

Research article

THE EUROPEAN HARE (*LEPUS EUROPAEUS*) AS A BIOMONITOR OF SELECTED HEAVY METAL POLLUTION IN THE MARMARA REGION, TÜRKİYE

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ABSTRACT

Since the early twentieth century, human-induced environmental pollution has reached levels that pose significant risks to the health of living organisms. The Marmara Region, located in northwestern Türkiye, is the most developed region of the country, with its industrial, commercial, tourism, and agricultural sectors holding significant importance compared to other regions. Therefore, the region is heavily affected by pollutant sources from various sectors. The aim of this study is to assess the levels of chromium (Cr), manganese (Mn), copper (Cu), zinc (Zn), arsenic (As), selenium (Se), cadmium (Cd), lead (Pb), and mercury (Hg) residues in the skin and muscle samples of European hares (*Lepus europaeus*) from the Marmara Region of Türkiye, to evaluate the environmental metal pollution and habitat quality in this region. Significant variations were recorded among the concentrations of heavy metals studied in the selected tissues. The highest average concentrations in the skin were recorded for Cr (8.69 mg/kg), Mn (3.27 mg/kg), Zn (48.37 mg/kg), As (0.07 mg/kg), Se (0.29 mg/kg), Cd (0.39 mg/kg), and Pb (1.12 mg/kg), while the concentrations of Cu (4.59 mg/kg) and Hg (0.03 mg/kg) were highest in muscle tissues. Correlation analyses revealed statistically significant relationships between metal concentrations accumulated in different tissues. The concentrations of Pb (in 27 out of 52 samples, 51.92%), Cd (in all 42 samples, 100%), Cr (in 47 out of 52 samples, 90.38%), and Hg (in 9 out of 52 samples, 16.98%) in the muscles of hares exceeded the maximum permissible limits (hygiene limits) stipulated in the regulations. Additionally, Pearson correlation analysis showed varying degrees of significant correlations among the heavy metals studied in European hares and confirmed the influence of various anthropogenic pollutant sources in the study area.

Key words:

European hare, biomonitor, muscle, skin, environmental metals pollution, hygienic limits

Citation:

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INTRODUCTION

With continuous industrial growth, accumulation of uncontrolled industrial waste, especially metals and their compounds, has led to widespread environmental contaminations and the emergence of their harmful effects. Heavy

metals, in particular, can accumulate in biological systems and, when reaching toxic concentrations, can cause serious diseases and deaths. Therefore, monitoring the levels of metals and their compounds in the environment and living organisms is extremely important. Metals essential for the human health (e.g. Cu, Se, Zn) and non-essential metals (e.g. As, Cd, Pb) are primarily ingested through food, as well as other pathways (such as water and air). This accumulation results in a "body metal burden", as some metals (such as aluminum, lead, magnesium, manganese, chromium, and cadmium) accumulate with age, leading to increased concentrations in the body over time (Başkan, 2010; Aslanhan, 2012; Türközü and Şanlıer, 2012; Naccari et al., 2013; Malmsten et al., 2021; Draghi et al., 2023; Ali et al., 2023; Petrović et al., 2024). Environmental pollution caused by heavy metals presents significant challenges, not only for tourism and agricultural industries but also for public health. Many metals have neurotoxic, carcinogenic, and mutagenic properties (Durube et al., 2007; Başkan, 2010; Briffa et al., 2020; Ali et al., 2023; Radfard et al., 2023). Nkosi et al. (2021) noted that game meat consumption raises public health concerns due to the presence of toxic metal residues. Furthermore, many compounds are known to cause DNA damage, and when cells with damaged DNA divide, they produce mutant cells. The relationship between mutations in somatic cells and cancer-causing events has long been established (Güven, 1999; Başkan, 2010; Luzzatto, 2011; Martincorena and Campbell, 2015; Akdemir et al., 2020).

Wild mammals with natural diets and relatively long lifespans, such as the red fox, wild boar, roe deer, mink, fallow deer, red deer, and jackal, have been recognized as effective biomonitors of trace elements in biological tissues, providing valuable insights into habitat pollution (Wren, 1986; Medvedev, 1999; Tataruch and Kierdorf, 2003; Kramářová et al., 2005; Filistowicz et al., 2011, 2012; Srebočan et al., 2011; Demirbaş and Erduran, 2017; Yarsan et al., 2014; Ćirović et al., 2015; Cokoski et al., 2023, 2024). Owing to their diverse natural habitats, high population density, wide geographic distribution, and herbivorous diet, the European hare (*Lepus europaeus*) is considered one of the essential species for assessing heavy metal pollution levels. In addition, its limited range of movement makes it particularly suitable for biomonitoring of localized environmental pollution (Tataruch & Kierdorf, 2003; Massányi et al., 2003; Wajdzik, 2006; Petrović et al., 2013; Beuković et al., 2022, 2023). In Türkiye, the European hare inhabits a diverse range of ecosystems, including forests, open steppe areas, and agricultural lands, and is an important game species (Demirbaş, 2015; Demirbaş & Erduran, 2017). This species can accumulate large amounts of pollutants in tissues such as liver, kidney, and muscle (Demirbaş & Erduran, 2017; Pilarczyk et al., 2020; Beuković et al., 2022, 2023). Additionally, skin and hair tissues of wild animals are considered valuable bioindicators for assessing metal pollution in wild animals, as they reflect environmental quality in both urban and rural areas (Filistowicz et al., 2011; Naccari et al., 2013). Long-term chemical accumulation in such terrestrial ecosystems serves as an early warning of potential toxic effects from environmental pollution. Therefore, it should be monitored and assessed periodically. To ensure accurate interpretation and comparability of results, information about the species' dietary habits, lifestyle, sampling period (seasonal variations), and the age of individuals must be considered (Tataruch & Kierdorf, 2003; Bilandžić et al., 2012; Srebočan et al., 2011; Yarsan et al., 2014; Tekeli et al., 2021; Beuković et al., 2022; Boişteanu et al., 2024).

Although habitat pollution is recognized as one of major causes of the decline in natural populations, studies on heavy metal contamination in wild mammalian game species in Türkiye have been limited (Yarsan et al., 2014; Demirbaş & Erduran, 2017; Tekeli et al., 2021). Yarsan et al. (2014) reported high levels of heavy metals in hair samples of wild boars in Antalya province (Western Mediterranean Region). Demirbaş & Erduran (2017) found that the meat and offal of European hares and wild boars from Kırıkkale province (Central Anatolia Region) were contaminated with heavy metals above hygienic levels. These studies also stressed that high concentrations of some heavy metals could be an environmental issue and that most wild animal species are natural components of the human food chain. Tekeli et al. (2021) analyzed muscle, liver, and kidney tissues of wild boars from Hatay province (Eastern Mediterranean Region), which is an ecologically significant area characterized by intensive industrial and agricultural activities, concluding that the region needs continued monitoring of major environmental pollutants, especially Cd and Pb metals.

The aim of this study is to assess environmental metal pollution in the Marmara Region, Türkiye, by examining the presence of chromium (Cr), manganese (Mn), copper (Cu), zinc (Zn), arsenic (As), selenium (Se), cadmium (Cd), lead (Pb), and mercury (Hg) in the skin and muscle samples of European hares.

MATERIAL AND METHODS

Study area

The Marmara Sea, the country's smallest inland sea, is located in the northwest of Türkiye, stretching along the west-east axis and dividing the Marmara Region into North Marmara (the European side of Marmara, Turkish Thrace) and South Marmara (the Anatolian side of Marmara), Figure 1. The Marmara Region is the most developed region in the

country, with more developed industrial, commercial, tourism, and agricultural sectors compared to other regions. Consequently, it is heavily affected by pollutant sources from various sectors. The region also has the highest population and energy consumption, with the Çatalca-Kocaeli section being the primary population center. Maritime transport has been reported as the major contributor to air pollution in the Marmara Region compared other sectors. Istanbul, Kocaeli, Sakarya, Bilecik, and Bursa are among the provinces with the highest industrial density in Türkiye. Istanbul is a large city with high population density and extensive international air and sea traffic, located on the highways connecting Asia and Europe. The city accounts for 20% of Türkiye's industrial employment and 38% of its industrial facilities (Başkan, 2010; Kılıç et al., 2014). Overall, approximately one-third of Türkiye's total employment and half of its industrial employment are in this region. Geographically, it is the sixth largest region in Türkiye, covering about 66,000 km², which is 8.5% of the country's total area. The most important feature of the Marmara Region's climate is its transitional nature. The region receives an average of 600 - 700 mm of rainfall, with average annual temperatures ranging 15-16 °C. The Marmara Region contains 13% of Türkiye's forests.

Sample collection

This study used 58 skin samples (30 from North Marmara and 28 from South Marmara) and 53 muscle samples (18 from North Marmara and 35 from South Marmara) of adult European hares obtained from hunters during the legal hunting seasons of 2022 and 2023 (mid-October to mid-January), Figure 1. Sample collection was carried out in cooperation with hunting organizations and conducted with research permit obtained from the General Directorate of Nature Conservation and National Parks of the Ministry of Agriculture and Forestry of Türkiye (Permit No: E-21264211-288.04-7112268). No animals were killed for this study. All skin and muscle samples were obtained from specimens hunted by hunters. Muscle samples were collected from the cheek area, while skin samples were taken from the ear of the animals. Age determination of the animals was based on several criteria, including the presence or absence of the swelling at the end of the ulna bone of the forelimb, referred to as the "Stroh Sign" (Stroh, 1931), the prominence of the joints of the bones in the skull (frontal and sagittal sutures), and the structure of the supraorbital process (Suchentrunk et al., 2000). Following collection, skin and muscle samples were placed in plastic bags, labeled, and stored at -20°C in a deep freezer until further analysis.

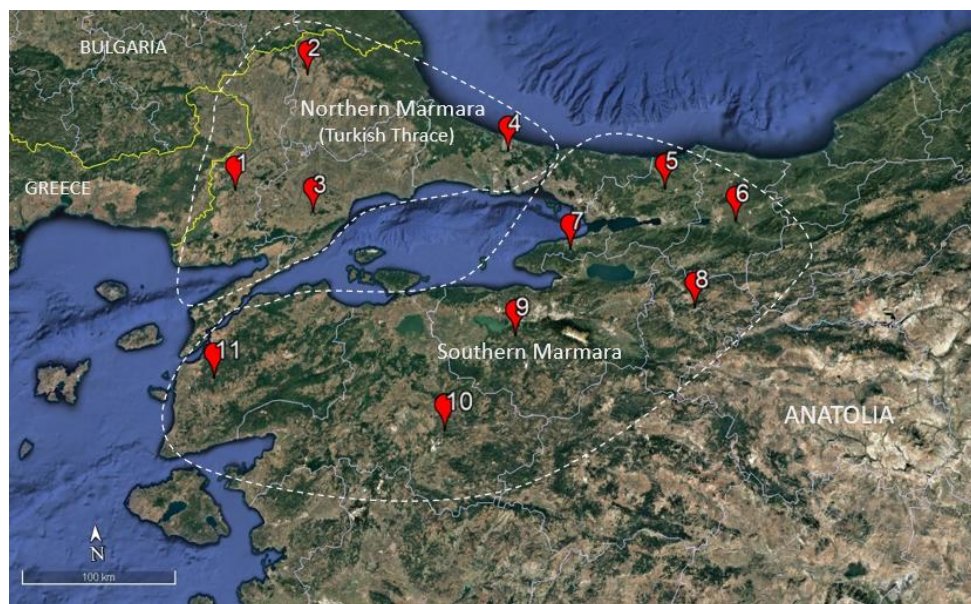


Figure 1. Sampling locations of European hare individuals included in the study: 1-Edirne; 2-Kırklareli; 3-Tekirdağ; 4-Istanbul; 5-Kocaeli; 6-Sakarya; 7-Yalova; 8-Bilecik; 9-Bursa; 10-Balıkesir; 11-Çanakkale

Determination of heavy metals

For heavy metal analysis, approximately 1 g of each skin and muscle sample was taken and placed in 50 mL erlenmeyer flasks. The samples were kept in an oven (Nüve) at 75°C for 17 hours. To solubilize the dried samples, 3 mL of concentrated HNO₃ (65% v/v Merck) was added to the samples and kept in a shaking water bath overnight. To accelerate the oxidation process, 2.5 mL of H₂O₂ (35% v/v Merck) was added and the samples were kept in an oven at 110°C for 3.5 hours until clear (Amici et al., 2012; Tekeli et al., 2021). At the end of this period, the cooled samples were diluted to a final volume of 30 mL with pure water and stored in capped polyethylene tubes.

The concentrations of heavy metals and metalloids, including Cr, Mn, Cu, Zn, As, Se, Cd, Hg, and Pb, were measured on a wet weight basis. An Inductively Coupled Plasma – Optical Emission Spectrometer (ICP-OES) device was used to determine the heavy metal concentrations in the samples. The results obtained from the ICP-OES device were multiplied by the dilution volume and divided by the sample mass, expressed as mg kg⁻¹. Hygiene limits for Pb, Cd, Cr, Hg, and As were obtained from the Turkish Food Codex, [Piskorová et al. \(2003\)](#), and [Gulin et al. \(2023\)](#). There are no established limit levels for the remaining heavy metal concentrations in the analyzed tissues.

Statistical analyses

Since the heavy metal concentrations are not normally distributed, statistical comparisons between sexes and tissues, as well as regional comparisons, were conducted using the Mann-Whitney U test. The results of Mann-Whitney U test showed no differences in the measured heavy metal concentration values between male and female individuals, so the data from both sexes were combined in further analyses. Correlations between heavy metal concentrations in different tissue samples were calculated using the Pearson correlation coefficient. Statistical significance was set at $p < 0.05$. Statistical analyses were performed using the SPSS v. 23.0 (IBM, USA) software package.

RESULTS AND DISCUSSION

The average concentrations of Cr, Mn, Cu, Zn, As, Se, Cd, Pb, and Hg in the tissues of hares in the Northern Marmara (Turkish Thrace) and Southern Marmara (Anatolian part of Marmara) regions are presented in [Table 1](#). Significant differences were found in the concentrations of Mn, Zn, As, Se, Cd, and Pb among the tissues of hares in the North Marmara region, while significant differences in Cr, Mn, Cu, and Cd concentrations were found among the tissues of samples obtained from the South Marmara region ($p < 0.05$). Additionally, significant regional differences were detected in the concentrations of Cr, Mn, Cu, Zn, Se, and Pb in the skin samples and Cu, As, and Cd in the muscle samples between European hares from the two regions.

Table 1. Average concentrations (mg/kg) and comparisons of results for nine heavy metals in the tissues of European hares (*Lepus europaeus*) from the North and South Marmara Regions

Heavy metals	Region	Skin	Muscle	P_{MW}
Cr	North Marmara	8.69 ± 8.21	5.47 ± 11.21	0.083
	South Marmara	2.77 ± 3.97	6.79 ± 9.99	0.019*
	P_{MW}	0.003*	0.501	
Mn	North Marmara	3.27 ± 2.04	0.57 ± 0.29	0.000*
	South Marmara	2.48 ± 2.02	0.62 ± 0.26	0.000*
	P_{MW}	0.030*	0.829	
Cu	North Marmara	3.12 ± 1.9	3.57 ± 1.31	0.160
	South Marmara	1.83 ± 0.84	4.59 ± 1.58	0.000*
	P_{MW}	0.001*	0.025*	
Zn	North Marmara	48.37 ± 23.9	19.37 ± 7.68	0.000*
	South Marmara	26.78 ± 16.96	22.14 ± 8.3	0.719
	P_{MW}	0.000*	0.645	
As	North Marmara	0.05 ± 0.03	0.02 ± 0.04	0.000*
	South Marmara	0.07 ± 0.09	0.03 ± 0.02	0.037
	P_{MW}	0.748	0.005*	
Se	North Marmara	0.29 ± 0.12	0.15 ± 0.08	0.000*
	South Marmara	0.19 ± 0.17	0.18 ± 0.17	0.524
	P_{MW}	0.001*	0.954	
Cd	North Marmara	0.39 ± 0.06	0.26 ± 0.06	0.000*
	South Marmara	0.38 ± 0.01	0.18 ± 0.08	0.000*
	P_{MW}	0.312	0.003*	
Pb	North Marmara	1.12 ± 1.91	0.28 ± 0.43	0.007*
	South Marmara	0.43 ± 1.14	0.25 ± 0.34	0.830
	P_{MW}	0.003*	0.891	
Hg	North Marmara	0.01 ± 0.01	0.03 ± 0.04	0.226
	South Marmara	0.02 ± 0.01	0.03 ± 0.05	0.380
	P_{MW}	0.085	0.531	

Legend: P_{MW} - significance level of Mann-Whitney U-test

Correlation analyses revealed statistically significant relationships between metal concentrations accumulated in different tissues. In the North Marmara region, significant correlations were found between Cu, Zn, and Se concentrations in both skin and muscle tissues ($r = 0.646$, $p = 0.04$; $r = 0.787$, $p = 0.000$; $r = 0.822$, $p = 0.000$, respectively). Furthermore, significant correlations were detected between Mn and As ($r = 0.733$, $p = 0.000$); Cu and Zn ($r = 0.837$, $p = 0.000$); Cu and Cd ($r = 0.787$, $p = 0.000$); Zn and Se ($r = 0.771$, $p = 0.000$); and Zn and Cd ($r = 0.752$, $p = 0.000$) concentrations in the skin samples of hares from this region. In the muscle samples, significant correlations were observed between Cr and Cd; Mn and Cu; Mn and Zn; Mn and Se; Cu and Zn; Cu and Pb; Zn and Se; and As and Pb ($r = -0.941$, $p = 0.000$; $r = 0.663$, $p = 0.003$; $r = 0.923$, $p = 0.000$; $r = 0.772$, $p = 0.000$; $r = 0.839$, $p = 0.000$; $r = 0.650$, $p = 0.005$; $r = 0.827$, $p = 0.000$; and $r = 0.838$, $p = 0.000$, respectively) in all North Marmara hare samples (Table 2).

In South Marmara region, significant correlations were found between Cr and Mn; Cr and Cu; Cr and Zn; Mn and Cu; Cu and Zn; Cu and Se; Cu and Hg; Zn and Se; Zn and Hg and As and Cd ($r = 0.706$, $p = 0.000$; $r = 0.822$, $p = 0.000$; $r = 0.738$, $p = 0.000$; $r = 0.633$, $p = 0.000$, $r = 0.959$, $p = 0.000$; $r = 0.625$, $p = 0.000$; $r = -0.708$, $p = 0.000$; $r = 0.653$, $p = 0.000$; $r = -0.713$, $p = 0.000$; $r = -0.900$, $p = 0.006$, respectively) in the skin hare samples. In the muscle samples, significant correlations were found between Mn and Cu; Mn and Zn; and Cu and Cd concentrations ($r = 0.667$, $p = 0.000$; $r = 0.772$, $p = 0.000$; $r = -0.665$, $p = 0.000$, respectively), Table 3.

The concentrations of Pb, Cd, Cr, and Hg found in muscle samples were compared with established hygienic limits (Pb- 0.1 mg/kg; Cd- 0.05 mg/kg; Cr- 0.5 mg/kg; and Hg- 0.03 mg/kg). Our results showed that Pb concentration in 30 muscle samples (57.59%), Cd concentration in all samples, Cr concentration in 47 samples (90.38%), and Hg concentration in 9 samples (16.98%) were above the hygienic limits.

Table 2. Correlations between heavy metals determined in skin and muscle tissues of hares in the Northern Marmara Region

Heavy Metal	Cr	Mn	Cu	Zn	As	Se	Cd	Pb	Hg
Cr	1	0.166	0.431*	0.394*	0.009	0.261	0.131	-0.096	-0.302
Mn	0.217	1	0.442*	0.450*	0.733**	0.407*	0.251	-0.014	-0.183
Cu	0.381	0.663**	1	0.837**	0.423*	0.464**	0.787**	0.169	-0.320
Zn	0.221	0.923**	0.839**	1	0.286	0.771**	0.752**	0.210	-0.484**
As	-0.055	-0.427	-0.294	-0.439	1	0.246	0.065	0.171	-0.121
Se	-0.017	0.772**	0.580*	0.827**	-0.36	1	0.308	0.146	-0.473**
Cd	-0.941**	0.176	-0.329	0.182	-0.046	0.269	1	0.402	0.145
Pb	0.534*	0.329	0.650**	0.484*	0.838**	0.076	-0.394	1	0.089
Hg	0.006	-0.078	-0.017	-0.056	-0.088	0.073	-0.026	-0.024	1

Legend: * - correlation is significant at the 0.05 level; ** - correlation is significant at the 0.01 level. The yellow marked text shows correlations between heavy metals in the skin of hares, while green marked text values below the diagonal indicate correlations between heavy metals in muscle tissue.

Table 3. Correlations between heavy metals determined in skin and muscle tissues of hares in the Southern Marmara Region

Heavy Metal	Cr	Mn	Cu	Zn	As	Se	Cd	Pb	Hg
Cr	1	0.706**	0.822**	0.738**	0.411*	0.529**	-0.004	0.403*	-0.504**
Mn	0.069	1	0.633**	0.500**	0.585**	0.198	-0.324	0.236	-0.401*
Cu	0.345*	0.677**	1	0.953**	0.24	0.625**	0.654	0.286	-0.708**
Zn	0.138	0.772**	0.568**	1	0.116	0.653**	0.683	0.232	-0.713**
As	-0.099	0.461**	0.231	0.444*	1	0.278	-0.900**	0.331	-0.225
Se	-0.119	0.26	0.278	0.23	0.33	1	0.055	0.284	-0.547**
Cd	-0.262	-0.490**	-0.655**	-0.314	-0.384*	-0.125	1	0.151	-0.354
Pb	-0.103	0.078	0.065	0.027	0.215	0.006	0.224	1	-0.318
Hg	-0.122	0.117	0.271	0.087	0.274	0.1	-0.273	0.21	1

Legend: * - correlation is significant at the 0.05 level; ** - correlation is significant at the 0.01 level. The yellow marked text shows correlations between heavy metals in the skin of hares, while green marked text values below the diagonal indicate correlations between heavy metals in muscle tissue.

Research on environmental metal pollution in the Marmara region is still limited, with most studies focusing on sediments in various locations of the Marmara Sea. Kocaeli (İzmit) province, located in the eastern part of the Marmara region, is one of Türkiye's major industrial hubs and among the most densely populated areas. The city is one of the most heavily affected areas by air pollution. Doğrul (2007) identified Pb, Cu, Zn, and Cd as the predominant pollutants in Kocaeli especially in the industrialized region, emphasizing that metal and chemical industries, along with fossil fuel combustion, are the primary sources of contamination. Dartan and Toröz (2013) detected intense Mn, Pb, Cu, and Zn pollution in agricultural soils in Bandırma, a port city in the Southern Marmara Region. They also noted that Cd pollution levels in the soil of the region are approximately 90 times higher compared to the Thrace, Edirne, and İzmit regions. Furthermore, their findings indicated that Cd, Ni, Cu, and Pb concentrations are much higher than the permissible limits established by EU countries. Otansev et al. (2016) detected Cr, Cu, Ni, and Pb pollution in water samples from the Sea of Marmara. Özyiğit et al. (2017) noted that a species of algae, *Ulva lactuca*, is useful in determining heavy metal pollution on the coasts of Istanbul. Yalçın et al. (2020) reported Cd, Co, Cr, and Pb pollution in Turkish red pines in Istanbul. Türk Çulha et al. (2022) found that Cd and Pb concentrations exceeded safety limits in sea snails collected from Yalova (İzmit Bay). More recently, Yinanc et al. (2024) documented As, Zn, and Co pollution in sediment samples from the Sea of Marmara.

Increases in environmental pollutant levels are reflected in wildlife, which serve as early indicators of pollution. In this study, the concentrations of Cr, Cu, and Se detected in the muscle tissue samples of European hare were higher than the values reported by Demirbaş and Erduran (2017) in hares from Kırıkkale, a province in the Central Anatolia Region characterized by intensive agricultural and industrial activities and heavy road traffic. Conversely, the concentrations of Mn, Zn, Cd, and Pb in the muscle tissues of European hare from the Marmara Region were lower than those recorded in hares from Central Anatolia. Notably, Cr values in muscle samples of hares from both the northern and southern Marmara regions were approximately 20 times higher than those recorded in Central Anatolia, while Pb concentration levels in hare muscles from Kırıkkale were approximately 30 times higher than those detected in hares from the Marmara Region. Heavy metals such as Cr, Pb, Cd, Zn, Cu, and Hg are primarily associated with anthropogenic and industrial sources (Kamala-Kannan et al., 2008; Başkan, 2010; Coşkun et al., 2011). Additionally, Demirbaş and Erduran (2017) reported that Cd and Pb concentrations in all hare samples examined in their study exceeded hygiene limits. In the present study, the concentrations of Pb (in 30 out of 52 samples, 57.69%), Cd (in all 42 samples, 100%), Cr (in 47 out of 52 samples, 90.38%), and Hg (in 9 out of 52 samples, 16.98%) in the muscle tissues of hares exceeded the maximum permissible limits (hygiene limits) stipulated by the regulations. Boişteanu et al. (2024), stressing the role of essential minerals in meat for human nutrition and health, emphasized that meat from responsibly managed wildlife also offers significant nutritional benefits. They underlined the importance of careful monitoring heavy metal accumulation in the tissues of animals hunted in polluted habitats to ensure food safety and environmental pollution management. Given the risks associated with high levels of heavy metal concentrations in food and the environment, consumption of hare meat may pose serious health hazards.

Petrović et al. (2024) analyzed Fe, Mn, and Cu concentrations in liver and kidney tissues of European hares from agricultural regions of Serbia and found both positive and negative significant correlations, though mostly weak, between individual or different elements in the same organ of hares and between two organs. The researchers noted that these correlations between elements are difficult to explain, but may be attributed to similar homeostatic mechanisms that regulate optimum tissue levels through kinetic behavior of the relevant elements, in line with the findings of Fairbrother et al. (2007). Mohammed et al. (2023) and Al Jufaili et al. (2024) used correlation analyses to investigate potential sources of heavy metals and suggested that significant positive correlations between heavy metals found in living tissues indicate similar anthropogenic sources (such as industrial wastes or agricultural inputs) causing toxic exposure. Al Jufaili et al. (2024) also proposed that negative correlations between heavy metals may indicate multiple pollutant sources in the studied area. In the present study, Pearson correlation analysis revealed significant correlations between the studied metals at varying degrees. However, a very strong negative correlation was detected between Cr and Cd concentrations in the muscle tissues of hares from Northern Marmara, while a very strong positive correlation was found between Mn and Zn concentrations. In addition, a very strong negative correlation was detected between As and Cd concentrations in the skins of all Southern Marmara hares (Table 2 and 3). These findings confirm the presence of multiple anthropogenic pollutant sources in the study area.

Arsenic accumulates primarily in keratin-rich tissues such as nails and hair (Amuno et al., 2018). Consistent with this, the present study found significantly higher As concentrations in skin samples compared to muscle tissues. Furthermore, the levels of As, Cd, Hg, and Pb determined in the muscle tissue samples in our study were comparable to the values reported in previous studies conducted in other European countries (Gulin et al., 2023).

CONCLUSION

This study represents the first use of a terrestrial mammal species as a biomonitor to determine environmental metal pollutants in the Marmara Region. The findings indicate that hares can be considered a valuable biomonitor for assessing environmental metal pollution, habitat quality, and human exposure to metals. High levels of Pb, Cd, Cr, and Hg were detected in the skin and muscle samples of hares in the study area, characterized by intensive industrial, agricultural, and transportation activities. These results confirm that the Marmara Region experiences significant environmental pollution as a result of anthropogenic activities. Consequently, hunting in this region, which is heavily impacted by industrial waste and agricultural inputs, may pose a toxic hazard for the local population. Therefore, further research is needed to conduct a comprehensive risk assessment to determine the safety of hare meat consumption and its potential implications for human health.

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