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RESEARCH ARTICLE

Enhancing environmental monitoring: utilizing plant and soil assays to track pollution in a Turkish organized industrial zone

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ABSTRACT

The aim of the current investigation was to determine the concentration of different metals in *Mentha spicata* L. subsp. *tomentosa* plants and soils in order to highlight the pollution level in a Turkish Organized Industrial Zone in Dilovasi District, in Kocaeli City. The concentration of metals in plant and soil samples were examined. When the soil values were examined, the highest cadmium, chromium, copper, iron, nickel, and lead levels were collected from the location which is hosting numerous industrial facilities. All elements except boron and copper, exceeded normal limits in the leaf samples while cadmium, chromium, iron, nickel, lead, and zinc reached "toxic levels" in leaf samples. Heavy metals were accumulated in leaves more than rhizomes. Mineral element uptake and accumulation were affected from heavy metal amounts, especially in rhizomes. Although washing procedure notably reduced the concentration of some heavy metals in leaves samples, the reduced values were higher than acceptable levels in some locations of the district. According to the data, it may be said that the region, especially its industrialized parts are heavily polluted by heavy metals. Moreover, in the accordance with the fact that, the highest values of elements were determined in regions having considerable industrial activity such as metal and plastic processing facilities. Additionally, *Mentha spicata* plants exhibited higher heavy metal values in areas with high heavy metal content in the soil, and lower heavy metal values in areas with low heavy metal concentration. These findings indicate that *Mentha spicata*, a plant known for its medicinal and culinary uses, can be considered as an effective biomonitor for heavy metal pollution in the region. Consequently, constant inspection is required to prevent the excessive buildup of metals in the region and similar areas with comparable characteristics in terms of human life.

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KEYWORDS
Bioaccumulation; Dilovasi district; elements; *Mentha spicata*

Introduction

Pollution defined as unwelcome waste that is dispersed into the air, land, water, and ocean without consideration for the costs or consequences poses an existential danger to the welfare of both people and the environment and imperils the viability of contemporary society. Pollution includes pesticides, industrial chemicals, heavy metals, electronic and radioactive waste poisoning of the land, as well as fine particulate matter and oxides of sulfur and nitrogen.[1,2] Both natural and man-made processes can release heavy metals into the environment. Wind-borne soil particles, volcanoes, forest fires, sea-salt sprays, and biogenic sources are some of the natural sources of emissions. However, for the majority of metals, anthropogenic sources of air emissions from various human activities outweigh natural fluxes.[3]

Among these pollutants, heavy metals are classified as those with a density more than $5\,g.cm^{-3}$.[4–6] Heavy metals cannot be biodegraded once they are released into the environment, unlike organic contaminants. They continue forever and contaminate the air, water, soil and organisms.

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Emission of metals into the air is probably the greatest source of heavy metal pollution, which in turn contaminates aquatic ecosystem and soils through atmospheric fallout. The main sources of atmospheric pollution by heavy metals include industry, cars, residential oil burning, and waste incineration. These heavy metals can precipitate from the contaminated air to contaminate soils and water supplies, also they can be absorbed and accumulated by plants and can enter the food chain.[7,8]

The most accurate and sensitive organisms that accumulate metals or contaminants in their bodies are known as bioindicators.[9] The species chosen to serve as a biomonitor must be able to accumulate heavy metals in their bodies while remaining resistant to the heavy metals' effects. They are plentiful in the study area, making it simple to access them when needed. They contain sufficient organs or tissues for metal analysis, and there ought to be a connection between heavy metal concentrations in the organisms and the concentration of heavy metals in the environment. In numerous studies about environmental heavy metal contamination, the plants have served as biomonitors to measure levels of contamination.[10–12]

Numerous medicinal plants, including *Mentha* species, when developing in their natural environments, may accumulate heavy metals. For many structural and biochemical processes, including plant growth, oxidation/reduction reactions, electron transport, and a variety of other metabolic activities in the plant, some of these heavy metals, such as copper (Cu), iron (Fe), manganese (Mn), nickel (Ni), and zinc (Zn) are considered essential trace [13] elements or mineral nutrients.[14–16] However, heavy metals including Cd and Pb can induce a variety of diseases in both plants and their consumers even at trace amounts.[17–19]

The accumulation of heavy metals in medicinal plants negatively impacts their physiology and photochemistry, changing the quantities of their active components or secondary metabolites.[20,21] Additionally, plants that accumulated heavy metals exhibit evident toxicological signs such as chlorosis, decline, stunted development, browning of the roots, and ultimately death.[22,23] Therefore, serious adverse effects may occur in people who will be treated using these plants.[24] Concerning the impact of heavy metals on health issues, there have been many studies that reported levels of heavy metals and the nutritional status of minerals on different variety of plants collected from disparate locations.[15,25,26]

Due to the high levels of air pollution in industrial locations, the accumulation of heavy metals in the environment has reached the upper limit values. Dilovasi organized industrial zone (DOIZ) of Kocaeli in the Marmara Region, is one of the most polluted provinces in Türkiye as it is a dense industrial area and two of the busiest highways (O4 and D-100) of Türkiye pass through the heart of DOIZ. Over the past 10 years, Kocaeli City has been home to 15% of Türkiye's total manufacturing industry.[27] There are 229 businesses operating in 35 different sectors in the DOIZ, the majority of which are quarries and chemical and metal (iron-steel, aluminum, and smelting) factories.[28]

The primary goal of this work is to measure the levels of heavy metals (Cr, Cd, and Pb) and micronutrient elements (Al, B, Ca, Cu*, Fe*, K, Mg, Mn*, Na, Ni*, and Zn*) in soils and various *M. spicata* L. subsp. *tomentosa* plant parts, which were collected from heavily industrialized DOIZ in the Marmara Region of Türkiye. Elements denoted by a "*" are also heavy metals. It is pointed primarily to gain knowledge about heavy metal pollution within the DOIZ, which serves as an example of distorted urbanization, where people live in close proximity to industrial facilities. Different plant species exhibit alterations in their physiologies and defense mechanisms, making them more tolerant to different contaminants.[29] Hence, *M. spicata* is investigated as an effective biomonitoring plant.[30] Soil samples and a selected plant species, *M. spicata* L. subsp. *tomentosa*, are used to gather information about the heavy metal pollution. Subsequently, the data collected from the heavy metal pollution and *M. spicata* L. subsp. *tomentosa*, which is widely consumed by the local population, is evaluated to understand the health risks faced by the people in the region. Finally, the study aims to compare the mineral nutrient levels of *M. spicata* L. subsp. *tomentosa* plants grown in the study area with not contaminated control plants, based on measurements taken.

Materials and method

Study area

Dilovasi, an industrial district of Kocaeli city, where the D100, E80 (TEM), and railroad all intersect, is near to Istanbul. Since the location is in the middle of a bowlike topographic structure, there are significant environmental issues in the area. DOIZ now has a significant location on the sea, road, and rail networks that link Istanbul, Europe, and Anatolia, the Turkish continent. DOIZ has had a large population expansion as a result of increased industry, particularly since the 1980s. The district's population has increased from 10,600 in 1985 to more than 50,000 as of the present.[31]

Despite having one of the smaller areas among Kocaeli's districts, Dilovasi is one of the areas with the highest concentration of business. Metal, mainly iron, and steel (39%), chemical (20%), storage (13%) and mining (7%) are the most common sector categories in structured industrial zones. The primary industrial operations in DOIZ include manufacture of food, textiles, forestry, plastics, chemicals, petrochemicals, glass, metal, hardware, electrical equipment, electronics, wire rope, machinery, and metal-heat processing.[28,32] DOIZ has a significant potential for air pollution from urban, industrial, and vehicular sources due to these factors. Additionally, the DOIZ's rocky topography and bowl shape hinder the air in the area from mixing properly, leading to inversion and severe air pollution.[33]

Used plant material

The Lamiaceae family, which includes the *Mentha* species, has a vast geographic distribution over North America, Europe, Australia, Asia, and Africa.[34] This species' plants may be found in a variety of different environments.[35] According to recent studies, the genus *Mentha* may be split into 42-species, 15-hybrids, and hundreds of subspecies, variants, and cultivars based on genetic, cytological and morphological characteristics. The majority of *Mentha* species are perennial, have essential oils, and are commonly grown as industrial crops for the extraction of essential oils.[36]

M. spicata, a perennial rhizomatous plant, has a four-cornered, hairless and branched verticle stem and can grow up to 30–100 cm in height. The leaves are oval/lanceolate, 2–7 cm long. The inflorescences of *M. spicata* are 3–12 cm long, 5–10 mm wide, terminal and dense. The peduncle flowers on thin spikes are pink or white and interrupted.[37] *M. spicata* is widely used worldwide, primarily in the pharmaceutical and food industries, and is extensively cultivated commercially.[38] The leaves have a serrated edge and measure 1.5–3 cm wide by 5–9 cm long. The square form of the stem is distinctive to the mint family of plants. The flowers of spearmint grow on thin spikes, each measuring 2.5–3 mm in length and width and being pink or white in color. The northern hemisphere's summer (from July to September) spearmint blooms and produces unusually big seeds, measuring 0.62–0.90 mm. The pointy leaf tips of *Mentha* (spearmint) give it its name. The size of the leaf blades, the prominence of the leaf veins, and pubescence vary widely among *M. spicata*.[39]

M. spicata L. subsp. *tomentosa* is always hairy, the leaves are 30–38 mm long and usually less than 12 mm in width, often undular on the margins and with numerous branched hairs on the underside; spica (35–) 70–110 (−140) mm, often very intermittent especially on the fruit.[40]

Mentha is easily adapted to grow in several types of soil. With lots of natural substance and full sun to part shade, spearmint often grows well. The plant is also known to grow in wet environments with sand or clay-based soil, such as wetland or streams. The best soil conditions for spearmint are deep, well-drained, wet, nutrient-rich, and crumbly in texture, hence, the pH range should be between 6.0 and 7.5.[41]

Tea made from *Mentha* leaves has long been used to heal minor illnesses including headaches, fever, digestive problems, and other aches and pains.[42] Additionally, postherpetic neuralgia, headache syndromes, and moderate bacterial and fungal infections of the human skin have all been successfully treated with mint essential oils.[43] *Mentha* species are frequently utilized to treat digestive system issues in modern medicine. For instance, a methanolic extract of *Mentha longifolia* L., which is high in eucalyptol, demonstrated antiulcer activity against acetic acid-induced colitis in rats. This effect may have been due to the plant's antioxidant and anti-inflammatory properties, even though it was not dose-dependent.[44]

Sample collection, determination of element contents and analysis

In the current research, soil, and plant samples were collected (8 samples from each location in one season) and analyzed from DOIZ and its surroundings. For this aim, four different locations, characterized by the concentration of different industries, human habitation, and the presence of busy highways were selected. As a control area, samples were collected from the forested southern part of Buyukada which is not inhabited at all (Fig. 1). Hence, Buyukada is an isolated area, where there is no traffic, and the pollutant effects of the city are not present. Location 1 is characterized by its pronounced industrial activity, hosting prominently dye, textile, metal, and plastic processing facilities as well as numerous other factories. Location 2, while also in close proximity to industrial facilities, is situated adjacent to the roadside, resulting in elevated emissions originating from heavy traffic, in addition to the discharge of factory waste. Location 3 represents an area where residential settlements and commercial opportunities are provided, relatively distant from industrial establishments. Conversely, Location 4 denotes a higher-altitude location, comparatively distanced from industrial facilities, and situated on a hill, thus benefiting from enhanced wind circulation.[28,32]

Buyukada encompasses an area situated along the Maltepe shore, which serves as the island's closest terrestrial location, with a proximity of approximately 2300 meters. In comparison to other research areas, the island exhibits a

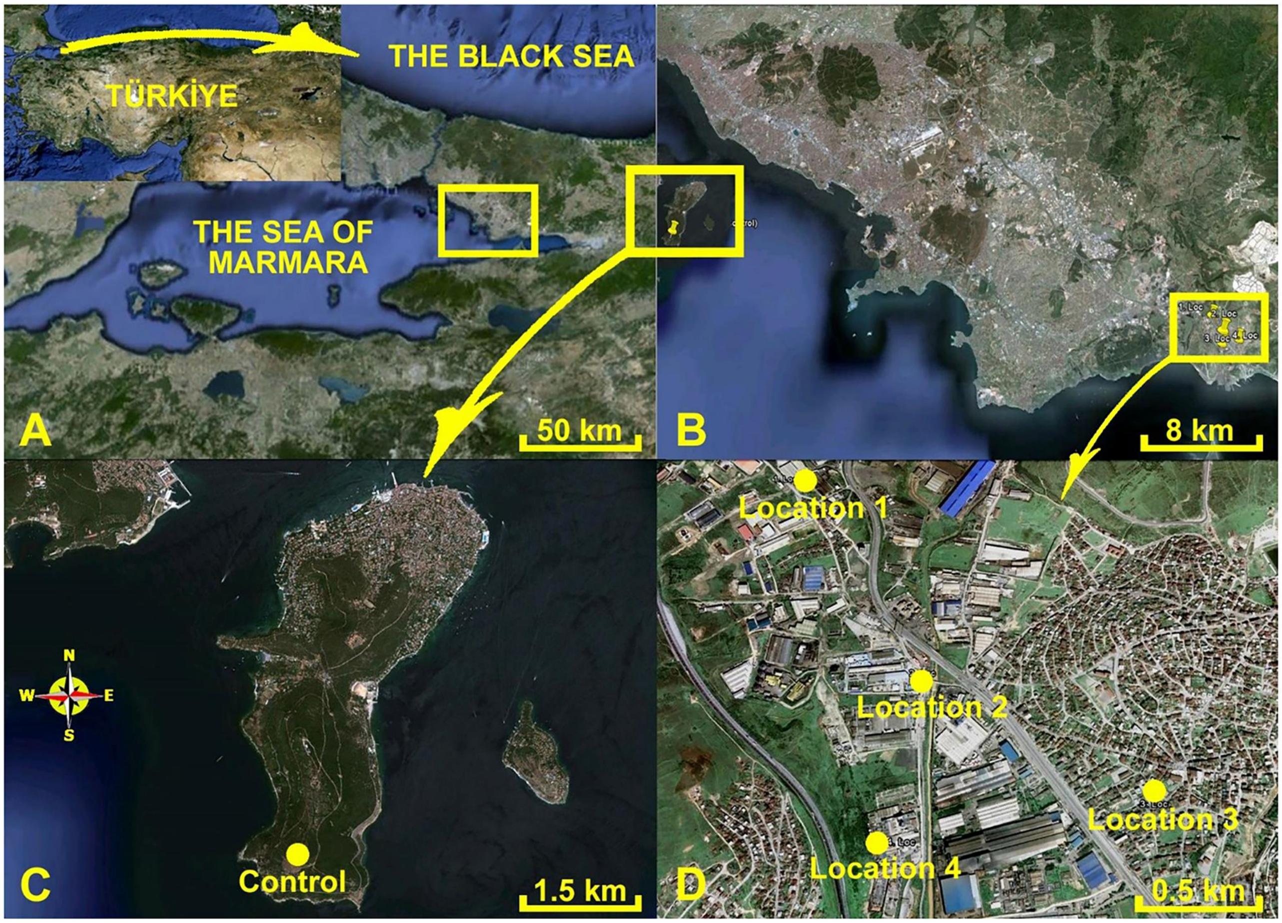

Figure 1. Study area and locations. (A) The Marmara Region, (B) sample's collected locations, (C) control (Buyukada), (D) Dilovasi organized industrial zone and locations (1–4).

relatively lower population density. Particularly during winter, the presence of motor vehicle traffic is minimal, especially in the absence of tourist activities. This distinctive characteristic renders Buyukada an ideal selection for the control group.[45]

Together with the control group, plant parts and soil samples taken from a total of 5 locations were brought to the laboratory in sterile bags. Leaf samples were separated as washed (W) and unwashed (UW) leaves and divided into parts. Stem and rhizome (together with tiny roots) parts of the plants were also collected as plant samples. Samples of plant parts were dried in an oven at 80 °C for 48 hr in blotting paper. Soil samples taken were transferred into glass petri dishes and after drying at 80 °C for 48 hr, they were passed through a steel sieve with a 2 mm pore diameter and made ready for weighing. After the samples of plant parts and soil samples are dried, samples weighing between 0.200 and 0.250g are transferred to Teflon combustion cells. For samples of plant parts, 8 mL of 65% Merck brand HNO_3 (for analysis EMSURE) was used on Teflon cells. For soil samples, 6 mL 65% Merck brand HNO_3, 3 mL 37% Merck brand HCl and 2 mL 48% Merck brand HF were added. The prepared samples were digested using a microwave digestion system (Berghof–MSW2). Then, digested samples were transferred into 50 mL sterile Falcon tubes by filtering through a blue band filter paper. The total volume was filled up to 50 mL with ultrapure water. In soil samples and plant parts prepared for macro, micro, trace elements, and heavy metal amounts determination of Al, B, Ca, Cd, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, Pb, and Zn were measured as mg kg^{-1} dry weight in inductively coupled plasma optical emission spectroscopy (ICP-OES) PerkinElmer-Optima 7000DV brand model device.[15]

Quality control and quality assurance

Analytical-grade substances were employed in this investigation. Ultrapure water (Human-Zeener PowerI) was employed as a solvent in the dilution procedures, as it was throughout the entirety of the research. To confirm linearity, the elemental sample values for medicinal plants were examined in triplicate. Using previously created calibration standards, all concentrations were measured with an extremely low margin of error of 0.71–1.97% (RSD) (Table 1). The EPA 3051 A Analytical Method for ICP-OES was used in conjunction with a microwave to dissolve plant samples. ICP-OES was used to examine the samples' element contents. The advantages of ICP include the capacity to test several elements consecutively, the presence of few or no organic molecules, and the absence of significant interferences of ionization.[46] To determine the concentration values of each element investigated for plant samples, calibration standards were made by diluting 1000 mg L^{-1} of ICP multi-element standard solution (Merck). The value of $R^2>0.999$ was discovered when calibration curves were created using calibration standards that were made in 8 different concentrations for each element (Table 1). The margins of error were controlled and the calibration standards were remeasured after the first calibration every ten samples throughout the tests to ensure that the initial measured conducted using the same calibration conditions. Moreover, repeated studies of solutions for multi-element calibration with previously known concentrations show the precision and consistency of elemental analyses. By examining blank solutions, LoD (Limit of Detection) and LoQ (Limit of Quantification) values were found and then computed for each of the elements (Table 1). The constants $\emptyset_n$ and $\emptyset_q$ in the LoD and LoQ calculations stand for multiplication factors of 3 and 10, respectively, while the

Table 1. Limit values and measurement parameters of analytical method analyzes.

Element	Spectral line (nm)	LoD (mg kg^{-1})	LoQ (mg kg^{-1})	RSD (%)	R^2
Al	396.153	0.304	1.013	0.54	.999863
B	249.677	0.132	0.440	0.82	.999795
Ca	317.933	0.853	2.843	1.11	.999956
Cd	228.802	0.005	0.017	0.73	.999944
Cr	267.716	0.008	0.027	0.92	.999903
Cu	327.393	0.018	0.060	0.81	.999794
Fe	238.204	0.263	0.877	1.05	.999915
K	766.490	0.585	1.950	1.17	.999857
Mg	285.213	0.203	0.677	0.92	.999883
Mn	257.610	0.095	0.317	1.19	.999797
Na	589.592	0.402	1.340	1.02	.999921
Ni	231.604	0.009	0.030	0.94	.999926
Pb	220.353	0.011	0.037	0.87	.999828
Zn	213.857	0.094	0.313	1.14	.999937

Note: LoD: limit of detection; LoQ: limit of quantification; RSD: relative standard deviation; R^2: determination coefficient.

word SD denotes the standard deviation of ten repetitions of the blank answer.[47,48] Spectral lines were chosen in accordance with the relevant literature, which is provided in Table 1, in order to identify the samples' elemental compositions.[48–50]

Data analysis

Using IBM SPSS Statistics25, "multivariate analysis of variance (MANOVA)" and "Pearson Correlation" were carried out. The statistical significance criteria for the correlations were 0.01 (**) and 0.05 (*) levels (two-tailed). The overall accumulation of potentially harmful elements and the amounts of necessary elements in all plant specimens examined were used to generate a dendrogram based on the similarities and differences of correlations found across plant species. In addition, Recommended Daily Allowance (RDA) values for Ca, Cu, Fe, K, Mg, Mn, Na, and Zn elements were determined in order to disclose the Dietary Reference Intake potentials of *M. spicata* L. subsp. *tomentosa* utilized as daily food, spice, and tea evaluated in this study.[51,52] RDA (%) (100 g/dw) calculated with mineral nutrient values in studied the plant samples (mg kg^{-1}; ppm) and international standards (mg per 100 g/dw). The target hazard quotient (THQ) estimated daily intake (EDI), and hazard index were used to determine Cd, Cr, Ni, and Pb exposures, which endanger consumers' lives who ingest plant leaves (HI).[53–55] The quantitative evaluation of each hazardous metal's possible non-carcinogenic effects was done using THQ.[50] For the exposed population, a THQ value less than 1 indicates no detectable risk of carcinogenicity. For each metal, RfDn (mg/kg/day) is the reference dosage established by the FAO/WHO. THQn is for the target hazard quotient of the hazardous metal, and EDIn stands for the average exposure per day dosage (mg/kg/day). Exposure to numerous contaminants may lead to the danger of several hazardous metals' effects on human health overall and the intake of therapeutic plants. In order to predict the overall health risks that exposure to different hazardous metals may produce, the Hazard Index (HI) was utilized. HI displays the overall health risk connected to exposure to hazardous metals in this equation. Injurious effects of hazardous metals are less likely to occur on human health when the HI value is smaller than 1. In contrast, hazardous metals are more likely to have a detrimental impact on human health if the HI value is higher than 1.

Results and discussion

In this study, concentration levels of some mineral nutrients and heavy/toxic metals, such as Al, Ca, Cd, Cr, Cu, Fe, K, Mg, Mn, Na, Pb, and Zn in *M. spicata* L. subsp. *tomentosa* plant parts (washed leaf, unwashed leaf, and rhizome), and their co-located soil samples, were analyzed and results are given and discussed below.

Lowest and highest observed Cd concentrations (mg kg^{-1} dry wt.) in soil were 0.740 and 7.637, according to literature, the anticipated natural Cd range in soil is 0.06–1.1 mg kg^{-1} dry wt.[14,56] This indicates that the highest detected value is found to be out of the normal limits. In the present study, lowest and highest soil Cr concentrations (mg kg^{-1} dry wt.) were 7.980 and 53.035, which were evaluated within the normal ranges based on the literature data; however, it is also said that the average soil Cr concentration is 54 mg kg^{-1} dry wt. despite the wide variation.[14] Furthermore, the 64 mg kg^{-1} dry wt. maximum permissible level in soil samples is stated to safeguard both human health and the environment.[57]

In the current study, lowest and highest Cu concentrations (mg kg^{-1} dry wt.) in soil were evaluated as 10.292 and 62.102, however, it is stated that soil contains between 25–75 mg kg^{-1} dry wt. of copper.[14] This indicated that the detected values are within a normal range of distribution. Lowest and highest soil Fe levels (mg kg^{-1} dry wt.) were investigated as 5830.880 and 9505.653. In literature, Fe concentrations are recorded to range 5000–50,000 mg kg^{-1} dry wt. in soil,[58] which indicates that the detected values were evaluated within the appropriate ranges. In addition, lowest and highest K concentrations (mg kg^{-1} dry wt.) in soil were evaluated as 14,016.960 and 18,360.960. The natural K concentration in soil is reported to be approximately 12,000 mg kg^{-1} dry wt.[59] Based on this it can be concluded that the detected values are discovered to be higher than allowable limits.

In this study it is reported that lowest and highest Mg concentrations (mg kg^{-1} dry wt.) in soil were 2447.307 and 3439.413, which shows a normal range of distribution based on the literature where Mg levels are recorded as 300–8000 mg kg^{-1} dry wt. in soil.[60] In addition, lowest and highest observed Mn concentrations (mg kg^{-1} dry wt.) in soil was 95.115 and 223.509, however in the literature the average amount of Mn in soil is 437 mg kg^{-1} dry wt., with a range of 10 to 9,000 mg kg^{-1} dry wt.,[14] this shows that the detected values were also evaluated within the appropriate ranges. Moreover, this study showed that lowest and highest Na concentrations (mg kg^{-1} dry wt.) in soil varying as 1868.363 and 3624.240, while soil Na concentrations reports indicate that they exhibit significant variation, in between 1000 and 10,000 mg kg^{-1} dry wt.,[59] which indicates that the reported values are in the normal range of distribution. Lowest and highest Pb concentrations (mg kg^{-1} dry wt.) in soil were 35.848 and 233.939. Pb concentrations in soil are reported to vary from 10 to 40 mg kg^{-1} dry wt., with an overall average of 25 mg kg^{-1} dry wt..[58,61] This indicates that the highest detected value is discovered to be higher than allowable limits. As well, lowest and highest Zn concentrations (mg kg^{-1} dry wt.) in soil were 40.005 and 394.058, which was also evaluated within the appropriate ranges, based on the literature the average natural Zn concentration in soil is 65 mg kg^{-1} dry wt., ranging from 3 to 770 mg kg^{-1} dry wt.[62,63] Lowest and highest Al concentrations (mg kg^{-1} dry wt.) in soil were 7924.693 and 11,240.907, which was also evaluated within the appropriate ranges, based on the relevant literature that reported the total contents of Al in soils to vary between 10,000 and 40,000 mg kg^{-1} dry wt.[14,64] Lowest and highest Ca concentrations (mg kg^{-1} dry wt.) in soil were 36,019.147 and 55,804.533, this indicates that the detected values are discovered to be higher than allowable limits, according to the fact that literature indicated the levels of Ca in soils to be varied between 13,700 (Earth's soils) and 53,800 mg kg^{-1} dry wt. (urban soils),[65] and between 7000 and 15,000 mg kg^{-1} dry wt., especially in rainy and temperate regions.[59] Furthermore, analysis of the soil samples (Table 2) revealed that the highest and lowest readings (in mg kg^{-1} dry wt.) were noted as follows: 74.050 and 11.965 for B; 3624.240 and 1868.363 for Na and 52.405 and 4.187 for Ni, respectively.

In the light of the above-mentioned data, it can be summarized that location 1 had the highest values among the soil samples in terms of the average concentrations of elements. For Cd, Cr, Cu, Fe, K, Mg, Mn, Pb, and Al the highest values were evaluated as 7.637, 53.035, 62.102, 9505.653, 18,360.960, 3439.413, 223.509, 233.939 and 11,240.907 mg kg^{-1} dry wt., respectively. The exception was investigated for Zn, the highest value for soil sample was recorded at location 4 (394.058 mg kg^{-1} dry wt.) whereas the lowest values were found at control locations. These findings are in the accordance with the fact that location 1 is distinguished by its considerable industrial activity, which includes various companies, well-known metal and plastic processing facilities, and other similar establishments. While the control location, which represents Buyukada island has a lower-than-average population density, where the amount of motor vehicle traffic is often limited (only a few official vehicles), especially during the winter when there aren't many visitor activities.

DOIZ is known for having a high prevalence of cancer (i.e., three times the national average.[66] According to a study conducted on this subject, people who lived in DOIZ for more than 10 years had a 4.4 times higher probability of dying from cancer than those who had lived there for fewer than 10 years.[67] In addition, DOIZ has a topography of a basin that, by restricting dispersion, worsens the contact with air pollution, which is accentuated by thermal inversion episodes. The district is also heavily industrialized, with densely populated residential areas scattered throughout the industrialized zones and many facilities connected to significant volatile organic compound (VOC) releases (e.g., paint manufacturing, metal, solvent storage) concentrated in the district's lowest part.[68] Due to all these reasons, it was crucial to determine the heavy metal distribution across the municipality. As a biomonitor organism,[69,70] *M. spicata* L.

Table 2. Concentrations of studied elements in the parts of *Mentha spicata* and co-located soil samples.

		Washed leaf	Unwashed leaf	Stem	Rhizome	Soil
Al	Control	142.944 ± 0.256	263.808 ± 6.486	30.200 ± 0.195	137.461 ± 1.097	7924.693 ± 14.312
	1. loc	395.424 ± 8.548	642.560 ± 8.785	315.328 ± 5.176	207.450 ± 6.313	11,240.907 ± 23.013
	2. loc	352.608 ± 7.536	583.200 ± 5.778	268.371 ± 6.157	174.954 ± 3.257	10,077.973 ± 55.054
	3. loc	280.806 ± 5.127	359.872 ± 6.272	150.080 ± 0.771	133.312 ± 0.393	8726.400 ± 43.107
	4. loc	335.200 ± 7.322	486.272 ± 6.553	191.837 ± 5.002	292.205 ± 5.704	9499.253 ± 5.641
B	Control	3.889 ± 0.106^{d}	5.676 ± 0.144^{d}	8.736 ± 0.179^{d}	12.178 ± 0.131^{d}	11.965 ± 0.144^{d}
	1. loc	$30.238 \pm 0.103^{**a}$	$41.573 \pm 0.387^{**a}$	$26.894 \pm 0.230^{**a}$	$28.160 \pm 0.269^{**a}$	$74.050 \pm 0.348^{**a}$
	2. loc	$22.236 \pm 0.295^{**b}$	$35.416 \pm 0.253^{**b}$	$22.063 \pm 0.279^{**b}$	$26.582 \pm 0.133^{**b}$	$47.068 \pm 0.472^{**b}$
	3. loc	$12.236 \pm 0.108^{*c}$	$16.901 \pm 0.178^{*c}$	$12.649 \pm 0.105^{*c}$	$19.228 \pm 0.284^{*c}$	$20.038 \pm 0.098^{*c}$
	4. loc	$18.801 \pm 0.218^{**b}$	$31.105 \pm 0.235^{**b}$	$19.818 \pm 0.214^{**b}$	$23.094 \pm 0.161^{**b}$	$26.834 \pm 0.314^{**b}$
Ca	Control	7762.720 ± 51.922	9366.560 ± 36.596	2031.680 ± 30.844	1098.080 ± 3.148	36,019.147 ± 530.529
	1. loc	10,348.160 ± 52.179	12,629.184 ± 22.424	3293.984 ± 27.709	2537.856 ± 12.646	55,804.533 ± 940.701
	2. loc	5719.680 ± 54.232	7096.480 ± 45.724	2150.368 ± 32.772	1501.696 ± 5.390	46,075.733 ± 780.842
	3. loc	4593.184 ± 59.964	5549.568 ± 78.025	1535.744 ± 4.234	1193.408 ± 4.011	38,693.120 ± 566.484
	4. loc	7231.840 ± 35.796	10,498.144 ± 39.189	982.496 ± 6.924	1544.896 ± 3.080	48,905.387 ± 887.906
Cd	Control	0.854 ± 0.054^{d}	1.029 ± 0.046^{d}	0.534 ± 0.051^{d}	0.905 ± 0.098^{d}	0.740 ± 0.019^{d}
	1. loc	$3.568 \pm 0.115^{**a}$	$5.611 \pm 0.139^{**a}$	$1.589 \pm 0.074^{**a}$	$2.365 \pm 0.080^{**a}$	$7.637 \pm 0.111^{**a}$
	2. loc	$2.349 \pm 0.077^{**bc}$	$3.730 \pm 0.112^{**bc}$	$1.056 \pm 0.059^{**bc}$	$2.034 \pm 0.085^{**bc}$	$4.273 \pm 0.053^{**bc}$
	3. loc	$1.366 \pm 0.076^{*cd}$	$2.451 \pm 0.118^{*cd}$	$0.958 \pm 0.070^{*cd}$	$1.545 \pm 0.092^{*cd}$	$2.989 \pm 0.107^{*cd}$
	4. loc	$2.538 \pm 0.073^{**ab}$	$5.677 \pm 0.114^{**ab}$	$1.088 \pm 0.086^{**ab}$	$2.408 \pm 0.060^{**ab}$	$5.118 \pm 0.153^{**ab}$
Cr	Control	1.586 ± 0.082^{d}	3.588 ± 0.140^{d}	1.051 ± 0.067^{d}	1.407 ± 0.087^{d}	7.980 ± 0.255^{d}
	1. loc	$24.210 \pm 0.219^{**a}$	$28.627 \pm 0.253^{**a}$	$17.742 \pm 0.287^{**a}$	$19.663 \pm 0.212^{**a}$	$53.035 \pm 0.862^{**a}$
	2. loc	$19.703 \pm 0.350^{**ab}$	$21.518 \pm 0.123^{**ab}$	$14.781 \pm 0.102^{**ab}$	$15.909 \pm 0.116^{**ab}$	$41.144 \pm 0.199^{**ab}$
	3. loc	$6.614 \pm 0.108^{**c}$	$10.356 \pm 0.156^{**c}$	$9.142 \pm 0.206^{**c}$	$11.935 \pm 0.135^{**c}$	$20.167 \pm 0.339^{**c}$
	4. loc	$13.193 \pm 0.106^{**b}$	$19.363 \pm 0.164^{**b}$	$13.005 \pm 0.089^{**b}$	$14.923 \pm 0.123^{**b}$	$31.540 \pm 0.200^{**b}$
Cu	Control	3.100 ± 0.106^{c}	3.796 ± 0.083^{c}	1.377 ± 0.068^{c}	3.476 ± 0.075^{c}	10.292 ± 0.093^{c}
	1. loc	$13.586 \pm 0.147^{**a}$	$19.043 \pm 0.086^{**a}$	$5.327 \pm 0.109^{**a}$	$6.475 \pm 0.107^{**a}$	$62.102 \pm 0.163^{**a}$
	2. loc	$10.461 \pm 0.110^{*ab}$	$14.386 \pm 0.084^{*ab}$	$2.331 \pm 0.084^{*ab}$	$3.552 \pm 0.290^{*ab}$	$44.126 \pm 0.127^{*ab}$
	3. loc	5.400 ± 0.143^{bc}	7.478 ± 0.143^{bc}	1.620 ± 0.106^{bc}	2.639 ± 0.146^{bc}	21.678 ± 0.244^{bc}
	4. loc	6.026 ± 0.213^{bc}	9.124 ± 0.112^{bc}	2.160 ± 0.140^{bc}	2.772 ± 0.220^{bc}	31.762 ± 0.093^{bc}
Fe	Control	129.800 ± 1.259	295.414 ± 6.393	30.164 ± 0.418	122.613 ± 0.588	5830.880 ± 58.645
	1. loc	1305.568 ± 11.047	1809.120 ± 76.152	311.904 ± 10.337	361.728 ± 9.877	9505.653 ± 45.847
	2. loc	1093.600 ± 13.556	1767.968 ± 83.525	280.096 ± 6.116	271.325 ± 10.688	7227.360 ± 58.062
	3. loc	183.392 ± 6.245	368.544 ± 7.076	219.680 ± 5.689	214.560 ± 4.226	5224.160 ± 85.452
	4. loc	444.032 ± 10.108	624.320 ± 12.335	247.799 ± 13.858	257.976 ± 14.451	6278.240 ± 62.030
K	Control	4106.016 ± 58.986	5028.192 ± 48.865	1512.256 ± 4.353	1100.096 ± 7.639	18,360.960 ± 309.103
	1. loc	3461.856 ± 77.872	3490.880 ± 49.671	1577.248 ± 4.441	1461.632 ± 4.279	14,016.960 ± 61.001
	2. loc	3672.384 ± 47.618	4133.024 ± 60.388	1818.272 ± 24.745	1790.816 ± 31.676	15,130.187 ± 36.581
	3. loc	3948.960 ± 43.231	4519.616 ± 30.949	1495.232 ± 28.627	1692.160 ± 35.263	17,157.813 ± 176.352
	4. loc	3583.680 ± 54.143	4077.152 ± 34.471	1696.736 ± 25.142	1588.608 ± 2.386	14,494.293 ± 37.341
Mg	Control	1438.816 ± 8.275	1596.992 ± 7.574	380.960 ± 8.693	437.184 ± 5.428	3439.413 ± 49.394
	1. loc	1819.808 ± 60.384	2512.768 ± 65.044	765.056 ± 9.807	727.168 ± 5.135	2447.307 ± 51.619
	2. loc	1614.144 ± 6.792	1695.168 ± 42.476	455.744 ± 9.357	418.944 ± 9.182	2815.573 ± 52.872
	3. loc	1141.664 ± 10.536	1293.280 ± 6.644	332.032 ± 5.120	296.288 ± 5.987	3097.547 ± 81.658
	4. loc	1775.520 ± 84.181	2022.304 ± 78.254	406.816 ± 3.475	377.760 ± 6.235	2651.787 ± 63.336
Mn	Control	12.486 ± 0.177^{c}	16.143 ± 0.187^{c}	2.772 ± 0.120^{c}	5.681 ± 0.108^{c}	95.115 ± 0.732^{c}
	1. loc	$85.082 \pm 0.390^{**a}$	$98.463 \pm 0.174^{**a}$	$14.261 \pm 0.154^{**a}$	$18.750 \pm 0.147^{**a}$	$223.509 \pm 3.731^{**a}$
	2. loc	$70.147 \pm 0.283^{*ab}$	$91.024 \pm 0.453^{*ab}$	$12.832 \pm 0.180^{*ab}$	$16.045 \pm 0.106^{*ab}$	$184.708 \pm 3.879^{*ab}$
	3. loc	17.704 ± 0.272^{bc}	28.531 ± 0.180^{bc}	10.265 ± 0.194^{bc}	12.790 ± 0.175^{bc}	130.413 ± 0.387^{bc}
	4. loc	46.572 ± 0.249^{abc}	57.263 ± 0.257^{abc}	12.074 ± 0.206^{abc}	15.835 ± 0.259^{abc}	158.124 ± 0.409^{abc}
Na	Control	232.384 ± 3.502	338.752 ± 5.198	424.960 ± 4.481	265.280 ± 8.320	1868.363 ± 18.388
	1. loc	589.114 ± 8.049	774.640 ± 7.346	572.141 ± 9.638	346.090 ± 6.431	3624.240 ± 19.080
	2. loc	401.024 ± 6.842	553.568 ± 5.837	311.744 ± 3.580	343.904 ± 6.215	2945.227 ± 16.954
	3. loc	282.278 ± 6.334	356.048 ± 5.903	215.843 ± 7.427	218.848 ± 6.354	2174.667 ± 31.984
	4. loc	346.976 ± 4.097	539.552 ± 8.374	281.050 ± 3.582	276.544 ± 7.462	3313.067 ± 22.666
Ni	Control	1.971 ± 0.109^{c}	3.478 ± 0.077^{c}	0.913 ± 0.079^{c}	1.243 ± 0.091^{c}	4.187 ± 0.148^{c}
	1. loc	$25.969 \pm 0.121^{**a}$	$43.326 \pm 0.341^{**a}$	$18.111 \pm 0.117^{**a}$	$24.734 \pm 0.085^{**a}$	$52.405 \pm 0.178^{**a}$
	2. loc	$21.488 \pm 0.113^{**a}$	$38.943 \pm 0.309^{**a}$	$15.004 \pm 0.153^{**a}$	$20.021 \pm 0.145^{**a}$	$41.149 \pm 0.197^{**a}$
	3. loc	$14.642 \pm 0.177^{**b}$	$19.818 \pm 0.146^{**b}$	$11.570 \pm 0.277^{**b}$	$15.087 \pm 0.138^{**b}$	$19.294 \pm 0.205^{**b}$
	4. loc	$22.594 \pm 0.168^{**a}$	$36.783 \pm 0.274^{**a}$	$16.753 \pm 0.148^{**a}$	$21.646 \pm 0.111^{**a}$	$38.287 \pm 0.214^{**a}$
Pb	Control	1.700 ± 0.056^{b}	2.815 ± 0.157^{b}	1.211 ± 0.056^{b}	2.164 ± 0.089^{b}	35.848 ± 0.382^{b}
	1. loc	$36.447 \pm 0.192^{**a}$	$53.806 \pm 0.118^{**a}$	$17.573 \pm 0.158^{**a}$	$35.185 \pm 0.195^{**a}$	$233.939 \pm 10.540^{**a}$
	2. loc	$25.490 \pm 0.239^{*a}$	$47.515 \pm 0.138^{*a}$	$17.655 \pm 0.178^{*a}$	$30.467 \pm 0.106^{*a}$	$156.505 \pm 0.426^{*a}$
	3. loc	17.818 ± 0.192^{ab}	34.595 ± 0.131^{ab}	12.339 ± 0.165^{ab}	16.100 ± 0.128^{ab}	88.688 ± 1.855^{ab}
	4. loc	$33.999 \pm 0.155^{**a}$	$53.386 \pm 0.191^{**a}$	$18.230 \pm 0.157^{**a}$	$24.845 \pm 0.114^{**a}$	$196.933 \pm 8.713^{**a}$
Zn	Control	19.567 ± 0.112^{c}	22.611 ± 0.106^{c}	7.708 ± 0.176^{c}	6.954 ± 0.111^{c}	40.005 ± 0.426^{c}
	1. loc	$72.143 \pm 0.079^{**ab}$	$125.460 \pm 0.383^{**ab}$	$23.096 \pm 0.110^{**ab}$	$12.787 \pm 0.079^{**ab}$	$355.273 \pm 5.128^{**ab}$
	2. loc	52.873 ± 0.107^{abc}	105.371 ± 0.257^{abc}	19.309 ± 0.182^{abc}	11.263 ± 0.108^{abc}	285.316 ± 8.729^{abc}
	3. loc	24.649 ± 0.118^{bc}	30.541 ± 0.483^{bc}	15.277 ± 0.226^{bc}	6.208 ± 0.166^{bc}	155.915 ± 0.277^{bc}
	4. loc	$87.718 \pm 0.187^{**a}$	$124.346 \pm 0.146^{**a}$	$19.239 \pm 0.253^{**a}$	$13.999 \pm 0.109^{**a}$	$394.058 \pm 26.367^{**a}$

Note: The mean difference is significant at 0.01 (**) and 0.05 (*) levels (mg kg^{-1}).

$^{a,\ b,\ c,\ d}$: Different letters indicate different averages within the same column, which are significant in terms of averages ($p < 0.05$).

subsp. *tomentosa* was used to gather data on the level of pollution in the DOIZ. The measured element concentrations of Al, Ca, Cd, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, B, Pb, and Zn in the plant's components and co-located soils were used to calculate the contamination rate. Additionally, the effects of metal deposition on the absorption of minerals in *M. spicata* L. subsp. *tomentosa* were examined. The data for heavy metal accumulation revealed that location 1, which was relatively near to densely inhabited regions, consistently had the greatest quantities of heavy metals (Table 2).

Findings from plant analysis of the leaves (W and UW), stems, rhizomes and collected soil samples from four different zones in DOIZ are presented in Table 2. The average concentrations of elements (Al, Cd, Cr, Cu, Fe, Mg, Mn, Ni, Pb, and Zn) in plant parts showed the highest values at location 1, whereas the lowest were found at the control location, except for Mg, Na and Zn, the lowest values were found at location 3 and for Ca the lowest value was found at location 4. The data of this study showed that the typical highest and lowest element accumulations (Al, Cd, Cr, Cu, Fe, Mg, Mn, Ni, Pb and Zn) in the plant parts (in mg kg^{-1}) were recorded as: 642.560 ± 8.785 (in uw leaf) and 30.200 ± 0.195 (in stem) for Al; 5.611 ± 0.139 (in uw leaf) and 0.534 ± 0.051 (in stem) for Cd; 28.627 ± 0.253 (in uw leaf) and 1.051 ± 0.067 (in stem) for Cr; 19.043 ± 0.086 (in uw leaf) and 1.377 ± 0.068 (in stem) for Cu; 1809.120 ± 76.152 (in uw leaf) and 30.164 ± 0.418 (in rhizome) for Fe; 2512.768 ± 65.044 (in uw leaf) and 296.288 ± 5.987 (in rhizome) for Mg; 98.463 ± 0.174 (in uw leaf) and 2.772 ± 0.120 (in stem) for Mn; 43.326 ± 0.341 (in uw leaf) and 0.913 ± 0.079 (in stem) for Ni; 53.806 ± 0.118 (in uw leaf) and 1.211 ± 0.056 (in stem) for Pb; 125.460 ± 0.383 (in uw leaf) and 6.208 ± 0.166 (in stem) for Zn, respectively.

In the meantime, the concentrations of the mineral nutrients (B, Ca, K, and Na) in the plant parts and adjacent soils were also measured in order to evaluate the absorption values. This research revealed that on the plant parts average highest and lowest macronutrient levels were; 41.573 ± 0.387 (in uw leaf) and 5.676 ± 0.144 (in uw leaf) for B; 12,629.184 ± 22.424 (in uw leaf) and 982.496 ± 6.924 (in stem) for Ca; 4519.616 ± 30.949 (in uw leaf) and 1100.096 ± 7.639 (in rhizome) for K; 774.640 ± 7.346 (in uw leaf) and 215.843 ± 7.427 (in stem) for Na, respectively.

Table 3. Reference values for normal and toxic concentrations of heavy metals in plants.[14,25]

Element	Normal Concentrations (mg kg^{-1})	Toxic Concentrations (mg kg^{-1})
Cr	0.006–18	>100
Cu	5–30	20–100
Fe	2–250	400–1000
Mn	30–300	300–500
Pb	0.1–10	30–300
Zn	25–150	100–400
Cd	0.2–0.8	5–30
Ni	0.1–5	30

The literature reports that the average values (Table 3 and Table 4) of Cd, Cr, Cu, Fe, Mn, Pb, Zn, and Ni in aromatic plants are in the ranges of 0.2–0.8, 0.006–18, 5–30, 2–250, 30–300, 0.1–10, 25–150 and 0.1–5 mg kg^{-1}, respectively, and values accepted as toxic are between or over 5–30, >100, 20–100, 400–1000, 300–500, 30–300, 100–400 and 30 mg kg^{-1}, respectively.[14,25,58] When the outcomes of this investigation were assessed in light of the aforementioned results, it was discovered that Cd concentrations in plant component samples were consistently higher than the recommended limits, not extending the toxic level; on the contrary, the concentrations of Cu, Mn and Zn were detected in the normal ranges in all locations; the concentrations of Cr in the plant samples were found to be in normal ranges, except in the W and UW leaf samples collected from the first and second locations and in the rhizome collected from first location; the concentrations of Ni and Pb in plant parts were discovered to be higher than the allowable limits in all locations, except in the control locations, in which the concentrations were discovered to be within normal levels, lastly, the concentrations of Fe in plant parts were discovered to be higher than the allowable limits in all locations, except in the control and third locations of W leaf, stem and rhizome. In accordance with these results, the findings of this study were also evaluated with the allowable limits established by FAO/WHO and the American Herbal Products Association for therapeutic herbs.[71,72] The

Table 4. Metal concentrations in *Mentha spicata* and *Mentha piperita* samples: comparison with previous studies.[73–76]

Metals	This study (washed leaves, from Location 1)	*M. spicata* from India	*M. spicata* from India (local market)	*M. spicata* from United Arab Emirates	*M. piperita* from Spain	*M. piperita* from Türkiye (local market)
Al	395.424 ± 8.548	570 ± 350			78.82 ± 13.38	536.1 ± 114.14
Cd	3.568 ± 0.115	0.369 ± 0.252	0.74 ± 0.07		0.20 ± 0.028	0.02 ± 0.02
Cr	24.210 ± 0.219	1.37 ± 0.25			1.33 ± 0.35	6.28 ± 1.61
Cu	13.586 ± 0.147	16.9 ± 1.8	29.83 ± 3.16	12.32 ± 0.31	12.41 ± 0.87	6.47 ± 0.41
Fe	1305.568 ± 11.047	108 ± 22	395.74 ± 4.09	821.02 ± 17.83	402.43 ± 60.19	451.40 ± 85.60
Mg	1819.808 ± 60.384	4830 ± 920	532.72 ± 0.93		4522.29 ± 320.21	2316.60 ± 136.29
Mn	85.082 ± 0.390	53.5 ± 9.6	85.72 ± 1.13		46.20 ± 5,32	43.5 ± 3.09
Ni	25.969 ± 0.121	0.002 ± 0.001			1.34 ± 0.23	3.52 ± 0.27
Pb	36.447 ± 0.192		9.89 ± 0.36	9.24 ± 1.02	0.61 ± 0.16	0.0 ± 0.0
Zn	36.447 ± 0.192	21.0 ± 4.7	49.76 ± 4.12	52.97 ± 2.81	27.05 ± 3.00	10.79 ± 0.19
B	30.238 ± 0.103				17.79 ± 1.45	9.8 ± 1.93
Ca	10,348.160 ± 52.179	12,400 ± 3500			10,328.06 ± 753.16	4200 ± 1435.87
K	3461.856 ± 77.872	23,400 ± 12,100			9086.25 ± 763.54	18,496.20 ± 1169.53
Na	589.114 ± 8.049	480 ± 200	808.09 ± 1.64		1670.07 ± 292.13	916.23 ± 76.53

Table 5. Correlation matrix data between soil and rhizome obtained by correlation method.

	Correlation matrix (R)													
Pearson correlation	Al soil	B soil	Ca soil	Cd soil	Cr soil	Cu soil	Fe soil	K soil	Mg soil	Mn soil	Na soil	Ni soil	Pb soil	Zn soil
Al rhizome	.443*	.264	.669**	.600**	.455*	.389	.291	−.746**	−.677**	.434*	.759**	.603**	.741**	.839**
B rhizome	.950**	.867**	.882**	.911**	.971**	.939**	.742**	−.927**	−.914**	.962**	.896**	.979**	.910**	.869**
Ca rhizome	.923**	.941**	.922**	.921**	.885**	.924**	.954**	−.791**	−.834**	.899**	.850**	.842**	.849**	.684**
Cd rhizome	.811**	.670**	.868**	.880**	.832**	.780**	.589**	−.940**	−.896**	.821**	.919**	.908**	.933**	.955**
Cr rhizome	.919**	.815**	.871**	.933**	.934**	.899**	.672**	−.917**	−.928**	.929**	.887**	.958**	.917**	.884**
Cu rhizome	.724**	.837**	.681**	.657**	.668**	.749**	.907**	−.472*	−.519**	.700**	.552**	.562**	.538**	.317
Fe rhizome	.953**	.898**	.923**	.957**	.950**	.944**	.811**	−.894**	−.913**	.955**	.894**	.945**	.915**	.820**
K rhizome	.422*	.275	.309	.407*	.486*	.402*	.027	−.493*	−.480*	.471*	.382	.539**	.430*	.535**
Mg rhizome	.723**	.832**	.716**	.664**	.669**	.747**	.938**	−.509**	−.539**	.692**	.602**	.575**	.581**	.364
Mn rhizome	.919**	.809**	.888**	.940**	.935**	.897**	.675**	−.937**	−.942**	.930**	.910**	.967**	.936**	.911**
Na rhizome	.770**	.809**	.714**	.616**	.779**	.794**	.837**	−.654**	−.574**	.777**	.675**	.724**	.644**	.541**
Ni rhizome	.884**	.753**	.874**	.929**	.902**	.855**	.616**	−.940**	−.943**	.894**	.908**	.952**	.935**	.931**
Pb rhizome	.959**	.875**	.904**	.931**	.978**	.947**	.759**	−.942**	−.932**	.970**	.917**	.989**	.929**	.885**
Zn rhizome	.749**	.622**	.876**	.798**	.763**	.716**	.636**	−.921**	−.854**	.742**	.935**	.848**	.903**	.930**

*Correlation is significant at the 0.05 level (two-tailed).
**Correlation is significant at the 0.01 level (two-tailed).

results revealed that, except the concentrations of Cu, the concentrations of Cd, Cr, Mn, Fe, Pb, and Ni were shown to be considerably higher than the permissible limits determined by FAO/WHO and AHPA.

Furthermore, the correlation coefficients between the elements' concentrations in rhizomes of *M. spicata* L. subsp. *tomentosa* and co-located soils (Table 5), and between the elements' concentrations in leaves and rhizomes of *M. spicata* L. subsp. *tomentosa* (Table 6) were statistically determined using the Pearson correlation method. When statistical analysis employing a linear correlation connection was conducted, significantly strong positive correlations (>0.910) were discovered between the values of B in rhizomes of *M. spicata* L. subsp. *tomentosa* and the values of elements (Al, Cd, Cr, Cu, Mn, Ni and Pb) in the co-located soil samples. In addition, higher than average positive correlations (>0.921) were evaluated between the values of Ca in rhizomes of *M. spicata* L. subsp. *tomentosa* and the values of other elements (Al, B, Cd, Cr, Cu, and Fe) in the co-located soil samples. However, higher than average positive correlations (>0.908) were found between the values of Cd in rhizomes of *M. spicata* L. subsp. *tomentosa* and the values of elements (Na, Ni, Pb and Zn) in the co-located soil samples. Furthermore, higher than average positive correlations (>0.917) were found between the values of Cr in rhizomes of *M. spicata* L. subsp. *tomentosa* and the values of heavy metals (Al, Cd, Cr, Mn, Ni and Pb) in the co-located soil samples. Higher than average positive correlations (>0.907) were found between the values of Cu and Mg in rhizomes of *M. spicata* L. subsp. *tomentosa* and the value of Fe in the co-located soil samples. Additionally, higher than average positive correlations (>0.904) were found between the values of Fe and Pb in rhizomes of *M. spicata* L. subsp.

Table 6. Correlation matrix data between rhizome and washed leaf obtained by correlation method.

	Correlation matrix (R)													
Pearson correlation	Al rhizome	B rhizome	Ca rhizome	Cd rhizome	Cr rhizome	Cu rhizome	Fe rhizome	K rhizome	Mg rhizome	Mn rhizome	Na rhizome	Ni rhizome	Pb rhizome	Zn rhizome
Al leaf	.543**	.971**	.750**	.907**	.988**	.455*	.922**	.688**	.424*	.991**	.600**	.980**	.978**	.744**
B leaf	.497*	.972**	.891**	.862**	.954**	.648**	.966**	.500*	.653**	.956**	.737**	.929**	.982**	.773**
Ca leaf	.347	.253	.771**	.288	.212	.824**	.434*	−.528**	.913**	.238	.546**	.198	.291	.500*
Cd leaf	.628**	.911**	.917**	.862**	.894**	.669**	.920**	.353	.708**	.908**	.727**	.887**	.923**	.844**
Cr leaf	.443*	.968**	.859**	.812**	.911**	.664**	.924**	.483*	.662**	.915**	.823**	.878**	.971**	.768**
Cu leaf	.239	.906**	.885**	.685**	.851**	.770**	.897**	.398*	.750**	.842**	.822**	.784**	.908**	.608**
Fe leaf	.266	.886**	.838**	.663**	.789**	.742**	.844**	.352	.741**	.788**	.899**	.730**	.885**	.656**
K leaf	−.641**	−.831**	−.757**	−.832**	−.839**	−.446*	−.816**	−.384	−.514**	−.835**	−.586**	−.843**	−.849**	−.816**
Mg leaf	.749**	.590**	.675**	.665**	.504*	.510**	.586**	−.023	.630**	.553**	.747**	.539**	.608**	.877**
Mn leaf	.449*	.931**	.862**	.778**	.853**	.691**	.892**	.391	.711**	.860**	.880**	.818**	.937**	.789**
Na leaf	.370	.863**	.973**	.728**	.832**	.835**	.917**	.243	.847**	.832**	.772**	.785**	.876**	.676**
Ni leaf	.635**	.966**	.744**	.937**	.986**	.406*	.921**	.672**	.400*	.994**	.564**	.996**	.974**	.807**
Pb leaf	.743**	.915**	.765**	.952**	.951**	.406*	.901**	.568**	.426*	.966**	.516**	.979**	.931**	.861**
Zn leaf	.934**	.740**	.655**	.893**	.746**	.312	.722**	.325	.393	.785**	.516**	.813**	.765**	.977**

*Correlation is significant at the 0.05 level (two-tailed).
**Correlation is significant at the 0.01 level (two-tailed).

tomentosa and the values of elements (Al, Ca, Cd, Cr, Cu, Mn, Ni and Pb) in the co-located soil samples. Higher than average positive correlations (>0.910) were found between the values of Mn in rhizomes of *M. spicata* L. subsp. *tomentosa* and the values of elements (Al, Cd, Cr, Mn, Na, Ni, Pb and Zn) in the co-located soil samples. In addition, higher than average positive correlations (>0.902) were found between the values of Ni in rhizomes of *M. spicata* L. subsp. *tomentosa* and the values of elements (Cd, Cr, Na, Ni, Pb and Zn) in the co-located soil samples. Furthermore, higher than average positive correlations (>0.903) were found between the values of Zn in rhizomes of *M. spicata* L. subsp. *tomentosa* and the values of elements (Na, Pb and Zn) in the co-located soil samples.

Strong negative correlation (->0.917, ->0.913) were found to be between the rhizome concentrations of B, Cr, Cd, Fe, Mn, Ni, Pb, and Zn evaluated in this study and the content of K and Mg present in co-located soil samples of *M. spicata* L. subsp. *tomentosa*. A significant positive correlation is found to be between the readings of Al, B, Ni and Pb in leaves of *M. spicata* and the values of B, Cd, Cr, Fe, Mn, Ni and Pb in the rhizomes of *M. spicata* L. subsp. *tomentosa*. In addition, high positive correlation was evaluated between the values of Cd and Cr in leaves of *M. spicata* L. subsp. *tomentosa* and the values of B, Ca, Cr, Fe, Mn and Pb in the rhizomes of *M. spicata* L. subsp. *tomentosa*. Furthermore, there was a significant positive correlation between the values of Cu and Mn in leaves of *M. spicata* L. subsp. *tomentosa* and the values of elements (B and Pb) in the rhizomes of *M. spicata* L. subsp. *tomentosa*. Additionally, a significant positive correlation is found to be between the values of Na in leaves of *M. spicata* L. subsp. *tomentosa* and the values of Ca and Fe in the rhizomes of *M. spicata* L. subsp. *tomentosa*. However, a significant positive correlation is found to be between the values of Ca in leaves of *M. spicata* and the values of Mg in the rhizomes of *M. spicata* L. subsp. *tomentosa*. Also, there was a significant positive correlation between the values of Zn in leaves of *M. spicata* L. subsp. *tomentosa* and the values of Al in the rhizomes of *M. spicata* L. subsp. *tomentosa*.

Negative correlation was evaluated between the leaf content of K and the content of all elements considered within the scope of this study present in rhizome of *M. spicata* L. subsp. *tomentosa*. In addition, negative correlation was also evaluated between the leaf content of Ca and the content of K present in rhizome of *M. spicata* L. subsp. *tomentosa*. Worldwide research has been done on the accumulation of trace elements, heavy metals, and possibly hazardous elements in medicinal plants (Table 4).

In a similar study realized in Dubai (United Arab Emirates), heavy metal concentrations of several commonly consumed herbs, including *M. spicata*, which were purchased from the local markets, were evaluated as follows; Cd (not detected), Pb (less than 9.24 mg kg^{-1}), Cu (12.32 mg kg^{-1}) Zn (52.97 mg kg^{-1}) and Fe (821.02 mg kg^{-1}).[73] According to the results evaluated in this study in the washed leaf samples collected in locations 1, 2 and 4, respectively, concentrations were found to be higher, except control location and location 3. Possible sources of contamination of plants purchased from local markets, that resulted in high heavy metal contents, may be due to the fact that drying conditions or transportation procedures which were not carried out under appropriate conditions.[51] In another study, *M. spicata* which is regularly used in cooking in Indian curries were evaluated in terms of heavy metals and mineral nutrients.[74] Na, Fe, Mn, Mg, Pb, Zn, Cd and Cu, respectively, were ranged from 808.09, 395.74, 85.72, 532.72, 9.89, 49.76, 0.74, 29.83 mg kg^{-1} dry wt., respectively. When the abovementioned results were compared with this study, Cd, Fe, Mg, and Pb contents in *M. spicata* sample were found to be higher, while Mn concentration was evaluated nearly on the same range. In addition, Cu, Zn, and Mn contents were evaluated in lower concentrations.

In the investigation reported from Tenerife, Canary Islands in Spain, 36 samples of *M. spicata* were considered, in particular, herbal shops, supermarkets, local markets, and pharmacies were used to procure mint tea leaves and bags at random. It was reported that *M. piperita* samples, the concentration of Cd, Pb, K, Na, Ca, Mg, Al, B, Cr, Cu, Fe, Mn, Zn and Ni were determined as follows, 0.20, 0.61, 9086.25, 1670.07, 10,328.06, 4522.29, 78.82, 17.79, 1.33, 12.41, 402.43, 46.20, 27.05 and 1.34 mg kg^{-1} dry wt., respectively. According to this study, concentrations in all evaluated elements in *M. spicata* L. subsp. *tomentosa* sample were found to be in higher ranges, Ca content was detected within the same range, additionally, Mg, K and Na contents were found to be in lower concentrations.[75] Furthermore, in the investigation performed in Türkiye, nineteen species of herbs and herbal teas, including *M. piperita*, were purchased from local markets. Concentration of mineral nutrients was aimed to be determined after infusion and decoction processes. For *M. piperita* sample, the content of the following elements Cd, K, Na, Ca, Mg, Al, B, Cr, Cu, Fe, Mn, Zn, and Ni were evaluated as 0.02, 18,496.20, 916.23, 4200, 2316.60, 536.1, 9.8, 6.28, 6.47, 451.40, 43.5, 10.79 and 10.79 mg kg^{-1} dry wt., respectively.[76] In accordance with the results claimed in this study, except the concentrations of Al, Mg, K, and Na, the other evaluated elements were found to be in higher concentration ranges.

The findings of this study show that location 1 was significantly polluted, while the control location was comparatively the cleanest area. The airborne removal rates on the leaves at location 1 were determined to be 38.46, 27.27, 18.06, 36.41, 15.43, 28.66, 27.58, 13.59, 23.95, 40.06, 32.26 and 42.40% for Al, B, Ca, Cd, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, Pb and Zn, respectively (Table 7). Despite the fact that washing the leave samples significantly lowered the content of various heavy metals, the reduced values were still over permissible limits in some parts of the district. This might be due to the attribution of air contaminants which has an adverse effect on crops and plants.[77,78] When the detected concentrations of all elements within the scope of this study were compared in W and UW leaves, in either case, the concentrations were higher than the allowable limits reported in previous studies and established by FAO/WHO and AHPA. This shows that the dust and debris containing heavy metals in the air that adhered to the leaves were at higher concentrations in heavily industrialized DOIZ and its surroundings, such that the washing procedure had no notable effect.

Table 7. Percentage change of element contents in leaves before and after washing.

	Al	B	Ca	Cd	Cr	Cu	Fe	K	Mg	Mn	Na	Ni	Pb	Zn
Control	45.82	31.48	17.12	17.05	55.79	18.33	56.06	18.34	9.90	22.65	31.40	43.32	39.62	13.46
1. loc	38.46	27.27	18.06	36.41	15.43	28.66	27.83	0.83	27.58	13.59	23.95	40.06	32.26	42.50
2. loc	39.54	37.21	19.40	37.02	8.43	27.28	38.14	11.15	4.78	22.94	27.56	44.82	46.35	49.82
3. loc	21.97	27.60	17.23	44.26	36.13	27.79	50.24	12.63	11.72	37.95	20.72	26.12	48.49	19.29
4. loc	31.07	39.56	31.11	55.28	31.87	33.95	28.88	12.10	12.20	18.67	35.69	38.57	36.32	29.46

As a result of both heavy traffic and industrial activity close to residential areas, air, and soil pollutions are among the primary environmental issues in the region. The impact of pollution on air in DOIZ was reported in several studies. In a study realized in the same region showed that atmospheric SO_2 have been surpassed international and governmental limitations on concentrations. The WHO's $20\,mg\ m^{-3}$ limit value has not been provided, despite the falling trend in PM (black fume) concentrations.[79] Furthermore, a significant level of toluene pollution was detected by Ozturk et al.[68] in industrial and residential areas of the district and continuous monitoring was recommended. Moreover, in another study, ALOHA software was used to determine the possible effects of air pollutants (CO, SO_2, NO, NO_2, O_3) in some parts of the district, where the industry is concentrated with. According to the obtained data, all effect values decreased in 2017 as a result of a fall in CO and O_3 air pollution concentrations. It has been suggested that quantitative analyses of the potential consequences of air pollution might make environmental restrictions more effective.[80]

In the present study, it is considered not only soil contamination aspect of the district, the evaluation of *M. spicata* L. subsp. *tomentosa* for consumption purposes were also introduced. In addition, the impact of pollution on soil in DOIZ was also reported in several studies. Cetin et al.[81] investigated that Sn, Mn, Ca, As, Zn, Pb, and Cd had a remarkably high average enrichment factors values, demonstrating that human activity had the greatest impact on their soil concentrations; industrial activities and traffic were discovered to be the primary factors influencing the soil profile.[81] In another study, the heavy/toxic metal (Cd, Co, Cr, Cu, Mn, Ni, Pb, and Zn) pollution in DOIZ is evaluated by applying multi-criteria decision making (MCDM) approach. It was found that location harbor of Hereke is the most polluted especially by Pb, Cd, Cr and As, at which point the farthest places from the harbors and industrialized zones are the least polluted areas.[82] In a different investigation, a chemometric method was proposed to evaluate the level of contamination of heavy/toxic metals (Cd, Co, Cr, Cu, Mn, Ni, Pb, and Zn) and to categorize the heavy metal content of surface soil samples collected from 10 different locations in the DOIZ region. The findings indicated that soil samples collected from various places had various characterization traits in terms of heavy metal levels.[83]

Hence, Cetin et al.[81] reported a study of polybrominated diphenyl ethers (PBDEs) levels in the soil within one year in highly industrialized region of Türkiye (DOIZ) at 23 locations for sampling. The highest values were reported to be measured in industrial or urban areas, whereas the lowest values were typically found at rural locations. They also indicated that, the lack of wind-mediated dilution due to the calm weather conditions raised the amounts of industrial and urban soil contaminants. However, Ulutas in a recent study reported that Si, Fe, Al, Mn, and Ti were the most prevalent components in the samples of roadway dust. They indicated that, Zn, Cr, Ba, Pb, Ni, Sr, V, and Co were detected in greater quantities than other elements after crustal elements. The mean amounts of Zn, Mn, Cr, Pb, Ni, Co, and Cd were significantly higher than their reference values, indicating that human sources may have had an impact on these metals in road dust. In another study, surface water chemistry and land data were studied in detail as well as water quality of Dil Stream Basin. They claimed that the uncontrolled land use, particularly in the south and west of the Dil Stream Basin, changed the geomorphological characteristics of the basin and destroyed its natural structure.[84]

To maintain proper metabolic functions, the human body requires many important plant

Table 8. Recommended dietary allowance values for nutrients in leaves that stand out in mint plant consumption.

	RDA	Ca 1000 (mg)	Cu 0.9 (mg)	Fe 8 (mg)	K 4700 (mg)	Mg 420 (mg)	Mn 2.3 (mg)	Na 1500 (mg)	Zn 11 (mg)
Washed leaf	Control	77.63	34.44	162.25	8.74	34.26	54.29	1.55	17.79
	1. loc	103.48	150.95	1631.96	7.37	43.33	369.92	3.93	65.58
	2. loc	57.20	116.24	1367.00	7.81	38.43	304.99	2.67	48.07
	3. loc	45.93	60.00	229.24	8.40	27.18	76.97	1.88	22.41
	4. loc	72.32	66.96	555.04	7.62	42.27	202.49	2.31	79.74
Unwashed leaf	Control	93.67	42.17	369.27	10.70	38.02	70.19	2.26	20.56
	1. loc	126.29	211.59	2261.40	7.43	59.83	428.10	5.16	114.05
	2. loc	70.96	159.84	2209.96	8.79	40.36	395.76	3.69	95.79
	3. loc	55.50	83.09	460.68	9.62	30.79	124.05	2.37	27.76
	4. loc	104.98	101.38	780.40	8.67	48.15	248.97	3.60	113.04

Note: 70 kg adults-based on 100 g dw^{-1} consumption per day.

nutrients. As a consequence, the RDA values (100 g dw^{-1}) for the Ca, Cu, Fe, K, Mg, Mn, Na and Zn were determined in *M. spicata* L. subsp. *tomentosa* for having comparative insights about the nutritional values collected from the DOIZ and its surroundings (Table 8). Dairy products provide high quantities of calcium, and the RDA for calcium is 1000 mg per day. In accordance with the findings of the present study, the RDA value of Ca was found to be a minimum of 45.93 for w leaf in location 3, and a maximum of 126.29 for uw leaf in location 1. Alternatively, a daily intake of 100 g uw *M. spicata* L. subsp. *tomentosa* meets only ~0.126% of daily Ca need. The RDA value of Cu varies between 34.44 in control sample for W leaf and 211.59 for UW leaf in location 1. Alternatively, a daily intake of 100 g of W and UW *M. spicata* L. subsp. *tomentosa* meets more than a thousand percent of daily Cu need. In accordance with the findings of the present study, the RDA value of Fe was found to be minimum 162.25 in control sample for W leaf, and maximum 2261.40 in location 1 for UW leaf samples of *M. spicata*, respectively. Alternatively, a daily intake of 100 g of W and UW of *M. spicata* L. subsp. *tomentosa* meets more than a thousand percent of daily Fe need. In the present work it is shown that K has the RDA values between 7.37 in location 1 for w leaf and 10.70 in control location for uw leaf, which demonstrates that a regular intake of 100 g *M. spicata* L. subsp. *tomentosa* provides only ~0.157% for w leaf and ~0,228% for uw leaf of the daily K requirements, respectively. In this study it is investigated that the RDA for Mg ranged from 27.18 in location 1 for W leaf samples and 59.83 in location 1 for UW leaf samples, which means 100 g consumed each day of W *M. spicata* L. subsp. *tomentosa* provides ~6.47% and 8.49% and UW *M. spicata* L. subsp. *tomentosa* provides ~14.25% and 18.7% of the daily requirements of Mg for men and women, respectively. In accordance with results, the RDA values of Mn were detected to be minimum 54.29 in control location for w leaf samples and maximum 428.10 in location 1 for uw leaf samples, respectively. As a result, 100 g of *M. spicata* L. subsp. *tomentosa* gives a benefit of more than a thousand times more Mn than is needed per day for males and women, respectively. This study demonstrated that the RDA values of Na ranged between 1.55 in control location for W leaf samples and 5.16 in location 1 for UW leaf samples of *M. spicata*, respectively. Consequently, 100 g gives a daily benefit of ~0.103% and ~0.34% Na, for w and UW leaf of *M. spicata* L. subsp. *tomentosa*, respectively. In accordance with the results, the lowest RDA values of Zn were found 17.79 in control location for W leaf samples, while the highest 114.05 in location 1 for UW leaf samples of *M. spicata* L. subsp. *tomentosa*. Thus, a 100 g consumption each day of W *M. spicata* L. subsp. *tomentosa* provides ~161.77% and 222.37% of the everyday needs for both men and women, whereas UW *M. spicata* L. subsp. *tomentosa* provides more than e thousand percent of the daily requirement. On the other hand, it is anticipated that more than 60% of the world's population lacks Zn and more than 30% lacks Fe. Additionally, both in affluent and developing nations, excessive Ca, Mg, and Cu deficits are prevalent.[85] RDA findings thus unequivocally provide evidence that the examined the potential for essential elements in plant species is very high. The high proportion of heavy metals can be attributed, in particular, to location 1's extremely dense metal industry. *M.*

Table 9. Estimated daily intake, target hazard quotient of heavy metals and hazard index values for adults* associated with the consumption of plants samples.

	Cd		Cr		Ni		Pb		
Locations	EDI	THQ	EDI	THQ	EDI	THQ	EDI	THQ	HI
Control	8.93E − 04	2.98E − 03	1.31E − 02	6.53E − 03	9.29E − 03	6.19E − 03	6.36E − 03	6.36E − 04	0.016
1. loc	3.53E − 03	1.18E − 02	1.54E − 01	7.72E − 02	1.37E − 01	9.13E − 02	1.15E − 01	1.15E − 02	0.192
2. loc	2.46E − 03	8.21E − 03	1.23E − 01	6.15E − 02	1.17E − 01	7.77E − 02	9.76E − 02	9.76E − 03	0.157
3. loc	1.70E − 03	5.66E − 03	6.51E − 02	3.25E − 02	7.47E − 02	4.98E − 02	6.52E − 02	6.52E − 03	0.094
4. loc	3.15E − 03	1.05E − 02	1.03E − 01	5.17E − 02	1.19E − 01	7.96E − 02	1.05E − 01	1.05E − 02	0.152

Note: EDI: estimated daily intake (mg/kg/day); THQ: target hazard quotient; HI: hazard index; *70 kg of adult person.

spicata L. subsp. *tomentosa* plants from the Buyukada control location, which is free of heavy metal pollution, can be consumed without any problems. However, even in those areas where the mineral nutritional values are higher than the control location, this should be disregarded because of the high levels of toxic heavy metals it contains. Therefore, by this study, the usage of this plant as food or medicine was not recommended.

The possibility of negative repercussions in adults following exposure to the four potentially harmful elements examined through the use of medicinal herbs was below the acceptable values, taking into account the estimated THQ values and cumulative HI values for Cd, Cr, Ni, and Pb. While the highest HI value was 0.192 at the first location, the lowest value was 0.016 at the location constituting the control group (Table 9). In addition to their detrimental effects on human health, hazardous metals in these plants must be assessed for risk in order to acquire accurate estimations of their intake through this traditional usage. The direct reflection of the pollution determined in the locations to the risk calculations is suitable for the purpose of the study and increases the importance of the correct positioning of agricultural lands and the use of clean water in irrigation. Also, it's critical to evaluate the danger of toxic metals in these plants in order to determine their harmful effects on human health as well as to make accurate projections of their absorption using this traditional method. Also, the maximum daily consumption of hazardous components for an adult who weighs 70 kg has been set by the Joint FAO/WHO Expert Committee on Food Additives.[72]

The HI values have exhibited variability in accordance with the density of heavy metals in the respective locations, reaching their highest levels in the region characterized by intensive industrialization. While the HI values may appear to fall within acceptable limits, the elevated concentration of heavy metals raises evident concerns regarding potential significant health issues if consumption of this plant species persists in the area. Finally, *M. spicata* L. subsp. *tomentosa* plants in some locations have higher mineral nutritional values than in the Buyukada control location, which is free of heavy metal pollution, this should be ignored due to the high level of toxic heavy metals it contains, and this study advises against ever using this plant as food or medicine.

Conclusion

In recent years, there has been an increase in the use of herbal medicine, whichever is the main type of treatment used in developing nations, hence, some of the herbs selectively absorb and accumulate the heavy metals from the soils. Based on this fact, in the present study, *M. spicata* L. subsp. *tomentosa* was used as the monitoring data, to outline a picture of the contamination level in the DOIZ and its surroundings, located in a heavily industrialized area. Metal contamination analyses have been carried out, for specific locations under investigation in the current effort. All elements were exceeded normal limits except B and Cu (only in unwashed leaf for one location) in DOIZ and its surroundings. Cd, Cr, Fe, Ni, Pb, and Zn were reached "toxic levels" in leaf (edible parts) samples. Heavy metals were accumulated in leaves at higher amounts in comparison with the rhizomes of the plant. Heavy metal concentrations had an impact on the intake and accumulation of mineral elements, particularly in rhizomes. However, due to natural and man-made sources, the soil was also rich in mineral elements. The concentration of heavy metals in leaf samples was unaffected by the washing technique. Hence, it can be concluded that *M. spicata* subsp. *tomentosa* grown in Dilovasi-Kocaeli-Türkiye is not an edible medicinal plant because of toxic amounts of Cd, Cr, Fe, Ni, Pb, and Zn and high amounts of B and Cu in their leaves. The above-mentioned results show that the region is under the threat of intense pollution, especially the industrialized parts of the region have enormous pollution values. Furthermore, this study supports the studies in the literature, in particular, the fact that location 1 has a very dense metal industry can be shown as the reason of the high content of heavy metals. *M. spicata* L. subsp. *tomentosa* plants of the Buyukada control location, which does not have heavy metal pollution, can be consumed without any difficulties, but even in some locations, the mineral nutritional values are higher than the control location, this should be ignored due to the high level of toxic heavy metals it contains, and this study recommends that this plant should never be consumed for medicinal or food purposes.

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References

[1] Fisher, S.; Bellinger, D. C.; Cropper, M. L.; Kumar, P.; Binagwaho, A.; Koudenoukpo, J. B.; Park, Y.; Taghian, G.; Landrigan, P. J. Air Pollution and Development in Africa: Impacts on Health, the Economy, and Human Capital. *The Lancet Planetary Health* **2021**, *5* (10), e681–e688. DOI: 10.1016/S2542-5196(21)00201-1.

[2] Fuller, R.; Landrigan, P. J.; Balakrishnan, K.; Bathan, G.; Bose-O'Reilly, S.; Brauer, M.; Caravanos, J.; Chiles, T.; Cohen, A.; Corra, L.; et al. Pollution and Health: A Progress Update. *The Lancet Planetary Health* **2022**, *6* (6), e535–e547. DOI: 10.1016/S2542-5196(22)00090-0.

[3] Zaimee, M. Z. A.; Sarjadi, M. S.; Rahman, M. L. Heavy Metals Removal from Water by Efficient Adsorbents. *Water* **2021**, *13* (19), 2659. DOI: 10.3390/w13192659.

[4] Ali, H.; Khan, E. What Are Heavy Metals? Long-Standing Controversy over the Scientific Use of the Term 'Heavy Metals' – Proposal of a Comprehensive Definition. *Toxicological and Environmental Chemistry* **2018**, *100* (1), 6–19. DOI: 10.1080/02772248.2017.1413652.

[5] Hocaoglu-Ozyigit, A.; Nazli Genc, B. Cadmium in Plants, Humans and the Environment. *Frontiers in Life Sciences and Related Technologies* **2020**, *1* (1), 12–21.

[6] Can, H.; Ozyigit, I. I.; Can, M.; Hocaoglu-Ozyigit, A.; Yalcin, I. E. Multidimensional Scaling of the Mineral Nutrient Status and Health Risk Assessment of Commonly Consumed Fruity Vegetables Marketed in Kyrgyzstan. *Biological Trace Element Research* **2022**, *200* (4), 1902–1916. DOI: 10.1007/s12011-021-02759-2.

[7] Vardhan, K. H.; Kumar, P. S.; Panda, R. C. A Review on Heavy Metal Pollution, Toxicity and Remedial Measures: Current Trends and Future Perspectives. *Journal of Molecular Liquids* **2019**, *290*, 111197. DOI: 10.1016/j.molliq.2019.111197.

[8] Edelstein, M.; Ben-Hur, M. Heavy Metals and Metalloids: Sources, Risks and Strategies to Reduce Their Accumulation in Horticultural Crops. *Scientia Horticulturae* **2018**, *234*, 431–444. DOI: 10.1016/j.scienta.2017.12.039.

[9] Baroudi, F.; Al Alam, J.; Fajloun, Z.; Millet, M. Snail as Sentinel Organism for Monitoring the Environmental Pollution; A Review. *Ecological Indicators* **2020**, *113*, 106240. DOI: 10.1016/j.ecolind.2020.106240.

[10] Eid, E. M.; Shaltout, K. H.; Al-Sodany, Y. M.; Haroun, S. A.; Galal, T. M.; Ayed, H.; Khedher, K. M.; Jensen, K. Common Reed (Phragmites Australis (Cav.) Trin. Ex Steudel) as a Candidate for Predicting Heavy Metal Contamination in Lake Burullus, Egypt: A Biomonitoring Approach. *Ecological Engineering* **2020**, *148*, 105787. DOI: 10.1016/j.ecoleng.2020.105787.

[11] Kumar, M.; Gupta, N.; Ratn, A.; Awasthi, Y.; Prasad, R.; Trivedi, A.; Trivedi, S. P. Biomonitoring of Heavy Metals in River Ganga Water, Sediments, Plant, and Fishes of Different Trophic Levels. *Biological Trace Element Research* **2020**, *193* (2), 536–547. DOI: 10.1007/s12011-019-01736-0.

[12] Yalcin, I. E.; Altay, V. Investigation of Water-Soil-Plant Relationships Based on Hazardous and Macro-Micro Element Concentrations on Orontes River, Türkiye. *International Journal of Phytoremediation* **2023**. DOI: 10.1080/15226514.2023.2202241.

[13] Cannas, D.; Loi, E.; Serra, M.; Firinu, D.; Valera, P.; Zavattari, P. Relevance of Essential Trace Elements in Nutrition and Drinking Water for Human Health and Autoimmune Disease Risk. *Nutrients* **2020**, *12* (7), 2074. DOI: 10.3390/nu12072074.

[14] Kabata-Pendias, A.; Mukherjee, A. B. The Biosphere. In Alloway, B. J.; Dexter, A., *Trace Elements from Soil to Human*; Springer: Berlin, 2007. DOI: 10.1007/978-3-540-32714-1_2.

[15] Karahan, F.; Ozyigit, I. I.; Saracoglu, I. A.; Yalcin, I. E.; Ozyigit, A. H.; Ilcim, A. Heavy Metal Levels and Mineral Nutrient Status in Different Parts of Various Medicinal Plants Collected from Eastern Mediterranean Region of Turkey. *Biological Trace Element Research* **2020**, *197* (1), 316–329. DOI: 10.1007/s12011-019-01974-2.

[16] Kaur, R.; Kumar, A.; Biswas, B.; Krishna, B. B.; Rout, P. K.; Bhaskar, T. Py-GC/MS and Pyrolysis Studies of Eucalyptus, Mentha, and Palmarosa Biomass. *Biomass Conversion and Biorefinery* **2022**. DOI: 10.1007/s13399-022-02729-1.

[17] Yilmaz, N.; Ozyigit, I. I.; Dogan, I.; Demir, G.; Yalcin, I. E. A Case Study Performed in Kucukcekmece Lagoon Channel/Istanbul, Turkey: How the Heavy Metal Contamination and the Seasonal Variations on Phytoplankton Composition Influence Water Quality. *Desalination and Water TREATMENT* **2021**, *239*, 126–136. DOI: 10.5004/dwt.2021.27817.

[18] Kandić, I.; Kragović, M.; Petrović, J.; Janaćković, P.; Gavrilović, M.; Momčilović, M.; Stojmenović, M. Heavy Metals Content in Selected Medicinal Plants Produced and Consumed in Serbia and Their Daily Intake in Herbal Infusions. *Toxics* **2023**, *11* (2), 198. DOI: 10.3390/toxics11020198.

[19] Mosallaei, S.; Abbasi, S.; Jalalian, E.; Amiri, H.; Hoseini, M. Heavy Metals in Edible Red Soil of the Rainbow Island in the Persian Gulf: Concentration and Health Risk Assessment. *Chemosphere* **2023**, *331*, 138778. DOI: 10.1016/j.chemosphere.2023.138778.

[20] Caldas, E. D.; Machado, L. L. Cadmium, Mercury and Lead in Medicinal Herbs in Brazil. *Food and Chemical Toxicology: An International Journal Published for the British Industrial Biological Research Association* **2004**, *42* (4), 599–603. DOI: 10.1016/j.fct.2003.11.004.

[21] Street, R. A. Heavy Metals in Medicinal Plant Products—An African Perspective. *South African Journal of Botany* **2012**, *82*, 67–74. DOI: 10.1016/j.sajb.2012.07.013.

[22] Goncharuk, E. A.; Zagoskina, N. V. Heavy Metals, Their Phytotoxicity, and the Role of Phenolic Antioxidants in Plant Stress Responses with Focus on Cadmium: Review. *Molecules* **2023**, *28* (9), 3921. DOI: 10.3390/molecules28093921.

[23] Riyazuddin, R.; Nisha, N.; Ejaz, B.; Khan, M. I. R.; Kumar, M.; Ramteke, P. W.; Gupta, R. A Comprehensive Review on the Heavy Metal Toxicity and Sequestration in Plants. *Biomolecules* **2021**, *12* (1), 43. DOI: 10.3390/biom12010043.

[24] Ekor, M. The Growing Use of Herbal Medicines: Issues Relating to Adverse Reactions and Challenges in Monitoring Safety. *Frontiers in Pharmacology* **2014**, *4*, 177. DOI: 10.3389/fphar.2013.00177.

[25] Yalcin, I.; Ozyigit, I.; Dogan, I.; Demir, G.; Yarci, C. Using the Turkish Red Pine Tree to Monitor Heavy Metal Pollution. *Polish Journal of Environmental Studies* **2020**, *29* (5), 3881–3889. DOI: 10.15244/pjoes/114505.

[26] Pietrelli, L.; Menegoni, P.; Papetti, P. Bioaccumulation of Heavy Metals by Herbaceous Species Grown in Urban and Rural Sites. *Water, Air, & Soil Pollution* **2022**, *233* (4), 141. DOI: 10.1007/s11270-022-05577-x.

[27] Yolcubal, I.; Gündüz, Ö. C.; Sönmez, F. Assessment of Impact of Environmental Pollution on Groundwater and Surface Water Qualities in a Heavily Industrialized District of Kocaeli (Dilovası), Turkey. *Environmental Earth Sciences* **2016**, *75* (2), 170. DOI: 10.1007/s12665-015-4986-2.

[28] DOIZ. 2023. Dilovasi Organize Sanayi Bolgesi (Dilovasi Organized Industrial Zone). http://www.dosb.com.tr/ (accessed May 22, 2023).

[29] Khalid, N.; Masood, A.; Noman, A.; Aqeel, M.; Qasim, M. Study of the Responses of Two Biomonitor Plant Species (Datura Alba & Ricinus Communis) to Roadside Air Pollution. *Chemosphere* **2019**, *235*, 832–841. DOI: 10.1016/j.chemosphere.2019.06.143.

[30] Kastratović, V.; Blagojević, N.; Vukašinović-Pešić, V. Bioaccumulation and Translocation of Some Transition Metals in *Mentha spicata* and *Mentha longifolia*. *Polish Journal of Environmental Studies* **2022**, *31* (5), 4703–4710. DOI: 10.15244/pjoes/150390.

[31] Yilmaz, M.; Emanet Beba, H.; Dinc, U.; Unal, Z. F.; Toros, H.; Ozturk, Z. Dilovası Hava Kalitesinin Ulusal Mevzuata Göre Değerlendirilmesi. *European Journal of Science and Technology* **2020**, *19*, 703–714. DOI: 10.31590/ejosat.703579.

[32] KPISR. 2023. Kocaeli Provincial Industry Status Report. https://korfezto.org.tr/ (accessed May 22, 2023).

[33] Ulutaş, K. Risk Assessment and Spatial Distribution of Heavy Metal in Street Dusts in the Densely Industrialized Area. *Environmental Monitoring and Assessment* **2022**, *194* (2), 99. DOI: 10.1007/s10661-022-09762-7.

[34] Mamadalieva, N.; Akramov, D.; Ovidi, E.; Tiezzi, A.; Nahar, L.; Azimova, S.; Sarker, S. Aromatic Medicinal Plants of the Lamiaceae Family from Uzbekistan: Ethnopharmacology, Essential Oils Composition, and Biological Activities. *Medicines* **2017**, *4* (1), 8. DOI: 10.3390/medicines4010008.

[35] Fatih, B.; Madani, K.; Chibane, M.; Duez, P. Chemical Composition and Biological Activities of

Mentha Species. *Aromatic and Medicinal Plants - Back to Nature* **2017**, *3,* 47–78. DOI: 10.5772/67291.

[36] Gupta, A. K.; Mishra, R.; Singh, A. K.; Srivastava, A.; Lal, R. K. Genetic Variability and Correlations of Essential Oil Yield with Agro-Economic Traits in Mentha Species and Identification of Promising Cultivars. *Industrial Crops and Products* **2017**, *95*, 726–732. DOI: 10.1016/j.indcrop.2016.11.041.

[37] Klinkenberg, B.; Mentha Spicata, L. *E-Flora BC: Electronic Atlas of the Plants of British Columbia. Lab for Advanced Spatial Analysis*; Department of Geography, University of British Columbia: Vancouver, BC, 2010.

[38] Morcia, C.; Tumino, G.; Ghizzoni, R.; Terzi, V. Carvone (*Mentha spicata* L.) Oils. In Preedy, V. R., *Essential Oils in Food Preservation, Flavor and Safety*; Elsevier: London, UK, 2016, 309–316. DOI: 10.1016/B978-0-12-416641-7.00035-3.

[39] Moetamedipoor, S. A.; Jowkar, A.; Saharkhiz, M. J.; Hassani, H. S. Hexaploidy Induction Improves Morphological, Physiological and Phytochemical Characteristics of Mojito Mint (Mentha × Villosa). *Scientia Horticulturae* **2022**, *295*, 110810. DOI: 10.1016/j.scienta.2021.110810.

[40] Davis, P. H. *Flora of Turkey and the East Aegean Island*; Edinburg Univ. Press: Edinburg, 1982; Vol. 7.

[41] Alaşalvar, H.; Çam, M. Ready to Drink Iced Teas from Microencapsulated Spearmint (*Mentha spicata* L.) and Peppermint (*Mentha piperita* L.) Extracts: Physicochemical, Bioactive and Sensory Characterization. *Journal of Food Measurement and Characterization* **2020**, *14* (3), 1366–1375. DOI: 10.1007/s11694-020-00386-4.

[42] Kumar, K. V.; Patra, D. D. Alteration in Yield and Chemical Composition of Essential Oil of *Mentha piperita* L. Plant: Effect of Fly Ash Amendments and Organic Wastes. *Ecological Engineering* **2012**, *47*, 237–241. DOI: 10.1016/j.ecoleng.2012.06.019.

[43] Shaikh, M. N.; Suryawanshi, Y. C.; Mokat, D. N. Volatile Profiling and Essential Oil Yield of *Cymbopogon citratus* (DC.) Stapf Treated with Rhizosphere Fungi and Some Important Fertilizers. *Journal of Essential Oil Bearing Plants* **2019**, *22* (2), 477–483. DOI: 10.1080/0972060X.2019.1613933.

[44] Murad, H. A. S.; Abdallah, H. M.; Ali, S. S. Mentha Longifolia Protects against Acetic-Acid Induced Colitis in Rats. *Journal of Ethnopharmacology* **2016**, *190*, 354–361. DOI: 10.1016/j.jep.2016.06.016.

[45] Karsan Ayanoğlu, S.; Kahya, Y. The Characteristics of Büyükada as a Cultural Landscape. *Heritage* **2019**, *2* (1), 86–103. DOI: 10.3390/heritage2010007.

[46] Sharma, N.; Singh, V. K.; Lee, Y.; Kumar, S.; Rai, P. K.; Pathak, A. K.; Singh, V. K. Analysis of Mineral Elements in Medicinal Plant Samples Using LIBS and ICP-OES. *Atomic Spectroscopy* **2020**, *41*(6), 234–241. DOI: 10.46770/AS.2020.06.003.

[47] Cao, L.; Zheng, J.; Tsukada, H.; Pan, S.; Wang, Z.; Tagami, K.; Uchida, S. Simultaneous Determination of Radiocesium (135Cs, 137Cs) and Plutonium (239Pu, 240Pu) Isotopes in River Suspended Particles by ICP-MS/MS and SF-ICP-MS. *Talanta* **2016**, *159*, 55–63. DOI: 10.1016/j.talanta.2016.06.008.

[48] Gonçalves, D. A.; de Souza, I. D.; Rosa, A. C. G.; Melo, E. S. P.; Goncalves, A.-M B.; de Oliveira, L. C. S.; do Nascimento, V. A. Multi-Wavelength Calibration: Determination of Trace Toxic Elements in Medicine Plants by ICP OES. *Microchemical Journal* **2019**, *146*, 381–386. DOI: 10.1016/j.microc.2019.01.021.

[49] Barin, J. S.; Pereira, J. S. F.; Mello, P. A.; Knorr, C. L.; Moraes, D. P.; Mesko, M. F.; Nóbrega, J. A.; Korn, M. G. A.; Flores, E. M. M. Focused Microwave-Induced Combustion for Digestion of Botanical Samples and Metals Determination by ICP OES and ICP-MS. *Talanta* **2012**, *94*, 308–314. DOI: 10.1016/j.talanta.2012.03.048.

[50] Hee Lee, J.; Kim, J. Y.; Park, S. G.; Lee, J.; Yoon, J. H.; Han, G. D. A Study on the Hazardous Metal Content of Herbal Medicines in the Daegu Area. *Korean Journal of Environmental Health Sciences* **2017**, *43* (4), 257–266. DOI: 10.5668/JEHS.2017.43.4.257.

[51] Ozyigit, I. I.; Yalcin, B.; Turan, S.; Saracoglu, I. A.; Karadeniz, S.; Yalcin, I. E.; Demir, G. Investigation of Heavy Metal Level and Mineral Nutrient Status in Widely Used Medicinal Plants' Leaves in Turkey: Insights into Health Implications. *Biological Trace Element Research* **2018**, *182* (2), 387–406. DOI: 10.1007/s12011-017-1070-7.

[52] Ozyigit, I. I.; Karahan, F.; Yalcin, I. E.; Hocaoglu-Ozyigit, A.; Ilcim, A. Heavy Metals and Trace Elements Detected in the Leaves of Medicinal Plants Collected in the Southeast Part of Turkey. *Arabian Journal of Geosciences* **2022**, *15* (1), 27. DOI: 10.1007/s12517-021-09264-9.

[53] Gruszecka-Kosowska, A.; Mazur-Kajta, K. Potential Health Risk of Selected Metals for Polish Consumers of Oolong Tea from the Fujian Province, China. *Human and Ecological Risk Assessment: An International Journal* **2016**, *22* (5), 1147–1165. DOI: 10.1080/10807039.2016.1146572.

[54] Li, L.; Fu, Q.-L.; Achal, V.; Liu, Y. A Comparison of the Potential Health Risk of Aluminum and Heavy Metals in Tea Leaves and Tea Infusion of Commercially Available Green Tea in Jiangxi, China. *Environmental Monitoring and Assessment* **2015**, *187* (5), 228. DOI: 10.1007/s10661-015-4445-2.

[55] Zhang, J.; Yang, R.; Chen, R.; Peng, Y.; Wen, X.; Gao, L. Accumulation of Heavy Metals in Tea Leaves and Potential Health Risk Assessment: A Case Study from Puan County, Guizhou Province, China. *International Journal of Environmental*

Research and Public Health **2018**, *15* (1), 133. DOI: 10.3390/ijerph15010133.

[56] Guo, J.; Wei, Z.; Zhang, C.; Li, C.; Dai, L.; Lu, X.; Xiao, K.; Mao, X.; Yang, X.; Jing, Y.; et al. Characteristics and DGT Based Bioavailability of Cadmium in the Soil–Crop Systems from the East Edge of the Dongting Lake, China. *International Journal of Environmental Research and Public Health* **2022**, *20* (1), 30. DOI: 10.3390/ijerph20010030.

[57] Shahid, M.; Dumat, C.; Khalid, S.; Schreck, E.; Xiong, T.; Niazi, N. K. Foliar Heavy Metal Uptake, Toxicity and Detoxification in Plants: A Comparison of Foliar and Root Metal Uptake. *Journal of Hazardous Materials* **2017**, *325*, 36–58. DOI: 10.1016/j.jhazmat.2016.11.063.

[58] Kabata-Pendias, A. Trace Metals in Soils-A Current Issue in Poland. *Acta Universitatis Wratislaviensis. Prace Botaniczne* **2001**, *79*, 13–20.

[59] Kacar, B.; Katkat, A. V. *Plant Nutrition. Nobel Publication No. 849*. Science and Biology Publication Series: Ankara, Turkey, 2007.

[60] Barker, A. V.; Pilbeam, D. J. *Handbook of Plant Nutrition*. CRC Press: Boca Raton, USA, 2007; Vol. 117.

[61] Peñuela, A.; Hurtado, S.; García-Gamero, V.; Mas, J. L.; Ketterer, M. E.; Vanwalleghem, T.; Gómez, J. A. A Comparison of 210Pbxs, 137Cs, and Pu Isotopes as Proxies of Soil Redistribution in South Spain under Severe Erosion Conditions. *Journal of Soils and Sediments* **2023**, *23*(9), 3326–3344. DOI: 10.1007/s11368-023-03560-5.

[62] Broadley, M.; Brown, P.; Cakmak, I.; Rengel, Z.; Zhao, F. Function of Nutrients. In Marschner, P., *Marschner's Mineral Nutrition of Higher Plants*; Elsevier: London, UK, 2012, 191–248. DOI: 10.1016/B978-0-12-384905-2.00007-8.

[63] Alloway, B. J. *Sources of Heavy Metals and Metalloids in Soils*. Springer: Dordrecht, Holland, 2013; 11–50. DOI: 10.1007/978-94-007-4470-7_2.

[64] Othman, O. C.; Kaswamila, A. L.; Bevanger, K.; Mwakipesile, A.; Haule, K.; Kihwele, E.; Summay, G.; Gereta, E. Assessment of Soil Quality along the Proposed Main Road through Ngorongoro and Northern Serengeti, Tanzania. *Tanzania Journal of Science* **2022**, *48* (1), 212–224. DOI: 10.4314/tjs.v48i1.19.

[65] Alekseenko, V.; Alekseenko, A. The Abundances of Chemical Elements in Urban Soils. *Journal of Geochemical Exploration* **2014**, *147*, 245–249. DOI: 10.1016/j.gexplo.2014.08.003.

[66] Karagence, M. D.; Dolcerocca, A. Our Plants Are Slowly Dying Here, Just Like Us": Coping with Pollution in Turkey's "Cancer Valley. *Human Ecology* **2023**, *51*(3), 547–557. DOI: 10.1007/s10745-023-00410-3.

[67] Hamzaoğlu, O. N. U. R.; Etiler, N.; Yavuz, C. I.; Çağlayan, Ç. The Causes of Deaths in an Industry-Dense Area: Example of Dilovası (Kocaeli)*. *Turkish Journal of Medical Sciences* **2011**, *41*(3), 369–375. DOI: 10.3906/sag-1007-943.

[68] Ozturk, B.; Kuru, C.; Aykac, H.; Kaya, S. VOC Separation Using Immobilized Liquid Membranes Impregnated with Oils. *Separation and Purification Technology* **2015**, *153*, 1–6. DOI: 10.1016/j.seppur.2015.08.032.

[69] Nagajyoti, P. C.; Lee, K. D.; Sreekanth, T. V. M. Heavy Metals, Occurrence and Toxicity for Plants: A Review. *Environmental Chemistry Letters* **2010**, *8* (3), 199–216. DOI: 10.1007/s10311-010-0297-8.

[70] Dogan, Y. A Study on Detecting Heavy Metal Accumulation through Biomonitoring: Content of Trace Elements in Plants at Mount Kazdagi in Turkey. *Applied Ecology and Environmental Research* **2014**, *12* (3), 627–636. DOI: 10.15666/aeer/1203_627636.

[71] AHPA. American Herbal Products Association. https://www.ahpa.org/ (accessed May 22, 2023).

[72] FAO/WHO. Food and Agriculture Organization/World Health Organization. https://www.fao.org/ (accessed May 22, 2023).

[73] Dghaim, R.; Al Khatib, S.; Rasool, H.; Ali Khan, M. Determination of Heavy Metals Concentration in Traditional Herbs Commonly Consumed in the United Arab Emirates. *Journal of Environmental and Public Health* **2015**, *2015*, 973878. DOI: 10.1155/2015/973878.

[74] Subramanian, R.; Gayathri, S.; Rathnavel, C.; Raj, V. Analysis of Mineral and Heavy Metals in Some Medicinal Plants Collected from Local Market. *Asian Pacific Journal of Tropical Biomedicine* **2012**, *2* (1), S74–S78. DOI: 10.1016/S2221-1691(12)60133-6.

[75] Okwany, R. O.; Peters, T. R.; Ringer, K. L.; Walsh, D. B.; Rubio, M. Impact of Sustained Deficit Irrigation on Spearmint (*Mentha spicata* L.) Biomass Production, Oil Yield, and Oil Quality. *Irrigation Science* **2012**, *30* (3), 213–219. DOI: 10.1007/s00271-011-0282-4.

[76] Musa Özcan, M.; Ünver, A.; Uçar, T.; Arslan, D. Mineral Content of Some Herbs and Herbal Teas by Infusion and Decoction. *Food Chemistry* **2008**, *106* (3), 1120–1127. DOI: 10.1016/j.foodchem.2007.07.042.

[77] Drobek, M.; Frąc, M.; Cybulska, J. Plant Biostimulants: Importance of the Quality and Yield of Horticultural Crops and the Improvement of Plant Tolerance to Abiotic Stress—A Review. *Agronomy* **2019**, *9* (6), 335. DOI: 10.3390/agronomy9060335.

[78] Osma, E.; Ibrahim, I. O.; Demir, G.; Yasar, U. Assessment of Some Heavy Metals in Wild Type and Cultivated Purslane (*Portulaca oleracea* L.) and Soils in Istanbul, Turkey. *Fresenius Environment Bulletin* **2014**, *23*(9), 2181–2189.

[79] Doğruparmak, Ş Ç.; Özbay, B. Investigating Correlations and Variations of Air Pollutant Concentrations under Conditions of Rapid

Industrialization - Kocaeli (1987-2009). *CLEAN - Soil, Air, Water* **2011**, *39* (7), 597–604. DOI: 10.1002/clen.201000478.

[80] Cetinyokus, S. Determination of Possible Effects of Air Pollutants for the Kocaeli-Dilovasi. *Aksaray University Journal of Science and Engineering* **2017**, *1* (2), 43–55. DOI: 10.29002/asujse.310026.

[81] Cetin, B.; Yurdakul, S.; Odabasi, M. Spatio-Temporal Variations of Atmospheric and Soil Polybrominated Diphenyl Ethers (PBDEs) in Highly Industrialized Region of Dilovasi. *The Science of the Total Environment* **2019**, *646*, 1164–1171. DOI: 10.1016/j.scitotenv.2018.07.299.

[82] Elevli, B.; Ozturk, H. Multi-Criteria Assessment of Heavy Metals Contaminations in Waters and Ranking the Sites by Using PROMETHEE/GAIA Method. *Journal of Environmental Health Science & Engineering* **2019**, *17* (1), 75–84. DOI: 10.1007/s40201-018-00328-9.

[83] Bingöl, D.; Karayünlü Bozbaş, S.; Ay, Ü.; Uzgören, N. Chemometric Evaluation of the Heavy Metal Contents in Surface Soils from the Dilovası Region (Kocaeli/Turkey). *Cumhuriyet Science Journal* **2018**, *39* (1), 23–33. DOI: 10.17776/csj.348921.

[84] Ozbey-Unal, B.; Omwene, P. I.; Yagcioglu, M.; Balcik-Canbolat, Ç.; Karagunduz, A.; Keskinler, B.; Dizge, N. Treatment of Organized Industrial Zone Wastewater by Microfiltration/Reverse Osmosis Membrane Process for Water Recovery: From Lab to Pilot Scale. *Journal of Water Process Engineering* **2020**, *38*, 101646. DOI: 10.1016/j.jwpe.2020.101646.

[85] White, P. J.; Broadley, M. R. Biofortification of Crops with Seven Mineral Elements Often Lacking in Human Diets – Iron, Zinc, Copper, Calcium, Magnesium, Selenium and Iodine. *The New Phytologist* **2009**, *182*(1), 49–84. DOI: 10.1111/j.1469-8137.2008.02738.x.