IJST (2014) 38A1: 75-85
Iranian Journal of Science & Technology

http://ijsts.shirazu.ac.ir

Assessment of trace elements contamination in surface sediments of the Bakhtegan lake, Iran

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Abstract

Concentrations of elements (As, Co, Cu, Ni, Mo, Pb, V, Cd, Cr and Zn) are studied in the surface sediments of Bakhtegan Lake, northwest of Nyriz City, Iran, to assess metal contamination. The average abundance order of trace elements content in Bakhtegan Lake sediments is Cr>Ni> V> Zn> Cu> Co> As> Pb> Mo>Cd. The comparison of trace elements concentration in Bakhtegan Lake sediments with toxicological reference values, reveal that the average concentration of As, Cr and Ni in the present sediments is higher than threshold effective level (TEL). Ni shows higher concentration than toxic effect threshold (TET) and probable effective level (PEL) values. The results of contamination factor (CF) based on background value reveal that Cr, Cu, Zn, V, Co, Pb, Mo, As and Ni have moderate and Cd has considerable contamination factor. The application of modified degree of contamination values (mC_d) based on background and mean shale values indicate low and very low degree of contamination in sediment samples, respectively. The calculated EF values indicate that Cd in Bakhtegan Lake sediments is enriched compared to the background value. The strong association of Cr, Ni, Zn, Co, Cu, Pb, and V in sediments and high loading of these trace elements with clay, Mn and Fe (PC1) agree with the measured correlation coefficients indicating that Mn and Fe hydroxides and clay content play a significant role in the distribution and sorption of trace elements in sediments. The results of PCA for As and Cd indicate that these elements are influenced by anthropogenic activities.

Keywords: Sediment; contamination; Factor analysis; toxicological reference; Bakhtegan Lake; Iran

1. Introduction

Studies on heavy metal and trace elements pollution, especially in aquatic environments have increased over the last few decades. Trace elements added to an aquatic system by anthropogenic and natural sources are distributed during their transport between different compartments of aquatic ecosystems, such as water, sediment and biota (Moore and Ramamoorthy, 1984; Celo et al., 1999). Bottom sediments are long-term integrators of geochemical processes; hence, information from sediments can establish the long-term behaviour of trace elements in aquatic systems (Scott and Wright, 1988). In these sediments, the distribution of trace elements is affected by mineralogical and chemical composition of suspended material, anthropogenic influences, and in situ processes such as deposition, sorption, and enrichment in organism (Jain et al., 2005). Trace elements are either associated with organic matter present in the thin fraction of the sediments, or adsorbed on Fe/Mn hydrous oxides, or precipitated as hydroxide, sulphides and carbonates (Singh et al., 2005a). Sediments play a significant role in the remobilization of contaminants in aquatic systems under favorable conditions and in interactions between water and sediment. Natural and anthropogenic activities have the capacity to cause changes in environmental conditions, such as acidification, redox potential, or organic ligand concentrations, which can remobilize contaminated sediments releasing the elements from sediments to the water column and cause contamination of surrounding waters (Carman et al., 2007; Massolo et al, 2012). Benthic organisms can take up directly from the sediments, which in turn enhance the potential of some metals entering into the food chain (Adamo et al., 2005; Chen et al., 2007). Methods used to evaluate the ecological risk posed by heavy metals and trace elements in sediments include, enrichment factor (EF), geoaccumulation index (I_{geo}), contamination factor (C_f) and modified degree of contamination (mC_d) of sampling sites. SQGs have been used to provide interpretive tools

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Received: 24 April 2012 / Accepted: 25 February 2014

for assessing the biological significance of individual chemicals (Mucha et al., 2003). In sediment quality guidelines, two sets of guidelines are commonly used, the effects range low/median (ERL/ERM) and threshold/probable effect level (TEL/PEL). The main objectives of the present study are (1) Determination of the distribution and total concentrations of trace elements (Cd, Cu, Cr, Zn, Ni, Mo, Pb, V, As and Co) in Bakhtegan Lake sediments. (2) Evaluating contamination and toxicological factor in the lake sediments; and (3) Identifying the anthropogenic or natural sources of elements.

2. Material and methods

2.1. Study area

Bakhtegan Lake is located 15km northwest of Neyriz City, Fars province, and south of Iran (Fig. 1). Bakhtegan Lake with a curvature shape surrounds Pichegan Mountains with trend of NW-SE. The northwest part of this lake is named Tashk (Fig. 1). The connection point of these 2 lakes and southern arms is dry in hot season. Intensive evaporation, especially in drought causes to wide zones of salty sand in the borders and northern arm of this lake to be extended. Bakhtegan Lake receives its water mainly from the Kor River, which enters at the west, and Sahlabad Spring on the south shore. The Kor river plays a key role in supplying water for municipal and industrial users, and for irrigation (Shykhi and Moore, 2011). In the last few decades rapid industrialization and urbanization along the Kor river course has increased the pollution load of the river water and Bakhtegan Lake (Shykhi and Moore, 2011). Rock association around Bakhtegan Lake at the surface is limestone, dolomite, shale, marl, radiolarites and to some extent ophiolitic rocks (Fig. 2).

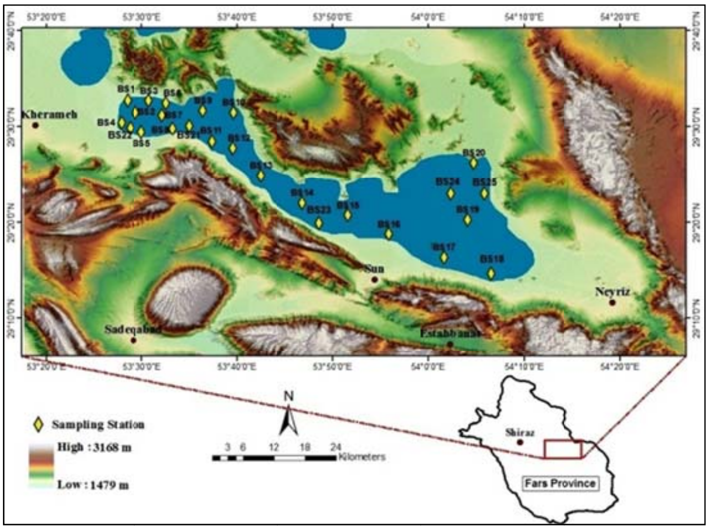

Fig. 1. Map of Bakhtegan Lake and the location of sampling sites

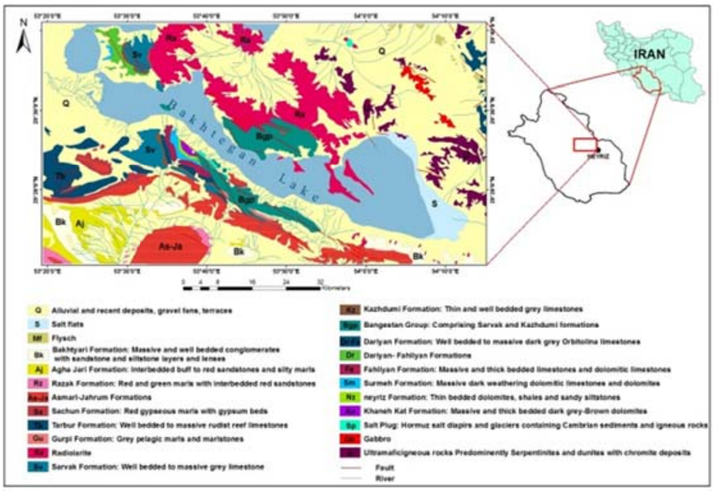

Fig. 2. Geological map of the study area

2.2. Sampling

Twenty-five samples were collected from the upper 15cm of the Bakhtegan Lake bottom sediments (Table 1). In order to take a representative sample, composite samples were prepared by mixing of four samples taken at the corners of a square with sides of 2 meters. The samples were mixed and a final sample with a weight of 1 kg was obtained by repeated coning and quartering.

In this study, deep sediment samples were analyzed in order to find the best local background composition (Wu et al., 2007; Fukue et al., 2006). For this purpose, six deep sediment samples (2 meter deep) were collected from the Bakhtegan Lake (BS2, BS12 BS14, BS15, BS17and BS24 stations). In choosing deep sampling points, care was taken to choose areas least disturbed by anthropogenic interferences such as rural settlements or agricultural activities. The deep samples were mixed to obtain a composite sample representing background concentration. The samples were collected in self-locking polythene bags and were sealed in double bags. Fig. 1 shows the location of the sampling points.

2.3. Analytical methods

In the laboratory, after air-drying the sediment samples at room temperature, the samples were passed through a 2mm nylon sieve. The <2mm fraction was ground in an agate mortar and pestle and passed through a 63 micron sieve to obtain the silt and clay fractions. Selected physico-chemical properties (pH, OC and texture) of sampled sediments were measured using standard analytical methods. Organic carbon content was determined using Gaudette et al (1974) titration method.

Sediment pH was measured in a suspension of 1:2 sediment/water ratios using a calibrated ELE pH meter. Textural analysis of sediment samples was carried out by international pipette method (Friedman and Johnson, 1982). In order to determine the concentration of trace elements, complete dissolution of sediment samples was carried out using a mixture of $HF/HNO_3/HClO_4/H_2O_2$ on sand bath at atmospheric pressure. The concentrations of the constituent elements were measured at Zar Azma Laboratory (Iran) using ICP-OES methods. All statistical evaluations were carried out using SPSS (version 16) for windows.

3. Results and discussion

3.1. Physico-chemical characteristics and trace elements concentration

Total concentrations of selected elements along with some statistical descriptions and physico-chemical characteristics of sediment samples are summarized in Table 1. Average composition of the background sample, along with mean shale contents are given for comparison.

Sediment texture is presented in Fig. 3. The major textural classes observed are loam, sandy clay loam, clayey loam, and clay. The cluster of points show that sediment texture spreads out from a sandy end-member to silty with an average ratio of sand over silt and clay being 1.39 and 1.44, respectively. Average organic carbon (OC) content in sediment samples is 1.7%. Maximum and minimum OC are 10.8 and 0.27% respectively. Sediment pH varies between 7.40 and 8.70. Average pH in lake sediments is (7.67). The lowest mean concentration in Bakhtegan Lake sediments is shown by Cd (0.52mg/kg) and Mo (1.55mg/kg). Cr holds the highest mean concentration in sediment samples (74.95mg/kg). The average abundance order of trace elements contents in Bakhtegan Lake sediments is Cr>Ni> V> Zn> Cu> Co> As> Pb> Mo>Cd. Comparison of mean concentration of the trace elements in sediment samples with the mean shale values (Turekian and Wedepohl, 1961) reveals that As and Ni concentrations are higher than the mean shale contents (Fig. 4).

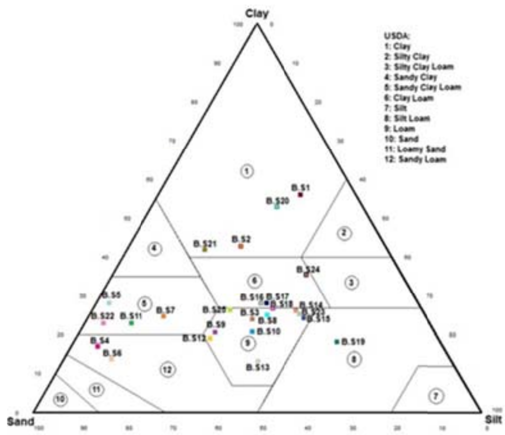

Fig. 3. Ternary diagram showing sediment texture: each point represents a sample

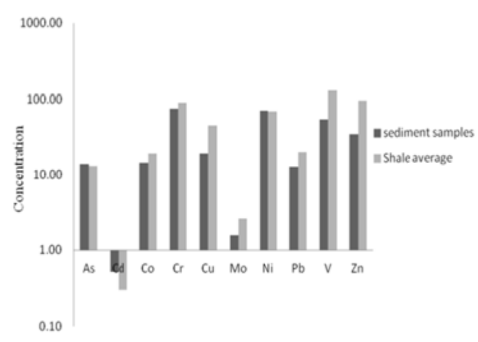

Fig. 4. Comparison of mean trace elements values in sediment samples with mean shale values (mg/kg; logarithmic scale)

Table 1. Total concentration and descriptive statistics of selected trace elements (mg/kg) along with some physico-chemical properties of sediment samples

Samples	As	Cd	Co	Cr	Cu	Fe	Mn	Mo	Ni	Pb	V	Zn	pH	OC	Sand	Clay	Silt
Detection limit(ppm)	0.5	0.1	1	1	1	100	5	0.5	1	1	1	1					
B.S1	13.9	0.53	20	160	34	185526	466	1.48	144	16	87	67	7.4	1.21	12	56	32
B.S2	14.1	0.52	16	97	21	102284	314	1.51	92	13	56	40	7.7	1.31	32	43	25
B.S3	13.5	0.51	15	98	19	88845	219	2.33	86	12	54	35	7.4	2.01	39	24	37
B.S4	13.4	0.52	12	39	13	25015	85	1.48	48	12	33	23	7.5	1.46	77	17	6
B.S5	13.9	0.53	12	35	12	19236	101	1.48	45	12	28	17	8.4	0.76	69	28	3
B.S6	13.3	0.52	13	40	12	25759	149	1.47	48	12	34	18	8.2	0.84	76	14	10
B.S7	13.7	0.52	12	49	13	32845	119	1.47	53	12	35	20	8	1	59	24	17
B.S8	13.3	0.54	14	63	18	71228	273	1.63	61	13	54	33	7.8	0.72	35	25	40
B.S9	13	0.53	13	50	18	50699	238	1.49	53	12	44	33	7.5	0.98	49	21	30
B.S10	13.4	0.51	14	75	23	92069	389	1.72	72	13	53	48	7.7	10.8	41	21	38
B.S11	13.6	0.52	14	61	17	57621	323	1.37	61	12	44	29	7.7	1.21	67	23	10
B.S12	13.9	0.53	14	60	16	69843	347	1.45	61	13	48	31	7.4	1.46	51	19	30
B.S13	13.5	0.52	13	59	19	66775	310	1.93	55	13	43	36	8.7	0.27	43	13	44
B.S14	13.9	0.52	15	71	17	69724	292	1.68	67	13	80	30	7.4	2.28	28	26	46
B.S15	13.8	0.52	16	106	21	94888	261	1.72	81	13	69	36	7.4	2.11	27	25	48
B.S16	13.2	0.52	14	80	19	91728	297	1.42	72	13	60	34	7.5	2.01	35	28	37
B.S17	13.6	0.52	13	59	16	65105	260	1.33	58	12	46	27	7.5	2.07	34	28	38
B.S18	14	0.53	16	94	22	111666	402	1.35	79	12	68	40	7.4	1.23	33	27	40
B.S19	14.4	0.52	14	72	20	102840	342	1.51	67	12	54	36	7.6	0.6	23	18	59
B.S20	14.7	0.51	16	98	23	121317	375	1.4	77	13	66	42	7.5	1.03	19	53	28
B.S21	14	0.53	18	128.5	27.5	143905	390	1.545	118	14.5	71.5	53.5	7.6	1.26	22	50	28.5
B.S22	13.65	0.53	12	38	12.5	22125.5	93	1.48	46.5	12	30.5	20	8	1.11	84	12	4
B.S23	14.85	0.52	15.5	88.5	19	82306	276.5	1.6	74	13	75.5	33	7.4	2.2	27.5	26	47
B.S24	14.55	0.52	15	80	21.5	112078.5	358.5	1.455	72	12.5	60	39	7.6	0.82	20	52	28
B.S25	14.11	0.52	14.30	72.80	18.55	77250.65	278.10	1.57	69.00	12.65	42.55	33.75	7.69	1.77	33	49	18
Maximum	14.85	0.54	20.00	160.00	34.00	185526.00	466.00	2.33	144.00	16.00	87.00	67.00	8.70	10.83	84	56	59
Minimum	13.00	0.51	12.00	35.00	12.00	19236.00	85.00	1.33	45.00	12.00	28.00	17.00	7.40	0.27	12	12	3
Average	13.81	0.52	14.43	74.95	18.88	79307.15	278.32	1.55	70.38	12.71	53.44	34.17	7.67	1.70	41.42	29	29.7
Background	8.45	0.16	10	34	8	53604	223	1.28	34	9	26	15					
Shale average[a]	13	0.3	19	90	45	47200	850	2.6	68	20	130	95					

[a]Shale average (Turekian and Wedepohl, 1961)

3.2. Statistical analysis

Pearson's correlation coefficients are calculated to determine relationships among different metals. Correlations among various metal contents, OC and clay in Bakhtegan Lake sediments are calculated and presented in Table 2. Significant positive correlations among various metals in sediments are evident. Cr, Pb, Ni, Co, Zn, V and Cu are significantly correlated ($0.72<r<0.99$). These elements are strongly and significantly correlated with total Mn and Fe contents in sediments. Arsenic displays moderate correlation with V(r =0.44), Co(r=0.44) and Fe(r=0.43). A significant and moderate correlation also exists between Cr, Co, Ni, Cu, Zn, Pb, V, As and clay content ($0.53<r<0.71$) in sediments and silt with Cr, Cu, V and Zn ($0.44<r<0.65$), probably reflecting clay minerals and silt content potential for adsorbing trace elements. OC indicates weak correlation with Zn, Mo and Mn. Principal component analysis (PCA) is the most common multivariate statistical method used in environmental studies (Loska and Wiechuya, 2003; Shakeri and Moore, 2010; Yinxian et al., 2011)The most common PCA type producing more interpretable components is the varimax rotation, which is applied in the current study. The number of significant principal components is selected based on the Kaiser criterion with eigenvalue higher than 1 (Kaiser, 1960). In the present study, estimates are obtained for the initial factors from principal component analysis (PCA). The results of factor analysis for selected elements along with Mn, Fe, clay, silt, pH, EC and OC data at Bakhtegan Lake sediments are tabulated in Table 3. Table 3 represents four factors that are retained in the analysis and account for 81.16% of variance in sediments. The first component, explaining 51.64% of the total variance, was strong loading related to Ni, Cr, Co, clay, Cu, Zn, Fe, Pb, V and Mn. The second component, explaining 11.71% of the total variance, showed high positive loading on As and moderate positive loading for clay. The third component, which described 9.66 % of the variance, has a high factor loading for Mo and OC. The strong and good association of elements such as Cr, Ni, Fe, Zn, Co, Cu, Pb, V and Mn in sediments suggests a common source. Also, high loading of these trace elements with clay, Mn and Fe agrees with the measured correlation coefficients, indicating that Mn and Fe hydroxides and clay content play a significant role in the distribution and sorption of trace elements in sediments. The results of PCA for As and Cd in sediments samples indicate that these elements are influenced by anthropogenic activities. High and moderate positive loading of As and clay reveals that sediment texture plays a significant role in the distribution and sorption of this trace element in the Bakhtegan lake sediments. High loading of Mo with OC shows that organic carbon controls the distribution of Mo for a small number of sediment samples. Also, the results of factor analysis indicate Cd behaves differently in sediment samples.

Table 2. Pearson correlation among selected physic-chemical properties and elements in sediments of the study area

	As	Cd	Co	Cr	Cu	Fe	Mn	Mo	Ni	Pb	V	Zn	pH	OC	Sand	Clay	Silt
As	1	-0.19	0.42*	0.38	0.31	0.43*	0.36	-0.17	0.30	0.19	0.44*	0.25	-0.25	-0.16	-0.51**	0.53**	0.21
Cd	-0.19		0.04	-0.03	-0.03	-0.05	-0.04	-0.32	0.03	0.20	-0.06	-0.01	0.10	-0.43	0.122	-0.04	-0.13
Co	0.33	0.04		0.97**	0.92**	0.93**	0.77**	0.11	0.96**	0.81**	0.88**	0.88**	-0.52	0.02	-0.76**	0.71**	0.39
Cr	0.22	-0.03	0.97**		0.94**	0.94**	0.74**	0.22	0.98**	0.80**	0.86**	0.90**	-0.51	0.08	-0.79**	0.70**	0.44*
Cu	0.21	-0.03	0.92**	0.94**		0.97**	0.85**	0.13	0.93**	0.82**	0.80**	0.99**	-0.42	0.18	-0.80**	0.68**	0.46*
Fe	0.28	-0.05	0.93**	0.94**	0.97**		0.88**	0.10	0.92**	0.76**	0.84**	0.95**	-0.50	0.09	-0.87**	0.72**	0.52**
Mn	0.36	-0.04	0.77**	0.74**	0.85**	0.88**		-0.02	0.70**	0.62**	0.75**	0.86**	-0.42	0.22	-0.79**	0.54**	0.57**
Mo	-0.16	-0.32	0.11	0.22	0.13	0.10	-0.02		0.18	0.10	0.15	0.17	0.09	0.20	-0.11	-0.20	0.33
Ni	0.12	0.03	0.96**	0.98**	0.93**	0.92**	0.70**	0.18		0.85**	0.79**	0.90**	-0.46	0.07	-0.70**	0.70**	0.317
Pb	0.13	0.20	0.81**	0.80**	0.82**	0.76**	0.62**	0.10	0.85**		0.72**	0.82**	-0.23	0.09	-0.58**	0.60**	0.248
V	0.54**	-0.06	0.88**	0.86**	0.80**	0.84**	0.75**	0.15	0.79**	0.72**		0.76**	-0.62	0.11	-0.84**	0.53**	0.65**
Zn	0.16	-0.01	0.88**	0.91**	0.99**	0.95**	0.86**	0.17	0.90**	0.82**	0.76**		-0.41	0.25	-0.76**	0.64**	0.45*
pH	-0.32	0.10	-0.52***	-0.51	-0.42	-0.50	-0.42	0.09	-0.46	-0.23	-0.62	-0.41		-0.16	0.50*	-0.33	-0.4
OC	0.18	-0.43	0.02	0.08	0.18	0.09	0.22	0.20	0.07	0.09	0.11	0.25	-0.16		-0.07	-0.10	0.175
Sand	-0.51**	0.122	-0.76**	-0.79**	-0.80**	-0.87**	-0.79**	-0.11	-0.70**	-0.58**	-0.84**	-0.76**	0.50*	-0.07		-0.66**	-0.75**
Clay	0.53**	-0.04	0.71**	0.70**	0.68**	0.72**	0.54**	-0.20	0.70**	0.60**	0.53**	0.64**	-0.33	-0.10	-0.66**		-0.01
Silt	0.21	-0.13	0.39	0.44*	0.46*	0.52**	0.57**	0.33	0.317	0.248	0.65**	0.45*	-0.4	0.175	-0.75**	-0.01	

*Correlation is significant at the 0.05 level (2-tailed)
**Correlation is significant at the 0.01 level (2-tailed)

Table 3. Principal component analysis for experimented variables in sediment samples

Rotated Component Matrix				
	PC1	**PC2**	**PC3**	**PC4**
Ni	0.96	0.03	0.02	-0.04
Co	0.96	0.17	-0.04	-0.08
Cu	0.95	0.09	0.12	0.16
Cr	0.95	0.15	0.08	-0.07
Zn	0.94	0.04	0.16	0.19
Fe	0.94	0.21	0.05	0.10
Pb	0.89	-0.17	-0.05	0.12
V	0.84	0.27	0.19	-0.20
Mn	0.80	0.25	0.18	0.21
Clay	0.70	0.41	-0.14	-0.15
Mo	0.03	-0.10	0.70	0.13
OC	0.10	-0.09	0.67	-0.15
Cd	0.14	-0.37	-0.71	0.17
Silt	0.41	0.23	0.36	0.17
As	0.27	0.86	-0.14	-0.08
pH	-0.46	-0.36	-0.05	0.67
% of Variance	51.64	11.71	9.69	8.13
Cumulative %	51.64	63.34	73.03	81.16
Extraction Method: Principal Component Analysis				
Rotation Method: Varimax with Kaiser Normalization				

3.3. Quantification of sediment pollution

In order to evaluate natural or anthropogenic sources of trace element content in sediments, an enrichment factor is calculated for sediment samples by using Fe as a reference element. A reference element is often a conservative one, such as the most commonly used elements Al, Fe, Sc, Ti, etc. (Reimann and de Caritat, 2002; Bergamaschi et al., 2002; Hernandez et al., 2003; Mishra et al., 2004; Abrahim and Parker, 2008; Kabata-Pendias and Mukherjee, 2007). As a comparison, the reference values were adopted from the background concentrations of trace elements in the study area as shown by the following equation.

$$EF = ([M]/[Fe])_{sediment} / ([M]/[Fe]_{background}$$

Where [M] = total trace element concentration measured in sediment sample (mg/kg) and [Fe] = total concentration of Fe (mg/kg). According to Hernandez et al (Hernandez et al., 2003) EF values ranging between 0.5 and 2 can be considered in the range of natural variability, whereas ratios greater than 2 indicate some enrichment corresponding mainly to anthropogenic inputs. EF can also assist in determining the degree of metal contamination. Five categories are recognized based on enrichment factor (Sutherland, 2000) (Table 4). The results of these calculations for Bakhtegan Lake sediments are summarized in Table 5. The calculated EF values indicate that Cd in Bakhtegan Lake sediments is enriched while average EF for other selected elements are <2. Maximum EF values for Cd, As and Cu in sediment samples are 9.23, 4.58 and 4.18 (B.S5) respectively (Table 5). Cd with average EF between 2 to 5 show moderate contamination for sediments.

Table 4. Classification of enrichment factor (Sutherland, 2000)

EF<2	Deficiency to minimal enrichment
EF=2-5	Moderate enrichment
EF=5-20	Significant enrichment
EF=20-40	Very high enrichment
EF>40	Extremely high enrichment

Table 5. Enrichment factors for trace elements in the sediment samples

Enrichment Factor (Background)										
Samples	**As**	**Cd**	**Co**	**Cr**	**Cu**	**Mo**	**Ni**	**Pb**	**V**	**Zn**
B.S1	0.48	0.96	0.58	1.36	1.23	0.33	1.22	0.51	0.97	1.29
B.S2	0.86	1.70	0.84	1.50	1.38	0.62	1.42	0.76	1.13	1.40
B.S3	0.96	1.92	0.91	1.74	1.43	1.10	1.53	0.80	1.25	1.41
B.S4	3.40	6.96	2.57	2.46	3.48	2.48	3.03	2.86	2.72	3.29
B.S5	4.58	9.23	3.34	2.87	4.18	3.22	3.69	3.72	3.00	3.16
B.S6	3.28	6.76	2.71	2.45	3.12	2.39	2.94	2.77	2.72	2.50
B.S7	2.65	5.30	1.96	2.35	2.65	1.87	2.54	2.18	2.20	2.18
B.S8	1.18	2.54	1.05	1.39	1.69	0.96	1.35	1.09	1.56	1.66
B.S9	1.63	3.50	1.37	1.55	2.38	1.23	1.65	1.41	1.79	2.33
B.S10	0.92	1.86	0.82	1.28	1.67	0.78	1.23	0.84	1.19	1.86
B.S11	1.50	3.02	1.30	1.67	1.98	1.00	1.67	1.24	1.57	1.80
B.S12	1.26	2.54	1.07	1.35	1.53	0.87	1.38	1.11	1.42	1.59
B.S13	1.28	2.61	1.04	1.39	1.91	1.21	1.30	1.16	1.33	1.93
B.S14	1.26	2.50	1.15	1.61	1.63	1.01	1.51	1.11	2.37	1.54
B.S15	0.92	1.84	0.90	1.76	1.48	0.76	1.35	0.82	1.50	1.36
B.S16	0.91	1.90	0.82	1.38	1.39	0.65	1.24	0.84	1.35	1.32
B.S17	1.33	2.68	1.07	1.43	1.65	0.86	1.40	1.10	1.46	1.48
B.S18	0.80	1.59	0.77	1.33	1.32	0.51	1.12	0.64	1.26	1.28
B.S19	0.89	1.69	0.73	1.10	1.30	0.61	1.03	0.69	1.08	1.25
B.S20	0.77	1.41	0.71	1.27	1.27	0.48	1.00	0.64	1.12	1.24
B.S21	0.62	1.23	0.67	1.41	1.28	0.45	1.29	0.60	1.02	1.33
B.S22	3.91	8.03	2.91	2.71	3.79	2.80	3.31	3.23	2.84	3.23
B.S23	1.14	2.12	1.01	1.70	1.55	0.81	1.42	0.94	1.89	1.43
B.S24	0.82	1.55	0.72	1.13	1.29	0.54	1.01	0.66	1.10	1.24
B.S25	1.16	2.26	0.99	1.49	1.61	0.85	1.41	0.98	1.14	1.56
Maximum	4.58	9.23	3.34	2.87	4.18	3.22	3.69	3.72	3.00	3.29
Minimum	0.48	0.96	0.58	1.10	1.23	0.33	1.00	0.51	0.97	1.24
Average	1.54	3.11	1.28	1.67	1.93	1.14	1.68	1.31	1.64	1.79

The assessment of sediments contamination is carried out using the contamination factor and degree of contamination. Hakanson (1980) proposed an overall indicator of contamination based on integrating data for a series of seven specific heavy metals and the organic pollutant polychlorinated biphenyl. This method is based on the calculation for each pollutant of a contamination factor (Cf). The C^i_f is the ratio obtained by dividing the mean concentration of each metal in the sediments (C^i_{o-1}) by the baseline or background value (Liu et al., 2005b):

$$C^i_f = C^i_{o-1} / C^i_n$$

C^i_f is defined according to four categories as Table 6 (Liu et al., 2005b). Abrahim (2005) presented a modified and generalized form of the Hakanson [27] equation for the calculation of the overall degree of contamination as:

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

Where n= number of analysed elements and i = ith element (or pollutant) and C_f = Contamination factor. For the classification and description of the modified degree of contamination (mC_d) in sediments, Table 7 gradations are proposed by Abrahim and Parker (2008) In this study, a simplified approach to risk assessment based on comparing the measured level of contamination in the Bahktegan Lake sediments with background and mean shale values (Tables 8 and 9) was adopted. Comparison of the results with threshold of metal in natural background sediment and mean shale values reveal some degree of trace elements contamination. The average contamination factor base of background in sediment samples for Cr, Cu, Zn, V, Co, Pb, Mo, As and Ni is moderate. The CF for Cd is considerable. The results of average CF with mean shale values for Bakhtegan Lake sediments reveal that Cr, Cu, Zn, Co, Pb, Mo and V have low contamination factor. Arsenic, Cd and Ni indicate moderate contamination factor. The highest CF is observed for Ni which is moderate (2.12) in sediments. Revised Hakanson equation is used to calculate the modified degree of contamination (mC_d) for the ten analysed elements (Tables 8 and 9). The average mC_d values base of background and mean shale values (1.99- 0.79) indicate low and very low degree of contamination in sediment samples, respectively.

Table 6. Gradations of contamination factor

$C^i_f < 1$	Low contamination factor
$1 < C^i_f < 3$	Moderate contamination factor
$3 < C^i_f < 6$	Considerable contamination factor
$C^i_f > 6$	Very high contamination factor

Table 7. Gradations of modified degree of contamination

$mC_d < 1.5$	Nil to very low degree of contamination
$1.5 \le mC_d < 2$	Low degree of contamination
$2 \le mC_d < 4$	Moderate degree of contamination
$4 \le mC_d < 8$	High degree of contamination
$8 \le mC_d < 16$	Very high degree of contamination
$16 \le mC_d < 32$	Extremely high degree of contamination
$mC_d \ge 32$	Ultra high degree of contamination

In order to predict the trace elements pollution in Bakhtegan Lake sediments, comparative study was made with toxicological reference values (Toxic Effect Threshold (TET) (EC, 1992), Probable Effective Level (PEL) (Smith, 1996) and Threshold Effective Level (TEL) (Smith, 1996). Comparative results are presented in Table 10. It is evident that the average concentration of As, Cr and Ni in the present sediments is higher than TEL. The average of Ni concentration is higher than PEL and TET values. In addition, Cr in 28 and 12% of sediment samples has higher concentration than PEL and TET values, respectively.

4. Conclusion

The comparison of trace elements concentration in Bakhtegan Lake sediments with toxicological reference values, reveals that the average concentration of As, Cr and Ni in the present sediments is higher than TEL. In addition, Ni and Cr (some samples) indicate higher concentration than TET and PEL values. The impact of anthropogenic trace element pollution on Bakhtegan Lake sediments was evaluated using enrichment factor (EF), contamination factor and modified degrees of contamination (mCd) for selected elements in fine fraction sediments. The calculated EF values indicate that Cd in Bakhtegan Lake sediments is enriched compared to the background value.The average contamination factor (CF) based on background in surface sediments for Cr, Cu, Zn, V, Co, Pb, Mo, As and Ni is moderate. The CF for Cd is considerable. The results of average CF with mean shale values reveal moderate contamination factors for As, Cd and Ni. The average mC_d values based on background and mean shale values indicate low and very low degree of contamination in sediment samples, respectively. The application of multivariate statistical techniques combined with correlation analysis and element concentration analysis has been proved to be an effective tool for source identification of trace elements in Bakhtegan Lake sediments. The strong association of Cr, Ni, Zn, Co, Cu, Pb, and V in sediments and high loading of these elements with clay, Mn and Fe (PC1) agrees with the measured correlation coefficients, indicating that Mn and Fe hydroxides and clay content play a significant role in the distribution and sorption of these trace elements in sediments. The results of PCA for As and Cd indicate that these elements are influenced by anthropogenic activities. High loading of Mo with OC shows that organic carbon controls the distribution of Mo for a small number of sediment samples. This study generally highlights that anthropogenic and geogenic pollutants have affected the freshly deposited sediments in Bakhtegan Lake, and that sediments surface accumulates trace elements. Thus, the concentration level of some trace elements found in the present sediments might create an adverse effect on the Bakhtegan Lake ecosystem. Also, according to the environmental quality criteria, the study area would require more monitoring of trace elements contamination in future.

Table 8. Contamination factors (C_f) and modified degree of contamination (mC_d) using background values for trace elements in fine fraction sediments from the study area

Contamination Factors(Background)												
Samples	**As**	**Cd**	**Co**	**Cr**	**Cu**	**Mo**	**Ni**	**Pb**	**V**	**Zn**	**Sum C_f**	**mC_d**
B.S1	1.64	3.31	2.00	4.71	4.25	1.16	4.24	1.78	3.35	4.47	30.90	3.09
B.S2	1.67	3.25	1.60	2.85	2.63	1.18	2.71	1.44	2.15	2.67	22.15	2.21
B.S3	1.60	3.19	1.50	2.88	2.38	1.82	2.53	1.33	2.08	2.33	21.64	2.16
B.S4	1.59	3.25	1.20	1.15	1.63	1.16	1.41	1.33	1.27	1.53	15.51	1.55
B.S5	1.64	3.31	1.20	1.03	1.50	1.16	1.32	1.33	1.08	1.13	14.71	1.47
B.S6	1.57	3.25	1.30	1.18	1.50	1.15	1.41	1.33	1.31	1.20	15.20	1.52
B.S7	1.62	3.25	1.20	1.44	1.63	1.15	1.56	1.33	1.35	1.33	15.86	1.59
B.S8	1.57	3.38	1.40	1.85	2.25	1.27	1.79	1.44	2.08	2.20	19.24	1.92
B.S9	1.54	3.31	1.30	1.47	2.25	1.16	1.56	1.33	1.69	2.20	17.82	1.78
B.S10	1.59	3.19	1.40	2.21	2.88	1.34	2.12	1.44	2.04	3.20	21.40	2.14
B.S11	1.61	3.25	1.40	1.79	2.13	1.07	1.79	1.33	1.69	1.93	18.00	1.80
B.S12	1.64	3.31	1.40	1.76	2.00	1.13	1.79	1.44	1.85	2.07	18.41	1.84
B.S13	1.60	3.25	1.30	1.74	2.38	1.51	1.62	1.44	1.65	2.40	18.88	1.89
B.S14	1.64	3.25	1.50	2.09	2.13	1.31	1.97	1.44	3.08	2.00	20.41	2.04
B.S15	1.63	3.25	1.60	3.12	2.63	1.34	2.38	1.44	2.65	2.40	22.45	2.25
B.S16	1.56	3.25	1.40	2.35	2.38	1.11	2.12	1.44	2.31	2.27	20.19	2.02
B.S17	1.61	3.25	1.30	1.74	2.00	1.04	1.71	1.33	1.77	1.80	17.54	1.75
B.S18	1.66	3.31	1.60	2.76	2.75	1.05	2.32	1.33	2.62	2.67	22.08	2.21
B.S19	1.70	3.25	1.40	2.12	2.50	1.18	1.97	1.33	2.08	2.40	19.93	1.99
B.S20	1.74	3.19	1.60	2.88	2.88	1.09	2.26	1.44	2.54	2.80	22.43	2.24
B.S21	1.66	3.31	1.80	3.78	3.44	1.21	3.47	1.61	2.75	3.57	26.59	2.66
B.S22	1.62	3.31	1.20	1.12	1.56	1.16	1.37	1.33	1.17	1.33	15.17	1.52
B.S23	1.76	3.25	1.55	2.60	2.38	1.25	2.18	1.44	2.90	2.20	21.51	2.15
B.S24	1.72	3.25	1.50	2.35	2.69	1.14	2.12	1.39	2.31	2.60	21.06	2.11
B.S25	1.67	3.25	1.43	2.14	2.32	1.22	2.03	1.41	1.64	2.25	19.35	1.94
Max	1.76	3.38	2.00	4.71	4.25	1.82	4.24	1.78	3.35	4.47	31.73	3.17
Min	1.54	3.19	1.20	1.03	1.50	1.04	1.32	1.33	1.08	1.13	14.36	1.44
Average	1.63	3.27	1.44	2.20	2.36	1.21	2.07	1.41	2.06	2.28	19.94	1.99

Table 9. Contamination factors (C_f) and modified degree of contamination (mC_d) using shale average values for trace elements in fine fraction sediments from the study area

Contamination Factors(Shale average)											
Samples	**As**	**Cd**	**Co**	**Cr**	**Cu**	**Mo**	**Ni**	**Pb**	**V**	**Zn**	**Sum C_f**	**mC_d**
B.S1	1.07	1.77	1.05	1.78	0.76	0.59	2.12	0.80	0.67	0.71	11.31	1.13
B.S2	1.08	1.73	0.84	1.08	0.47	0.60	1.35	0.65	0.43	0.42	8.66	0.87
B.S3	1.04	1.70	0.79	1.09	0.42	0.93	1.26	0.60	0.42	0.37	8.62	0.86
B.S4	1.03	1.73	0.63	0.43	0.29	0.59	0.71	0.60	0.25	0.24	6.51	0.65
B.S5	1.07	1.77	0.63	0.39	0.27	0.59	0.66	0.60	0.22	0.18	6.37	0.64
B.S6	1.02	1.73	0.68	0.44	0.27	0.59	0.71	0.60	0.26	0.19	6.50	0.65
B.S7	1.05	1.73	0.63	0.54	0.29	0.59	0.78	0.60	0.27	0.21	6.70	0.67
B.S8	1.02	1.80	0.74	0.70	0.40	0.65	0.90	0.65	0.42	0.35	7.62	0.76
B.S9	1.00	1.77	0.68	0.56	0.40	0.60	0.78	0.60	0.34	0.35	7.07	0.71
B.S10	1.03	1.70	0.74	0.83	0.51	0.69	1.06	0.65	0.41	0.51	8.12	0.81
B.S11	1.05	1.73	0.74	0.68	0.38	0.55	0.90	0.60	0.34	0.31	7.26	0.73
B.S12	1.07	1.77	0.74	0.67	0.36	0.58	0.90	0.65	0.37	0.33	7.42	0.74
B.S13	1.04	1.73	0.68	0.66	0.42	0.77	0.81	0.65	0.33	0.38	7.47	0.75
B.S14	1.07	1.73	0.79	0.79	0.38	0.67	0.99	0.65	0.62	0.32	8.00	0.8
B.S15	1.06	1.73	0.84	1.18	0.47	0.69	1.19	0.65	0.53	0.38	8.72	0.87
B.S16	1.02	1.73	0.74	0.89	0.42	0.57	1.06	0.65	0.46	0.36	7.89	0.79
B.S17	1.05	1.73	0.68	0.66	0.36	0.53	0.85	0.60	0.35	0.28	7.10	0.71
B.S18	1.08	1.77	0.84	1.04	0.49	0.54	1.16	0.60	0.52	0.42	8.46	0.85
B.S19	1.11	1.73	0.74	0.80	0.44	0.60	0.99	0.60	0.42	0.38	7.81	0.78
B.S20	1.13	1.70	0.84	1.09	0.51	0.56	1.13	0.65	0.51	0.44	8.57	0.86
B.S21	1.08	1.77	0.95	1.43	0.61	0.62	1.74	0.73	0.55	0.56	10.02	1
B.S22	1.05	1.77	0.63	0.42	0.28	0.59	0.68	0.60	0.23	0.21	6.47	0.65
B.S23	1.14	1.73	0.82	0.98	0.42	0.64	1.09	0.65	0.58	0.35	8.40	0.84
B.S24	1.12	1.73	0.79	0.89	0.48	0.58	1.06	0.63	0.46	0.41	8.15	0.81
B.S25	1.09	1.73	0.75	0.81	0.41	0.63	1.01	0.63	0.33	0.36	7.75	0.77
Max	1.14	1.80	1.05	1.78	0.76	0.93	2.12	0.80	0.67	0.71	11.75	1.18
Min	1.00	1.70	0.63	0.39	0.27	0.53	0.66	0.60	0.22	0.18	6.18	0.62
Average	1.06	1.74	0.76	0.83	0.42	0.62	1.04	0.64	0.41	0.36	7.88	0.79

Table 10. Comparison of trace elements concentration with toxicological reference values (TET, PEL and TEL) in sediment samples

Toxicological reference values							
	As	**Cd**	**Cr**	**Cu**	**Ni**	**Pb**	**Zn**
Bakhtegan sediments	13.81	0.52	74.95	18.88	70.38	12.71	34.17
PEL[1]	17	3.53	90	197	36	91.3	315
Bakhtegan sediments/PEL	0.81	0.15	0.83	0.10	1.96	0.14	0.11
TET[2]	17	3	100	86	61	170	540
Bakhtegan sediments/TET	0.81	0.17	0.75	0.22	1.15	0.07	0.06
TEL[3]	5.9	0.6	37.3	35.7	18	35	123
Bakhtegan sediments/TEL	2.34	0.87	2.01	0.53	3.91	0.36	0.28

1=Probable EffectiveLevel(Smith et al, 1996)

2=Toxic Effect Threshold(EC and MENVIQ, 1992)

3=Threshold Effective Level(Smith et al, 1996)

Acknowledgements

The authors would like to thank the research committee of Kharazmie University for financial support and providing the necessary equipment.

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