

Article

Potentially Toxic Element Content in Arid Agricultural Soils in South Iran

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Abstract: Potentially toxic elements (PTE) are considered to be dangerous threats, both for human health and the environment. Here, the contamination level, sources, and ecological risks posed by PTE were investigated in 19 topsoils from agricultural lands in the Bandar Abbas County on the southern coast of Iran. The soil fraction $<63 \mu\text{m}$ was used for the analysis of the pseudototal contents of PTE (arsenic, cadmium, cobalt, chromium, copper, lead, manganese, molybdenum, nickel, vanadium, and zinc). The results were analyzed using principal component analysis (PCA) and Pearson's correlations, different pollution indices [enrichment factor (EF), contamination factor (Cf), and modified degree of contamination (mCd), and the potential ecological risk index (PERI). The results of the pollution indices showed that the contamination levels of the studied agricultural soils are low to moderate, while the average PERI values indicate that the ecological risks of PTE range from low to high in the soils of the studied area. Correlations and PCA analyses suggest that studied elements have three possible origins: geogenic (chromium, cobalt, copper, manganese, vanadium, and zinc), anthropogenic (cadmium, nickel, phosphorus and lead) and atmospheric (arsenic) sources. These findings are helpful for the long-term assessment of PTE in the Bandar Abbas County.

Keywords: arid environment; metals; principal component analysis; soil contamination

1. Introduction

Soil plays an essential role in human development as an environment that supports life, a natural buffer of contaminants, a substrate for food production, and a source of biodiversity. However, soils are also highly impacted by anthropogenic activities as a result of industrialization and human development and are sometimes neglected in the environmental guidelines of national governments [1–6]. Agricultural soils, in particular, are essential for humans due to their role in food production, but are sometimes highly degraded at the physical, chemical, and biological levels by inorganic (potentially toxic elements, PTE) and organic contaminants [5,6]. These contaminants reach the soils due to agricultural activities (fertilization, pesticides, etc.) and/or the agricultural area's proximity to sources of soil contamination, such as industrial or urbanized areas, energy production infrastructure or landfills. Moreover, agricultural soil contamination is not only an environmental issue, since the potential transfer of contaminants from soils to crops can also pose a safety concern based on their risk to humans [7,8].

Iran has experienced widespread development in the last four decades, including fast urbanization of large areas, industrialization, and intensive agriculture in several regions. These changes have sometimes been accompanied by overlooked environmental depreciation [9–13]. In this sense, Bandar Abbas is one of Iran's most industrialized regions, hosting a major shipping hub, zinc-smelting industry, and an important petrochemical industry, including several petroleum industries and oil fields [9]. At the same time, it is an important agricultural area with the cultivation of crops such as wheat, barley, and sugar beet.

Soils in agricultural areas can be polluted by contaminants from industrial as well as urban developments, creating a risk for humans through the consumption of food cultivated in these soils, as indicated by Doabi et al. [12,13] for other regions of Iran. Although some works have highlighted the influences of anthropogenic activities on street dust [14] and industrial soils [9] on the study region, available information about the contamination levels and potential sources of PTE in the agricultural soils is still scarce.

This work is the first detailed research about the PTE accumulation in the farmlands of the Bandar Abbas region, an important region in Iran with more than 0.6 million inhabitants. The objectives of this study were: (1) to determine the main physicochemical soil properties (soil texture, pH, organic carbon, and cation exchange capacity), and the levels of several PTE [arsenic (As), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), manganese (Mn), molybdenum (Mo), nickel (Ni), lead (Pb), vanadium (V), and zinc (Zn)] in the agricultural soils from the study area; (2) to estimate the degree of contamination through several environmental indicators (contamination factor, enrichment factor, potential ecological risk index, and the modified degree of contamination), and (3) to identify the possible origin (natural or anthropogenic) of the studied elements.

2. Materials and Methods

2.1. Study Area

This study was performed in Bandar Abbas County South District (BAC); which covers 4063 km² and is located at 27° 00'–27° 30' N, 55° 54'–56° 29' E [9]. The city of Bandar Abbas is the capital of the Hormozgan province and is the seventh most populated city in Iran. Figure 1 provides the location map and the selected samples in the study area. The climate of the study area is semi-arid to arid with an average precipitation of 250 mm and an annual temperature of 27.2 °C [9,15]. It is recognized as one of the agricultural and industrial pole in Iran, with significant economical activities, such as fishing and commercial ports, petrochemical and steel, zinc and aluminum complexes, cement factories, etc. [10,16]. The major fertilizers used in this area are superphosphate, ammonium phosphate, and potassium chlorate fertilizers. The geology of the study area is mainly composed by limestone, shale, marl, sandstone, and conglomerate, while the soils are mainly entisols and arid soils [9].

2.2. Soil Collection and Sample Characterisation

A total of 19 topsoil samples (0–10 cm sampling depth) were gathered from agricultural lands from BAC. Sampling sites were selected in such a way as to cover an impacted area based on recognized pollution sources such as industrial complex zones, landfills, etc. following the methodology developed for previous work with industrial areas [9]. Details about sampling methodology were previously indicated for industrial areas [9].

After the collection and once in the laboratory, samples were air-dried, sieved (2 mm nylon sieve) to eliminate impurities (e.g., stones, agricultural plastics, roots, or cigarette butts) following the methodology indicated by Keshavarzi et al. [14], ground with an agate mortar and pestle, and finally passed through a 63- μ m nylon sieve. The soil fraction <63 μ m was selected for further metal analysis [17]. According to Zheng et al. [18] and Doabi et al. [12], the health risks associated with fine particles are more significant than those for coarser fractions. The physical and chemical properties of the studied samples were measured using standard methods for the <2 mm fraction: soil pH (1:5,

soil:water ratio), particle size distribution determined by Pippete method [19], organic carbon content was measured by titration method [20], and the cation exchange capacity (CEC) [21].

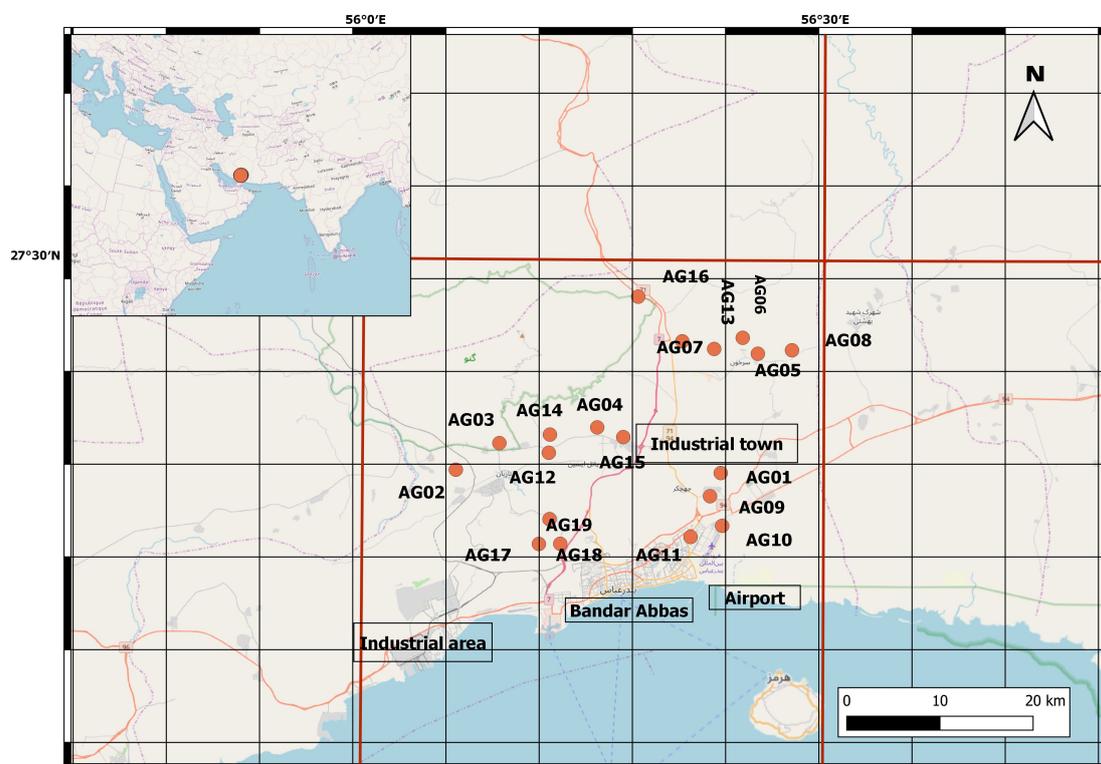


Figure 1. Study area and location of the sampling stations (orange dots).

The contents of the studied PTE [aluminum (Al), As, Cd, Co, Cr, iron (Fe), Mn, Mo, Ni, phosphorous (P), Pb, scandium (Sc), V, and Zn] were measured using a mixture of different acid combinations (HF, HClO₄, HNO₃, and H₂O₂) following the methodology indicated in Moghtaderi et al. [9]. The concentrations of the selected elements were evaluated using ICP–MS (Agilent, 7700x, Santa Clara, CA, USA). Details about internal quality standards were previously indicated [9].

2.3. Determination of Pollution Indices

In accordance with several previous studies [17,22–24], different environmental indices were used to assess soil contamination on the basis of PTE concentrations, including the contamination factor (Cf), enrichment factor (EF), the modified degree of contamination (mCd), and the potential ecological risk index (PERI). These indexes are widely used in different soils since can be used to assess the presence/intensity of a contaminant deposition on sediments or surface soils, allowing a quick and robust assessment of soil contamination e.g., [8,9,13,17,22–24]. As indicated by [25], these calculation methods allow converting numerical results into broad descriptive bands of pollution ranging from low to high intensity.

Cf was employed to evaluate the potential contamination of studied soils by individual elements [26]. It was calculated according to Hakanson (1980) using the following Equation (Equation (1)):

$$Cf = Mx/Mb \quad (1)$$

where Mx and Mb are the contents of each PTE in the soil and reference environment, respectively is divided into four categories (Table S1).

Abraham [27] presents a modified and comprehensive version of Hakanson's [26] equation for the computation of the modified degree of contamination (mCd), following Shakeri et al. [28] and Krzysztof et al. [22] (Equation (2)):

$$mCd = \sum Cf/n \quad (2)$$

where n is the number of 11 PTE. The different degrees of mCd are shown in Table S1.

PERI was used to determine the toxicity of PTE in the soils [26,29]. In accordance with this methodology, the potential ecological risk factor (Eir) of each PTE and the PERI of multiple elements can be calculated by Equation (3):

$$PERI = \sum_{i=1}^n E_r^i = \sum_{i=1}^n Cf \times T_r^i \quad (3)$$

where Cf and Tr are the contamination factor and toxic-response factor, respectively, for each PTE (i.e., each element of i). The toxic-response factors for As, Cd, Cr, Cu, Ni, Pb and Zn are 10, 2, 5, 5, 30, 5, and 1. PERI indicates the sensitivity at the biological level to the PTE and explains the potential ecological risk caused by the overall contamination [30,31]. The degree of ecological risk of each element (E_r^i) and the Potential Ecological risk Index (PERI) classes are shown in Table S1 [30–33].

The enrichment factor (EF) relative to background was computed to measure the fractions of PTE in soil that originated from human sources/anthropogenic vs. lithogenic. It is supposed that the contents of Al, Fe, Sc, and Ti in the soil can be described solely by geogenic source [23,34–36]. In this study, the EF was measured by the following Equation (Equation (4)):

$$EF = [M]/[Sc]_{soil}/[M]/[Sc]_{background} \quad (4)$$

where M is the element under consideration and Sc is a reference element. The range of EF from 0.5 to 2 regarded as natural variation, while ratios higher than 2 represent enrichment due primarily to human inputs [31,37]. Finally, the EF values for each toxic element are classified in five categories that are shown in Table S1.

2.4. Data Analysis

Pearson's correlation analysis was carried out using R (v. 3.1.3, R Core Team, Vienna, Austria) to determine the associations between the different PTE. A Principal component analysis (PCA) was also carried out using SPSS 19.0 (Armonk, NY: IBM Corp.) to explore potential sources of toxic elements in agricultural soil samples from the study area. The PCA is an efficient statistical technique used to identify probable sources of PTE [38]. Varimax rotation with Kaiser Normalization was used to simplify the data and their interpretation [10,11].

3. Results and Discussion

3.1. Soil Physicochemical Properties and PTE Levels in Studied Soils

Physicochemical properties of studied soils are shown in Table 1. Briefly, soils are loam and silt loam according to the USDA classification, with slightly to moderately alkaline soils. Organic matter content was lower (up to 1.13%), while CEC values were lower. The values are similar to the samples from industrial soils previously characterized [9], although, in the agricultural soils, more alkaline values were observed but with less organic carbon content.

Regarding the studied PTE, only Cr and Ni showed higher levels that exceeded the Iranian Environmental Quality Standards for agricultural lands (200 and 110 mg·kg⁻¹, respectively) [13], and also the Canadian soil quality guidelines (CSQG) for agricultural soils (64 and 45 mg·kg⁻¹, respectively) [39]. Although these elevated levels can be related to the geogenic origin, according to the higher background levels of these elements (74.5 and 77 mg·kg⁻¹, respectively), it's also widely known that Cr and Ni can be related to fertilizers, limestone and manures [40–43]. It was interesting

also to advise that our soils have higher levels of P, probably by the widespread use of sulfate and phosphate fertilizers as indicated by Keshavarzi al. for Iranian soils [44] that can reinforce the origin of Cr and Ni in our soils.

The PTE levels obtained in this studied were compared with data reported by other studies carried out for agricultural soils in Iran (Table 2). When compared with the results of previous studies in Iran e.g., [13,40,41,43–47], average values are similar or lower to indicate by them, probably due to some of these studies were carried out near to industrial areas e.g., [40,41]. Results showed significant enrichment of Cr and Ni in studied agricultural lands, although with similar values as indicated by Doabi et al. [13] for agricultural areas in Kermanshah province, Western Iran. When compared with other agricultural areas from arid/semiarid environments e.g., [3,48–52], our studied soils showed similar values to studies from other regions. In general, the contamination level of our samples was low, and higher contents seem to be related to inputs of fertilizers and pesticides [42,53], with a low influence from industrial or urban sources.

Table 1. Summary statistics of physical and chemical properties and potentially toxic elements (PTE) levels ($\text{mg}\cdot\text{kg}^{-1}$) for the agricultural soil samples of Bandar Abbas County South District (BAC).

Parameter	Units	Minimum	Maximum	Average	Standard Deviation	Skewness	Kurtosis	Coefficient of Variation	IEQS	CSQG	WMS	Background
pH	-	7.3	8.45	7.73	0.33	0.61	-0.34	4.25			-	-
Organic Carbon	%	<i>Bdl</i>	1.13	0.42	0.35	0.85	-0.03	82.51			-	-
CEC	$\text{meq } 100\text{g}^{-1}$	5.4	15.63	8.73	2.71	0.85	0.67	0.29				
Sand	%	14	80	43.53	18.79	0.27	-0.42	43.16			-	-
Silt		12	68	42.05	17.89	-0.10	-1.21	42.54			-	-
Clay		8	20	14.42	3.86	-0.18	-0.86	26.79			-	-
Al	$\text{mg}\cdot\text{kg}^{-1}$	18,156	36,702	26,516	5424	0.37	-0.7	20.46			80,000	2800
As		4.4	8.8	6.53	1.28	-0.06	-0.94	19.58	-	12	4.7	7.65
Cd		0.07	0.34	0.15	0.07	1.67	3.08	43	-	1.4	1.1	0.17
Co		9.2	25.55	14.64	4.19	1.01	0.99	28.63	-	40	6.9	10.64
Cr		61	237	126.68	50.86	0.61	-0.37	40.15	110	64	42	74.5
Cu		14.8	39.05	24.39	7.02	0.55	-0.68	28.77	200	63	14	30.89
Fe		21,790	40,180	30,746	5463	0.06	-0.66	17.77	-	-	47,200	40,857
Mn		509	886	694.71	115.82	-0.04	-1.25	16.67	-	-	418	879.70
Mo		0.7	1.35	0.96	0.25	0.52	-1.5	25.64	-	5	1.8	1.06
Ni		65	299.5	125.32	57.07	1.65	3.74	45.54	110	45	18	77
P		412	88	629.43	141.88	0.23	-0.91	22.54	-	-	-	-
Pb		6.2	13.5	8.8	2	1.29	1.32	22.75	-	70	25	10.8
Sc		6	14	9.58	2.46	0.37	-0.89	25.65	-	-	9.5	10.08
V		58.5	118	87.03	18.37	0.13	-0.98	21.1	-	130	60	98.08
Zn		35.2	60.3	50.02	7.46	-0.68	-0.26	14.92	500	250	62	65.09

IEQS—Iranian Environmental Quality Standards for agricultural soils [13], CSQG Canadian Soil Quality Guidelines [39], WMS—World average values in soils [42], CEC Cation exchange capacity.

Table 2. Comparison of studied PTE in agricultural soils between the present work and other studies from arid and semiarid environments (mean values, mg·kg⁻¹).

Location	Soil Type	n	Al	As	Cd	Co	Cr	Cu	Fe	Mn	Mo	Ni	P	Pb	Sb	V	Zn	Reference
Bandar Abbas, Southern Iran	AGS	19	26,516	6.53	0.15	14.64	126.68	24.39	30,746	694.71	0.96	125.32	629.43	8.8	-	87.03	50.02	This study
Granada and Almeria provinces, South-East of Spain	AGS	142	-	-	0.4	-	29.6	25.7	-	-	-	26.9	13.6	25.6	-	-	65.7	[3]
Kermanshah province, Western Iran	AGS	53	-	-	-	-	79.21	41.21	25,936	559.06	-	131.46	-	-	-	-	74.62	[13]
Hamedan Province, Western Iran	AGS	58	-	-	-	-	-	-	37,690	403.37	-	-	21.98	-	2.43	-	-	[43]
Teheran area, Northwestern Iran	AGS	141	-	-	-	-	87.15	-	-	665.06	-	43.60	-	35.08	-	67.14	130.36	[41]
Industrial area Isfahan, Center Iran	AGS	105	53,000	-	0.43	14.7	85.9	35.7	28,000	649.9	-	66.2	-	34.6	-	-	111.5	[40]
Isfahan Province, Center Iran	AGS	114	-	-	-	-	-	35.28	35,600	-	-	-	3750	32.14	-	-	100.96	[44]
Qazvin Province, North-West Iran	AGS	71	-	-	0.14	18.9	34.5	-	-	-	-	-	-	17.36	-	-	-	[45]
Semnan Province, Northern Iran	AGS	47	-	-	0.3	-	83.7	24.3	-	-	-	33.3	-	18.1	-	-	80.4	[46]
Aghili plain, Khuzestan province, Western Iran	AGS	55	-	2.81	0.29	-	-	-	-	-	-	-	-	6.12	-	-	-	[47]
Gansu Province, China	AGS	5	-	8.8	-	-	40.1	17.1	-	-	-	-	-	23.30	-	-	-	[48]
Gansu Province, China	AGS-i	13	-	11.17	-	-	38.82	27.2	-	-	-	-	-	21.44	-	-	-	[48]
Saiss plain, Northern Morocco	AGS-i	-	-	-	-	-	78	55	-	-	-	31	-	-	-	-	119	[49]
Copiapó, Northern Chile	AGS	7	-	32.1	-	13.3	-	209	21,180	1049	-	-	-	50.4	-	-	176	[50]
Hebei Province, Eastern China	AGS	100	-	6.16	0.15	-	57.77	21.22	-	-	-	25.04	-	18.80	-	-	69.96	[51]
Alicante province, Eastern Spain	AGS	29	-	-	0.38	7.9	28.3	21.6	15,274	320	-	23.7	-	19.6	-	-	57.8	[52]
Castellón province, Eastern Spain	AGS	77	-	-	0.32	7.7	33.3	36.6	16,915	385	-	19.5	-	55.8	-	-	78.5	[53]

n—number of samples, AGS—Agricultural Soil, AGS-I—Agricultural irrigation soil.

3.2. Assessment of Potentially Toxic Elements Pollution

The EF, Cf, mCd, and PERI indexes were used to determine the possibility of PTE pollution in the studied soils. The ranges of average EF values for the agricultural areas for Ni, Cr, and Cd show that the soils are moderately enriched by these elements (Figure 2). In contrast, the average EF values for the other elements show that the agricultural soil samples were minimally enriched. PTE with low EF values (<2) in the agricultural soil samples indicate that those elements originated from geogenic causes. Geological and lithological maps support this since, in the northeast (NE) of the study area, tuffs and shale were observed [9]. Higher concentrations of PTE have also been observed for similar environments like our study [31], where Cr and Cd showed moderate to severe enrichment.

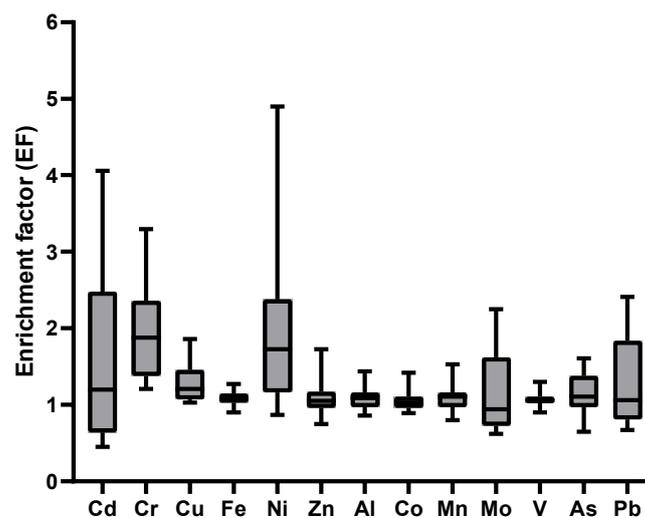


Figure 2. Box plot of the enrichment factor for studied PTE in agricultural soils.

Contamination factor (Cf) was determined based on the background concentrations of PTE in BAC soils (Figure 3). The highest Cf values were observed in agricultural soil samples collected from (AG5), (AG8), and (AG16). The mCd values in agricultural soil samples varied from 0.83 to 1.63, with an average of 1.22, illustrating that the degree of contamination of these soil samples is very low.

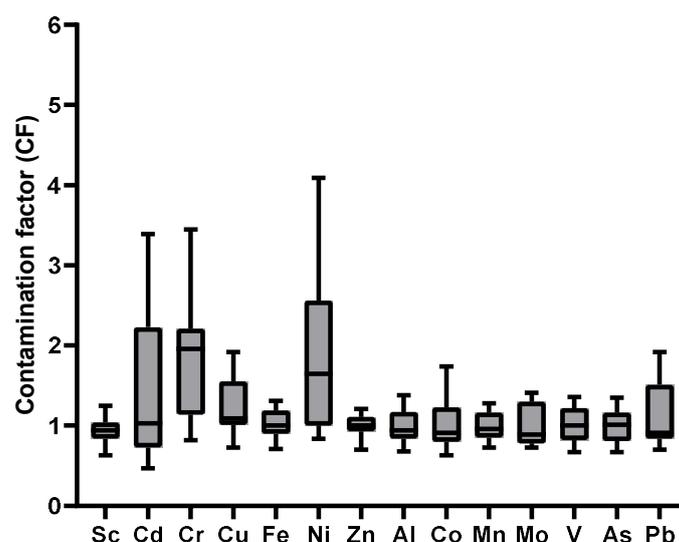


Figure 3. Box plot of the contamination factor for studied PTE in agricultural soils.

PERI indicates the sensitivity of diverse functional groups to toxic substances and also quantifies the PERI posed by the PTE [32,54,55]. The results for the measured selected elements in BAC soil samples are given in Table 3. The mean values of the PTE in the samples were, in decreasing order, Cd > As > Ni > Cu > Pb > Co > Cr > Zn. Only the values for Cd were in the range of moderate to considerable ecological risk. Based on these data, five of the sampling locations in the agricultural area pose a high potential ecological risk (potential ecological risk index >130).

Table 3. Potential ecological risk and potential ecological risk index (PERI) of PTE in the agricultural soils.

	Degree of Ecological Risk of Each Element							Potential Ecological Risk Index	
	As	Cd	Co	Cr	Cu	Ni	Pb		Zn
Maximum	13.47	101.73	8.72	6.90	9.58	20.45	9.60	1.21	156.22
Mean	10.00	41.71	5.00	3.71	5.98	9.06	5.60	1.00	82.05
Minimum	6.73	13.96	3.14	1.64	3.63	4.22	3.52	0.70	156.22

3.3. Multivariate Statistical Analysis

Potential correlations between the studied PTE and the soil physicochemical parameters were identified through Pearson's correlation analysis (Table 4). A significant and positive correlation were found between Sc and Al, Fe, Cd, Cr, Cu, Mn, Mo, Ni, V, and Zn. Except for As and Pb, all of the PTE concentrations are highly associated with each other, indicating probable similar origins. As indicated by Peris et al. for agricultural soils in Spain [53], Cr and Mn are also highly correlated with Fe, Co, and Ni suggesting an affinity between them ($r > 0.55$; $p < 0.01$). Element concentrations were not well correlated with physicochemical properties, suggesting that the effect of the physicochemical properties on the total contents of studied elements is not very important in the study area. Similar results were also indicated by Manta et al. [56] or Acosta et al. [57] for neutral–alkaline soils, like our samples (soil pH = 7.3–8.45).

The inter-element relationships give information useful for identifying the sources of PTE in environmental matrices [58]. In the present study, the PCA was used to identify different element sources and anthropogenic activities (Table 5).

According to the PCA analyses, three components were described to classify the possible sources of elements. These components explain 77% of the variance in the data. Component 1, which explains 42.9% of the variance, was significantly loaded by Fe, Co, Al, Cu, Cr, Sc, V, Mn, and Zn. Component 2 explained 19.45% of the variance and was loaded by Cd, Ni, P, and Pb. Finally, component 3 explained 14% of the variance and was composed of clay, Pb and As. Also, Cr received approximately similar loading factors in PC1 and PC2. Hence, it exhibited a quasi-independent behaviour in the agricultural soil samples, indicating that Cr might have mixed sources.

Table 4. Pearson’s correlation analysis of PTE in agricultural soils.

	Sc	Cd	Cr	Cu	Fe	Ni	Zn	Al	Co	Mn	Mo	V	As_	Pb	CEC	pH	OC	Sand	Silt	Clay
Sc	1																			
Cd	0.65	1																		
Cr	0.66	-0.65	1																	
Cu	0.88	<i>-0.56</i>	<i>0.51</i>	1																
Fe	0.96	-0.59	0.69	0.87	1															
Ni	0.86	-0.58	0.79	0.76	0.83	1														
Zn	0.60	NC	NC	0.64	0.66	<i>0.46</i>	1													
Al	0.87	NC	NC	0.84	0.86	0.75	0.78	1												
Co	0.95	-0.6	0.74	0.87	0.93	0.94	0.59	0.86	1											
Mn	0.67	<i>-0.46</i>	0.61	0.76	0.76	<i>0.55</i>	NC	<i>0.51</i>	0.62	1										
Mo	-0.84	0.72	-0.75	-0.638	-0.81	-0.72	NC	-0.63	0.76	<i>-0.52</i>	1									
V	0.95	-0.68	0.73	0.82	0.96	0.77	<i>0.519</i>	0.76	0.88	0.67	-0.88	1								
As	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	1							
Pb	NC	0.63	<i>-0.55</i>	NC	NC	NC	NC	NC	NC	NC	NC	<i>-0.46</i>	NC	1						
CEC	<i>0.51</i>	-0.61	<i>0.46</i>	<i>0.49</i>	NC	<i>0.48</i>	NC	NC	<i>0.52</i>	NC	NC	<i>0.50</i>	NC	NC	1					
pH	NC	NC	<i>0.52</i>	NC	NC	NC	NC	NC	NC	0.62	NC	<i>0.51</i>	NC	NC	NC	1				
OC	<i>-0.49</i>	NC	NC	-0.58	<i>-0.48</i>	NC	NC	<i>-0.53</i>	<i>-0.47</i>	<i>-0.55</i>	NC	NC	NC	NC	NC	NC	1			
Sand	NC	NC	NC	NC	NC	NC	NC	-0.58	NC	NC	NC	NC	NC	NC	NC	NC	NC	1		
Silt	<i>0.48</i>	NC	NC	NC	NC	NC	NC	0.68	<i>0.50</i>	NC	NC	NC	NC	NC	<i>0.48</i>	NC	NC	-0.98	1	
Clay	-0.61	NC	-0.58	NC	-0.68	NC	NC	NC	<i>-0.48</i>	-0.74	0.60	-0.67	NC	<i>0.517</i>	NC	-0.61	<i>0.46</i>	NC	NC	1

NC No correlation; bold letter, stands for highly significant correlations ($p < 0.01$); Italic letter stands for significant correlations ($p < 0.05$).

In general, it seems that a “geogenic factor” is the most significant source of PTE in the studied soils, as indicated by component 1 and previously indicated by Moghtaderi et al. (2018) for industrial areas [9]. Component 2 could be called as “anthropogenic factor” and was constituted by Cd, Ni, P, and Pb with a source from anthropogenic origins, such as industrial/transport emissions or agricultural practices (e.g., agricultural machinery, pesticides, and fertilizers) [13,36,42,48,59]. The presence of P with these PTEs in this component reinforces the possibility that agricultural malpractice could be the source of these elements, such as phosphate fertilizers and uncontrolled uses of pesticides [8,48,51,59,60]. Although Cd levels were lower, uncontrolled use of phosphate fertilizers could be an explanation for this common origin on Component 2 [59,61], as also observed by Cheraghi et al. [60] for agricultural farmlands in the Hamadan province (Western Iran) or by Micó et al. [59] for agricultural soils in Spain. Interestingly, component 3 was formed by clay and As. This combination could have an “atmospheric origin”, as indicated by Li et al. [48] for arid agricultural soils in China, where arsenic is related to fine soil fractions (e.g., clay fraction) with an origin of wind erosion.

Table 5. Principal component analysis for physicochemical properties and PTE in BAC soils.

	Agricultural Soils		
	PC1	PC2	PC3
Fe	0.96	−0.04	−0.22
Co	0.94	−0.20	0.01
Al	0.94	0.10	0.24
Cu	0.91	−0.17	0.02
V	0.90	−0.17	−0.29
Sc	0.89	−0.02	−0.19
Mo	−0.78	0.11	0.31
Zn	0.72	0.43	0.14
Mn	0.70	−0.15	−0.45
Cr	0.64	0.47	−0.33
OC	−0.53	0.13	0.12
P	−0.01	0.89	0.26
Cd	−0.29	0.87	0.25
Ni	0.02	0.65	−0.02
Pb	−0.08	0.71	0.49
CEC	0.49	−0.51	0.16
Clay	−0.53	−0.05	0.78
As	0.19	0.23	0.76
pH	0.31	−0.34	−0.66
% of Variance	42.92	19.45	14.00
Cumulative %	42.92	62.37	76.37

Bartlett’s sphericity tests ($p = 0$); Kaiser–Meyer–Olkin (KMO = 0.715).

4. Conclusions

The concentrations of 11 PTEs and their pollution level in agricultural soils from BAC were quantified in this study. In general, the contamination level of our samples was low, and seems to be related to the agricultural activities, with a low influence from industrial or urban sources. According to the different analysis, there are mixed natural/geogenic and anthropogenic sources in the studied soils, mainly to the malpractices of application of phosphate fertilizers. In general, chromium and nickel are priority PTEs for control in the studied soils. Furthermore, the potential impact of these PTEs on plant uptake or water resources should be considered for further works. Finally, this work provides a basis for the implementation of public policies to reduce the input of PTE in agricultural soils, and therefore, to reduce their long term accumulation, both in soils and in their possible uptake by biota.

Supplementary Materials: The following are available online at <http://www.mdpi.com/2073-4395/10/4/564/s1>, Table S1: Indices of pollution assessment for studied potentially toxic elements.

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