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RESEARCH ARTICLE

An Assessment of Metal Contamination Risk in Sediments of the Mohammad Abad River, Northern Iran

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ABSTRACT

Background: Sediments in the aquatic ecosystems can be used as suitable indicators for monitoring contaminants. Then, objectives of this study were to evaluate the concentration of heavy metals in the surface sediments of the Mohammad Abad River, to determine the degree of pollution of heavy metals in sediments using some major contamination indices; to identify the major sources (anthropogenic or natural sources) of the studied metals; and to evaluate the "reference river" of the river under study for ecotoxicology studies.

Methods: Samples of sediment were taken from six sites of the river. The present study, eleven heavy metals (chromium, manganese, iron, cobalt, nickel, zinc, selenium, magnesium, silver, aluminum and arsenic) were studied.

Results: Comparison of metal concentrations with those of Sediment Quality Guidelines (SQGs) showed no association with harmful biological effects for the heavy metals studied except for Se and As. The results of the contamination factor index (C_f) showed low pollution levels for most metals (Cr, Mn, Fe, Co, Ni, Zn and Al), moderate pollution levels for As, and very high pollution levels for Se. The degree of contamination (Cd) and modified degree of contamination (mCd), showing the total contamination of elements, demonstrated very high degree contamination status in the study area. According to the index of quantification of contamination, the values of Cr, Mn, Fe, Ni, Zn and Al were derived mainly from geogenic sources of enrichment, while the values for Se and As were enriched by anthropogenic source of enrichment.

Conclusion: These findings suggest that continuous monitoring of Se and As in sediment and organisms of the Mohammad Abad River should be directed to evaluate the threat of these elements to the public health and to the ecology of the river under study.

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- River

INTRODUCTION

Sediment can be regarded as a vital and integral part of the aquatic environment, but are usually regarded as a potential sink for various pollutants discharged into this environment. In this context, sediments in the aquatic ecosystems can be used as suitable indicators for monitoring contaminants [1,2]. Many pollutants, such as heavy metals and Persistent Organic Pollutants (POPs), have been detected in the sediments [3]. Some pollutants accumulate in sediment and tissues of living organisms. Toxic metals are an example of a group of the pollutants whose their levels are increasing in various environmental matrices, especially in sediment [4,5]. The discharge of these compounds into the aquatic environment can be extremely harmful for the health of humans, aquatic organisms, and ecosystems [6,7].

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Heavy metals are released into aquatic ecosystems through natural processes such as soil erosion, rock weathering and the dissolution of the water-soluble salts as well as through human activities such as agriculture (through the entry of runoff from agricultural and adjacent lands), production of wastewater from houses, municipalities, and industrial uses, and through riverine fluxes [8]. Their stability against degradation combined with their toxicity, persistence, bioaccumulation, and biomagnification make heavy metals serious contaminations in aquatic ecosystems. Hence, many studies have been conducted to assess the concentrations of these compounds in rivers, wetlands, lakes and seas [9-13].

The potential ecological risk of heavy metals in the aquatic ecosystems is determined not only by their total levels in the sediments, but also using pollution indices [7]. The pollution indices provide benefits and advantages which can include: easy for public understanding, classify sediment contamination risk within the studied reign, easier interpretation of results and output more rapidly and more understandable to researchers, decision-makers and managers. To date, many calculation methods have been developed to evaluate the degree of metal contamination or enrichment in sediments. Some of these, such as the contamination factor (C_f) and potential Contamination Index (C_p), are suitable only for ecological risk assessment of a single element [14-16], while others, such as degree of contamination (C_d), Modified Degree of Contamination (mC_d), and Nemerow Pollution Index (PI), are suitable to evaluate the combined contamination risk for an ecological system [2,17-20]. In addition, some of the Sediment Quality Guidelines (SQGs) have been applied to protect aquatic organisms from the toxic and adverse effects associated with sediment-bound pollutants; they are suitable tools to assess potential contamination [17,21].

Management and control of aquatic ecosystem contamination is required for the conservation of aquatic organisms and the aquatic environment [2]. A lot of studies have examined the concentration of heavy metals in the rivers of the world [4,22-25], but the heavy metal levels of sediments in the Mohammad Abad River, Iran, have not been studied. Therefore, this is the first study conducted with the aim of assessing the risk of heavy metals in the Mohammad Abad River. The objectives of this study were: (1) to evaluate the concentration of heavy metals in the surface sediments of the Mohammad Abad River; (2) to determine the degree of pollution of heavy metals in sediments using some major contamination indices; and (3) to identify the major sources (anthropogenic or natural sources) of the studied metals. Another significant important of this study was to investigate the possibility of selecting the river as a «reference river» and using it in ecotoxicology studies.

MATERIALS AND METHODS

Study area

This study was conducted in the Mohammad Abad River, which is a small river situated in the eastern Elburz mountains (Golestan province in northern Iran. The Mohammad Abad River originates in the Golestan District of Aliabad Katoul city and joins the Gorganrood River. The annual mean water temperature is between 9°C and 18°C. The river is approximately 25 km long, and an average water flow of 1.46 m³s⁻¹. The river is important for a number of reasons, including its role in controlling seasonal floods, agricultural water supply, aquaculture activities, groundwater recharge, habitat for many living organisms, and maintaining the ecological balance of the region.

Sample collection

The survey was performed in the spring and summer of 2014. Samples of sediment (10 cm of surface sediment) were taken from six sites in triplicates based on human activities and ecological conditions (Figure 1). The sediment samples were placed into pre-cleaned polyethylene bottles, packed in a cooler at 4°C, and brought to the laboratory for further analysis. All of the reagents used were of supra-pure grade. Prior to any analysis, glassware, plastic containers, and all equipment were soaked in 10% HNO₃ for 24h, rinsed with deionized water, and then dried before use [4,26].

Analysis of sediment samples

Sediment samples were dried at room temperature, mixed thoroughly, sieved through a 230 ASTM sieve mesh (mesh size 63 µm), and then ground to a fine powder. To assess total heavy metal concentrations, 1 g of sediment samples were digested in Teflon tubes with HClO₄-HNO₃-HF mixture in an oven (at 160°C for 6h). After digestion, the extracted solutions were filtered through filter paper and diluted using double deionized water to a volume of 25 mL [27]. The sediment extracts were analyzed for Cr, Mn, Fe, Co, Ni, Zn, As, Se, Al, Ag, and Mg by inductively Coupled Plasma Atomic Absorption Spectrometry (ICP/AES). The detection limits were 1.5 for Cr and Zn, 5 for Mn and Mg, 6 for Fe, 0.5 for Co, 1 for Ni, As and Ag, 2 for Se and 8 mg kg⁻¹ for Al.

Figure 1 Mohammad Abad river location map and sampling sites.

In this study, the analytical data quality was ensured through the implementation of laboratory quality assurance and quality control methods, including the use of calibration with standards, standard operating procedures, recovery of spiked samples, analysis of reagent blanks, and analysis of replicates. The accuracy and precision of the analytical methods were investigated using recovery measurements on spiked sediment samples. The percentage recoveries of the elements ranged from 90.7% to 108.5%. The precision of the analytical procedures, expressed as the Relative Standard Deviation (RSD), ranged from 3 to 8%.

Assessment of heavy metals in sediment

Contamination factor (C_f^i): Contamination factor (C_f^i), proposed by Hakanson [28], is an index that expresses the level of pollution in the study area. The contamination factor (C_f^i) is calculated by the following equation:

$$C_f^i = \frac{C_i}{C_n^i}$$

Where C_i is the average level of element i in sediments and C_n^i is the reference content for the element [29]. The C_f^i index was divided into four categories by Hakanson, which are shown in table 1. The background values used for all indices for Se, Co, As, Ni, Cr, Zn, Mn, and Fe, Al were 0.6, 19, 13, 68, 90, 95, 850, 47,200 and 80,000 mg/kg, respectively.

Degree of contamination (C_d): The index of degree of contamination (C_d) reflects the

sum of all contamination factors for the study area [1]. The degree of contamination (C_d) is calculated by the following equation:

$$C_d = \sum_{i=1}^n C_f^i$$

On the basis of the degree of contamination (C_d) values, sediments were classified into the four groups. These values can be found in table 1.

Modified degree of contamination (mC_d): The index of modified degree of contamination (mC_d) is obtained using the following equation.

$$mC_d = \frac{\sum_{i=1}^n C_f^i}{n}$$

where C_f^i = contamination factor, n = number of investigated metals and i = i th metals [2]. Seven classes have been proposed for this index [14], which are shown in table 1.

Potential contamination index (C_p): The following method is used to calculate of the potential contamination index:

$$C_p = \frac{C_{\max}}{C_b}$$

where $C_{\max}$ is the maximum level of an element in sediment and C_b is the average background level of the same element [16]. Davaulter and Rognerud [30] have proposed three classes of the C_p index, which are shown in table 1.

Nemerow Pollution Index (PI): The overall

Table 1: The contamination indices (contamination factor, degree of contamination, modified degree of contamination, potential contamination index and Nemerow pollution index) and contamination levels for heavy metals (Data are adapted from the references of [1,14,19,28-31]).

Index						
Contamination factor (C_f^i)			Degree of contamination (C_d)		Modified degree of contamination (mC_d)	
No. class	C_f^i value	Contamination level	C_d value	Contamination level	mC_d value	Contamination level
1	$(C_f^i < 1)$	low	$C_d < 7$	low	$mC_d < 1.5$	nil to very low
2	$1 \leq C_f^i < 3$	moderate	$7 \leq C_d < 14$	moderate	$1.5 \leq mC_d < 2$	low
3	$3 \leq C_f^i < 6$	considerable	$14 \leq C_d < 28$	considerable	$2 \leq mC_d < 4$	moderate
4	$C_f^i \geq 6$	very high	$C_d \geq 28$	very high	$4 \leq mC_d < 8$	high
5	-	-	-	-	$8 \leq mC_d < 16$	very high
6	-	-	-	-	$16 \leq mC_d < 32$	extremely high
7	-	-	-	-	$mC_d \geq 32$	ultra high
Potential contamination index (C_p)			Nemerow pollution index (PI)			
No. class	C_p value	Contamination level	PI value	Contamination level		
1	$C_p < 1$	low	$PI < 0.7$	non-polluted		
2	$1 < C_p < 3$	moderate	$0.7 < PI < 1$	nearly polluted		
3	$C_p > 3$	severe or very severe	$1 < PI < 2$	lightly polluted		
4	-	-	$2 < PI < 3$	moderately polluted		
5	-	-	$PI > 3$	seriously polluted		

contamination status of the surface sediments by heavy metals has been investigated using the Nemerow Pollution Index (PI) in several studies [20]. The PI is calculated using the following equation:

$$PI = \sqrt{\frac{(C_f^i)_{Ave} + (C_f^i)_{max}}{2}}$$

where $(C_f^i)_{Ave}$ and $(C_f^i)_{max}$ are the average and maximum contamination indices of an individual heavy metal, respectively. Five categories have been proposed for this index [19], which are shown in table 1.

Quantification of contamination (QoC): The Quantification of Contamination (QoC) index was used to evaluate the main sources (anthropogenic or natural sources) of metals [29]. The index is estimated in accordance with the following equation:

$$QoC(\%) = \left[\frac{(C_i - C_n)}{C_i} \right] \times 100$$

where C_i is the mean content of the element in the sediment sample under study and C_n is the background content for the element [29,31]. Negative values obtained from the above formula represent a natural source and positive values reflect an anthropogenic source.

RESULTS AND DISCUSSION

In some studies in Golestan province, Iran, the Mohammad Abad River is assumed as a non-polluted river, while, very little information exists on the elements levels of sediment in the river. Therefore, in the present study, the levels of Cr, Mn, Fe, Co, Ni, Zn, As, Se, Al, Ag, and Mg in surface sediments of the Mohammad Abad River have been investigated, and the degree of pollution of elements (Cr, Mn, Fe, Co, Ni, Zn, As, Se, Al, Ag, and Mg) using some major contamination indices has been evaluated. Table 2 summarizes the heavy metal content in the surface sediment samples of the Mohammad Abad River. In the present

investigation, Fe had the highest levels in these samples. The mean level of Cr was approximately 39.56 mg kg⁻¹ dw. A comparison of Cr level in sediment samples with the corresponding values of this metal in the sediment quality guidelines (SQG) demonstrated that the concentrations of Cr were greater than the Threshold Effects Level (TEL), while the concentrations of this metal were lower than the sediment quality guidelines (Threshold Effects Level (TEL), Effect Range Low (ERL), Probable Effect Level (PEL) and Effect Range Median (ERM) (Figure 2a). The average concentrations of Mn, Fe, Co, Ni, Zn, Se, Al, Ag and Mg in sediments were 300.60, 14438.59, 9.23, 13.01, 34.31, 3070.05, ND and 825.26 µg g⁻¹, respectively. The mean concentrations of Ni and Zn in sediments were below the sediment quality guidelines (Figures 2b,2c). The average concentration of As in sediments was 23.00 µg g⁻¹. The comparison of As levels with the studied standard values demonstrated that the concentrations of As were greater than TEL, and PEL values up to 4 times and 1.3 times, respectively (Figure 2d).

Table 3 presents the estimated values of contamination factor (C_f^i), degree of contamination (C_d) and modified degree of contamination (mC_d) for each metal. The range of (C_f^i) values in the investigated sediments were 0.355–0.586 for Cr, 0.243–0.722 for Mn, 0.214–0.362 for Fe, 0.413–0.625 for Co, 0.156–0.228 for Ni, 0.290–0.440 for Zn, , 0.864–2.422 for As, 65.683–78.700 for Se, and 0.036–0.043 for Al (Table 3). In general, the contamination factors of heavy metals in this investigation are arranged as follows: Se > As > Co > Cr > Mn=Zn > Fe > Ni > Al. According to the values of degree of contamination (C_d), the different studied sites are arranged as follows: S-6 > S-4 > S-5 > S-3 = S-1 > S-2. According to the calculated contamination factors (C_f^i), Cr, Mn, Fe, Co, Ni, Zn and Al all showed a low level of contamination at all sites, while As indicated a moderate level of contamination (except for S-6 site, low degree of contamination). In all stations, Se showed a very high level of contamination (Table 4).

Table 2: Descriptive statistics of heavy metal concentrations (mg kg⁻¹) measured in the Mohammad Abad River and the corresponding sediment quality guidelines.

Metal	Sites												Sediment quality guidelines			
	S-1		S-2		S-3		S-4		S-5		S-6		TEL	ERL	PEL	ERM
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD				
Cr	40.72	2.22	31.93	3.24	52.62	2.18	40.75	2.55	32.09	2.15	39.23	2.67	37.3	80	90	145
Mn	222.11	10.19	206.73	0.90	233	14.74	283.72	24.37	244	3.58	614.01	2.95	-	-	-	-
Fe	14701.38	375.04	17064.58	994.12	16394.11	867.71	16023.19	783.88	12357.64	111.16	10090.64	320.25	-	-	-	-
Co	9.38	0.60	11.88	0.33	9.67	0.09	8.63	0.82	7.84	0.39	7.98	0.41	-	-	-	-
Ni	10.6	0.79	14.53	0.40	13.28	0.29	12.69	0.67	11.48	0.02	15.5	0.74	18	30	42.8	50
Zn	33.06	4.23	38.22	0.70	33.32	0.29	31.95	2.06	27.53	0.01	41.8	1.03	123	120	315	270
As	22.65	10.03	23.66	0.73	27.68	5.62	31.48	8.33	21.3	3.31	11.23	0.01	5.9	33	17	85
Se	39.96	0.02	39.41	3.35	39.59	6.15	45.26	4.38	44.27	1.42	47.22	3.60	-	-	-	-
Al	3080.23	543.77	2951.87	818.67	2953.76	43.63	3426.12	2.35	2890.01	223.64	3118.31	7.02	-	-	-	-
Ag	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	-	-	-	-
Mg	691.29	79.19	1661.3	831.54	711.33	41.45	708.42	5.17	652.85	28.46	526.34	12.68	-	-	-	-

Figure 2 Comparison of concentrations of heavy metals in the Mohammad Abad River with the Sediment Quality Guideline (SQG) values.

Table 3: Contamination factor (C_f^i), contamination degree (C_d) and modified degree of contamination (mC_d) of sediment heavy metals in the Mohammad Abad River.

Index	Sites							
Contamination factor (C_f^i)	Metals	S-1	S-2	S-3	S-4	S-5	S-6	Average
	Cr	0.452	0.355	0.585	0.453	0.357	0.436	0.440
	Mn	0.261	0.243	0.274	0.334	0.287	0.722	0.354
	Fe	0.312	0.362	0.347	0.340	0.262	0.214	0.306
	Co	0.494	0.625	0.509	0.454	0.413	0.420	0.486
	Ni	0.156	0.214	0.195	0.187	0.169	0.228	0.191
	Zn	0.348	0.402	0.351	0.336	0.290	0.440	0.361
	As	1.742	1.820	2.129	2.422	1.639	0.864	1.769
	Se	66.600	65.683	65.983	75.433	73.783	78.700	71.031
C_d		70.404	69.741	70.410	80.001	77.235	82.063	71.410
mC_d		7.823	7.749	7.823	8.889	8.582	9.118	7.934

Table 4: Risk level of studied metals (based on C_f^i), contamination degree (based on C_d), and modified degree of contamination (based on mC_d) in the Mohammad Abad River. The term in parentheses indicates the pollution level.

Index	Sites							
Contamination factors (C_f^i)		S-1	S-2	S-3	S-4	S-5	S-6	Average
	Cr	$C_f^i < 1$	$C_f^i < 1$	$C_f^i < 1$	$C_f^i < 1$	$C_f^i < 1$	$C_f^i < 1$	$C_f^i < 1$
		(low)	(low)	(low)	(low)	(low)	(low)	(low)
	Mn	$C_f^i < 1$	$C_f^i < 1$	$C_f^i < 1$	$C_f^i < 1$	$C_f^i < 1$	$C_f^i < 1$	$C_f^i < 1$
		(low)	(low)	(low)	(low)	(low)	(low)	(low)
	Fe	$C_f^i < 1$	$C_f^i < 1$	$C_f^i < 1$	$C_f^i < 1$	$C_f^i < 1$	$C_f^i < 1$	$C_f^i < 1$
		(low)	(low)	(low)	(low)	(low)	(low)	(low)
	Co	$C_f^i < 1$	$C_f^i < 1$	$C_f^i < 1$	$C_f^i < 1$	$C_f^i < 1$	$C_f^i < 1$	$C_f^i < 1$
		(low)	(low)	(low)	(low)	(low)	(low)	(low)
	Ni	$C_f^i < 1$	$C_f^i < 1$	$C_f^i < 1$	$C_f^i < 1$	$C_f^i < 1$	$C_f^i < 1$	$C_f^i < 1$
		(low)	(low)	(low)	(low)	(low)	(low)	(low)
	Zn	$C_f^i < 1$	$C_f^i < 1$	$C_f^i < 1$	$C_f^i < 1$	$C_f^i < 1$	$C_f^i < 1$	$C_f^i < 1$
		(low)	(low)	(low)	(low)	(low)	(low)	(low)
	As	$1 \leq C_f^i < 3$	$1 \leq C_f^i < 3$	$1 \leq C_f^i < 3$	$1 \leq C_f^i < 3$	$1 \leq C_f^i < 3$	$1 \leq C_f^i < 3$	$1 \leq C_f^i < 3$
		(Moderate)	(Moderate)	(Moderate)	(Moderate)	(Moderate)	(low)	(Moderate)
	Se	$C_f^i < 6$	$C_f^i < 6$	$C_f^i < 6$	$C_f^i < 6$	$C_f^i < 6$	$C_f^i < 6$	$C_f^i < 6$
		(Very high)	(Very high)	(Very high)	(Very high)	(Very high)	(Very high)	(Very high)
	Al	$C_f^i < 1$	$C_f^i < 1$	$C_f^i < 1$	$C_f^i < 1$	$C_f^i < 1$	$C_f^i < 1$	$C_f^i < 1$
		(low)	(low)	(low)	(low)	(low)	(low)	(low)
C_d		$C_d \geq 28$	$C_d \geq 28$	$C_d \geq 28$	$C_d \geq 28$	$C_d \geq 28$	$C_d \geq 28$	$C_d \geq 28$
		(Very high)	(Very high)	(Very high)	(Very high)	(Very high)	(Very high)	(Very high)
mC_d		$4 < mC_d < 8$	$4 < mC_d < 8$	$4 < mC_d < 8$	$8 < mC_d < 16$	$8 < mC_d < 16$	$8 < mC_d < 16$	$4 < mC_d < 8$
		(High)	(High)	(High)	(Very high)	(Very high)	(Very high)	(High)

The contamination factor (C_f^i) index has been studied and reports for many locations, including the Tigris River [32], the Shitalakhya River [33], the Bernam River [34], the Subarnarekha River [35], and the Jiaozhou Bay rivers [36]. In the Tigris River, CF index values were in the range of 0.43 to 34.68 for arsenic, cadmium, cobalt, chromium, copper, iron, manganese, nickel, lead and zinc [32]. In the Shitalakhya River, values were in the range of 0.00 to 97.09 for aluminum, potassium, calcium, magnesium, iron, arsenic, copper, cobalt, chromium and zinc [33]. In the Bernam River, values were in the range of 0.02 to 17.76 for cadmium, nickel, chromium, tin and iron [34]. In the Subarnarekha River, values were in the range of 0.01 to 25.00 for chromium, cadmium, copper, lead, nickel and zinc [35]. Finally, in the Jiaozhou Bay rivers, values in the range of 0.30 to 18.81 for lead, cadmium and arsenic [36] have been reported.

According to the values of degree of contamination (C_d), the different studied sites are arranged as follows: $S-6 > S-4 > S-5 > S-3 = S-1 > S-2$. The levels of contamination degree (C_d) at all sites were more than 8. The index values were in a range close to each other among the sampling sites, there were no difference between them. In general the values indicated that the contamination in the Mohammad Abad River was very high (Table 4). The contamination degree (Cd) index has been studied in many locations, such as the Shitalakhya River [33], the Trepça and Sitnica Rivers [37], the Subarnarekha River [35], the Sefidrood River, and the Shirinrood River [38]. In the Shitalakhya River, Cd index values were in the range of 9.78 to 114.03 for aluminum, potassium, calcium, magnesium, iron, arsenic, copper, cobalt, chromium and zinc [33]. In the Trepça and Sitnica Rivers, values were in the range of 40.53 to 1598.44

for arsenic, cadmium, cobalt, chromium, copper, nickel, lead and zinc [37]. In the Subarnarekha River, values were in the range of 1.19 to 10.62 for chromium, cadmium, copper, lead, nickel and zinc [35]. In the Sefidrood and Shirinrood Rivers, values were in the range of 0.6 to 0.9 and 0.6 to 6.1 for arsenic, cadmium, cobalt, chromium, copper, nickel, lead and zinc, respectively [38]. It seems, the Sefidrood and Shirinrood rivers are most similar to the river under study for the following reasons: the absence of polluting industries in the watershed of rivers; having almost similar agricultural activities; and location of the three rivers in an area with vegetation type almost similar to each other (Hyrcanian forest).

Table 3 shows the mCd index for each element. The values of mCd index for the individual sites were in the range from 7.749 to 9.118 in table 3. The low variability was observed among the sampling sites and no significant difference was found among the mC_d values in the sampling sites. In general, the data of mCd showed very high degree of pollution in all sampling sites (Table 4). The modified degree of contamination (mC_d) index has been studied in the Trepça and Sitnica Rivers [37], the Sefidrood River, the Shirinrood River [38], and the Qua-Iboe River. In the Trepça and Sitnica Rivers, mC_d index values were in the range of 5.07 to 199.81 for arsenic, cadmium, cobalt, chromium, copper, nickel, lead and zinc [37]. In the Sefidrood and Shirinrood Rivers, values were in the range of 0.8 to 1.1 and 0.7 to 1.7 for arsenic, cadmium, cobalt, chromium, copper, nickel, lead and zinc, respectively [38]. In the Qua-Iboe River, the index values were in the range of 0.61 to 40.00 for cadmium, chromium, copper, iron, lead, zinc, nickel and mercury [39].

Table 5: Potential contamination index (C_p) and Nemerow pollution index of sediment heavy metals in the Mohammad Abad River. The term in parentheses indicates the pollution level.

Index	Sites							
Potential contamination index (C_p)	Metals	S-1	S-2	S-3	S-4	S-5	S-6	Nemerow pollution index
	Cr	0.46	0.39	0.61	0.48	0.36	0.47	0.50 (Non-polluted)
	Mn	0.27	0.24	0.29	0.36	0.29	0.76	0.55 (Non-polluted)
	Fe	0.39	0.38	0.37	0.36	0.29	0.24	0.32 (Non-polluted)
	Co	0.53	0.64	0.51	0.5	0.43	0.44	0.55 (Non-polluted)
	Ni	0.17	0.22	0.2	0.2	0.17	0.24	0.21 (Non-polluted)
	Zn	0.39	0.41	0.35	0.36	0.29	0.45	0.39 (Non-polluted)
	As	2.58	1.88	2.58	3.1	1.91	0.87	2.06 (Moderately polluted)
	Se	66.62	71.54	76.76	83.11	76.27	85.02	73.02 (Seriously polluted)
	Al	0.05	0.05	0.04	0.05	0.04	0.05	0.04 (Non-polluted)
Nemerow pollution index		47.42 (Seriously polluted)	46.77 (Seriously polluted)	46.98 (Seriously polluted)	53.71 (Seriously polluted)	52.52 (Seriously polluted)	56.02 (Seriously polluted)	

The values of the potential contamination index (C_p) for the nine studied heavy metals for each site are recorded in table 5. The results of the C_p index indicated that all heavy metals, except As and Se, were at low contamination levels. At all sites except for of S-6, As was at a moderate level of contamination and Se was at a severe or very severe contamination level based on the C_p index. The Al values showed the lowest pollution, while the Se values were the highest.

Based on the C_p index, low contamination have been reported for magnesium, aluminum, potassium, calcium, iron, vanadium, chromium, manganese, cobalt, nickel and zinc, while severe contamination have been reported for titanium in coastal sediment from south east coast of Tamilnadu, India [40]. In the Tapacurá River, the values of C_p index have been reported in the range of 5.07 to 199.81 for iron, manganese, copper, lead, cadmium, zinc, nickel and chromium [41]. In that study, more than 50% of the samples showed severe and very severe pollution. Also, the values of this index have been reported in the range of 0.05 to 29.73 for iron, manganese, zinc, nickel, chromium, lead, copper, cadmium, cobalt and arsenic in sediments of the ship breaking area of Sitakund Upazilla, Bangladesh [42]. In that study, more than 50% of the samples indicated moderate, severe and very severe pollution. However, in the present study, the values of C_p index were in the range of 0.04 to 80.97 for the studied heavy metals and more than 9% and 11% of the samples showed moderate and severe pollution, respectively.

The values of Nemerow pollution index are shown in table 5. On one hand, the Nemerow pollution indices for the sites S-1, S-2, S-3, S-4, S-5 and S-6 were 47.42, 46.77, 46.98, 53.71, 52.52 and 56.02, respectively. These results indicated that the contamination levels at all sites can be classified as seriously polluted. On the other hand, all sites were non-polluted with heavy metals with the exception of As and Se. The Nemerow pollution indices of Cr, Mn, Fe, Co, Ni, Zn and Al were 0.50, 0.55, 0.32, 0.55, 0.21, 0.39 and

0.04, respectively. These Nemerow pollution indices were considerably lower than 0.07, indicating that the sampling sites were non-polluted with Cr, Mn, Fe, Co, Ni, Zn and Al. In contrast, the results of the Nemerow pollution indices showed that the contamination levels of the As and Se from the sampling sites were moderately polluted and seriously polluted, respectively.

According to the Nemerow pollution index values, the Yiluo River [43] and Jiu River [44] have been reported as highly polluted and seriously contaminated, respectively. In general, the contamination levels of the Nemerow pollution index reported in the present study were similar to those observed in the Jiu River in Romania. It should be noted that the comparison between the indices values in this study with other studies should be performed with caution, because factors such as the number of elements and selected reference levels can have a significant impact on indices results [45]. For example, in comparing the values of the indices obtained in this study with the values of other studies, if all the elements studied in the calculation of indices values are considered, the indices values in this study are similar to the values of most other studies. But if only one element (Se) is not considered in the calculation of index values, the index values of this study are less than most other studies.

In the present investigation, the Quantification of Contamination index (QoC) was used to determine possible sources of contaminants (heavy metals) in surface sediments of the Mohammad Abad River. In other words, the purpose of using this index was to distinguish between anthropogenic and geogenic sources involved in the level of metals in sediments from each other. In table 6, the results of QoC index for each element were presented. In this study, a total of 9 metals were investigated, out of which Cr, Mn, Fe, Ni, Zn and Al for all the sites sampled were considered to be of lithogenic sources with no evidence of anthropogenic activities, while Se in the surface sediments of all the sites studied were considered to be of anthropogenic sources according to the QoC index values.

Table 6: The values of Quantification of Contamination (QoC) of heavy metals in the surface sediments of the Mohammad Abad River. Values describe the magnitude of geogenic (negative values) and anthropogenic (positive values) impacts. The numbers have been reported in percentage terms.

Index	Sites							Average
Quantification of Contamination (QoC)	Metals	S-1	S-2	S-3	S-4	S-5	S-6	
	Cr	-121.02*	-181.87*	-71.04*	-120.86*	-180.46*	-129.42*	-127.52*
	Mn	-282.69*	-311.16*	-264.81*	-199.59*	-248.36*	-38.43*	-182.77*
	Fe	-221.06*	-176.6*	-187.91*	-194.57*	-281.95*	-367.76*	-226.9*
	Co	-102.56*	-59.93*	-96.48*	-120.16*	-142.35*	-138.1*	-105.85*
	Ni	-541.51*	-368.00*	-412.05*	-435.86*	-492.33*	-338.71*	-422.54*
	Zn	-187.36*	-148.56*	-185.11*	-197.34*	-245.08*	-127.27*	-176.86*
	As	42.6**	45.05**	53.03**	58.7**	38.97**	-15.76*	43.48**
	Se	98.5**	98.48**	98.48**	98.67**	98.64**	98.73**	98.59**
	Al	-2497.21*	-2610.15*	-2608.41*	-2235*	-2668.16*	-2465.5*	-2505.82*

*GS: Geogenic source

**AM: Anthropogenic magnitude

Figure 3 The QoC index variations for the studied heavy metals in all sites. Negative values explain the geogenic source (at the bottom of the horizontal axis of the chart), while the positive values (at the top of the horizontal axis of the chart) explain the anthropogenic source of pollution.

Additionally, the QoC values of As indicated mixed source-anthropogenic and geogenic sources (Figure 3). Figure 3 includes the QoC values of As showing that the values at all sites except site 6 are positive (reflecting an anthropogenic source) and are located at the top of the horizontal axis of the chart (with 39.74 %, 42.31 %, 50.69 %, 56.64 % and 35.92 % magnitude at sites 1, 2, 3, 4 and 5, respectively). These results could be due to human activities in the area, such as the use of fertilizer and pesticides contaminating agricultural wastewater, use of water for domestic purposes, and urban water use. Therefore, sediment contamination with As and Se from the above-listed sources and other geogenic and anthropogenic sources is a serious problem in the study area.

CONCLUSION

A variety of suitable methods, tools, guidelines, and indices were used to assess sediment contamination and ecological risk index in the Mohammad Abad River, Iran. The average concentration of heavy metals in surface sediments of the Mohammad Abad River declined according to this sequence: Fe>Al>Mg>Mn>Se>Cr>Zn>Ni>Co>Ag. A comparison of contaminant levels of all of these sites with Sediment Quality Guidelines (SQGs) proposed that most of the heavy metals studied had no association with deleterious biological responses, except for possible association of Se and As with harmful effects. The results of the contamination factors index (C_f^i) demonstrated that all sites could be considered as low levels of pollution for Cr, Mn, Fe, Co, Ni, Zn and Al, while the values of As and Se demonstrated to have moderate and very high levels of contamination based on C_f^i values, respectively. Similar results were also found for the analysis of the potential contamination index (C_p), where the values of all trace metals, except As and Se, demonstrated low contamination levels and the values of As and Se had moderate and severe or very severe contamination levels, respectively.

According to the results of the Cd and mCd indices a very

high degree of contamination of heavy metals in surface sediments of study area was calculated. The quantification of contamination results demonstrated that the values of Cr, Mn, Fe, Ni, Zn and Al were derived a geogenic source with no evidence of anthropogenic activities, while the values of Se and As were demonstrated to have an anthropogenic source. In general, the results showed that if the degree of contamination for each element is considered individually, the river could be a "reference river" in terms of elements pollution (excluding arsenic and selenium). But if the degree of contamination is considered on the basis of all elements (degree of contamination of all studied elements), the studied river cannot be considered as a «reference river» for ecotoxicology studies. Finally, it should be noted that this conclusion is not conclusive and needs further research.

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