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Health Risk Assessment due to Some Potentially Toxic Elements in Sepiolite Mineral

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Abstract: Potentially toxic elements (PTEs) can cause several health problems. Sepiolite is a clay mineral containing hydrated magnesium silicate and widely utilized in agriculture, food, detergent, pharmaceutical, cosmetics, paint, paper, fertilizer, construction, etc. The aim of this study is to assess the health risks that may arise from some PTEs present in the sepiolite mineral contained in the products we use in our daily lives. For this purpose, first of all, some PTEs contained in the sepiolite mineral were analyzed by EDXRF technique, and then non-carcinogenic and carcinogenic risks were estimated based on the analysis results. According to the average concentration (mg/kg), PTEs analyzed in sepiolite samples were ordered as Al (5457) > Fe (3832) > Ti (361) > Mn (65) > V (42) > Zr (25) > Ni (24) > Cr (16) > Zn (12) > Co (9) > Cu (8) > As (5) > Pb (5) > Cd (4). The values of hazard quotient and hazard index estimated for non-carcinogenic risk and the incremental lifetime cancer risk and cancer risk index estimated for carcinogenic risk caused by PTEs in sepiolite samples were within the acceptable limit and the safe range except for the Beylikova quarry.

Keywords: Sepiolite, Potentially toxic element, Hazard index, Cancer risk.

1. INTRODUCTION

Today, various chemical, biological, and physical pollutants arising as a result of rapid population growth, industrialization, and excessive mining activities have become a major problem that adversely affects people, animals, plants, organisms, and ecosystems all over the world (Abbaslou & Bakhtiari, 2017; Tyagi et al., 2022; Kolawole et al., 2023). Contamination of agricultural soils, water resources, and food crops with potentially toxic elements (PTEs) as chemical pollutants remains a major environmental issue at the global due to their persistence in the environment, their tendency to bioaccumulate in the food chain, and their toxicity to humans, animals and plants (Rinklebe et al., 2019; Liu et al., 2020; Pham et al., 2022; Belanović et al., 2023; Agbasi et al., 2023). The main sources of PTEs are human activities such as chemical and metallurgical industries, mining, agriculture, combustion from vehicle emissions, power plants, and coal burning, etc. lithogenic sources such as volcanic eruptions and weathering of element-containing rocks (Marín et al., 2022). The availability of PTE and its toxicity effects on human health and other organisms depend on its chemical properties (Rinklebe et al., 2019). PTEs are generally classified as carcinogens and non-carcinogens. Carcinogenic PTEs contain arsenic (As), mercury (Hg), cadmium (Cd), lead (Pb), chromium (Cr), nickel (Ni), etc. (Agbasi et al., 2023). Non-carcinogenic PTEs such as Cu (copper), Fe (iron), Co (cobalt), Zn (zinc), and Mn (manganese) have functional roles and are essential for biochemical and physiological functions in humans (Niede & Benbi, 2022). Exposure to PTEs can cause serious health diseases such as cardiovascular problems, insomnia, insanity, cancer, Alzheimer, anemia, abdominal discomfort, depression, headache, constipation, cramping in the abdomen, exhaustion, irritability, etc. (Jaishankar et al., 2014; Golia et al., 2021; Niede & Benbi, 2022; Agbasi et al., 2023). Mining activities containing exploration, construction, operation (grinding the rock and ores, etc.) maintenance, expansion, abandonment, and dumping the waste into a tailing or holding pond may have negative impacts on the environment such as erosion, deforestation, contamination, and alteration of soil profiles, and an increase in dust and emissions (Haddaway et al., 2019). Türkiye has the largest mineral resources in the world and is an important industrial mineral (boron, sepiolite, feldspar, barite, marble, pumice, bentonite, gypsum, etc.). The proven sepiolite reserves of the world are approximately 80 million tons. The main raw sepiolite production is from quarries in Spain, followed by China, the United States, and Türkiye (Wang et al., 2018).

Sepiolite ($Mg_8Si_{12}O_{30}(OH)_4(OH_2)_4 \cdot 8H_2O$), which occurs naturally as a result of geological processes on Earth, is a natural fibrous magnesium-rich silicate clay mineral (He et al., 2020). Sepiolite is widely used in industrial applications such as agricultural carries, adhesives, industrial floor absorbents, drilling fluids, animal feed bonds, paint and coatings, paper, pharmaceuticals, polishes, suspension fertilizers, and raw materials in the ceramics and cement industry as it has superior absorbent, rheological and catalytic properties due to its unique crystalline tubular structure (Álvarez et al., 2011). Considering the mining of sepiolite and the widespread use of the sepiolite mineral in a wide variety of consumer products, it is inevitable that quarry workers, the general population, and the environment will be exposed to PTEs contained in sepiolite. Thus, there is a necessity for a study involving data on PTEs in sepiolite, which is associated with health risk concerns. Moreover, many previous studies investigated the mineralogical and radiometric characterization of sepiolite minerals and the removal of PTEs (or heavy metals) or radioactive elements in various environmental samples by using sepiolites (Doğan et al., 2008; Donat, 2009; Işık et al., 2010; Kadir et al., 2016; Suárez et al., 2016; Kocaoba, 2019; Hançerlioğulları et al., 2019; Bashir et al., 2020; He et al., 2020; Hamid et al., 2021; Tekin & Açıkel, 2023; Wang et al., 2023). However, there has never been a comprehensive study linking PTE levels in sepiolite minerals to human health risks for adults. This study particularly aims to (1) determine the levels of fourteen PTEs in thirty sepiolite samples collected from three quarries located in the Central Anatolian Region of Türkiye by using an energy dispersive X-ray fluorescence (EDXRF) spectrometry to estimate the potential environmental risk due to concentrations of PTEs in sepiolites and (2) evaluate the associated health risk for adults by estimating the non-carcinogenic (hazard quotient and hazard index) and carcinogenic (incremental lifetime cancer risk and cancer risk) index. By this way, this study represents the first attempt to raise the awareness of sepiolite consumers and mine workers about the presence of PTEs accompanying the sepiolite mineral and to establish a database on the distributions of PTEs in the three sepiolite quarries.

2. MATERIALS AND METHODS

2.1. Sample Collection and Preparation

A total of thirty sepiolite samples were collected randomly from sepiolite open quarries (SQs) located in Polatlı-Ankara (SQ1), Beylikova-Eskişehir (SQ2), and Sivrihisar-Eskişehir (SQ3) in Central Anatolia of Türkiye as shown in Figure 1 (Hançerlioğulları et al., 2019). Sepiolite samples were taken from the upper layers of each quarry, that is, from a depth of 0-5 cm. Each sepiolite sample placed in polyethylene bags was brought to the sample preparation laboratory. After the samples were kept in the open air in the laboratory for a while, they were dried in a furnace at 110 °C for 5-10 h to remove moisture. The dry samples were grounded and powdered to make them fit the calibrated powder geometry in the EDXRF spectrometer (Turhan et al., 2020; Altıkulaç et al., 2022). Each powder sample was homogenized with an agate pestle and made ready for elemental analysis (Turhan et al., 2020). The X-ray emission underlying the XRF technique is simple, systematic, relatively independent of the chemical state, and has uniform excitation and absorption based on an atomic number. Interference in the X-ray peak in the spectrum can be easily corrected, thus ensuring high accuracy and sensitivity easily. Wavelength and energy dispersive X-ray fluorescence spectrometers are utilized for qualitative and quantitative multi-element analysis in a sample of geological, archaeological, industrial, food, biological, and environmental and require minimal sample preparation compared to other chemical analytical analysis techniques (Oyedotun, 2018; Tyagi et al., 2022; Qingyu et al., 2023). Determination of PTEs in the sepiolite samples was carried out using an EDXRF spectrometer (Spectro Xepos, Ametek) equipped with an anode X-ray tube (50 W, 60 kV) consisting of a dual thick Pd/Co mixture. Detailed information on the spectrometer and analysis processes was given in detail in the study done by Turhan et al. (2020). The EDXRF has many different excitation conditions that guarantee the best detection of all elements from Na to U (Turhan et al., 2020). The spectral resolution of the system is lower than 155 eV. The EDXRF spectrometer has twelve automatic sampling devices and software to analyze samples at the same time. It uses sophisticated calibration techniques such as "no-standard" calibration, often based on the basic parameters method. Soil-certified reference material (NIST SRM 2709) was used for quality assurance of the EDXRF system (Turhan et al., 2020). Sample containers prepared for each sepiolite sample were placed in an automatic sampler and the analysis procedures were completed by counting for two hours. The total uncertainty of the analytical procedure is between 2% and 16%. The XRF spectrum of each sepiolite sample was assessed with the help of the software installed in the system.

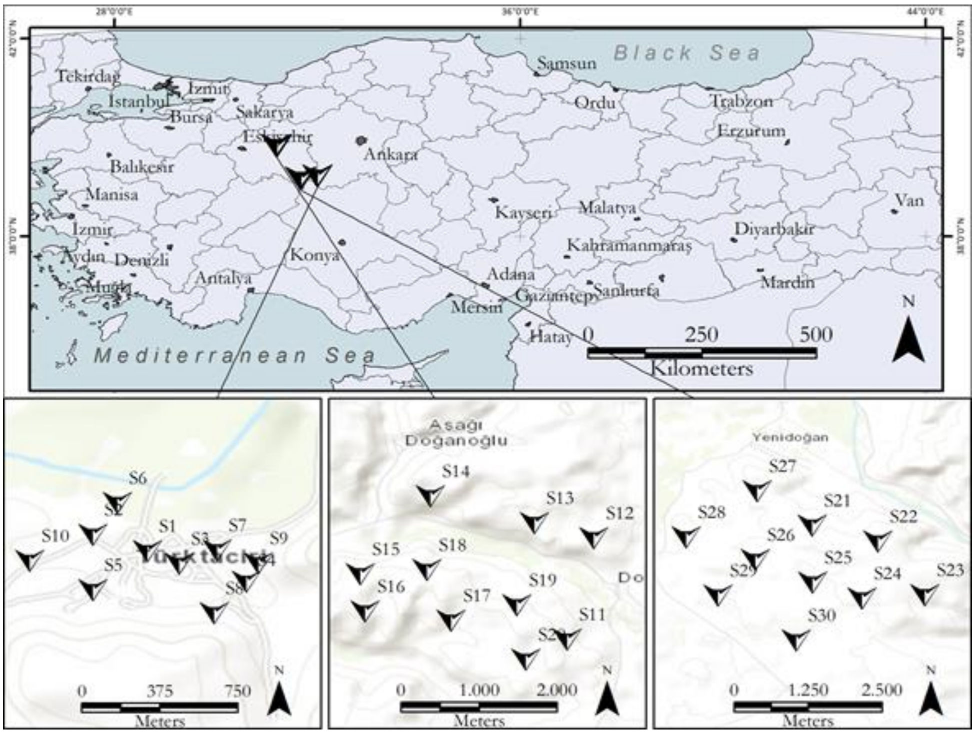

Figure 1. Locations of sampling points and sepiolite quarries (Hançerlioğulları et al., 2019).

2.2. Potential Health Risk Evaluation

Potential health risk evaluation is the process of estimating the nature and probability of adverse health effects on people who may be exposed to hazards in polluted or contaminated environmental media. Health risks of pollutants often include carcinogens and non-carcinogenic risks. This study accepted the potential health risk evaluation model recommended by the USEPA. The Ingestion of soil and dust is a potential way of exposure to environmental chemicals for both adults and children (USEPA, 2011). The cumulative non-carcinogenic risk and carcinogenic risk are represented by hazard index (HI) and carcinogenic risk (CR), respectively. The average daily dose (ADD) was calculated for adults as follows (Tyagi et al., 2022; Shentu et al., 2023):

$$\text{ADD (mg/kg/day)} = \frac{\text{C}\times\text{IR}\times\text{FE}\times\text{ED}\times10^{-6}}{\text{BM}\times\text{AT}} \quad (1)$$

where C is the PTE concentration in sepiolite samples (mg/kg); IR is the ingestion rate of soil and dust (100 mg/day) given for adults in Final Report prepared by USEPA (2011); ED is the average exposure duration of adults (79 y); FE is the frequency of exposure (365 day/y); BM is the average body weight of adults (77 kg) and AT is the average exposure time (79 y x 365 day/y) (TÜİK, 2022). Then, based on ADD value, the hazard quotient (HQ) for non-carcinogenic risk (HI) was calculated using the following equation (Tyagi et al., 2022; Shentu et al., 2023):

$$HQ = \frac{ADD}{R_f D} \quad (2)$$

$$HI = \sum_{i=1}^{n} HQ_i \quad (3)$$

where R_fD is the PTE oral reference dose and 1, 2, …, n are the individual PTE in the sepiolite samples. The RfD value for Al, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Sr, Cd, Ba and Pb was taken as 0.1, 0.009, 0.003, 0.14, 0.007, 0.0003, 0.02, 0.005, 0.3, 0.0003, 0.6, 0.0005, 0.2 and 0.0035 mg/kg/day, respectively (USEPA, 2012). For non-carcinogenic risk, values of HQ and HI > 1 indicate high potential adverse health effects (Tyagi et al., 2022; Shentu et al., 2023). Based on ADD value, the incremental lifetime cancer risk (ILCR) for carcinogenic risk (CR) was calculated for Cr, Ni, As, Cd, and Pb by using the following equation (Tyagi et al., 2022; Shentu et al., 2023):

$$ILCR = ADD \times SF \quad (4)$$

$$CR = \sum_{i=1}^{n} ILCR_i \quad (5)$$

where SF is the slope factor and is taken as 0.5, 1.7, 1.5, 6.1 and 0.0085 per mg/kg/day for Cr, Ni, As, Cd and Pb, respectively (USEPA, 2012). The safe range of CR risk is suggested as $10^{-6} < CR > 10^{-4}$. However, $CR > 10^{-4}$ indicates cancer risk and needs some sort of intervention and remediation (Shentu et al., 2023).

3. RESULTS AND DISCUSSION

3.1. Potentially Toxic Element Content of Sepiolites

Some descriptive statistical data (average, median, standard deviation, etc.) on the concentrations of PTEs analyzed in all sepiolite samples is given in Table 1. PTE concentration distributions in sepiolite quarries and Earth's crust average of PTE are presented in Table 2. It can be seen from Tables 1 and 2 that the concentrations of the PTEs in sepiolite samples vary depending on the geological and geochemical structure of the location of the quarries. According to the average values, the levels of PTEs analyzed in the sepiolite samples are ranked as Al > Fe > Ti > Mn > V > Zr > Ni > Cr > Zn > Co > Cu > As > Pb > Cd. According to the average values of PTEs, except for As and Cu, the sepiolite quarries are ranked in descending order as follows: SQ2 > SQ3 > SQ1.

Table 1. Some descriptive statistical data on concentration of PTEs in sepiolite samples.

PTE	PTE concentration (mg/kg)								N
	Average	**Median**	**SD**	**SE**	**Kurtosis**	**Skewness**	**Min**	**Max**	
Al	5456.5	2269.5	5201.3	949.6	-1.0	0.9	1281.0	15390.0	30
Ti	361.0	161.2	315.3	57.6	-1.0	0.9	109.6	942.7	30
V	42.0	21.6	31.2	5.7	-1.4	0.4	3.5	104.4	30
Cr	15.5	5.3	16.6	3.0	-0.2	1.1	1.8	54.8	30
Mn	65.2	43.7	40.4	7.4	-0.6	1.0	19.6	158.2	30
Fe	3831.5	1655.5	3451.8	630.2	-1.1	0.9	942.7	9853.0	30
Co	8.6	6.2	6.9	1.3	-1.0	0.7	2.1	22.6	30
Ni	23.7	10.5	21.0	3.8	-1.1	0.9	7.4	61.0	30
Cu	7.8	4.9	5.5	1.0	-1.0	0.8	2.6	18.2	30
Zn	11.8	7.8	6.7	1.2	-1.3	0.7	5.2	24.9	30
As	5.3	4.0	4.4	0.8	-1.0	0.7	0.8	13.4	30
Zr	25.3	26.9	3.0	1.0	-1.7	-0.4	21.3	29.2	10
Cd	3.7	3.4	1.0	0.3	-0.7	0.3	2.1	5.4	10
Pb	5.3	5.5	1.4	0.3	1.9	-1.3	1.4	7.2	26

SE: standard error; SD: standard deviation.

Table 2. The average and range (min-max) of concentrations of PTEs in sepiolite quarries.

PTE	Concentration (mg/kg)						
	SQ1		SQ2		SQ3		Earth's crust
	Average	**Range**	**Average**	**Range**	**Average**	**Range**	
Al	1808.7	1281-273	12432.3	8141-15390	2128.4	1690-2700	80500
Ti	136.5	109.6-153.3	786.2	524.2-942.7	160.2	124-226.8	4500
V	26.6	3.5-75.9	68.1	47.5-85.4	31.2	11.5-104.4	90
Cr	4.4	2.6-6.1	37.2	25.3-54.8	4.9	1.8-10.5	83
Mn	37.7	19.6-45.7	117.6	70.2-158.2	40.2	26.2-47.0	1000

Table 2. (continued)

PTE	Concentration (mg/kg)						
	SQ1		SQ2		SQ3		Earth's crust
	Average	Range	Average	Range	Average	Range	
Fe	1432.9	942.7-1962.0	8457.5	4824-9853	1604.2	1245-2305	46500
Co	4.0	2.1-10.0	17.2	11.1-22.6	4.5	2.4-10.8	18
Ni	9.0	7.4-10.9	52.0	34.8-61.0	10.1	8.4-12.6	58
Cu	4.2	2.6-6.2	15.2	10.9-18.2	4.1	2.7-5.9	47
Zn	8.0	5.2-21.5	18.9	12.7-24.9	8.4	6.1-21.8	83
As	2.6	1.4-4.7	11.1	7.8-13.4	2.4	0.8-5.3	1.7
Zr	< 1.0	25.3	21.3-29.2	< 1.0	170		
Cd	< 2.0	3.7	2.1-5.4	< 2.0	0.13		
Pb	4.6	1.9-6.1	6.1	5.1-7.2	5.1	1.4-7.1	16

It can be seen from Table 1 that the concentrations of Al in all samples varied from 1281 to 15390 mg/kg with an average value of 5457 mg/kg. From Table 2, the highest average concentration (HAC) value of Al was analyzed in the sepiolite samples (S17) from the SQ2 quarry while the lowest average concentration (LAC) value was in the sepiolite samples (S2) from the SQ1 quarry. The average Al concentration is significantly lower than the earth's crust average of 80500 mg/kg (Yaroshevsky, 2006). The concentrations of Fe in all samples varied from 943 to 9853 mg/kg with an average value of 3832 mg/kg. The HAC value of Fe was analyzed in the sepiolite samples (S12) from the SQ2 quarry while the LAC value was in the sepiolite samples (S9) from the SQ1 quarry. The average Fe concentration is significantly lower than the earth's crust average of 46500 mg/kg (Yaroshevsky, 2006). The concentrations of Sr in all samples varied from 135 to 2129 mg/kg with an average value of 1183 mg/kg. The HAC value of Sr was analyzed in the sepiolite samples (S1) from the SQ1 quarry while the LAC value was in the sepiolite samples (S11) from the SQ2 quarry. The concentrations of Ti in all samples varied from 110 to 943 mg/kg with an average value of 361 mg/kg. The HAC value of Ti was analyzed in the sepiolite samples (S12) from the SQ2 quarry while the LAC value was in the sepiolite samples (S9) from the SQ1 quarry. The average Ti concentration is significantly lower than the earth's crust average of 4500 mg/kg (Yaroshevsky, 2006). The concentrations of Mn in all samples varied from 20 to 158 mg/kg with an average value of 65 mg/kg. The HAC value of Mn was analyzed in the sepiolite samples (S20) from the SQ2 quarry while the LAC value was in the sepiolite samples (S9) from the SQ1 quarry. The average Mn concentration significantly is lower than the earth's crust average of 1000 mg/kg (Yaroshevsky, 2006). The concentrations of V in all samples varied from 4 to 104 mg/kg with an average value of 42 mg/kg. The HAC value of V was analyzed in the sepiolite samples (S28) from the SQ3 quarry while the LAC value was in the sepiolite samples (S2) from the SQ1 quarry. The average V concentration is lower than the earth's crust average of 90 mg/kg (Yaroshevsky, 2006). The concentration of Zr analyzed only in sepiolite samples collected from the SQ2 quarry varied from 21 to 29 mg/kg with an average value of 25 mg/kg. The HAC value of Zr was analyzed in the sepiolite samples (S13) from the SQ2 quarry while the LAC value was in the sepiolite samples (S18) from the SQ2 quarry. The average Zr concentration is significantly lower than the earth's crust average of 170 mg/kg (Yaroshevsky, 2006). The concentrations of Cr in all samples varied from 2 to 55 mg/kg with an average value of 83 mg/kg. The HAC value of Cr was analyzed in the sepiolite samples (S14) from the SQ2 quarry while the LAC value was in the sepiolite samples (S23) from the SQ3 quarry. The average Cr concentration is lower than the earth's crust average of 83 mg/kg (Yaroshevsky, 2006). The concentrations of Zn in all samples varied from 5 to 25 mg/kg with an average value of 12 mg/kg. The HAC value of Zn was analyzed in the sepiolite samples (S12) from the SQ2 quarry while the LAC value was in the sepiolite samples (S10) from the SQ1 quarry. The average Zn concentration is lower than the earth's crust average of 83 mg/kg (Yaroshevsky, 2006). The concentrations of Co in all samples varied from 2 to 23 mg/kg with an average value of 9 mg/kg. The HAC value of Co was analyzed in the sepiolite samples (S12) from the SQ2 quarry while the LAC value was in the sepiolite samples (S4) from the SQ1 quarry. The average Co concentration is lower than the earth's crust average of 18 mg/kg (Yaroshevsky, 2006). The concentrations of Cu in all samples varied from 3 to 18 mg/kg with an average value of 8 mg/kg. The HAC value of Cu was analyzed in the sepiolite samples (S15) from the SQ2 quarry while the LAC value was in the sepiolite samples (S1) from the SQ1 quarry. According to the average values of Cu, the sepiolite quarries are ranked in descending order as follows: SQ2 > SQ1 > SQ3. The average Cu concentration is lower than the earth's crust average of 47 mg/kg (Yaroshevsky, 2006). The concentrations of As in all samples varied from 1 to 13.4 mg/kg with an average value of 5 mg/kg. The HAC value of As was analyzed in the sepiolite samples (S19) from the SQ2 quarry while the LAC value was in the sepiolite samples (S26) from the SQ3 quarry. According to the average values of As the sepiolite quarries are ranked in descending order as follows: SQ2 > SQ1 > SQ3. The average As concentration is approximately three times higher than the earth's crust average of 1.7 mg/kg (Yaroshevsky, 2006). The concentration of Pb analyzed only in 26 sepiolite samples varied from 1.4 to 7 mg/kg with an average value of 5 mg/kg. The HAC value of Pb was analyzed in the sepiolite samples (S15) from the SQ2 quarry while the LAC value was in the sepiolite samples (S21) from the SQ3 quarry. The average Pb concentration is lower than the earth's crust average of 16 mg/kg (Yaroshevsky, 2006). The concentration of Cd analyzed only in sepiolite samples collected from the SQ2 quarry varied from 2 to 5 mg/kg with an average value of 4 mg/kg. The HAC value of Zr was analyzed in the sepiolite samples (S18) from the SQ2 quarry while the LAC value was in the sepiolite samples (S16) from the SQ2 quarry. The average Cd concentration is significantly higher than the earth's crust average of 0.13 mg/kg (Yaroshevsky, 2006).

3.2. Human Health Risk Evaluation

The values of the average daily dose, health quotient, hazard index, incremental lifetime cancer risk, and cancer risk estimated for PTEs analyzed in the investigated sepiolite samples are summarized in Table 3. The ADD values varied from 4.8 x 10^{-6} mg/kg/day (Cd) to 7.1 x 10^{-3} (Al) mg/kg/day. The average ADD values of the PTEs decreased in the following order: Al < Fe < Ti < Mn < V < Zr < Ni < Cr < Zn < Co < Cu < As < Pb < Cd. The HQ values estimated for the PTEs in the investigated sepiolite samples varied from 0.0001 (Zn) to 0.7109 (Fe). The average HQ values of the PTES were found in the descending order of Fe < Al < Co < As < Cd < Cr < V < Cu < Pb < Ni < Mn < Zn. The HQ values estimated for adults revealed that there is no individual PTE posed a significant non-carcinogenic risk (HQ < 1). The combined non-carcinogenic health risk HI values estimated for all samples varied from 0.2 to 2.2 with an average of 0.9. Although the average HI values were below the safe limit of 1, HI values calculated for sepiolite samples (33% of the total sample) from the SQ2 quarry varied from 1.2 to 2.2 with an average of 1.9, implying a non-negligible risk to adults.

Table 3. Non-carcinogenic and carcinogenic risks to adults from PTEs in sepiolite samples.

PTE		ADD (mg/kg/day)	HQ	ILCR
Al	Average	7.1 x 10^{-3}	7.1 x 10^{-2}	-
	Range	1.7 x 10^{-3} - 2.0 x 10^{-2}	1.7 x 10^{-2} - 2.0 x 10^{-1}	-
V	Average	5.4 x 10^{-5}	6.1 x 10^{-3}	-
	Range	4.5 x 10^{-6} - 1.4 x 10^{-4}	5.1 x 10^{-4} - 1.5 x 10^{-2}	-
Cr	Average	2.0 x 10^{-5}	6.7 x 10^{-3}	1.0 x 10^{-5}
	Range	2.3 x 10^{-6} - 7.1 x 10^{-5}	7.8 x 10^{-4} - 2.4 x 10^{-2}	1.2 x 10^{-6} - 3.6 x 10^{-5}
Mn	Average	8.5 x 10^{-5}	6.0 x 10^{-4}	-
	Range	2.5 x 10^{-5} - 2.1 x 10^{-4}	1.8 x 10^{-4} - 1.5 x 10^{-3}	-
Fe	Average	5.0 x 10^{-3}	7.1 x 10^{-1}	-
	Range	1.2 x 10^{-3} - 1.3 x 10^{-2}	1.7 x 10^{-1} - 1.8	-
Co	Average	1.1 x 10^{-5}	3.7 x 10^{-2}	-
	Range	2.7 x 10^{-6} - 2.9 x 10^{-5}	9.1 x 10^{-3} - 9.8 x 10^{-2}	-
Ni	Average	3.1 x 10^{-5}	1.5 x 10^{-3}	5.2 x 10^{-5}
	Range	9.6 x 10^{-6} - 7.9 x 10^{-5}	4.8 x 10^{-4} - 4.0 x 10^{-3}	1.6 x 10^{-5} - 1.3 x 10^{-4}
Cu	Average	1.0 x 10^{-5}	2.0 x 10^{-3}	-
	Range	3.4 x 10^{-6} - 2.4 x 10^{-5}	6.8 x 10^{-4} - 4.7 x 10^{-3}	-
Zn	Average	1.5 x 10^{-5}	5.1 x 10^{-5}	-
	Range	6.8 x 10^{-6} - 3.2 x 10^{-5}	2.3 x 10^{-5} - 1.1 x 10^{-4}	-

Table 3. (continued)

PTE		ADD (mg/kg/day)	HQ	ILCR
As	Average	6.9×10^{-6}	2.3×10^{-2}	1.0×10^{-5}
	Range	1.0×10^{-6} - 1.7×10^{-5}	3.5×10^{-3} - 5.8×10^{-2}	1.6×10^{-6} - 2.6×10^{-5}
Zr	Average	3.3×10^{-5}	-	-
	Range	2.8×10^{-5} - 3.8×10^{-5}	-	-
Cd	Average	4.8×10^{-6}	9.6×10^{-3}	2.9×10^{-5}
	Range	2.7×10^{-6} - 7.0×10^{-6}	5.5×10^{-3} - 1.4×10^{-2}	1.7×10^{-5} - 4.3×10^{-5}
Pb	Average	6.9×10^{-6}	2.0×10^{-3}	5.9×10^{-8}
	Range	1.8×10^{-6} - 9.4×10^{-6}	5.2×10^{-4} - 2.7×10^{-3}	1.5×10^{-8} - 7.9×10^{-8}
HI=∑HQ	Average		0.9	
	Range		0.2-2.2	
CR=∑ILCR	Average			8.3×10^{-5}
	Range			2.4×10^{-5} - 2.3×10^{-4}

The average ILCR estimated for Ni, As, Cd, Cr and Pb in the sepiolite samples varied from 5.9×10^{-8} to 5.2×10^{-5}. The average values for ILCR were found in the order of Ni > Cd > As > Cr > Pb. The values of the carcinogenic risk index were within the safe index range of 10^{-6} to 10^{-4}. However, the combined carcinogenic health risk CR values estimated for all samples varied from 2.4×10^{-5} to 2.3×10^{-4} with an average of 8.3×10^{-5}. Although the average CR was within the safe limit, the CR values for 33% of the total samples collected from SQ2 exceeded the safety limit.

4. CONCLUSION

In this study, for the first time, (1) the concentrations of PTEs (Al, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Zr, Cd, and Pb) in sepiolite samples from three selected commercial quarries located in the Central Anatolian region of Türkiye were analyzed, and (2) potential non-carcinogenic and carcinogenic health risk caused by PTEs contained in the investigated sepiolite samples was evaluated. Analysis results revealed that the average concentration of As and Cd in sepiolite samples was higher than the Earth's crust averages. Potential health risk evaluation results indicated that some PTEs in sepiolite samples from the SQ2 quarry may pose carcinogenic and non-carcinogenic risks to adults and quarry workers. Therefore, at least, it should be necessary to take necessary precautions such as not breathing dust to eliminate situations that may threaten the health of the quarry workers. In conclusion, this study highlighted the status of potentially toxic elements, enrichment factors, and risk characterization in sepiolite minerals. The data are information that can create awareness for both those who use sepiolite-added products and those who work in the quarries.

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