

Research Article

Study of Selected Metals Distribution, Source Apportionment, and Risk Assessment in Suburban Soil, Pakistan

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Composite soil samples collected from suburban areas were analyzed for Cd, Co, Cr, Cu, Fe, Mn, Pb, Sr, and Zn by atomic absorption spectrophotometry. Based on pseudototal metal analysis, Fe, Mn, Sr, and Zn were the prevailing metals while Cd, Co, Cr, and Pb were the least participants. However, based on bioavailability, Cd, Co, Pb, and Sr were easily leachable and might pose adverse effects to soil biota. In ecological risk assessment, contamination factor demonstrated moderate contamination by Co, Sr, and Zn and high contamination by Cd, Cu, and Pb; geoaccumulation index indicated heavy to extreme contamination by Cd and heavy contamination by Pb; enrichment factor revealed significant enrichment by Co, Cr, Cu, Mn, Sr, and Zn and extreme enrichment by Cd and Pb. Substantial human inputs for Cd, Co, Cr, Cu, Mn, Pb, Sr, and Zn were also revealed by principal component analysis in the examined soil. Overall the study area was found to be contaminated at considerable/high degree.

1. Introduction

Recently, there has been considerable concern pertaining to soil contamination due to rapid industrialization, urbanization, and intense human activities, particularly contamination by different heavy metals [1–4]. Metals are the most studied soil pollutants because of their ubiquity, toxicity, and persistence. Some metals are essential for the metabolism of living organisms at low concentrations but, above certain levels, they become toxic [5–7]. Major anthropogenic sources of the metals include mining, waste disposal, fertilizers, traffic emission (vehicle exhaust, tire wear, and brake lining wear), industrial effluents, domestic emissions, and atmospheric depositions [8–10]. Metals accumulation in soil is of great concern due to their potential ecological risks and damaging effects on soil ecosystems [1, 11]. Thus, it is necessary to quantify the extent of metals contamination and associated ecological risks of soil to potential receptors.

The pseudototal/total concentrations of metals in soil are useful indicators of contamination and ecological risk assessment [12, 13]. However, total contents do not provide enough information about potential mobility, bioavailability,

and toxicity of the metals [14, 15]. Recently, bioavailability of the metals in soil has become an important consideration for many researchers [14, 16, 17]. Several methods have been designed to simulate and quantify the metal reactivity as well as the physicochemical and biologically available pools of the metals in soil [17]. One of the most popular methods for estimating metal bioavailability is chemical extraction by means of various mild to strong extracting agents, resulting in operationally defined specific metal fractions [18]. The assumption in these chemical extraction approaches is that the extracted metals are mobile and easily available for plants and leaching to groundwater and/or could possibly be detrimental to soil biota [19]. Therefore, efforts should also be focused on measurement of bioavailable fractions of selected metals.

The present study aimed to (1) investigate concentrations of Cd, Co, Cr, Cu, Fe, Mn, Pb, Sr, and Zn in soil during summer and winter seasons, (2) determine their associated ecological risks, (3) identify pollution sources by principal component analysis, and (4) find out bioavailability of these metals to soil biota.

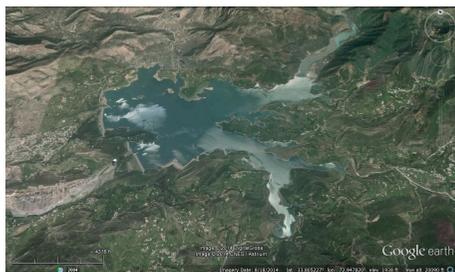


FIGURE 1: Locations map of the study area.

2. Materials and Methods

2.1. Site Description. In present study, soil samples were collected around Khanpur Lake ($72^{\circ}56' E$, $33^{\circ}48' N$) which is located on Haro River near the town of Khanpur, about 40 km northwest of Islamabad, Pakistan (Figure 1). It supplies drinking water to Islamabad and Rawalpindi and irrigation water to the surrounding agricultural areas. It was constructed in 1983 with the storage capacity of 140 million m^3 . Its average water depth is about 15 m. The gross storage of the reservoir is 0.132 km^3 with a total catchment area of 798 km^2 . The surface area of the reservoir varies from a maximum of 1806 ha to a minimum of 215 ha. The surrounding area of the lake is planted with flowering trees and set with gardens, picnic points, and isolated paths. The water stored in Khanpur Lake is fed by melting snow, seasonal rains, and the natural springs of Margalla Hills, Pakistan.

2.2. Sampling, Processing, and Chemical Analysis. A total of 80 composite surface (1–10 cm top layer) soil samples (each containing 5–10 subsamples) were collected from residential and picnic areas around the lake in summer (June 2012) and winter (January 2013) in precleaned zip-locked polythene bags using a plastic scoop. To determine pseudototal metal contents, the soil samples were oven dried, grounded, homogenized, sieved through a 2 mm plastic sieve to remove stones, gravels, and coarse particles, and then stored in zip-locked polythene bags before chemical analysis [6, 20].

To find out the pseudototal metal concentrations, the soil sample (1–2 g, dry weight) was digested using freshly prepared acid mixture of HNO_3 and HCl (3:1, v/v) in a microwave system [21]. Each digested sample was then filtered through fine filter paper ($0.45 \mu m$, pore size) and then diluted with 1% HNO_3 [22]. A reagent blank was also prepared having the same amount of acids without the sample with each batch.

A selective single step extraction procedure, using 0.1M $Ca(NO_3)_2$, was performed at room temperature to determine the bioavailable metal contents [16]. An aliquot of 5.0 g of air dried soil sample was added to 50 mL solution of 0.1M $Ca(NO_3)_2$ and the extraction was performed in precleaned glass vessel by shaking on an autosshaker @ 240 vibrations per minute for 16 h. A reagent blank was also prepared with the same amount of 0.1M $Ca(NO_3)_2$ solution without soil sample. Solid residue was separated from the extracts through filtration using fine filter papers [16, 23, 24]. The extractions were carried out in triplicate for each sample.

TABLE 1: Metal concentrations (mg/kg) and recoveries (%) in standard reference material (SRM-2711).

Metal	Certified concentration (mg/kg)	Measured concentration (mg/kg)	Recovery (%)
Cd	41.7	40.98	98
Co	10	9.7	97
Cr	47	47.56	101
Cu	114	112.3	99
Fe	28900	27601	96
Mn	638	642	101
Pb	1162	1180	102
Sr	245.3	241.7	99
Zn	350.4	341	97

The concentrations of Cd, Co, Cr, Cu, Fe, Mn, Pb, Sr, and Zn in $Ca(NO_3)_2$ and acid-extracts were measured using flame atomic absorption spectrophotometer (Shimadzu AA-670, Japan) under optimum analytical conditions. Selected metals concentrations were estimated by following calibration line method and dilutions were done duly whenever needed [20, 23].

2.3. Quality Control and Quality Assurance. Analytical grade chemicals were used throughout the study. All the reagents and calibration standards were prepared using deionized water. The preparation of calibration metal standards from stock solutions of 1000 mg/L was carried out by succeeding dilutions with deionized water. All glassware used was soaked overnight in HNO_3 solution (10%, v/v) and then rinsed thoroughly with several portions of distilled water prior to use [22]. The reagent blanks were prepared throughout chemical analysis and were used to correct the analytical results. Reproducibility of the results was also ensured following analysis sequence of calibration of standards and blind standard solution analysis as unknown (quality control solutions). Standard reference material (SRM 2711) was also analyzed as part of the quality assurance and quality control (QA/QC) procedure and good agreement was observed between the data got from present study and the certified values (Table 1). Some soil samples were also analyzed at an independent laboratory for cross comparison and a maximum of $\pm 2.5\%$ difference was observed in the two results. All the measurements were made in triplicate.

2.4. Statistical Analysis. The analyzed data were summarized using basic statistical parameters such as minimum, maximum, median, arithmetic mean, geometric mean, harmonic mean, skewness, and coefficients of variation. STATISTICA software was used for multivariate statistical analysis such as principal component analysis (PCA) of the obtained data [25]. PCA was applied both to discriminate between various geogenic inputs that cause variations in soil composition and to find out pollution sources affecting the metal levels of soil [20, 26–28]. It was employed to investigate the associations among selected metals and their grouping into

a small number of factors. After grouping, metals within each factor are highly associated among themselves than with metals in other factors. Varimax rotation was applied as it minimizes the number of variables with a high loading on each component and assists in the explication of results. PCA with Varimax rotation was performed on log-transformed data.

2.5. Ecological Risk Assessment. Contamination levels of Cd, Co, Cr, Cu, Fe, Mn, Pb, Sr, and Zn were assessed using contamination factor (CF) and degree of contamination (C_{deg}). The CF is calculated using the following equation as suggested by Hakanson [29]:

$$CF = \frac{C_n}{C_b}, \quad (1)$$

where C_n and C_b are the average concentrations of a metal in the studied and the preindustrial soil, respectively. The CF is the single-element index whereas C_{deg} is a multielement index which is computed by adding contamination factors of all metals studied as

$$C_{deg} = \sum_{i=1}^{i=n} CF. \quad (2)$$

In this study, mean concentrations of elements in continental earth's crust [30] were used as reference values as suggested by Loska et al. [31]. The results were interpreted as [29] $CF < 1$ = low contamination, $1 \leq CF < 3$ = moderate contamination, $3 \leq CF < 6$ = considerable contamination, $6 \leq CF$ = very high contamination, $C_{deg} < 8$ = low degree of contamination, $8 \leq C_{deg} < 16$ = moderate degree of contamination, $16 \leq C_{deg} < 32$ = considerable degree of contamination, and $32 \leq C_{deg}$ = very high degree of contamination.

The I_{geo} estimates contamination by comparing preindustrial and studied metal concentrations [32]. It is calculated using the following equation:

$$I_{geo} = \log_2 \left(\frac{C_n}{1.5B_n} \right), \quad (3)$$

where C_n is the mean content of element examined in soil and B_n is the geochemical background concentration in continental earth crust. The factor, 1.5, was established to reduce the outcome of promising changes in the background levels due to natural inputs. In this investigation, B_n designates concentration of metal in earth crust [30, 31]. According to Muller [32], the contamination levels can be categorized as $I_{geo} \leq 0$ = practically uncontaminated, $0 < I_{geo} < 1$ = uncontaminated to moderately contaminated, $1 < I_{geo} < 2$ = moderately contaminated, $2 < I_{geo} < 3$ = moderately to heavily contaminated, $3 < I_{geo} < 4$ = heavily contaminated, $4 < I_{geo} < 5$ = heavily to extremely contaminated, and $5 < I_{geo}$ = extremely contaminated.

Enrichment factor (EF) represents the extent to which metals are enriched or reduced comparative to a particular source and can be used to segregate between metals contributed by human intrusions and those from geogenic

provenance [33–35]. It is based on the normalization of a measured metal against a reference metal. Generally, Al, Ca, Fe, Mg, and Mn are used as the reference elements. In this study, EFs were computed using Fe as a reference metal using the following relationship:

$$EF = \frac{(C_x/C_{ref})_{Sample}}{(C_x/C_{ref})_{Crust}}, \quad (4)$$

where C_x is the average concentration of metal of interest and C_{ref} refers to mean concentration of reference element for normalization. EF values were interpreted as follows [36]: $EF < 2$ indicated minimal enrichment, $EF = 2-5$ showed moderate enrichment, $EF = 5-20$ exhibited significant enrichment, $EF = 20-40$ manifested very high enrichment, and $EF > 40$ reflected extremely high enrichment.

3. Results and Discussion

3.1. Soil Characteristics and Metals Distribution. Hydrogen ion concentration (pH) in the studied soil ranged 7.4–8.2 and 7.2–7.8 with average values of 7.8 and 7.6 in summer and winter, respectively. On the average basis, the levels of pH were observed slightly higher in summer than winter. Table 2 shows the statistical summary related to selected metals distribution based on pseudototal contents in surface soil in summer and winter. The results related to the distribution of the metals based on pseudototal contents in soil in summer and winter revealed that Fe (3993–5429 in summer and 2462–4171 mg/kg in winter), Mn (212–778 in summer and 179–561 mg/kg in winter), and Sr (47–1356 in summer and 62–739 mg/kg in winter) were the dominant contributors, while Cd (0.35–6.1 in summer and <0.01–5.2 mg/kg in winter) was the least participant in the studied soil in both seasons. On the arithmetic mean basis, the decreasing concentration order of the metals was $Fe > Sr > Mn > Zn > Pb > Cr > Cu > Co > Cd$ and $Fe > Mn > Sr > Zn > Co > Cu > Cr > Pb > Cd$ in summer and winter, successively. Total metal load of these selected metals varied as 4404–8376 mg/kg and 2784–5731 mg/kg with mean values of 6061 mg/kg and 4585 mg/kg in summer and winter, respectively. Moreover the average levels of these metals were also found to be higher in summer than winter ($P < 0.05$). Overall, Cd, Sr, and Pb showed relatively higher coefficients of variance (CV), demonstrating that these metals were highly influenced by anthropogenic activities in the study area.

In comparison with the results of urban soils in the previous study [20], it was found that the measured concentrations of selected metals in the current study in suburban soils were relatively higher than the reported levels in urban soils, indicating that there were intensive human intrusions in suburban soils. The order of selected metals distribution was also found different from that of previous study. Furthermore, the estimated levels of selected metals were found higher in summer than winter in suburban soils whereas in previous study [20] the measured levels for most of the metals were noted to be higher in winter than summer, indicating that these results were entirely different from the reported results related to urban soils.

TABLE 2: Descriptive statistics of pseudototal (T , mg/kg) and bioavailable (B , %) concentrations of selected metals in summer and winter.

	Variable	Min	Max	Median	Arith. mean	Geo. mean	Har. mean	Skew.	CV (%)
Summer	Cd _T	0.35	6.1	3.7	3.6	3.1	2.3	-0.28	47
	Co _T	18	44	35	32	31	30	-0.20	23
	Cr _T	33	86	54	54	53	52	0.48	22
	Cu _T	29	421	38	51	41	38	5.4	138
	Fe _T	3993	5429	4887	4863	4851	4839	-0.64	7.0
	Mn _T	212	778	392	435	404	376	0.41	39
	Pb _T	0.99	112	54	57	45	18	0.21	52
	Sr _T	47	1356	251	468	289	183	1.1	96
	Zn _T	70	143	96	98	96	95	0.69	17
Winter	Cd _T	<0.01	5.2	1.6	1.8	1.2	0.52	0.75	71
	Co _T	18	43	30	31	30	30	0.34	19
	Cr _T	2.5	32	24	23	21	17	-1.3	30
	Cu _T	17	44	27	28	27	26	0.59	21
	Fe _T	2462	4171	3921	3802	3786	3766	-2.5	8.6
	Mn _T	179	561	408	393	378	361	-0.46	26
	Pb _T	2.4	45	16	19	15	10	0.47	67
	Sr _T	62	739	160	225	183	157	2.0	80
	Zn _T	41	91	61	62	60	59	0.47	22
Summer	Cd _B	0.11	70	2.2	5.6	2.3	1.2	4.6	235
	Co _B	0.39	2.5	1.3	1.3	1.1	1.0	0.32	46
	Cr _B	<0.01	0.83	0.26	0.32	0.20	0.06	0.51	73
	Cu _B	0.03	0.62	0.39	0.37	0.33	0.24	-0.45	37
	Fe _B	<0.01	0.17	0.02	0.03	0.02	0.01	3.4	118
	Mn _B	<0.01	0.04	0.01	0.01	0.01	0.01	1.1	64
	Pb _B	0.03	65	2.5	7.4	1.97	0.38	5.4	330
	Sr _B	0.11	2.9	0.70	0.76	0.62	0.49	2.3	70
	Zn _B	0.05	0.28	0.13	0.15	0.14	0.12	0.47	39
Winter	Cd _B	2.5	79	7.7	25	10	6.4	4.2	205
	Co _B	0.36	6.7	2.8	2.6	2.3	1.8	0.68	49
	Cr _B	0.02	1.4	0.31	0.46	0.33	0.20	1.2	76
	Cu _B	0.01	0.81	0.26	0.27	0.17	0.07	0.74	77
	Fe _B	<0.01	0.02	0.01	0.01	<0.01	<0.01	0.94	61
	Mn _B	<0.01	0.04	0.01	0.01	<0.01	<0.01	2.4	88
	Pb _B	0.61	23	2.9	4.4	3.0	2.1	2.6	106
	Sr _B	0.29	4.9	1.1	1.3	1.1	0.93	2.5	77
	Zn _B	0.01	0.55	0.09	0.09	0.07	0.04	4.1	103

3.2. *Bioavailability.* Potential bioavailability of the metals was also evaluated in the study area in summer and winter (Table 2). The results manifested the highest bioavailability by Cd (0.11–70% in summer and 2.5–79% in winter), Pb (0.03–65% in summer and 0.61–23% in winter), Co (0.39–2.5% in summer and 0.36–6.7% in winter), and Sr (0.11–2.9% in summer and 0.29–4.9% in winter), while Fe (<0.01–0.17% in summer and <0.01–0.02% in winter), Mn (<0.01–0.04% in both seasons), and Zn (0.05–0.28% in summer and 0.01–0.55% in winter) were the least contributors towards potential bioavailability of the metals to soil biota in both seasons. Consequently, Pb, Cd, Co, and Sr showed higher bioavailability, while Fe, Mn, and Zn indicated the least. On the arithmetic mean basis, the metals followed the decreasing

bioavailable concentrations order: Pb > Cd > Co > Sr > Cu > Cr > Zn > Fe > Mn and Cd > Pb > Co > Sr > Cr > Cu > Zn > Mn > Fe in summer and winter, respectively. The results clearly revealed that the sequences of pseudototal and bioavailable contents of the metals were different from one another. Furthermore the leachability for Cd, Co, Cr, and Sr was quite higher in winter, while Pb and Zn indicated higher bioavailability in summer ($P < 0.05$). However total metals load of these metals was relatively higher in summer than winter.

3.3. *Ecological Risk Evaluation.* The range and mean values of CF of selected metals in acid-extract of the soils around the reservoir in summer and winter are portrayed in Figure 2(a).

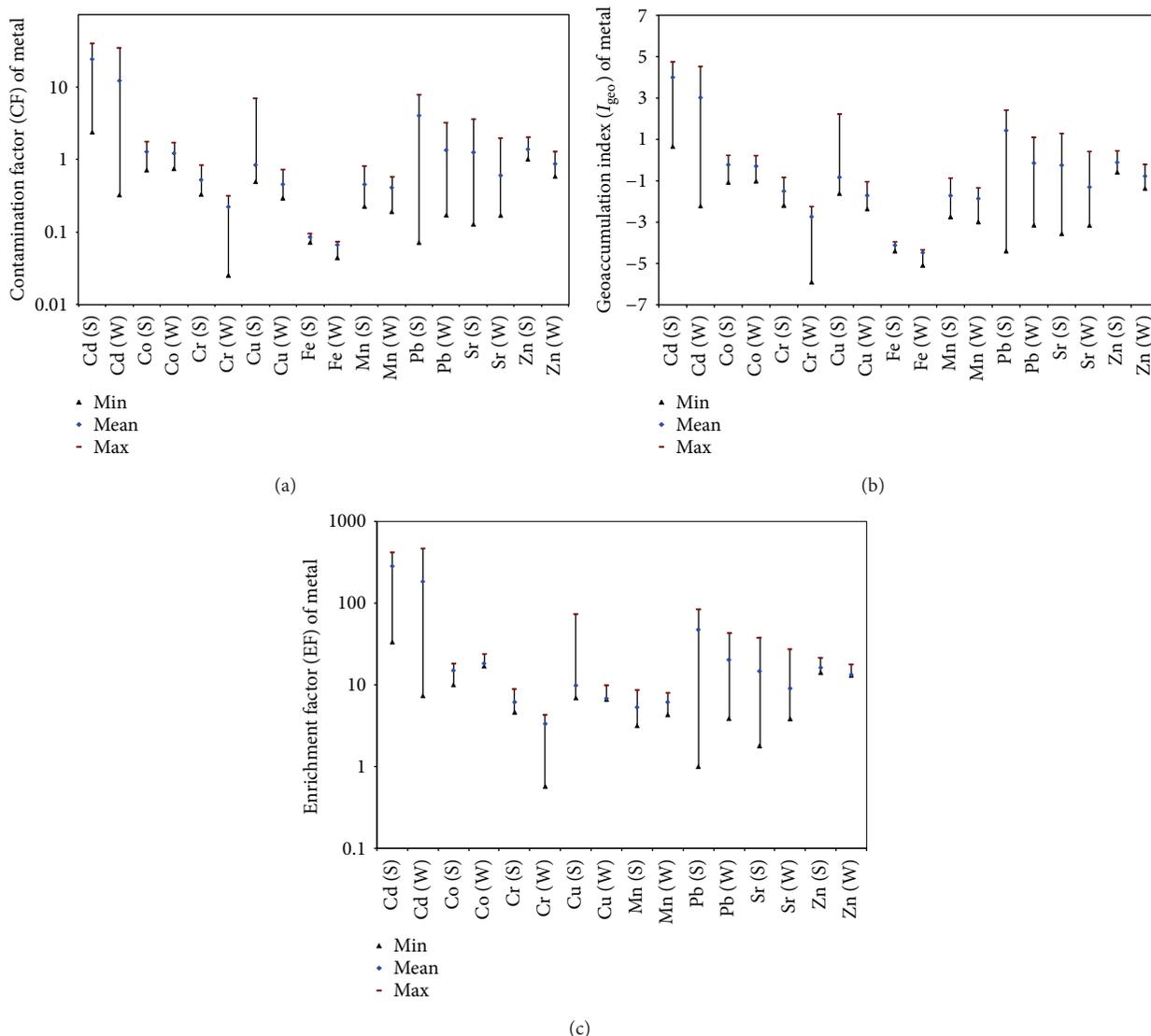


FIGURE 2: Description of contamination factor (CF), geoaccumulation index (I_{geo}), and enrichment factor (EF) in soil in summer (S) and winter (W).

In summer, on the average basis, Co, Sr, and Zn exhibited moderate contamination, Pb could cause considerable contamination, and Cd might pose very high contamination. The highest CF values of Cd, Cu, Pb, Sr, and Zn were 40.5, 7.1, 8.0, 3.7, and 2.1, respectively, thus indicating that the soils were highly contaminated with Cd, Cu, and Pb; Sr might cause considerable contamination; and Zn moderate contamination in the soils. In winter, on mean scale, the soils demonstrated moderate contamination by Co and Pb, while Cd showed very high contamination and the rest of the metals indicated low or no contamination of the soils. The CF manifested that Co, Sr, and Zn could cause moderate contamination, Pb showed considerable contamination, and Cd might pose very high contamination of the soils. Iron and Mn showed low contamination in the studied soils in both seasons. However, the highest CF values of Mn were 0.6 and 0.8 in summer and winter, respectively, indicating

that it might cause contamination to the soils in the future. In comparison with the results of CF in the previous study [20], it was found that there was more extent of metals contamination in the suburban soils than urban soils due to intensive human intrusions in these areas. Moreover, the extent of metals contamination was found relatively higher in summer than winter in suburban soils whereas it was greater in winter than summer in urban soils [20].

The assessment of the soil based on the degree of contamination (C_{deg}) was also carried out as suggested by Hakanson [29]. It is considered as more appropriate parameter to assess the overall contamination by all measured metals in the soils and hence act as a cumulative index. The lowest to highest values of C_{deg} in summer and winter were 6.6–69.7 and 3.5–46.4 with the average values of 37.2 and 18.9, respectively. On the average basis, the soils belonged to very high degree of contamination class in summer, while considerable degree of

TABLE 3: Principal component loadings of selected metals in soil in summer and winter.

	Summer			Winter			
	PC1	PC2	PC3	PC1	PC2	PC3	PC4
Eigen value	2.8	2.3	1.5	2.3	1.8	1.5	1.2
% total variance	36	25	17	25	21	17	13
% cumulative variance	36	61	78	25	46	63	76
Cd	0.80	-0.13	-0.20	-0.18	-0.08	0.76	-0.21
Co	0.87	-0.07	0.07	0.05	0.12	0.90	0.10
Cr	0.84	0.04	0.19	0.75	0.20	0.30	0.19
Cu	-0.24	0.17	0.88	0.35	0.07	0.14	0.79
Fe	0.17	0.68	-0.02	-0.03	0.87	-0.07	-0.23
Mn	-0.36	0.82	0.11	0.88	-0.06	0.03	-0.09
Pb	0.77	-0.31	0.02	0.14	0.00	0.77	0.09
Sr	0.91	0.08	-0.02	0.74	0.09	0.33	0.07
Zn	0.31	-0.12	0.83	-0.38	0.08	-0.19	0.85

contamination category in winter. Overall, higher contamination by selected metals was observed in summer compared to the winter in the studied soil. In comparison with the results of C_{deg} in urban soils in our previous study [20], it was noted that there was more degree of contamination in the suburban soils around the Khanpur Lake. Moreover, in this study, the levels of C_{deg} were observed to be higher in summer than winter while in our previous study the values of C_{deg} were noted higher in winter than summer.

The contamination levels of selected metals were assessed using geoaccumulation index (I_{geo}). Any increase in the current levels is envisaged to be anthropogenic in nature. Figure 2(b) describes the lowest, mean and highest I_{geo} values of selected metals in acid-extract of the soils in summer and winter. In summer, mean values of I_{geo} indicated that the soils were heavily to extremely contaminated by Cd; Pb showed moderate contamination and the remaining metals exhibited practically no contamination of the soils. Maximum I_{geo} value of Cd might cause heavy to extreme contamination; Co and Zn posed no contamination to moderate contamination; Sr caused moderate contamination; and Pb caused moderate to heavy contamination of the soils. In winter, on the average basis, Cd might pose heavy contamination, while the rest of the metals showed practically no contamination of the soils. The maximum values of Cd might cause heavy to extreme contamination, Co and Sr could pose moderate contamination, and Pb caused heavy contamination of the soils. Overall geoaccumulation index revealed accumulation of Cd, Co, Pb, and Sr in both seasons, while Zn showed accumulation in soils in summer only. In current study, it was noted that there was more geoaccumulation of selected metals in suburban soils around the Khanpur Lake than in urban soils around Rawal Lake [20]. Moreover, in this study more geoaccumulation was observed in summer than winter whereas in the previous study higher geoaccumulation was observed in winter than summer.

Enrichment factor (EF) is a comparatively simple and easy tool to assess enrichment extent of elements in soils [33–35]. The minimum, mean, and maximum EF values of the selected metals in acid-extract of the soil around the lake

in summer and winter are shown in Figure 2(c). In summer, average EF values of Co, Cr, Cu, Mn, Sr, and Zn revealed that the soils were significantly enriched with these metals, while Cd and Pb were observed to be extremely/highly enriched in the soils. The rest of the metals were not significantly enriched in the soils. The highest EF values of Sr and Zn (EF = 20–40) graded the soils as very highly enriched; and Cd (EF > 400), Cu (EF > 70), and Pb (EF > 80) classified the soils as extremely enriched. However, average EF results in winter showed that Co, Cu, Mn, Sr, and Zn were significantly enriched; Cr was moderately enriched; Pb was very highly enriched; and Cd was found to be extremely enriched in the soils. The rest of the metals showed deficiency to minimal enrichment in the soils. The highest EF values of Cd (EF > 450) and Pb (EF > 40) categorized the soils as extremely enriched, and Co and Sr (EF > 20) indicated that the soils were highly enriched with these metals. Overall, the mean EF values of Co, Cu, Mn, Sr, and Zn graded the soils as significantly enriched in both seasons; Cr categorized as significantly enriched in summer and moderately enriched in winter; Pb classified as extremely enriched in summer and very highly enriched in winter; and Cd graded the soils as extremely enriched in both seasons. In comparison with the results of EF in urban soils around Rawal Lake [20], the calculated levels of EF were found relatively higher in the suburban soils around Khanpur Lake than in urban soils in the previous study. Moreover, in current study, the extent of pollution was found relatively higher in summer than winter while in our previous study the degree of pollution was found relatively higher in winter than summer.

3.4. Source Apportionment. PCA was applied to find out the sources of selected metals in the studied soil. In this study, three principal components (PCs) and four PCs with eigenvalues greater than 1 were extracted which explained about 78% and 76% of the total variance in the analyzed data in summer and winter, respectively. Principal component loadings of selected metals in summer and winter are described in Table 3. In summer, PC1 (36% of total variance) showed positive loadings of Cd, Co, Cr, Pb, and Sr; PC2 (25%

of total variance) exhibited higher loadings of Fe and Mn; and PC3 (17% of total variance) had elevated loadings in favor of Cu and Zn. Nevertheless in winter, PC1 (25% variance) had positive associations of Cr, Mn, and Sr; PC2 (21% variance) indicated positive loading of Fe; PC3 (17% variance) had higher loadings for Cd, Co, and Pb; and PC4 (13% variance) exhibited elevated loadings for Cu and Zn. Cadmium, Co, Cr, Cu, Mn, Pb, Sr, and Zn were likely to be contributed by anthropogenic intrusions, such as agricultural and industrial activities, discharge of untreated domestic wastes, sewage sludge, road runoff, and atmospheric deposition [1, 37–40]. Though Fe showed close association with Mn in summer even then it was supposed to be contributed mainly by geogenic inputs as it was not highlighted in ecological risk assessment in both seasons.

4. Conclusions

The present study showed divergent disparity of selected metals in surface soil around freshwater Khanpur Lake, Pakistan, in summer and winter. On the arithmetic mean basis, Fe, Sr, Mn, and Zn were the dominant metals, while Cd, Pb, Co, and Cr were in lower concentrations in acid-extract. However, Cd, Co, Sr, and Pb were easily leachable and bioavailable to soil biota in the study area. In ecological risk assessment, contamination factor demonstrated moderate contamination by Co, Sr, and Zn and high contamination by Cd, Cu, and Pb; geoaccumulation index indicated heavy to extreme contamination by Cd and heavy contamination by Pb; enrichment factor revealed significant enrichment by Co, Cr, Cu, Mn, Sr, and Zn and extreme enrichment by Cd and Pb. Principal component analysis evidenced significant anthropogenic intrusions of Cd, Cr, Co, Cu, Mn, Pb, Sr, and Zn in the soil. Overall considerable/high degree of contamination was found in the soil.

Conflict of Interests

The authors do not have any conflict of interests.

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