

\[
E_i^j = T_i^j \times C_i^j
\]

\[
IR = \sum_{i=1}^{n} E_i^j
\]

where \(C_i^j\) is the concentration factor of heavy metals, \(C_i\) is the content of heavy metals in the sediments, \(B_i\) is the geochemical background of the heavy metals, \(E_i^j\) is the ecological risk index for a single element, and \(T_i^j\) is the toxicity coefficient for each heavy metal. The values of \(T_i^j\) were 5, 30, 2, 3, and 10 for lead, cadmium, chromium, nickel, and arsenic, respectively.

**Geochemical factors**

The enrichment factor (EF) and geoaccumulation factors (Igeo) are two widely used indices to assess the role and intensity of anthropogenic sources of soil contamination.
Geoaccumulation index
The geoaccumulation index (Igeo) was developed by Muller (1969); Muller 1969). It was computed using the following equation:

\[ I_{\text{geo}} = \log_2 \left( \frac{C_n}{1.5B_n} \right) \]  (4)

where, \( C_n \) is the heavy metal concentration in the sediment, and \( B_n \) is the background concentration considered for the given metal. The measure of 1.5 is applied as a lithogenic background matrix correction. Different classes of Igeo are depicted in Table 1.

Enrichment factor
Enrichment factor (EF) is a frequently used way to predict the origin of heavy metals in sediments. The EF is usually applied to estimate the proportion of natural (lithogenic) or human-made (anthropogenic) sources of interest in the heavy metal content in sediments. \( EF < 2 \) is defined as minimal enrichment where it is assumed that the heavy metals are enriched from natural sources. \( EF > 2 \) indicates that the origin of the heavy metal is related to anthropogenic sources. The values of EF and the attributed soil quality are illustrated in Table 2.

The EF was estimated as:

\[ EF = \frac{(C_n/C_{fe})_{\text{sample}}}{(C_n/C_{fe})_{\text{averageshale}}} \]  (5)

where \( (C_n/C_{fe})_{\text{sample}} \) = the ratio of the concentration of the given element to the Fe concentration in the sample, \( (C_n/C_{fe})_{\text{averageshale}} \) = the ratio of the average value of the given element in the shale to that of Fe.

As there was no information regarding the background content of heavy metals in the sediments of Gomishan wetland, we used the average values of the shale for background concentrations.

Table 1 | The classes of Igeo

| Classes of Igeo | Values of Igeo | Soil quality               |
|-----------------|----------------|----------------------------|
| 0               | 0 \leq Igeo < 0| Uncontaminated             |
| 1               | 0 < Igeo < 1   | Uncontaminated to moderately contaminated |
| 2               | 1 < Igeo < 2   | Moderately contaminated    |
| 3               | 2 < Igeo < 3   | Moderately to heavily contaminated |
| 4               | 3 < Igeo < 4   | Heavily contaminated       |
| 5               | 4 < Igeo < 5   | Heavily to extremely contaminated |
| 6               | Igeo \geq 5   | Extremely contaminated     |

Table 2 | The categories of enrichment factor

| The value of EF | Soil quality                        |
|----------------|-------------------------------------|
| EF < 2         | Deficiency to minimal enrichment    |
| 2 < EF < 5     | Moderate enrichment                 |
| 5 < EF < 20    | Significant enrichment              |
| 20 < EF < 40   | Very high enrichment                |
| EF > 40        | Extremely high enrichment           |
Statistical analysis
The descriptive analysis, calculation of percentiles, was performed in Microsoft Excel. The statistical analyses were performed in SPSS 19.0 (SPSS Inc). Using the Shapiro–Wilk test, the normality of data was tested. To evaluate the relationship between the heavy metals, the Pearson correlation test was utilized. The significance level for the statistical analyses was 0.05 and 0.01 based on confidence intervals of 95 and 99%, respectively.

RESULTS
We examined the content of five heavy metals, including Pb, Cd, As, Cr, and Ni, in water (n = 60) and sediment samples (n = 100). According to the result in Table 3, the average concentration of the heavy metals in water was in the following order: Pb (94.65 μg/L) > As (23.12 μg/L) > Cr (10.04 μg/L) > Ni (6.71 μg/L) > Cd (4.14 μg/L). Table 3 also presents the concentration of heavy metals in the sediments collected from Gomishan wetland where the highest mean concentration of heavy metals belonged to Pb (2130 ppb), and the lowest to Cd and Ni (148 ppb). The percentiles and standard deviations of the collected water and sediment samples are given in Table 3.

The concentrations of heavy metals in the sediments taken from four sampling stations are illustrated in Figure 2. The concentration of Pb was significantly higher than the rest of the heavy metals. Furthermore, the highest total content of heavy metals (6051 ppb) in the sediment was observed in sampling Station No. 2, whereas the lowest one, 2522, ppb belonged to Station No. 4.

As presented in Table 4, there were significant correlations between the concentrations of Pb and As (p < 0.05), Cr (p < 0.01), and Ni (p < 0.01). In addition, a correlation was observed for the Ni-Cr heavy metal pair (p < 0.05).

Ecological risk assessment
The potential ecological risk indices (Er) of the sediment samples in the studied area in different seasons are summarized in Table 5. The results for heavy metal pollution by a single element were calculated as Er (Table 3). The degree of pollution for five heavy metals in two sampling sessions decreased in the following sequences:

Spring Cd > As > Pb > Ni > Cr
Summer Cd > Pb > As > Ni > Cr

The corresponding Er as the individual ecological risk for all heavy metals, except for Cd, was categorized as low-risk. However, the measures of Er attributed to Cd were mostly in the range of moderate risk. The potential risk of Cd in the sediments collected from sampling Stations 1 and 4 during spring displayed a considerable ecological risk. The values of RI as the risk index for all evaluated heavy metals differed in two sampling sessions. The IR level of the sediments sampled during spring ranged from 93.32 to 145.95, and that of summer ranged from 86.29 to 114.24. All the values of IR were in the low-risk range, i.e., <150.

Table 3 | Descriptive analysis of the heavy metal content in the water and sediment samples

| Concentration of heavy metals in water samples (μg/L) | Concentration of heavy metals in sediment samples (ppb) |
|-----------------------------------------------|-----------------------------------------------|
| As | Cd | Cr | Ni | Pb | As | Cd | Cr | Ni | Pb |
|-----|----|----|----|----|----|----|----|----|----|
| Mean | 23.12 | 4.14 | 10.04 | 6.71 | 94.63 | 655 | 148.8 | 295 | 148.8 | 2,130 |
| 5 | 13.81 | 3.80 | 8.59 | 4.89 | 51.43 | 530 | 88 | 124.5 | 83.5 | 959.4 |
| 10 | 13.81 | 3.86 | 8.68 | 5.86 | 51.43 | 530 | 106 | 129 | 97 | 1,529.7 |
| 25 | 15.69 | 3.94 | 9.07 | 6.36 | 78.40 | 577.5 | 140.6 | 268.1 | 112.5 | 1,722.8 |
| Median | 22.35 | 4.14 | 9.35 | 6.99 | 83.09 | 655 | 148.8 | 295 | 148.8 | 2,130 |
| 75 | 23.14 | 4.21 | 10.11 | 7.33 | 94.63 | 815 | 150 | 324.4 | 190 | 2,931 |
| 90 | 40.67 | 4.40 | 13.10 | 7.56 | 164.51 | 914 | 191 | 366 | 201 | 3,653.1 |
| 95 | 41.33 | 4.70 | 13.15 | 7.91 | 165.67 | 932 | 195.5 | 438 | 205.5 | 3,982.1 |
| Standard deviation | 9.31 | 0.33 | 1.55 | 1.08 | 36.47 | 148.2 | 34.7 | 104.6 | 47 | 1,035.4 |
Table 4 | Pearson correlations between the heavy metals in the sediments sampled from the Gomishan wetland

| Correlations | As   | Cd   | Cr   | Ni   | Pb   |
|--------------|------|------|------|------|------|
| As           | 1    | -    | -    | -    | -    |
| Cd           | 0.010| 1    | -    | -    | -    |
| Cr           | 0.245| -0.401| 1    | -    | -    |
| Ni           | 0.247| -0.159| .517*| 1    | -    |
| Pb           | 0.616*| -0.451| .628**| .703**| 1    |

*Significant coefficient $p<0.05$.
**Significant coefficient $p<0.01$.

Table 5 | The calculated values of Er and IR for the heavy metals collected during spring and summer from different sampling stations

| Sampling station | Er attributed to the heavy metals (samples collected in spring) | Er attributed to the heavy metals (samples collected in spring) |
|------------------|---------------------------------------------------------------|---------------------------------------------------------------|
|                  | As    | Cd    | Cr    | Ni    | Pb    | IR    | As    | Cd    | Cr    | Ni    | Pb    | IR    |
| Station No. 1    | 17.92 | 85.71 | 5.00  | 14.29 | 23.02 | 145.95| 11.32 | 60.00 | 5.83  | 7.86  | 15.79 | 100.80|
| Station No. 2    | 17.17 | 47.14 | 8.50  | 15.00 | 36.60 | 124.41| 11.70 | 64.29 | 4.50  | 8.57  | 19.19 | 114.24|
| Station No. 3    | 14.53 | 30.00 | 4.83  | 13.57 | 30.39 | 93.32 | 10.00 | 64.29 | 4.50  | 8.57  | 16.98 | 104.34|
| Station No. 4    | 13.02 | 81.43 | 2.40  | 7.14  | 11.99 | 115.74| 10.00 | 64.29 | 2.00  | 3.56  | 5.00  | 86.29 |
| Standard deviation| 2.28  | 26.96 | 2.60  | 3.62  | 10.58 | 21.78 | 0.89  | 2.15  | 1.73  | 3.56  | 6.32  | 11.58 |
EF and Igeo factors

The enrichment factor (EF) of the given heavy metals is presented in Table 6. The EF values for all the heavy metals in the surface sediments collected in spring were higher compared to those of summer. The highest levels of EF belonged to Pb (1.4 and 0.79 in spring and summer, respectively), whereas the lowest ones were observed for As (0.41 and 0.29 in spring and summer, in that order). Furthermore, all EF values were <2, indicating a deficit to minimum enrichment.

We calculated the geo-accumulation factor (Igeo) to assess the level of soil pollution by heavy metals. According to the measures in Table 6, the values of Igeo were ranked from the highest to the lowest in the following order:

Spring Pb > Cr > Ni > Cd > As
Summer Pb > Cr > Cd > Ni > As

According to soil qualification based on the Igeo index, while the soil quality for heavy metals was mainly categorized as uncontaminated to moderately contaminated, the Igeo index for Pb in sediments collected during spring was between 1 and 2, suggesting that the sediments were moderately contaminated by Pb. In addition, the samples gathered in summer were uncontaminated by Ar, and Igeo was <0.

DISCUSSION

This study was conducted to measure five prioritized heavy metals, including lead, chromium, arsenic, nickel, and cadmium, in the sediments sampled from an international wetland, Gomishan. We also assessed the potential ecological risk and soil quality related to the given heavy metals.

Both water and sediment samples were moderately contaminated by Pb. This result is consistent with those of previous studies conducted in the same region and also in other countries (Shokrzadeh & Saeedi Saravi 2009; Tabari et al. 2010). High lead contamination is due to the farms’ drainage, runoff, and uncontrolled application of pesticides in neighbors of the wetlands (Yargholi et al. 2014; Shi et al. 2018). Specifically, Gomishan wetland is highly polluted by sewage discharge of Gomish-Tappe city. The wastewater effluent with no appropriate treatment is directly disposing into the wetland in the vicinity of sampling Station No. 1. Fertilizers are highly used in the farms surrounding the wetland, which could eventually increase the amount of Pb and Ni in the water and sediments of the wetland (Hu et al. 2018; Arfaeinia et al. 2019). The southwestern coast of the Caspian Sea is highly affected by a growing population and contaminating industries as well as tourism; in nearby cities, there are some large industries such as painting and paper that use different components containing Pb, Cr, As, Ni, and Cd. In addition, natural events such as soil erosion and floods can act as heavy metal contamination resources (Quinton & Catt 2007; Lim et al. 2020); unfortunately, both soil erosion and seasonal floods have been increasing in the studied region.

The concentration of the heavy metals in collected sediments varied in different sampling stations, where the highest and lowest total content of the heavy metals were observed in Station No. 2 (6051 ppb) and Station No. 4 (2522 ppb). The heavy metal concentration in sediments depends on several factors such as the geological properties of the bedrock, physiochemical characteristics of the soil, depth, the presence of polluting sources, and human activities (Palumbo et al. 2000; Navas &

Table 6 | The values of enrichment factor (EF) and geo-accumulation factor (Igeo) for the heavy metals collected in spring and summer

| Heavy metals | Spring EF | Spring Soil Quality | Summer EF | Summer Soil Quality | Spring Igeo | Spring Soil Quality | Summer Igeo | Summer Soil Quality |
|--------------|-----------|---------------------|-----------|---------------------|-------------|---------------------|-------------|---------------------|
| As           | 0.41      | Def to ME           | 0.29      | Def to ME           | 0.06        | UC to MC            | −0.48       | UC                  |
| Cd           | 0.56      | Def to ME           | 0.58      | Def to ME           | 0.44        | UC to MC            | 0.49        | UC to MC            |
| Cr           | 0.7       | Def to ME           | 0.62      | Def to ME           | 0.77        | UC to MC            | 0.57        | UC to MC            |
| Ni           | 0.68      | Def to ME           | 0.48      | Def to ME           | 0.73        | UC to MC            | 0.22        | UC to MC            |
| Pb           | 1.4       | Def to ME           | 0.79      | Def to ME           | 1.76        | MC                  | 0.92        | UC to MC            |

Def to ME, Deficiency to minimal enrichment.
UC, Uncontaminated.
UC to MC, Uncontaminated to moderately contaminated.
MC, Moderately contaminated.
Machin 2002). For example, while Station No. 1 is in the close vicinity of the wastewater disposal entrance, Station No. 2 is located slightly away from Station No. 1 where organic matter and suspended solid carrying heavy metals can settle without distributing the turbulence made by sewage flow in the wetland. In addition, Station No. 4 is located adjacent to the Turkmen border where the wetland is deeper and human activities and human-made pollution are more limited.

According to the statistical analysis, there was some correlation, especially for Pb, and other metals. Meanwhile, there was a correlation between Ni and Cr. In previous studies, the correlation between the main metals such as Cd, Hg, As, Co, Cu, Ni, Pb, and Cr indicated the presence of an anthropogenic resource for the heavy metals (Fu et al. 2014; Maanan et al. 2015). In this study, however, there was a limited number of paired elements strongly correlated with each other (P ≤ 0.01), except for Pb-Cr and Pb-Ni. These findings may display the more prominent role of natural resources of heavy metals in the Gomishan wetland.

We used Er and RI indexes to evaluate the potential ecological risk attributed to the heavy metal content in the sediments taken from the Gomishan wetland. In the case of Er indicating the risk of individual heavy metals, Cd had the highest values. It caused a moderate risk in summer and considerable risk in the sediment collected from sampling Stations Nos. 1 and 4 during spring. The estimated ecological risk for other heavy metals was low. RI also displays the sensitivity of different biological populations against contamination with heavy metals. Higher values of IR were exhibited in sampling Stations Nos. 1 and 4, especially in spring; however, the measures of RI for all sampling stations and both sampling sessions were <150, showing a low-risk level. The risk index values calculated in this study are significantly less than those of other studies conducted in Iran, such as in Shadegan wetland (Yavar Ashayeri & Keshavarzi 2019) and the studies conducted on the coast of the Persian Gulf. For example, in the study by Arfaeinia et al. (2019), the ecological risk index ranged from unpolluted for Ni, Pb, Cr, and Cu (Arfaeinia et al. 2019).

The EF of all heavy metals in the sediments was classified as a minimum level of enrichment. The highest value of EF was observed for Pb and the lowest for As. The calculated values of EF are recommended as appropriate criteria to distinguish the source of heavy metals in the sediment. Based on the guidelines (Table 2), EF < 2 illustrates that the natural sources play a key role in the heavy metal content in the sediments. In this study, we found that the role of the natural source is likely to be more significant, as the EF factor for all the elements in both sampling seasons was <2. Our findings were not consistent with the majority of studies focusing on heavy metal source identification in sediments where the values of EF were usually >2, the cut-off measure for distinguishing the source of pollutants. This may be due to the values considered for the background of heavy metals, which were rather high. In this study, we took into account the local reference material as the background amount of the heavy metals. Our findings for EF are compared with those of other studies in Table 7.

Table 7 | Comparison of EF and Igeo with other studies

| Location             | Country | EF factor for the heavy metals | Igeo reported for the heavy metals |
|----------------------|---------|--------------------------------|-----------------------------------|
| Gomishan wetland     | Iran    | Pb 1.095, Cd 0.57, Cr 0.66, Ni 0.35 | Pb 0.34, Cd 0.465, Cr 0.67, Ni 0.475, As -0.21 |
| Yangtze River        | China   | Pb 1.69, Cd 4.95, Cr 0.78, Ni 1.2 | Pb 1.14, Cd 2.7, Cr 0.09, Ni NA, As 0.66 |
| Liaohe River         | China   | Pb NA, Cd NA, Cr NA, Ni NA | Pb NA, Cd NA, Cr NA, Ni NA |
| Tajan River          | Iran    | Pb 2.42, Cd 1.39, Ni 9.5 | Pb NA, Cd NA, Cr Igeo ≤ 0, Ni Igeo ≤ 0 |
| Coast of Red Sea     | Egypt   | Pb 3.62, Cd 11.17, Cr NA, Ni 1.46 | Pb 0.12, Cd 0.36, Cr NA, Ni 0.05 |
| Nador lagoon         | Morocco | Pb 5, Cd 7.3, Cr 1, Ni 2.3 | Pb NA, Cd NA, Cr NA, Ni NA |
| Throughout India     | India   | Pb 4.09, Cd 128.18, Cr 8.32, Ni 4.09 | Pb 0.8, Cd 23.47, Cr 1.59, Ni 0.75 |
| Shadegan wetland     | Iran    | Pb 4.9, Cd 5.9, Cr 3.7, Ni 6.8 | Pb NA, Cd NA, Cr NA, Ni NA |
| Bamdezh wetland      | Iran    | Pb 1.22, Cd 52.22, Cr 1.38, Ni 0.32 | Pb Igeo ≤ 0, Cd 4.98, Cr NA, Ni Igeo ≤ 0 |
| Huixian wetland      | China   | Pb NA, Cd NA, Cr NA, Ni NA | Pb 0.48, Cd -0.01, Cr -0.015, Ni -0.2 |

References:
- Current study
- Yi et al. (2016)
- Ke et al. (2017)
- Alahabadi & Malvandi (2018)
- Nour et al. (2019)
- Maanan et al. (2015)
- Kumar et al. (2020)
- Yavar Ashayeri & Keshavarzi (2019)
- Vaezi et al. (2015)
- Xiao et al. (2019)
Igeo indexes for soil qualification were dominantly uncontaminated to moderately contaminated. Pb had the highest value of Igeo, 1.76, classified as moderately contaminated. This low level of contamination indicated a natural source of heavy metals. According to the findings of studies in which the major fraction of heavy metals was related to anthropogenic sources, the values of both EF and Igeo indexes were notably higher compared to the results of our study. Table 7 gives a comparison of our data with those of other studies focusing on the ecological risk of heavy metals in sediments.

CONCLUSION

We provided data on the concentration of some prioritized heavy metals in water and sediments sampled from different parts of an international wetland, Gomishan, located on the southeastern coast of the Caspian Sea. A rather high concentration of heavy metals was observed in the sediment, especially in the case of Pb; however, the ecological risk indexes for single elements and all the heavy metals, determined as Er and IR, respectively, were mostly ranged low to moderate. It seems that preservation activities should be established to prevent potential ecological risks from increasing. Additionally, low values of enrichment and geo-accumulation factors indicated that the natural or lithogenic sources are more likely to influence the concentration of the heavy metals in the sediments gathered from the Gomishan wetland.

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DECLARATION OF INTEREST STATEMENT

The authors declare that they have no conflict of interest.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

REFERENCES

Akoto, O., Bismark, E. F., Darko, G. & Adei, E. 2014 Concentrations and health risk assessments of heavy metals in fish from the Fosu Lagoon. *International Journal of Environmental Research (IJER)* 8, 403–410.

Alahabadi, A. & Malvandi, H. 2018 Contamination and ecological risk assessment of heavy metals and metalloids in surface sediments of the Tajan River, Iran. *Marine Pollution Bulletin* 133, 741–749.

Arfaeinia, H., Dobaranadaran, S., Moradi, M., Pasalar, H., Mehrizi, E. A., Taghizadeh, F., Esmaili, A. & Ansarizadeh, M. 2019 The effect of land use configurations on concentration, spatial distribution, and ecological risk of heavy metals in coastal sediments of northern part along the Persian Gulf. *Science of The Total Environment* 653, 783–791.

Basatnia, N., Hossein, S. A., Rodrigo-Comino, J., Khaledian, Y., Brevik, E. C., Aitkenhead-Peterson, J. & Natesan, U. 2018 Assessment of temporal and spatial water quality in international Gomishan Lagoon, Iran, using multivariate analysis. *Environmental Monitoring and Assessment* 190, 314.

Chen, X. & Lu, X. 2018 Contamination characteristics and source apportionment of heavy metals in topsoil from an area in Xi’an city, China. *Ecotoxicology and Environmental Safety* 151, 153–160.

Chen, H., Teng, Y., Li, J., Wu, J. & Wang, J. 2016 Source apportionment of trace metals in river sediments: a comparison of three methods. *Environmental Pollution* 211, 28–37.

Fu, J., Zhao, C., Luo, Y., Liu, C., Kyzas, G. Z., Luo, Y., Zhao, D., An, S. & Zhu, H. 2014 Heavy metals in surface sediments of the Jialu River, China: their relations to environmental factors. *Journal of Hazardous Materials* 270, 102–109.

Hakanson, L. 1980 An ecological risk index for aquatic pollution control. A sedimentological approach. *Water Research* 14, 975–1001.

Hu, W., Wang, H., Dong, L., Huang, B., Borggaard, O. K., Brun Hansen, H. C., He, Y. & Holm, P. E. 2018 Source identification of heavy metals in peri-urban agricultural soils of southeast China: an integrated approach. *Environmental Pollution* 237, 650–661.

Hu, B., Xue, J., Zhou, Y., Shao, S., Fu, Z., Li, Y., Chen, S., Qi, L. & Shi, Z. 2020 Modelling bioaccumulation of heavy metals in soil-crop ecosystems and identifying its controlling factors using machine learning. *Environmental Pollution* 262, 114308.

Huang, L., Rad, S., Xu, L., Gui, L., Song, X., Li, Y., Wu, Z. & Chen, Z. 2020 Heavy metals distribution, sources, and ecological risk assessment in Huixian wetland, South China. *Water* 12, 431.

Kanmani, S. & Gandhimathi, R. 2013 Assessment of heavy metal contamination in soil due to leachate migration from an open dumping site. *Applied Water Science* 3, 193–205.

Ke, X., Gui, S., Huang, H., Zhang, H., Wang, C. & Guo, W. 2017 Ecological risk assessment and source identification for heavy metals in surface sediment from the Liaohe River protected area, China. *Chemosphere* 175, 475–481.
Kumar, V., Sharma, A., Pandita, S., Bhardwaj, R., Thukral, A. K. & Cerda, A. 2020 A review of ecological risk assessment and associated health risks with heavy metals in sediment from India. *International Journal of Sediment Research* 35, 516–526.

Lim, K. Y., Zakaria, N. A. & Foo, K. Y. 2020 Geochemistry pollution status and ecotoxicological risk assessment of heavy metals in the Pahang River sediment after the high magnitude of flood event. *Hydrology Research* 52, 107–124.

Liu, M., Chen, J., Sun, X., Hu, Z. & Fan, D. 2019 Accumulation and transformation of heavy metals in surface sediments from the Yangtze River estuary to the East China Sea shelf. *Environmental Pollution* 245, 111–121.

Liu, M., Li, X., He, Y. & Li, H. 2020 Aquatic toxicity of heavy metal-containing wastewater effluent treated using vertical flow constructed wetlands. *Science of The Total Environment* 727, 138616.

Lovell, S. T. & Sullivan, W. C. 2006 Environmental benefits of conservation buffers in the United States: evidence, promise, and open questions. *Agriculture, Ecosystems & Environment* 112, 249–260.

Maan, M., Saddik, M., Maan, M., Chaibi, M., Assobhe, O. & Zourarah, B. 2015 Environmental and ecotoxicological risk assessment of heavy metals in sediments of Nadir lagoon, Morocco. *Ecological Indicators* 48, 616–626.

Muller, G. J. G. 1969 Index of geoaccumulation in sediments of the Rhine River. *Geojournal* 2, 108–118.

Navas, A. & Machin, J. 2002 Spatial distribution of heavy metals and arsenic in soils of Aragón (northeast Spain): controlling factors and environmental implications. *Applied Geochemistry* 17, 961–973.

Neckel, A., Kocerelci, C., Kujawa, H. A., Schaefer Da Silva, I., Prezoto, F., Walker Amorin, A. L., Maculan, L. S., Goncalves, A. C., Bodah, E. T., Bodah, B. W., Dotto, G. L. & Silva, L. F. O. 2021 Hazardous elements in the soil of urban cemeteries; constructive solutions aimed at sustainability. *Chemosphere* 262, 128248.

Nour, H. E., El-Sorogy, A. S., Abd El-Wahab, M., Nouh, E. S., Mohamaden, M. & Al-Kahtany, K. 2019 Contamination and ecological risk assessment of heavy metal pollution from the Shalateen coastal sediments, Red Sea, Egypt. *Marine Pollution Bulletin* 144, 167–172.

Palumbo, B., Angelone, M., Bellanca, A., Dazzi, C., Hauser, S., Neri, R. & Wilson, J. 2000 Influence of inheritance and pedogenesis on heavy metal distribution in soils of Sicily, Italy. *Geoderma* 95, 247–266.

Quinton, J. N. & Catt, J. A. 2007 Enrichment of heavy metals in sediment resulting from soil erosion on agricultural fields. *Environment Science & Technology* 41, 3495–3500.

Rajeshkumar, S., Liu, Y., Zhang, X., Ravikumar, B., Bai, G. & Li, X. 2018 Studies on seasonal pollution of heavy metals in water, sediment, fish and oyster from the Meiliang Bay of Taihu Lake in China. *Chemosphere* 191, 626–638.

Rakhami, A., Tahiri, A.-I., Bechtaoui, N., Abdelhay, E. G., Pajuelo, E., Baslam, M., Meddich, A. & Oufdou, K. 2021 Restoring the plant productivity of heavy metal-contaminated soil using phosphate sludge, marble waste, and beneficial microorganisms. *Journal of Environmental Sciences* 99, 210–221.

Sevik, H., Cetin, M., Ozel, H. B., Ozel, S. & Zeren Cetin, I. 2020 Changes in heavy metal accumulation in some edible landscape plants depending on traffic density. *Environmental Monitoring and Assessment* 192, 78.

Shi, T., Ma, J., Wu, X., Ju, T., Lin, X., Zhang, Y., Li, X., Gong, Y., Hou, H., Zhao, L. & Wu, F. 2018 Inventories of heavy metal inputs and outputs to and from agricultural soils: a review. *Ecotoxicology and Environmental Safety* 164, 118–124.

Shokrzadeh, M. & Saeedi Saravi, S. S. 2009 The study of heavy metals (zinc, lead, cadmium, and chromium) in water sampled from Gorgan and Marid meteors. *International Journal of Environmental Science and Technology* 6, 55–63.

Sievers, M., Hale, R., Parris, K. M. & Swearer, S. E. 2018 Impacts of human-induced environmental change in wetlands on aquatic animals. *Biological Reviews* 93, 529–554.

Silva, L. F. O., Hower, J. C., Dotto, G. L., Oliveira, M. L. S. & Pinto, D. 2021 Titanium nanoparticles in sedimented dust aggregates from urban children's parks around coal ashes wastes. *Fuel* 285, 119162.

Solgi, E. & Mohammad Galangashi, M. 2018 Assessing the health of marine and lacustrine wetland using measurement of heavy metal in fish species: case study from two Iranian international wetland (Gomishan and Zarivar). *Environmental Nanotechnology, Monitoring & Management* 10, 73–78.

Strzebońska, M., Jarosz-Krzemińska, E. & Adamiec, E. 2017 Assessing historical mining and smelting effects on heavy metal pollution of river systems over span of two decades. *Water, Air, & Soil Pollution* 228, 141.

Tabari, S., Saravi, S. S. S., Bandany, G. A., Dehghan, A. & Shokrzadeh, M. 2010 Heavy metals (Zn, Pb, Cd and Cr) in fish, water and sediments sampled form Southern Caspian Sea, Iran. *Toxicology and Industrial Health* 26, 649–656.

USEPA 1996 *Method 3050B Acid Digestion of Sediments, Sludges, and Soils 1.0 Scope and Application*. U.S. Environmental Protection Agency, Washington, DC, USA.

Vaezi, A. R., Karbassi, A. R., Valavi, S. & Ganjali, M. R. 2015 Ecological risk assessment of metals contamination in the sediment of the Bamdezh wetland, Iran. *International Journal of Environmental Science and Technology* 12, 951–958.

Volpe, M. G., La Cara, F., Volpe, F., De Mattia, A., Serino, V., Petitto, F., Zavalloni, C., Limone, F., Pellecchia, R., De Prisco, P. P. & Di Stasio, M. 2009 Heavy metal uptake in the enological food chain. *Food Chemistry* 117, 553–560.

Weng, P., Sánchez-Pérez, J. M., Sauvage, S., Vervier, P. & Giraud, F. 2003 Assessment of the quantitative and qualitative buffer function of an alluvial wetland: hydrological modelling of a large floodplain (Garonne River, France). *Hydrological Processes* 17, 2375–2392.

Xia, P., Ma, L., Sun, R., Yang, Y., Tang, X., Yan, D., Lin, T., Zhang, Y. & Yi, Y. 2020 Evaluation of potential ecological risk, possible sources and controlling factors of heavy metals in surface sediment of Caohai Wetland, China. *Science of The Total Environment* 740, 140231.

Xiao, H., Shahab, A., Li, J., Xi, B., Sun, X., He, H. & Yu, G. 2019 Distribution, ecological risk assessment and source identification of heavy metals in surface sediments of Huixian karst wetland, China. *Ecotoxicology and Environmental Safety* 185, 109700.
Yargholi, B. & Azarneshan, S. 2014 Long-term effects of pesticides and chemical fertilizers usage on some soil properties and accumulation of heavy metals in the soil (case study of Moghan plain's (Iran) irrigation and drainage network. *International Journal of Agriculture and Crop Sciences* 7, 518.

Yavar Ashayeri, N. & Keshavarzi, B. 2019 Geochemical characteristics, partitioning, quantitative source apportionment, and ecological and health risk of heavy metals in sediments and water: a case study in Shadegan Wetland, Iran. *Marine Pollution Bulletin* 149, 110495.

Yi, Y.-J., Sun, J., Tang, C.-H. & Zhang, S.-H. 2016 Ecological risk assessment of heavy metals in sediment in the upper reach of the Yangtze River. *Environmental Science and Pollution Research* 23, 11002–11013.

Yin, K., Wang, Q., Lv, M. & Chen, L. 2019 Microorganism remediation strategies towards heavy metals. *Chemical Engineering Journal* 360, 1553–1563.

Zolfaghari, G. 2018 Risk assessment of mercury and lead in fish species from Iranian international wetlands. *MethodsX* 5, 438–447.

Zwolak, A., Sarzyńska, M., Szpyrka, E. & Stawarczyk, K. 2019 Sources of soil pollution by heavy metals and their accumulation in vegetables: a review. *Water, Air, & Soil Pollution* 230, 164.

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