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Accumulation of Heavy Metals and Determination of Natural Radioactivity in the Soil-Thyme System in Omerli, Istanbul: Assessment of Ecological and Health Risk

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Highlights

- Heavy metals were studied in a soil-thyme system in a populated area.
- Pollution posed by Pb and Ni is serious.
- Heavy metals' health risks to children should be given more consideration.
- Soil radioactivity levels were negligible compared to World average values.

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Abstract

A significant pathway for human exposure to environmental pollutants is the metal transfer from soil to plants. In this study accumulation of different metals was investigated and natural radioactivity levels were measured in the soil–thyme system. It was found that the soil had higher concentrations of Br, Cr, Mn, Ni, and Pb than the world average and P, Ca, and Zn had higher transfer factors. The natural radioactivity level in the soils is similar to the World average. For thyme samples the average values for ^{226}Ra, ^{232}Th and ^{40}K were found as 22.7 ± 10.9 Bqkg^{-1}, 61.3 ± 19.9 Bqkg^{-1} and 722 ± 391 Bqkg^{-1}, respectively. The health and ecological risks of soil were evaluated. The total hazard index of the child was 1.453 on average, greater than that of the adult (0.175), primarily due to the contribution of Cr. Ecological risk assessed based on various indices indicated that Pb and Ni show environmental contamination risk. Our findings confirm that metal concentrations in plants are influenced by metal concentrations in soil, and that metal interactions are important for pollution risk management.

1. INTRODUCTION

Pollution is one of the world's most pressing issues today; due to the release of industrial waste, which has caused heavy metal contamination in soils, plants, and the atmosphere, people suffer from health issues. Recent studies show that rapid industrialization, urbanization, and the existence of extensive human activities have increased the issue of heavy metal pollution in soil [1–4]. Plants taking up heavy metals in soil can enter the food chain and endanger human health. Because of the potential health risks and effects on the ecosystem, heavy metal deposition in soils has become a major issue. Due to the importance of the topic, there has been extensive research on the effects of heavy metals in soil on both human health and the environment [5–9].

Heavy metals accumulated in polluted soil can cause crop pollution [10,11]. Furthermore, due to crop environment characteristics such as air, water, and soil, different crops have a variable capability to accumulate certain heavy metals in soil, resulting in varying levels of heavy metal accumulation [12–15]. Because industrial contamination of agricultural lands and forests is becoming a serious ecological issue in the world, determining metal concentrations, particularly toxic ones in plants, is of particular importance. The genus Thymus is a well-known herb that originated from the Mediterranean region and is widely used

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in the culinary, medicinal, and cosmetic industries [16]. Several publications report element concentrations in varied species of thyme from various locations [17–23]. These studies show that different elements can be found in a variety of amounts in thyme, with beneficial or undesirable health effects. Only the element concentrations in the thyme were evaluated in these studies; neither the element concentrations in the soil where the thyme was grown nor the relationship between the soil-thyme systems were examined. Not only should element concentrations in the thyme be considered, but also element transfer from the soil to the thyme. In this context, this study was designed to address the gap in scientific literature.

As environmental radioactive material is absorbed by plants and consumed by animals, it can be absorbed into the food, when consumed may expose people to radiation [24,25]. For this reason, it is important to know the level of radioactivity in plants. The main source of radiation exposure for humans and biota is naturally occurring radionuclides in the environment. Anthropogenic activities including coal burning, manufacturing and usage of phosphorus fertilizers, and the mining sector influence the distribution of natural radioactivity [26].

The goals of this study are: 1) to determine the accumulation of elements in soil and thyme by X-ray fluorescence spectroscopy method, 2) to examine the relationship between elemental concentrations in soil and thyme, 3) to evaluate the potential health risks related to heavy metal exposure, 4) to evaluate the pollution level in soil employing ecological risk indices, and 5) to calculate the natural radioactivity level in soil and thyme samples by gamma-ray spectroscopy method.

2. MATERIAL METHOD

2.1. Area of Study and Sampling

Omerli watershed, which is Istanbul's primary source of drinking water, is the study area. In May 2018, soil samples from nine sampling points (S1-S9) were taken at depths from 0 to 10 cm around Pasakoy village from flat areas. Sampling was applied along transects with a 10 m distance defined by a rectangle with the following corner coordinates: 41°2′8.71″ to 41°2′9.66″N and 29°12′24.83″ to 29°12′26.64″ E (Figure 1). Additionally, wild thyme (Thymus serpyllum) samples from points adjacent to the soil sampling points were taken.

The samples were placed in polyethylene bags that were labelled after removing the surface sundries, then conveyed to the laboratory and dried in a 40°C oven, sieved through 2 mm mesh and packed.

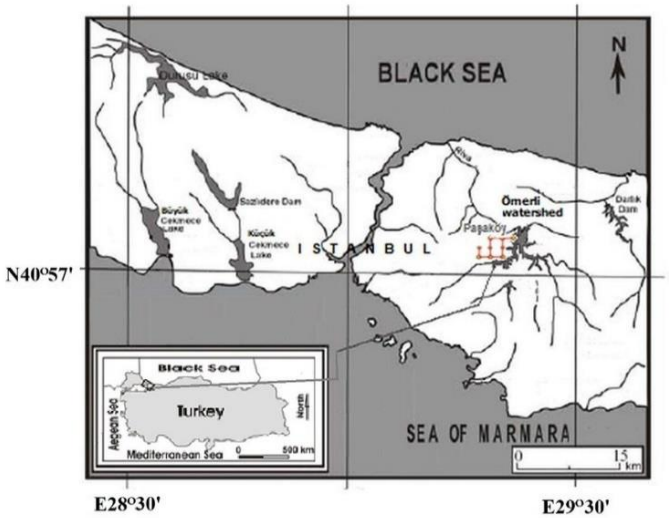

Figure 1. *Area of study and sampling cores*

2.2. Elemental Analysis

A quantity of 4 g of soil and plant samples were analysed using the ED-XRF technique. The analyses were carried out with a sequential spectrometer with the dispersion of Energy (MAGIXpro) with its X-ray tube equipped with a silver anode. In this work, the high voltage generator used is 30 kV and the maximum current is 20 μA. These parameters were selected to achieve a low detection limit (DL) calculated using background value (B):

$$DL \geq 3\sqrt{B}\,. \tag{1}$$

The X-ray spectra of the samples were obtained using a silicon drift detector (SDD) with a 7.62 μm Mylar thickness window, and 25 mm^2 active area. The detector resolution is 135 eV for the 5.9 keV γ-ray peak of ^{55}Fe. The measurement time of 60 s allows for reducing the Compton Effect that appears as a backscatter peak on the X-ray spectra. The quantitative analysis was applied by standard reference materials, IAEA/Soil 7 and IAEA-373.

2.3. Soil to Plant Transfer Factor

Transfer factor (TF) is a measure of a plant's capacity to uptake elements and is described as the ratio of elements in the plant to those in the soil [27]

$$TF = \frac{C_p}{C_s} \tag{2}$$

where C is the element concentration and p and s indicate plant and soil, respectively.

2.4. Assessing the Risk to Human Health

Calculations for risk assessments may be used to establish if heavy metals in soil cause carcinogenic or non-carcinogenic harm to human health [28]. In general, oral intake, dermal contact, and particle inhalation are the three main ways that heavy metals in a structure can enter a person's body and negatively impact health. Consequently, the relation with various pathways of heavy metals is defined for adults and children with the following equations [6]:

$$ADD_{ing} = C \times \frac{IngR \times EF \times ED}{BW \times AT} \times 10^{-6} \tag{3}$$

$$ADD_{inh} = C \times \frac{InhR \times EF \times ED}{PEF \times BW \times AT} \tag{4}$$

$$ADI_{dermal} = C \times \frac{SA \times AF \times ABS \times EF \times ED}{BW \times AT} \times 10^{-6} \tag{5}$$

where ADD represents the daily average doses for ingestion (ing), inhalation (inh), and dermal pathways, C represents the metal concentration in soil ($mgkg^{-1}$), IngR is the ingestion rate (adult: 100 mgd^{-1}, children: 200 mgd^{-1}) [28], InhR is the inhalation rate (adult: 20 m^3d^{-1}, children: 7.6 m^3d^{-1}) [29,30], EF is the exposure frequency (350 dy^{-1}) [31], ED is the exposure duration (adult: 30, children: 6) [28], BW is bodyweight of the exposed individual (adult: 70 kg, children: 15 kg) [32], AT is the average time (365×ED d) [31], PEF is the particle emission factor (1.36×10^9 m^3kg^{-1}) [28], SA is the exposed skin's surface area (adult: 1530 cm^2, children: 860 cm^2) [28], ABS is the dimensionless dermal absorption factor (0.001 for all metals) [30,33,34] and AF is the adherence factor (adult: 0.07 mg $cm^{-2}d^{-1}$, children: 0.2 mg $cm^{-2}d^{-1}$) [28].

The hazard quotient (HQ) and the hazard index (HI) are used to estimate the non-carcinogenic risk to the population. ADD for ingestion, inhalation, and dermal contact is used in the HQ calculation [32]:

$$HQ = \frac{ADD}{RfD} \tag{6}$$

where RfD is the reference dose for metal.

The sum of HQ values of ingestion, inhalation and dermal contact is used to calculate the HI for each metal (i) [32].

$$HI_i = HI_{ing} + HI_{inh} + HI_{dermal} \quad (7)$$

The sum of HI values of metals yields the total hazard index (THI).

$$THI = \sum HI_i \quad (8)$$

The carcinogenic risk for all exposure pathways is calculated by multiplying ADD values by the corresponding slope factor SF_i [32]:

$$CR = ADD \times SF_i \quad (9)$$

Risk of developing cancer in humans according to CR value is classified as CR < 10^{-6}: negligible, 10^{-6} < CR <10^{-4}: acceptable or tolerable, CR > 10^{-4}: high [35].

2.5. Ecological Risk Assessment

Various quality indices have been applied to assess metal pollution of soil from several aspects. These are contamination factor (CF) [36], potential ecological risk (E_i) [36], pollution load index (PLI) [37] and geo-accumulation index (I_{geo}) [38].

The contamination factor stands for the ratio of the metal concentration to the worldwide value of the same metal [36].

$$CF = \frac{C_s}{C_r} \quad (10)$$

where C is the concentration of the metal and s and r indicate sample and reference worldwide value of the metal, respectively. Contamination according to CR value is classified as CF < 1: low, 1 ≤ CF < 3: moderate, 3 ≤ CF < 6: considerable and CF ≥ 6: high.

Metal concentrations in soil were used to determine the potential ecological risk [36]

$$E_i = T_i \times CF \quad (11)$$

where T_i is the toxic response factor and CF is the contamination factor of the metal. T_i of metals in ascending order are Zn = 1, Cr = 2, Cu = Ni = Pb = 5, As = 10, Cd = 30, Hg = 40 [36]. The classification of the risk according to E_i is E_i < 40: low, 40 ≤ E_i < 80: moderate, 80 ≤ E_i < 160: considerable, 160 ≤ E_i < 320: high and 320 ≤ E_i: very high.

The pollutant load index (PLI) measures the level of anthropogenic metal contamination [37].

$$PLI = (CF_{M1} \times CF_{M2} \times \ldots \times CF_{Mn})^{1/n} \quad (12)$$

where CF_M is the factor of contamination and n is the number of metals. There is metal pollution if PLI is larger than one; otherwise, if PLI is lower than one, there is not any metal pollution.

A common method for estimating metal concentration enrichment above background or baseline levels is the calculation of geo-accumulation index (I_{geo}) [38]

$$I_{geo} = log_2 \frac{C_n}{1.5B_n} \quad (13)$$

where C_n is the element's concentration in the sample and Bn is the element's background value. To lessen the impact of potential changes, factor 1.5 is used in the background values due to lithologic differences [39]. I_{geo} consists of seven contamination classes as proposed by [38,40]: $I_{geo} \leq 0$: uncontaminated, $0 < I_{geo} < 1$: uncontaminated to moderate, $1 < I_{geo} < 2$: moderate, $2 < I_{geo} < 3$: moderate to heavy, $3 < I_{geo} < 4$: heavy, $4 < I_{geo} < 5$: heavy to extremely, $5 > I_{geo}$: extreme.

2.6. Radioactivity Analysis

The soil and plant samples were ground and sieved through ≤ 2 mm sieve after being dried at 105 °C for 24 hours for radioactivity analysis. Masses of soil samples ranged from 50 to 70 g and plant samples from 7 to 10 g in a cylindrical container with 72 mm diameter and 22 mm height. To achieve secular equilibrium between ^{226}Ra and its daughters ^{214}Bi and ^{214}Pb, the samples were sealed and left for 35 days.

To measure the activity concentrations in soil and plant samples, gamma spectrometry was employed using two HPGe detectors with different specifications: the first one has a 35% relative efficiency and 1.85 keV resolution (FWHM) at 1332.5 keV, the second one has 40% relative efficiency with 1.8 keV (FWHM) at 1332.5 keV, and 0.86 keV at 122 keV.

The minimum detectable activity (MDA in Bqkg^{-1}) at 95% confidence level was calculated by [41]:

$$MDA = \frac{DL}{\varepsilon(E)\, I_\gamma\, t\, m} \quad (14)$$

where ε(E) is the detector efficiency and I_γ is the intensity of the interested gamma ray energy E, t is the measurement time (s), m is the mass of the sample (kg), and DL is the detection limit given by [41]:

$$DL = 2.71 + 4.65\sqrt{B} \quad (15)$$

where B is the background value.

The detector with higher relative efficiency was used for the measurement of the plant samples considering their low masses. Both detectors were provided by Canberra, shielded by lead (Canberra 747 Series lead shield). The interior was covered with 3 mm tin and 1.5 mm copper layers to achieve a low background. The detectors are linked to a Digital Spectrum Analyzer (DSA 1000) to acquire gamma spectra of soil and plant samples. Each sample was measured during 86400 s to achieve good counting statistics. The obtained measurement errors were less than 5%. The Genie 2000 program was used to process spectra. In this study, the detector efficiencies were determined by Monte Carlo simulation method using MCNP5 code for the specified gamma ray energies to calculate radionuclide activities [42,43].

The activity concentrations of the ^{226}Ra and ^{232}Th were determined by their daughter products. The gamma energies were 351.9 keV (^{214}Pb) and 609.9 keV (^{214}Bi) for ^{226}Ra and 238.2 keV (^{212}Pb), 727.3 keV (^{212}Bi) and 911.3 keV (^{228}Ac) for ^{232}Th. The gamma energy of 1460.8 keV of ^{40}K was used to calculate its activity concentration [41].

3. THE RESEARCH FINDINGS AND DISCUSSION

3.1. Element Concentrations in Soil and Thyme

Table 1 shows multivariate statistics of element concentrations in Omerli soils determined by XRF analysis method. In this work, the detection limit for trace element concentrations was in the order of 1 ppm.

A comparison with world average values [27] might help to realize the level of elements in the soil. It is found that the mean values of Br, Cr, Mn, Ni, and Pb are greater than the world average values. Co, Cu, Se, and Zn mean values, however, are lower than their world mean concentrations.

Table 1. *Statistics of elements in soil (mgkg^{-1})*

	Br	Ca	Co	Cr	Cu	Fe	Mn	Ni	P	Pb	Se	Zn
Mean	13	2838	8.8	83	7.6	40067	780	174	84	71	0.23	33
Median	12	2825	9.0	82	7.5	40412	776	175	74	67	0.23	33
SD	2.3	223	0.80	3.1	0.26	2065	45	5.8	24	8.1	0.04	4.4
Minimum	11	2573	7.5	79	7.2	35969	699	165	47	59	0.16	26
Maximum	17	3205	9.5	88	7.9	42480	841	186	112	83	0.28	39
World Average	10		11	60	39		488	29		27	0.44	70

Multivariate statistics of element concentration found in thyme are presented in Table 2. Thyme is high in Macronutrients (P, Ca, and Fe) with Ca being present in higher concentrations amongst them. Among the micronutrients, Mn and Zn are abundant in thyme. Toxic elements like Se and Pb are present in thyme, but Se concentrations are found to be too low to have any toxic effect. Pb, on the other hand, exceeded the allowable limit (> 0.3 mgkg^{-1}) for leafy vegetables [44].

Table 2. *Statistics of elements in thyme (mgkg^{-1})*

	Br	Ca	Co	Cr	Cu	Fe	Mn	Ni	P	Pb	Se	Zn
Mean	16	18609	1.5	3.4	13	4281	328	13	1983	50	0.42	153
Median	18	17556	1.4	3.4	13	4362	323	13	1762	46	0.43	151
SD	4.7	2594	0.41	0.37	1.2	599	20	1.3	547	23	0.15	33
Minimum	6.1	14103	0.92	2.7	10	3433	308	11	1312	18	0.09	88
Maximum	21	22510	2.4	4.1	14	5000	374	16	2860	82	0.62	208

Table 3 compares the mean element concentrations in thyme in this study to those obtained from other studies around the world. In the case of Ca, the mean concentration in our study is lower in comparison to Tunisia and much higher than its value in Morocco and Ethiopia. The mean value of Co is comparable to its value in Morocco (T. pallidus), and lower than its value in Morocco (T. broussonetii, T. maroccanus, T. leptobotrys), Ethiopia, and Jordan. Except for Morocco (T. satureioides), the mean concentration of Cr in our study is significantly greater than its value in other countries. The study area's mean values for Cu, Fe, Mn, Ni, and Zn are higher than those reported in other countries. In the case of Pb, the value obtained in our study is significantly greater than the value reported in Jordan.

Table 3. *Comparison of elements in varied species of thyme around world (mgkg^{-1})*

Country	Species	Ca	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Turkey (present study)	T.serpyllum L.	18609	1.5	3.4	13	4281	328	13	50	153
Italy [22]	T. vulgaris	16200			2.7	234	5.0			35
Tunisia [22]	T. vulgaris	24500			11	592	27			49
Serbia [21]	T.serpyllum L.				8.9	446	127			44
Morocco [18]	T. broussonetii	14991	2.8	1.5	7.0	272	29	2.3		33
Morocco [18]	T. maroccanus	14831	6.0	1.3	9.8	275	58	2.3		44
Morocco [18]	T. leptobotrys	5952	2.7	1.5	7.0	153	74	1.5		73
Morocco [18]	T. pallidus	8335	1.5	3.0	4.7	423	49	1.8		43
Morocco [18]	T. satureioides	6684		11	5.5	222	32	1.5		28
Ethiopia [19]	T. schimperi and T. vulgaris	2015	3.6		9.0	1467	77	11		35
Jordan [17]	T.serpyllum L.		2.9		9.7	117			0.89	

Figure 2 shows the average soil-to-thyme transfer factors for the elements considered in this study. P, Ca, and Zn are found to have higher transfer factors ranging from 11.9 to 59.8, 4.5 to 8.5 and 2.4 to 6.8, respectively. The average transfer factors for Cr, Fe, Mn, Ni and Pb are low (< 1) compared to other elements.

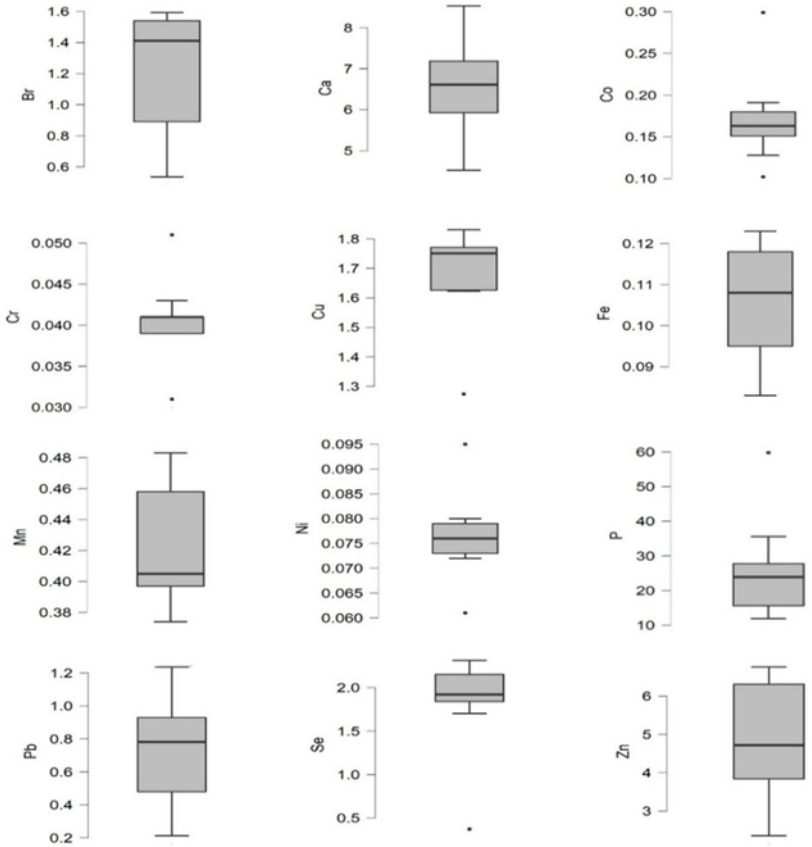

Figure 2. *Soil-to-thyme transfer factors*

The correlations between element concentrations in soil and thyme were determined using the Pearson linear coefficient. Table 4 shows the Pearson correlations between the elements of the soil and the thyme. In soils, there is a moderately positive correlation between Br and Pb and Fe and Pb ($p < 0.01$); a positive correlation is also observed between Br and Se, Ca and Ni, Co and Fe, Co and Pb, Co and Zn, Fe and Se, Mn and Ni, Mn, and P, Pb and Se, and Se and Zn. In thyme, a strong positive correlation is observed between Ca and Zn, Cr and Cu, Cr and Ni, Fe and Pb, and Mn and Ni ($p < 0.001$); a moderate negative correlation is also observed between Br and Cr, Br and Ni, Ca and Co, Co and Zn, and Fe and P.

Table 4. *The Pearson correlations of the elements in soil and thyme*

	Br	Ca	Co	Cr	Cu	Fe	Mn	Ni	P	Pb	Se	Zn
Soil												
Br	1											
Ca	0.244	1										
Co	0.301	0.051	1									
Cr	0.336	0.450	0.256	1								
Cu	-0.065	-0.373	0.213	-0.277	1							
Fe	0.346	-0.043	0.727*	0.351	0.176	1						
Mn	0.494	0.281	-0.282	0.446	-0.298	-0.228	1					
Ni	0.321	0.595*	-0.303	0.456	0.004	-0.292	0.602*	1				
P	0.029	0.091	-0.178	0.147	-0.038	-0.346	0.726*	0.207	1			
Pb	0.762**	0.196	0.589*	0.307	-0.144	0.786**	0.077	-0.046	-0.334	1		

Se	0.739*	0.113	0.421	0.431	0.297	0.729*	0.339	0.21	0.058	0.747*	1	
Zn	0.409	0.366	0.660*	0.404	0.43	0.546	-0.067	0.091	0.045	0.398	0.624*	1
Thyme												
Br	1											
Ca	-0.020	1										
Co	0.127	-0.757**	1									
Cr	-0.850**	0.366	-0.495	1								
Cu	-0.560	0.704*	-0.625*	0.820***	1							
Fe	-0.159	-0.725*	0.575	-0.027	-0.169	1						
Mn	-0.608*	0.277	-0.012	0.567	0.386	-0.341	1					
Ni	-0.826**	0.305	-0.384	0.881***	0.630*	-0.263	0.816***	1				
P	0.144	0.425	-0.553	-0.020	-0.072	-0.755**	0.057	0.110	1			
Pb	-0.013	-0.387	0.524	-0.162	-0.034	0.750***	-0.306	-0.395	-0.519	1		
Se	0.280	-0.120	0.472	-0.265	-0.183	0.351	0.004	-0.365	-0.517	0.255	1	
Zn	-0.109	0.852***	-0.803**	0.515	0.725	-0.453	0.087	0.293	0.249	-0.415	0.009	1

$p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

3.2. Human Health Risk Evaluation

The health risks associated with some heavy metals for humans were evaluated using the amounts of heavy metals in soil from nine different cores. Table 5 shows the calculated total hazard index (THI) and total carcinogenic risk (TCR) data for each heavy metal, as well as sample overall values. The THI data for each metal and their overall values for all metals were less than one for adults which means non-carcinogenic harmful effect. The THI overall values for all metals were less than one for adults in all cores. Children, on the other hand, have THI values for chromium in one core and overall values greater than one for all metals. According to this study, long-term soil heavy metal exposure may induce non-carcinogenic damage in children [28,45]. TCR for Cu and Zn was not determined, because there was insufficient data to compute their HQ values. Furthermore, TCR values for Ni did not hold ingestion because slope parameters for Ni carcinogenicity were not defined in the literature for ingestion [31]. There is no considerable carcinogenic effect of heavy metals in the soil because the TCR values for both children and adults are below 10^{-4}. Higher TCR values in children indicate that they are more vulnerable to heavy metal pollution [28,35].

Table 5. *Risks in soil that are non-carcinogenic and carcinogenic*

Sample	Element	THI		TCR	
		Adults	Child	Adults	Child
S1	Cr	0.117	0.942	5.64E-05	5.21E-04
	Cu	0.000	0.003	-	-
	Ni	0.028	0.229	2.86E-08	5.08E-08
	Pb	0.027	0.252	7.76E-07	7.24E-06
	Zn	0.0001	0.001	-	-
	All metals	0.172	1.427	5.72E-05	5.28E-04
S2	Cr	0.117	0.946	5.66E-05	5.23E-04
	Cu	0.0004	0.003	-	-
	Ni	0.028	0.234	2.92E-08	5.19E-08
	Pb	0.034	0.312	9.61E-07	8.97E-06
	Zn	0.0002	0.002	-	-
	All metals	0.180	1.497	5.76E-05	5.32E-04
S3	Cr	0.116	0.934	5.59E-05	5.16E-04
	Cu	0.0004	0.003	-	-
	Ni	0.028	0.230	2.88E-08	5.11E-08
	Pb	0.027	0.252	7.75E-07	7.24E-06
	Zn	0.0002	0.002	-	-
	All metals	0.171	1.420	5.67E-05	5.23E-04

S4	Cr	0.122	0.988	5.91E-05	5.46E-04
	Cu	0.0003	0.003	-	-
	Ni	0.029	0.237	2.97E-08	5.26E-08
	Pb	0.034	0.314	9.69E-07	9.04E-06
	Zn	0.0002	0.002	-	-
	All metals	0.185	1.543	6.01E-05	5.55E-04
S5	Cr	0.126	1.022	6.11E-05	5.65E-04
	Cu	0.0003	0.003	-	-
	Ni	0.029	0.236	2.95E-08	5.24E-08
	Pb	0.027	0.250	7.71E-07	7.20E-06
	Zn	0.0002	0.001	-	-
	All metals	0.183	1.512	6.19E-05	5.72E-04
S6	Cr	0.116	0.940	5.62E-05	5.20E-04
	Cu	0.0004	0.003	-	-
	Ni	0.027	0.223	2.79E-08	4.95E-08
	Pb	0.028	0.264	8.12E-07	7.58E-06
	Zn	0.0002	0.002	-	-
	All metals	0.172	1.431	5.71E-05	5.27E-04
S7	Cr	0.113	0.912	5.46E-05	5.04E-04
	Cu	0.0004	0.003	-	-
	P	0.010	0.087	1.09E-08	1.92E-08
	Pb	0.024	0.222	6.84E-07	6.38E-06
	Zn	0.0001	0.001	-	-
	All metals	0.148	1.225	5.53E-05	5.11E-04
S8	Cr	0.122	0.988	5.91E-05	5.46E-04
	Cu	0.0003	0.003	-	-
	Ni	0.029	0.237	2.96E-08	5.25E-08
	Pb	0.031	0.286	8.80E-07	8.22E-06
	Zn	0.0002	0.002	-	-
	All metals	0.182	1.515	6.00E-05	5.55E-04
S9	Cr	0.123	0.992	5.93E-05	5.48E-04
	Cu	0.0004	0.003	-	-
	Ni	0.030	0.251	3.15E-08	5.58E-08
	Pb	0.028	0.255	7.85E-07	7.33E-06
	Zn	0.0002	0.002	-	-
	All metals	0.181	1.503	6.02E-05	5.56E-04

3.3. Human Health Risk Evaluation

Figure 3a-c show the contamination factor, potential ecological risk, and geo-accumulation index of soils. Contamination factors for Cr, Cu, Co, Ni, Pb, and Zn in all soils in Figure 3a were found 1.15, 0.08, 1.14, 11.78, 3.95, and 0.46, respectively. The potential ecological risks of soils in Figure 3b show that all heavy metals pose a low ecological risk. For lead and nickel, I_{geo} values in Figure 3c are higher than 5 which says extreme contamination risk to the environment. The concentration of other heavy metals in soils poses no contamination risk according to the I_{geo} values. PLI values were found 1.19, 1.35, 1.31, 1.36, 1.30, 1.34, 1.18, 1.35 and 1.33 for S-1-S-9, respectively. PLI values (> 1) indicate the slight pollution for all soils.

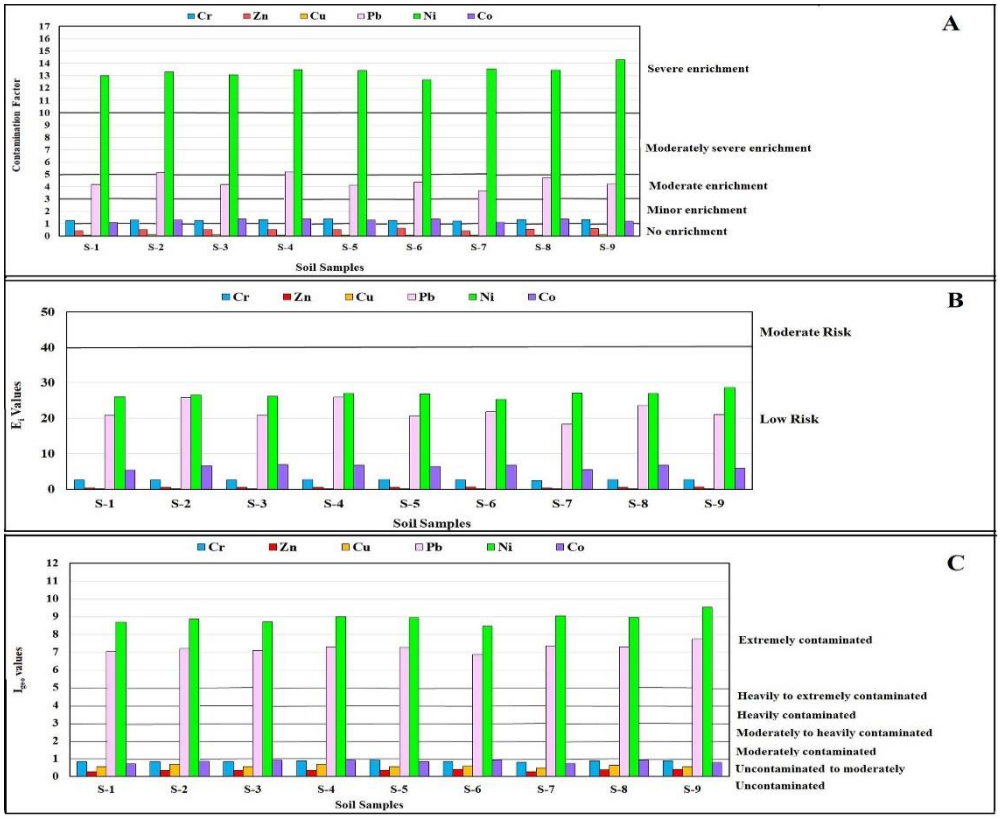

Figure 3. *Contamination factors, potential ecological risks, and geo-accumulation index for soils*

3.4. Radioactivity Concentrations in Soil and Thyme

Gamma spectrometry results of the soil and thyme are presented in Table 6. The minimum detectable activities calculated for each radionuclide were given elsewhere [46]. There are no substantial changes among the specific activities of radionuclides in soils at different sampling locations, i.e., the differences are within the measurement uncertainty. However, a difference in specific activities is determined in thyme at different sampling locations.

The average world activity concentrations of ^{40}K, ^{238}U and ^{232}Th in the soil are 400 Bqkg^{-1}, 35 Bqkg^{-1} and 30 Bqkg^{-1}, respectively [47]. The mean activity concentrations of ^{226}Ra and ^{232}Th in soil are comparable to the world average, however, ^{40}K in the soil is slightly above the world average.

Table 6. *Statistics of radioactivity concentrations in soil and thyme (Bqkg^{-1})*

	Soil			Thyme		
	^{226}Ra	^{232}Th	^{40}K	^{226}Ra	^{232}Th	^{40}K
Mean	21.7	31.0	423	22.7	61.3	722
Median	21.5	30.8	423	24.3	53.5	620
SD	1.31	1.97	15.1	10.9	19.9	391
Minimum	19.7	27.8	406	7.44	39.9	183
Maximum	24.2	33.1	449	39.2	105	1575

4. RESULTS

This research introduced a detailed characterization of element concentrations of soil and thyme from Omerli, Istanbul (Turkey). Metal pollution status was assessed through different indices.

- The amounts of Br, Cr, Mn, Ni, and Pb in soils were found to be higher than average for the world.

- Pb had a greater value in thymes, which could be related to plants growing on grounds near roadways. When element concentrations in thyme were compared to those reported in other nations, the mean values of Cu, Fe, Mn, Ni, and Zn in the Omerli watershed were found to be greater.
- The mean soil-to-thyme transfer factors of the Br, Ca, Cu, P, Se, and Zn were found to be higher than one.
- The hazard quotient, hazard index, total hazard index, and carcinogenic risk were chosen as indices to assess the risk to human health. In summary, the findings indicated that long-term heavy metal exposure in soil poses a non-carcinogenic risk to children.
- The contamination factor, potential ecological risk, geo-accumulation index, and pollution load index were used to estimate the ecological risk of heavy metals in soil. The contamination factor for Cu and Zn suggests low pollution, for Cr and Co moderate pollution, considerable pollution for Pb, and very high pollution for Ni. The potential ecological risk results indicated that there is low environmental risk in terms of Cr, Zn, Cu, Pb, Ni, and Co in soils. Considering the geoaccumulation index, only Pb and Ni show extreme contamination risk to the environment. According to the pollution load indices, all soils are under slightly polluted conditions.
- Radioactivity concentrations in soils are close to the World average levels. While there were no significant changes in the activities of radionuclides in the soil at different sampling locations, a difference in the activities of thyme samples was observed. Element concentrations have also shown a tendency in the same pattern. The variation of the elements determined in each thyme sample is higher than in soil samples.

CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

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