EVALUATION OF HEAVY METAL POLLUTION IN THE BOĞAZIÇI TUZLA LAGOON, SOUTHEASTERN AEGEAN SEA, TÜRKIYE

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Abstract. The Boğaziçi Tuzla Lagoon, located in the southeastern Aegean Sea in Türkiye, is an ecologically important habitat that faces significant threats from various human activities. We initiated a comprehensive research project to assess the levels and distribution of heavy metals in sediment and plants. The analysis of heavy metal concentrations in *Salicornia europea*, *Dittrichia viscosa*, *Halocnemum strobilaceum*, and *Mesembryanthemum nodiflorum* revealed distinct accumulation patterns among these plant species. Notably, *S. europea* demonstrated the highest concentration of zinc, indicating its potential as a hyperaccumulator for this metal. Conversely, *D. viscosa* exhibited significant levels of copper (Cu), suggesting its ability to tolerate and potentially remediate copper contamination. Although *H. strobilaceum* showed lower overall concentrations, it still presented notable levels of cadmium (Cd). The standard deviation analysis revealed greater variability in the measurements of Zn, Fe, Mn, Cu, Cd, Cr, and Pb in Region A, while Region B displayed higher variability in cobalt (Co) measurements. Overall, the averages for Zn, Fe, and Cu were higher in Region A, whereas the averages for Mn, Cd, Co, Cr. Consequently, the Bosphorus Tuzla Lagoon is adversely affected by numerous ecological parameters. The results of our analyses indicate ecological deterioration and pollution in the sediment, and plant samples.
Keywords: *analyses, contamination factor, monitoring, plants, sediment*

Introduction

The Boğaziçi Tuzla Lagoon, located in the southeastern Aegean Sea, is an important ecological site with considerable potential as an aquatic ecosystem. However, it is currently impacted by various human activities. The rise of industrialization and technological advances has led to pollution in these aquatic ecosystems, primarily due to waste from human activities, which affects both plant and animal life. Although heavy metals are naturally present in low concentrations in aquatic ecosystems, their levels can increase due to waste from industrial, agricultural, and sewage sources. Pollution from heavy metals can stem from industrial waste, geological factors, and mining operations (Briffa et al., 2020; Oladimeji et al., 2024). Under certain environmental conditions, these metals can accumulate to toxic levels, causing ecological harm (Mitra et al., 2022; El-Sharkawy et al., 2025). The persistence of heavy metals in the environment is a significant concern for human health and ecological

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integrity, as many are known to be carcinogenic and mutagenic. These metals do not break down into harmless substances and thus remain in the environment indefinitely. Their prevalence as contaminants and low solubility in living organisms raise serious concerns for health and the environment, as they cannot be degraded and persist in ecosystems. Heavy metals are regarded as major environmental pollutants when their concentrations exceed natural background levels, often introduced through weathering of rocks and exacerbated by human activities such as urbanization, industrialization, transportation, and energy production. The accumulation of heavy metals in marine sediments is influenced by both natural geological processes and human activities; their distribution in sea water is affected by complex physicochemical interactions, classifying them as contaminants when levels exceed established safe thresholds for environmental protection. Due to their toxicity, persistence, and potential for bioaccumulation, heavy metals pose a significant pollution challenge. Their introduction into various environmental compartments through human activities reduces the ecosystem's ability to sustain life, posing risks to human, animal, and plant health through bioaccumulation in food chains, further intensified by the non-degradable nature of heavy metals (Yuan et al., 2022; Fatullayeva et al., 2024; Paula et al., 2025).

The contamination of aquatic ecosystems with heavy metals is exacerbated by industrial and agricultural development, as these metals do not biodegrade upon release but accumulate in both the environment and living organisms (Hama Aziz et al., 2023; Saravanan et al., 2024). Furthermore, the geochemical speciation and distribution of metals within defined chemical fractions serve as predictive indicators of potential contamination, bioavailability, and mobility, enabling a more comprehensive risk assessment (Chaithanya et al., 2023; Saleem et al., 2015; Soliman et al., 2024).

The aim of the research was to determine the pollution rates, pollution factor (Cf), sediment pollution level and pollution level in plant species in Tuzla Lagoon of Bosphorus. For this purpose, strategic stations were identified in the Tuzla Lagoon of the Bosphorus to assess the potential pollution and the risk of polluted water entering the lagoon area. The lagoon was divided into two regions A and B. Sediment samples were collected annually from 19 stations in Region A and 22 stations in Region B to analyze Pb, Cd, Cu, Fe, Mn, Zn, Co and Cr concentrations in sediment and plant samples.

Statistical analyses were conducted to identify significant differences among the measurements. Additionally, Monitoring heavy metal concentrations in sediment and aquatic plants is crucial for evaluating pollution levels and their potential impacts on the ecosystem (Saroop and Tamchos, 2021; Kutlu et al., 2024). Measurements of heavy metal concentrations in sediments, and plants along with calculations of bioaccumulation factors and metal pollution indices, are conducted to assess pollution load.

These metals do not decompose into harmless products, leading to their indefinite persistence in the environment. To evaluate potential pollution in the Boğaziçi Tuzla Lagoon, strategic stations were established at locations indicative of possible polluted water input.

The comprehensive data collected from these different environmental components provides a strong basis for assessing the ecological health of the lagoon and understanding the impact of human activities on its water quality and sediment composition (Bueno et al., 2019; Hlal et al., 2025).

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Materials and methods

Sampling area

Boğaziçi Tuzla Lagoon is located within the borders of Milas district of Muğla province, surrounded by Didim to the north, Bodrum to the south and Güllük Bay to the east in Türkiye. The lagoon area has a total area of 36.852 ha. The fact that the lagoon area has a saline water ecosystem causes it to be inefficient in terms of plant species diversity. Despite this, the lagoon area is very rich in terms of bird species diversity and is home to 197 different bird species (Tüfekçi, 2005).

In the research area, Boğaziçi Tuzla Lagoon, stations at strategic points that symbolize possible pollution and have the potential for polluted water input to the lagoon area were identified (*Fig. 1*).

Figure 1. *A view from the Güllük Lagoon area*

The lagoon area was divided into 2 regions as A and B (*Fig. 2* and *Fig. 3*) of these, 19 stations were identified in zone A, 22 stations in zone B (*Table 1*).

Figure 2. *A Zone stations*

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Figure 3. *B Zone stations*

Table 1. *Sampling coordinates of A and B zones*

Sampling station	Coordinates	Sampling Station	Coordinates
A1	37°11’83”K-27°36’25”D	B1	37°10’70”K-27°35’03”D
A2	37°11’61”K-27°36’02”D	B2	37°10’83”K-27°35’02”D
A2.1.	37°11’13”K-27°36’03”D	B3	37°10’73”K-27°35’68”D
A3	37°11’80”K-27°36’49”D	B4	37°11’69”K-27°35’83”D
A3.1.	37°11’02”K-27°36’26”D	B5	37°11’31”K-27°35’04”D
A4	37°11’05”K-27°36’77”D	B6	37°11’90”K-27°35’05”D
A5	37°11’98”K-27°35’72”D	B7	37°11’00”K-27°35’83”D
A6	37°11’60”K-27°35’12”D	B8	37°11’92”K-27°35’49”D
A6.1.	37°11’57”K-27°35’35”D	B9	37°11’07”K-27°35’56”D
A7	37°11’43”K-27°35’88”D	B10	37°11’40”K-27°35’99”D
A8	37°11’67”K-27°36’87”D	B11	37°11’76”K-27°35’63”D
A8.1.	37°11’71”K-27°36’76”D	B12	37°11’86”K-27°35’44”D
A8.2.	37°11’86”K-27°36’93”D	B13	37°11’03”K-27°34’76”D
A8.3.	37°11’11”K-27°36’57”D	B14	37°11’39”K-27°34’24”D
A8.4.	37°11’29”K-27°36’85”D	B15	37°11’00”K-27°34’40”D
A9	37°11’38”K-27°36’74”D	B16	37°11’01”K-27°34’51”D
A9.1.	37°11’35”K-27°36’65”D	B17	37°10’81”K-27°34’41”D
A10	37°11’93”K-27°36’56”D	B18	37°10’29”K-27°34’92”D
A10.1.	37°11’74”K-27°36’70”D	B19	37°10’04”K-27°34’37”D
		B20	37°10’34”K-27°35’79”D
		B21	37°10’19”K-27°35’28”D
		B22	37°10’46”K-27°35’72”D
		B(Mazı)	37°10’95”K-27°36’91”D

Method of collection of samples

The study was carried out by taking samples once a year in November from the stations determined in Boğaziçi-Tuzla Lagoon, which was selected as the research area.

Sediment samples were taken homogenously from the sediment surface. Water samples were taken from the determined stations and filled into 2 L polyethylene bottles.

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The samples taken in the bottles were kept in the freezer until they were brought to the laboratory in order not to be exposed to microbiological and physico-chemical deterioration that may be affected by outdoor conditions. Samples that could be analyzed within 1 h were stored in the cold chain at 0 to +4°C under laboratory conditions. Plant samples were taken as root, stem and leaf homogenously from the determined stations.

Methods of analysis

The analyses were performed at Muğla Sıtkı Koçman University Environmental Problems Research and Application Centre (MUÇEMER) according to APHA (2023) and EPA (2017) methods.

(a) Sediment samples were collected annually from 45 stations across the Boğaziçi Tuzla Lagoon. Sediment samples were processed and analyzed in the laboratory (*Fig. 4*). The concentrations of heavy metals, including Pb, Cd, Cu, Fe, Mn, Zn, Co, and Cr, were determined in the sediment samples using standard analytical methods (EPA, 2017; APHA, 2023; *Fig. 4*).

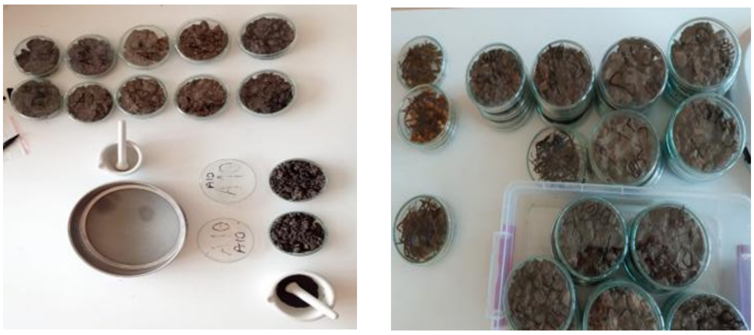

Figure 4. *Photos of sediment analyses preparations in the laboratory*

(b) Heavy metals in sediment, plant samples were measured by ICP-OES Perkin Elmer Optical Emission Spectrometer Optima 2000 DV. The species of the plant samples were determined (*Figs. 5–8*).

Figure 5. *Salicornia europaea L.*

Figure 6. *Dittrichia viscosa L.*

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Figure 7. *Halocnemum strobilaceum*

Figure 8. *Mesembryanthemum nodiflorum L.*

Salicornia europaea L.

Salicornia europaea L. belongs to the *Amaranthaceae* family (formerly *Chenopodiaceae*), subfam. *Salicornioideae*. The genus *Salicornia* is widespread in temperate and subtropical regions of the Northern Hemisphere but absent in South America and Australia (Santos et al., 2016). Despite the high phenotypic variability, several common features can be distinguished (Cárdenas-Pérez et al., 2020). *S. europaea* has an erect, highly branched stem. Secondary shoots are formed on the primary cylindrical shoots. The plant has strongly reduced leaves, and the assimilation area is located in the shoots. It is green most of its life, but at the end of life cycle, the stems turn red due to chlorophyll destruction which reduces photosynthesis and finally affects nutrient loss, biomass, and hydric balance (Negrão et al., 2017). Branches have spikes consisting of three flowers, one main and two laterals. Seeds are small, dark, ellipsoidal, and characterized by heteromorphism, i.e., color, shape, and size variability (Philipupillai and Ungar, 1984; Katel et al., 2023).

S. *europaea* grows in areas periodically flooded by salty or brackish water (Vicente et al., 2022). Salicornia is found around much of the coastline of Europe from the Arctic to the Mediterranean, as well as on the shores of both the Black Sea and Caspian Sea; it is also present sporadically where inland salines occur across Europe. This adaptability to various saline environments highlights its significance as a halophyte, thriving in coastal regions and contributing to ecological stability and potential agricultural development in saline conditions (Davy et al., 2001; Katel Shambhu et al., 2023).

It has potential economic value because it is edible, either raw or cooked (Antunes et al., 2021). In addition, it can be used as a forage for animals or a biofuel and has potential in pharmaceuticals and cosmetics (Rhee et al., 2009; Cárdenas-Pérez et al., 2021). It also has a high fatty acid content in its seeds, which increases its nutritional value (Liu et al., 2020). Moreover, S. *europaea* ash can be used to produce glass and soap (Stefany Cárdenas-Pérez et al., 2022). The healing properties should also be mentioned because S. europaea is rich in tungsten acids, quercetin, and isorhamnetin, which have anti-inflammatory and antioxidant properties. It is also emerging as a suitable tool and indicator for biological monitoring of Zn and especially Cu, while at the same time it can be used for the removal of heavy metals (Nel et al., 2020; Smillie, 2015). This species belongs to extreme

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halophytes (Grigore and Toma, 2020), which is a They evolved some specific mechanisms to cope with saline environment like reduction of the Na + levels, compartmentalization, and excretion of sodium ions (Fipwers et al., 1991; Flowers and Colmer, 2008).

Dittrichia viscosa L.

The Asteraceae family, also known as the sunflower or daisy family, stands as one of the most expansive angiosperm lineages, encompassing a remarkable diversity of approximately 23,000 species distributed across more than 1600 genera (Sharma et al., 2022). This taxonomic magnitude positions Asteraceae as the third largest flowering plant family, following Orchidaceae and Fabaceae, highlighting its significant contribution to global plant biodiversity (Tsai and Chen, 2006; Gore and Gaikwad, 2015). Asteraceae's prevalence is evident in a wide array of habitats, from temperate to tropical zones, and from arid deserts to lush rainforests, demonstrating its remarkable adaptability and ecological success (Soltis and Soltis, 2004). This species is native to the Mediterranean region but has demonstrated a remarkable ability to adapt to various environments, leading to its spread in other regions, including parts of North America and South America (Sladonja et al., 2021). *D. viscosa* is a highly branched, perennial shrub that can reach up to 150 cm in height. It features long, narrow leaves with jagged edges and glandular hairs on the surfaces, which produce a sticky exudate with an unpleasant smell. The plant produces numerous yellow flower heads during its blooming period, each consisting of up to 16 ray florets and 44 disc florets. It is adapted to adverse abiotic conditions, thriving in degraded environments (Grauso et al., 2020). The *D. viscosa* blooms from August to October, producing numerous yellow capitula (flower heads) that are grouped in composite clusters. This prolonged flowering period attracts a variety of pollinators, including bees and butterflies, due to its entomophilous character. The plant's vibrant flowers play a significant role in the Mediterranean ecosystem, contributing to its ecological functions and interactions with pollinators during the warm season (Parolin et al., 2014; Hassan et al., 2016). The ecological significance of *D. viscosa* is notable, as it plays a role in soil stabilization and erosion control, particularly in disturbed habitats (Sladonja et al., 2021; Luna et al., 2022). Its ability to thrive in poor soil conditions and resist drought makes it an important species for restoration projects in arid and semi-arid regions (Papadia et al., 2020). Furthermore, *D. viscosa* is rich in secondary compounds such as flavonoids, sesquiterpenes and essential oils. The allelopathic potential of the leaf exudates increases during the dry, hot, and sunny summer. Seasonal and geographic variations have also been found, but all inside native growing areas (Araniti et al., 2017).

In addition to its ecological roles, *D. viscosa* has garnered attention for its potential applications in various fields. Traditionally, it has been used in folk medicine for its anti-inflammatory and analgesic properties (Jerada et al., 2024). Recent studies have explored its phytochemical composition, revealing a rich array of bioactive compounds, including flavonoids, terpenoids, and phenolic acids, which contribute to its medicinal properties (Jerada et al., 2024). *D. viscosa* is one of the potential biomonitor species, and it correlates the concentration of metals in plant tissues with the concentration of metals in soil, especially in contaminated dry riverbeds (Cuevas et al., 2023).

Halocnemum strobilaceum (Pall.) M. Bieb.

Halocnemum strobilaceum, a prominent member of the Amaranthaceae family, stands out as a perennial halophyte, demonstrating an exceptional capacity to flourish in

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environments characterized by elevated salinity levels (Calabon et al., 2021). This remarkable plant species, commonly found in salt marsh ecosystems across the globe, exhibits specialized adaptations that enable it to not only survive but thrive in these challenging habitats. Its distribution spans a wide geographical range, encompassing coastal regions, inland salt flats, and other saline environments across several continents (Sarika and Zikos, 2020). The ability of *Halocnemum strobilaceum* to tolerate high salt concentrations makes it a subject of considerable interest in the context of understanding plant adaptation to abiotic stress (Nasernakhaei and Zahraei, 2021; Jurakulov et al., 2023). Halophytes such as *H. strobilaceum* possess significant ecological value, as they often constitute the primary vegetation in saline environments, providing habitat and food sources for various animal species. Furthermore, they play a crucial role in preventing soil erosion and stabilizing shorelines in coastal areas. In addition to their ecological importance, halophytes are gaining recognition for their potential applications in various fields, including agriculture, phytoremediation, and biofuel production (Martini and Papafotiou, 2020). The study of *H. strobilaceum* offers valuable insights into the mechanisms of salt tolerance in plants, which could have implications for improving the salt tolerance of crop plants and developing sustainable agricultural practices in saline-prone regions (Brinker et al., 2010). *Halocnemum strobilaceum* also has the potential to be used as a bio indicator for heavy metals (Al-Khateeb and Leilah, 2005).

The exploration of *H. strobilaceum*'s unique attributes extends to its potential in phytoremediation, where its salt-accumulating capabilities can be harnessed to remove excess salts from contaminated soils, thus restoring soil health and fertility. Moreover, its biomass can be explored as a source of biofuel, contributing to sustainable energy production (Hasnain et al., 2023). Understanding the intricate physiological and biochemical processes that underpin the salt tolerance of *H. strobilaceum* is critical for unlocking its full potential and harnessing its benefits for environmental and agricultural sustainability. The morphological adaptations observed in *H. strobilaceum* are crucial for its survival in saline environments (Butnik et al., 2001; Franchi et al., 2024).

Mesembryanthemum nodiflorum L.

Mesembryanthemum nodiflorum L., an intriguing member of the Aizoaceae family, presents a fascinating subject for botanical investigation due to its unique morphological adaptations and ecological preferences (El-Raouf, 2020). This species, commonly referred to as the slender leaf ice plant, showcases a remarkable ability to thrive in arid and saline environments, making it a subject of interest for researchers studying plant adaptation and ecological resilience. Understanding the intricacies of its biology, from its micro-morphological features to its potential phytochemical array, provides valuable insights into the survival strategies of plants in challenging habitats (El-Amier et al., 2021a). The plant's success in such environments hints at specialized physiological mechanisms, possibly involving efficient water storage, salt tolerance, and unique photosynthetic pathways, all of which deserve detailed examination (Supel et al., 2025). Delving into the anatomy and morphology of *M. nodiflorum* could reveal specific structural adaptations that enable it to withstand osmotic stress and maintain water balance under saline conditions (Himabindu et al., 2016; Zhou et al., 2024). In addition, the investigation of its reproductive strategies, including pollination mechanisms and seed dispersal, can further elucidate its adaptive strategies and ecological role within its specific habitat. The plant's widespread distribution throughout arid and semi-arid regions suggests a high degree of adaptability, making it a valuable model for studying

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plant evolution and adaptation to extreme environmental conditions (Himabindu et al., 2016; Okuhle, 2023). Furthermore, the other species of *Mesembryanthemum, M. crystallinum* shows exceptional tolerance to high levels of salt in soil and is able to accumulate this substance in its shoots, and the findings suggest that it has considerable potential for phytoextraction or phyto-stabilization of heavy metals such as chromium (Cr), cadmium (Cd), nickel (Ni) or Copper (Cu) and Zinc (Zn) (Supel et al., 2025).

Investigating its metabolic plasticity, the plant's ability to adjust its metabolism in response to environmental changes, could reveal how it efficiently copes with water stress (Shaar-Moshe et al., 2019; Šola et al., 2025). Furthermore, understanding its interaction with other organisms, including symbiotic relationships with microorganisms, could provide insights into its ability to acquire nutrients and withstand environmental stresses (Fadiji et al., 2023; Tharanath et al., 2024).

Measurements of heavy metals in sediment samples

Sediment samples brought from the field were placed in glass petri dishes for heavy metal analyses and dried in an oven at 80°C for 24 h. The samples were then ground in a mortar and passed through a 200 mesh sieve and prepared for analysis. After taking 0.25 g of the sediment samples ready for analysis, 6 ml of HNO3 and 4 ml of HF were added and digestion was carried out in the Ethos Easy Advanced Microwave Digestion System in the Laboratory of the Department of Basic Sciences, Faculty of Fisheries, Muğla Sıtkı Koçman University. Zn, Fe, Mn, Cu, Cd, Cd, Co, Cr and Pb metals were measured in the liquidized samples by ICP-OES Perkin Elmer Optical Emission Spectrometer Optima 2000 DV at Muğla Food Control Laboratory Directorate. Sediment quality guidelines (SQGs) are widely used to estimate potential heavy metal threats to aquatic organisms (Liu et al., 2021). Sediment quality guidelines (SQGs) are widely used to estimate potential heavy metal threats to aquatic organisms (Liu et al., 2021). Limit values of heavy metal concentrations in sediment are given in *Table 2*.

Table 2. *Limit values of sediment heavy metal concentrations*

Metal	Non-polluted	Moderately polluted	Heavily polluted
As (ppm)	<3	3 – 8	>8
Pb (ppm)	<40	40 – 60	>60
Cd (ppm)	*	*	>6
Cr (ppm)	<25	25 – 75	>75
Cu (ppm)	<25	25 – 50	>50
Ni (ppm)	<20	20 – 50	>50
Zn (ppm)	<90	90 – 200	>200

Measurement of heavy metals in plant samples

Plant samples taken from the study area were cut homogenously with the help of scissors. After drying at 80°C, 0.25 g of the plant samples prepared for analysis were taken, 6 ml of HNO3 was added and burned in the Ethos Easy Advanced Microwave Digestion System device in the laboratory of Muğla Sıtkı Koçman University, Faculty of Fisheries, Department of Basic Sciences. Zn, Fe, Mn, Cu, Pb, Cr, Cd, Cd and Co metals were measured in the liquidized samples by ICP-OES Perkin Elmer Optical Emission Spectrometer Optima 2000 DV at Muğla Food Control Laboratory Directorate.

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Contamination factor (Cf)

The calculation of the contamination factor, which is one of the indices used to assess potential pollution risks, is made by the following formula:

$$C_f^i = \frac{Ci}{C_n^i}$$

Here the symbol of capital letter C_n^i is the value of metals for pre-industrial, *Ci* is the content of the measured metals values. If the value obtained as a result of the calculation is <1, it indicates low pollution, 1–3 indicates moderate pollution, 3–6 indicates high pollution and ≥6 indicates very high pollution (Varol et al., 2022).

Results and discussion

The results of physicochemical analyses of sediment samples taken from Boğaziçi-Tuzla Lagoon for a single season (November) are given in *Tables 2* and *3*. Care was taken to select the stations from strategic points and in order to determine the possible effects of these stations for the lagoon area; they were divided into 2 regions as A, B.

Table 3*. Sediment analysis results of Zone A (mg kg^{-1})*

Station	Zn	Fe	Mn	Cu	Cd	Co	Cr	Pb
A1	85.9	19.200	218.1	25	1.5	8.3	64.1*	21.2
A2	52.3	28.000	**516.3**	32.9*	1.3	13.6	49.2*	24.3
A2.1.	49.6	**38.400**	321.2	25.8*	1	15.4	48*	21.3
A3	49.5	36.800	163.2	27.2*	1.1	16	67.5*	23.3
A3.1.	39.7	28.800	183.2	25.8*	1.6	13.7	61.8*	26.3
A4	49	21.600	222	25*	2	12.4	45.4*	22.6
A5	53.1	10.000	233.2	30*	1.5	12.2	60.4*	10.7
A6	80.7	11.200	333.5	42.9*	1	10.9	85.3**	53.8*
A6.1.	22.9	3.680	88	30.9*	0.3	17.5	13.5	21.9
A7	388.4**	3.040	116	31*	2.7	14.6	11.7	48.1*
A8	722**	2.000	231.8	31*	3.8	17.5	87.4**	62.5**
A8.1.	198.7*	9.600	486.6	35.7*	2.3	10.3	40.6*	30.3
A8.2.	185*	14.400	227.4	48.8*	1.8	21.3	51.9*	29.8
A8.3.	208**	10.960	192	47*	2.7	16	47.1*	38.5
A8.4.	227**	16.000	304	35.6*	3.9	14.5	102.4**	39.2
A9	650**	13.600	238	43.2*	2.3	23.7	49*	31.6
A9.1.	142*	16.320	205	21.2	4.2	21	69*	45.7*
A10	165.1*	16.000	323	28.6*	4.2	21.2	61.7*	43**
A10.1.	96*	14.800	228	34.1*	4.1	23.2	80.5**	53.4*
Max	722**	38.400	**516.3**	48.8*	4.2	**23.7**	102.4**	62.5**
Min	22.9	2.000	88	21.2	0.3	8.3	11.7	10.7
Avg.	182.36*	16.547	254	33*	2	15.96	57.71*	34.07
Std.D.	199.55*	10.353	109	8	1	4.45	22.81	13.93

*Moderately polluted, **heavily polluted

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Heavy metal concentrations in sediment samples

Sediment samples from Regions A and B were subjected to a detailed analysis of various elements: zinc, iron, manganese, copper, cadmium, cobalt, chromium, and lead. Each parameter was measured three times, with average values carefully recorded in *Tables 3* and *4*. The results provide a comprehensive view, highlighting maximum, minimum, mean, and standard deviation values.

Table 4. *Sediment analysis results of Zone B (mg kg^{-1})*

Station	Zn	Fe	Mn	Cu	Cd	Co	Cr	Pb
B1	322**	30.500	204.1	29.6*	2.8	22.4	87.2**	44.6*
B2	675**	25.000	177.4	32.2*	3.6	21.9	86**	51.9*
B3	324.5**	27.500	276.2	29.5*	3.2	24.3	91.6**	44.5*
B4	252**	20.500	276	30*	3.7	20.8	72.4*	58*
B5	93.2*	16.000	200	30.3*	1.8	20.8	68.8*	35.9
B6	107.7*	19.600	256	33.7*	2.8	20.1	80**	50.4*
B7	88.3	22.000	280	35.4*	2.8	22.4	81.5**	47.1*
B8	82.1	21.600	234	30.5*	2.7	24	82.5**	46.4*
B9	84.6	14.000	323	31.7*	2.9	23.1	74.5*	44.8*
B10	112*	15.400	395.3	40.9*	2.6	26.6	85.2**	46*
B11	91*	13.500	393	35.2*	3	24.1	78**	54.6*
B12	501.5**	14.000	402.6	31.7*	1.1	25.2	74*	29.8
B13	50.2	10.000	277.3	16.9	1.7	16.4	53.7*	31.3
B14	75.5	12.000	392.6	24.8	3.3	27.7	69.3*	63**
B15	107.7*	12.000	415.4	39.7*	0.2	41.4	90.7**	27.6
B16	115.6*	15.800	305.4	45.2*	4.4	35.4	99.2**	73.7**
B17	65.3	9.000	388.5	33.5*	2.5	18.9	59.7*	50.8*
B18	67.2	7.400	451.6	26.4*	2	19.1	55.6*	39.7
B19	62	8.800	203.6	39.1*	2.2	19.8	67.3*	40
B20	64.5	7.500	209.1	19.9	1.9	15.2	39.6*	37.4
B21	57.5	6.000	173.7	23.7	2.2	15.5	40.7*	37.2
B22	38.4	6.300	222.5	18.9	3.9	21	46*	63.3**
Max	675**	30.500	451.6	45.2*	4.4	41.4	99.2**	73.7**
Min	38.4	6.000	173.7	16.9	0.2	15.2	39.6*	29.8
Avg.	156.26*	15.200	293.51	30.85*	2.6	23	71.97*	46.27
Std. D.	163.29*	7.016	88.01	7.17	0.95	6.02	16.74	11.55

*Moderately polluted, **heavily polluted

At Site A, the average zinc concentration settled at 182.36 ± 199.55 mg kg^{-1}. The peak value, a striking 722.00 mg kg^{-1}, was obtained from station A8, while the low point of 22.90 mg kg^{-1} was measured at A6.1 (*Table 3*).

Iron showed an average concentration of 16.547 ± 10.353 mg kg^{-1} at Site A. Here, the maximum concentration of 38.400 mg kg^{-1} was recorded at station A2.1, whereas station A8 revealed a modest minimum of 2.000 mg kg^{-1}.

For manganese, Site A yielded an average concentration of 254.00 ± 109.00 mg kg^{-1}. The highest concentration, 516.30 mg kg^{-1}, appeared at station A2, while A6.1 had the lowest at 88.00 mg kg^{-1}. Copper's average concentration across Site A was

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33.00 ± 8.00 mg kg^{-1}. The maximum was found at station A8.2 with a concentration of 48.80 mg kg^{-1}, while A9.1 recorded the minimum at 21.20 mg kg^{-1}. In terms of cadmium, the average concentration stood at 2.00 ± 1.00 mg kg^{-1}. The highest levels of 4.20 mg kg^{-1} were detected at stations A9.1 and A10, with the lowest being 0.30 mg kg^{-1} at A6.1. Cobalt at Site A displayed an average concentration of 15.96 ± 4.45 mg kg^{-1}. Here, the maximum concentration trimmed in at 23.70 mg kg^{-1} at station A9, while the minimum was 8.30 mg kg^{-1} recorded at station A1. Chromium's average concentration settled at 57.71 ± 22.81 mg kg^{-1} at Site A. The top value was measured at 102.40 mg kg^{-1} in station A8.4, while the bottom was seen at 11.70 mg kg^{-1} in station A7. Lastly, lead showed an average concentration of 34.07 ± 13.93 mg kg^{-1} at Site A. The highest concentration was logged at station A8 with 62.50 mg kg^{-1}, with station A5 reporting the lowest at 10.70 mg kg^{-1}. Overall, our analysis paints a clear picture of the sediment's elemental landscape, revealing vital insights into its chemical composition.

For Site B, the sediment unveils key concentration figures for various metals. The average zinc concentration is measured at 156.26 ± 163.29 mg kg^{-1}. Notably, station B2 claims the highest concentration, with a value of 675.00 mg kg^{-1}, while station B22 registers the lowest at 38.40 mg kg^{-1} (*Table 4*).

When it comes to iron, the average concentration is recorded at 15,200 ± 7016 mg kg^{-1}. The peak concentration can be found at station B1, reaching 30,500 mg kg^{-1}, whereas the minimum occurs at station B21, showing 6000 mg kg^{-1}. Next, manganese averages 293.51 ± 88.01 mg kg^{-1} in the sediment samples. Station B18 boasts the highest concentration at 451.60 mg kg^{-1}, while station B21 highlights a minimum of 173.70 mg kg^{-1}. For copper, the average stands at 30.85 ± 7 mg kg^{-1}. The maximum concentration is identified at station B16, hitting 45.20 mg kg-1, while station B13 indicates a minimum of 16.90 mg kg^{-1}. The average concentration of cadmium measures at 2.60 ± 0.95 mg kg-1. The highest value is detected at station B16, where it reaches 4.40 mg kg^{-1}, and station B15 shows a minimum of 0.20 mg kg^{-1}. Cobalt demonstrates an average concentration of 23.00 ± 6.02 mg kg^{-1}. The maximum concentration is found at station B15 with 41.40 mg kg^{-1}, whereas the minimum is reported at station B20, sitting at 15.20 mg kg^{-1}. The average chromium concentration in the sediment is 71.97 ± 16.74 mg kg^{-1}. Station B16 showcases a peak of 99.20 mg kg^{-1}, while station B20 records a minimum of 39.60 mg kg^{-1}. Lastly, lead displays an average concentration of 46.27 ± 11.55 mg kg^{-1}. The maximum value is noted at station B16 with 73.70 mg kg^{-1}, while station B15 presents a minimum of 27.60 mg kg^{-1} (*Table 4*).

Heavy metal concentrations in plant samples

Salicornia europaea, *Dittrichia viscosa*, *Halocnemum strobilaceum* and *M. nodiflorum* plant species were collected and analyzed for heavy metals throughout the study in Boğaziçi-Tuzla Lagoon. Plant samples were taken from stations A1, A3, A8, A6, B3, B8, B13 and B10 (*Tables 5* and *6*).

Plant heavy metal concentrations at station A1 were between 0.30-167.50 mg kg^{-1} and the order of metal concentrations was Fe > Zn > Mn > Cu > Cr > Pb > Co > Cd. Plant heavy metal concentrations at station A3 are between 0.10-100.50 mg kg^{-1} and the order of metal concentrations is Fe > Zn > Mn > Cu > Pb > Cr = Cd > Co. Plant heavy metal concentrations at station A8 are between 0.30-279.00 mg kg^{-1} and the order of metal concentrations is Fe > Mn > Zn > Cu > Pb > Cr > Cd = Co. Plant heavy metal concentrations at station A6 are between 0.20 and 57.60 mg kg^{-1} and the order of metal concentrations is Fe > Mn > Zn > Cu > Pb > Cd > Cr > Co.

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At station B3, heavy metal concentrations were between 0.20-340.50 mg kg^{-1} and the order of metal concentrations was Fe > Zn > Mn > Cu > Pb > Cr > Co > Cd. Plant heavy metal concentrations at station B8 are between 0.20 and 125.00 mg kg^{-1} and the order of metal concentrations is Fe > Zn > Mn > Cu > Pb > Cr > Cd > Co. Plant heavy metal concentrations at station B13 are between 0.20-154.00 mg kg^{-1} and the order of metal concentrations is Fe > Zn > Mn > Cu > Pb > Cr > Cd = Co. Plant heavy metal concentrations at station B10 are between 0.20 and 196.20 mg kg^{-1} and the order of metal concentrations is Fe > Mn > Zn > Cu > Pb > Cr > Co > Cd.

Table 5. *Heavy metal concentrations (mg kg^{-1}) in plant samples from Zone A*

Station	Plant species	Zn	Fe	Mn	Cu	Cd	Co	Cr	Pb
A1	Salicornia europea	167.50*	**633.50**	27.20	4.50	0.30	0.40	1.60	1.20
A3	Dittrichia viscosa	25.10	100.50	14.40	4.50	0.50	0.10	0.50	1.70
A8	Halocnemum strobilaceum	22.50	279.00	22.70	3.00	0.30	0.30	0.70	1.60
A6	Mesembryanthemum nodiflorum	11.00	57.60	11.60	3.80	0.40	0.20	0.30	1.00
Max		167.50*	633.50	27.20	4.50	0.50	0.40	1.60	1.70
Min		11.00	57.60	11.60	3.00	0.30	0.10	0.30	1.00
Avg.		56.52	267.65	18.97	3.95	0.37	0.25	0.77	1.37
Std. D.		74.23	262.06	7.23	0.71	0.09	0.13	0.57	0.33

Table 6. *Heavy metal concentrations (mg kg^{-1}) in plant samples taken from Site B*

Station	Plant species	Zn	Fe	Mn	Cu	Cd	Co	Cr	Pb
B3	Salicornia europea	15.00	340.50	16.10	3.20	0.20	0.30	0.90	1.10
B8	Dittrichia viscosa	39.60	125.00	19.00	3.00	0.20	0.20	0.50	1.00
B13	Halocnemum strobilaceum	50.00	154.00	14.00	12.80	0.20	0.20	0.70	1.30
B10	Mesembryanthemum nodiflorum	13.00	196.20	14.20	10.00	0.20	0.30	0.80	1.10
Max		50.00	340.50	19.00	12.80	0.20	0.30	0.90	1.30
Min		13.00	125.00	14.00	3.00	0.20	0.20	0.50	1.00
Avg.		29.40	203.92	15.82	7.25	0.20	0.25	0.72	1.12
Std. D.		18.30	95.62	2.31	4.92	0.00	0.05	0.17	0.12

Contamination factor (Cf)

The average CF values of Region A were measured as Cd > Zn > Pb > Co > Cu > Cr > Fe > Mn. CF values for Region A are given in *Table 7*. <1, it indicates low pollution, 1–3 indicates moderate pollution, 3-6 indicates high pollution and ≥ 6 indicates very high pollution.

The detailed classification table of the CF values of Area B is given in the table below (*Table 8*). The average CF values of Site B were measured as Cd > Pb > Zn > Co > Cr > Cu > Fe > Mn.

Pearson Correlation Analysis was used to determine the relationship between heavy metal values found in sediment and plants in Region A and Regin B (*Tables 9* and *10*). Pearson's and Kendall's tau_b correlation analyses were used to determine the relationship between the amounts of heavy metals found in the sediment and plant samples. In A region, positive (r = 569) and significant (P < 0.001) correlation was found

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between the amounts of total heavy metals in sediment and plant samples. In sediment analyses conducted in Area A, the quantities of Fe, Mn and Cd determined exhibited a positive correlation with the amounts present in the plant material. However, a negative correlation is exhibited by Zn, Cu, Co, Cr and Pb.

A positive (r = 920) and significant (P < 0.001) correlation was identified between the total heavy metal amounts determined in the sediment and plant samples taken in Area B. The Fe, Mn, Cu, Cd, and Cr quantities ascertained through sediment analyses in Area A exhibited a positive correlation with the amounts present in the plant material. However, a negative correlation was observed between Zn, Co, and Pb.

Table 7. *CF values of sediment samples from Area A*

Station	Zn	Fe	Mn	Cu	Cd	Co	Cr	Pb
A1	1.32*	0.57	0.32	0.63	5.00**	0.52	0.87	1.25*
A2	0.80	0.83	0.76	0.82	4.33**	0.85	0.66	1.43*
A2.1.	0.76	1.1*	0.47	0.65	3.33**	0.96	0.65	1.25*
A3	0.76	1.09*	0.24	0.68	3.67**	1.00	0.91	1.37*
A3.1.	0.61	0.85	0.27	0.65	5.33**	0.86	0.84	1.55*
A4	0.75	0.64	0.33	0.63	6.67***	0.78	0.61	1.33*
A5	0.82	0.3	0.34	0.75	5	0.76	0.82	0.63
A6	1.24*	0.33	0.49	1.07*	3.33**	0.68	1.15	3.16**
A6.1.	0.35	0.11	0.13	0.77	1	1.09	0.18	1.29*
A7	5.98**	0.09	0.17	0.78	9***	0.91	0.16	2.83*
A8	11.11***	0.06	0.34	0.78	12.67***	1.09*	1.18*	3.68**
A8.1.	3.06*	0.28	0.72	0.89	7.67***	0.64	0.55	1.78*
A8.2.	2.85*	0.43	0.33	1.22*	6***	1.33*	0.7	1.75*
A8.3.	3.2*	0.32	0.28	1.18*	9***	1	0.64	2.26*
A8.4.	3.49*	0.47	0.45	0.89	13***	0.91	1.38*	2.31*
A9	10***	0.4	0.35	1.08*	7.67***	1.48*	0.66	1.86*
A9.1.	2.18*	0.48	0.3	0.53	14***	1.31*	0.93	2.69*
A10	2.54*	0.47	0.48	0.72	14***	1.33*	0.83	2.53*
A10.1.	1.48*	0.44	0.34	0.85	13.67***	1.45*	1.09*	3.14**

*Moderate pollution, **high pollution, ***very high pollution

Table 8. *CF values of sediment samples from Area B*

Station	Zn	Fe	Mn	Cu	Cd	Co	Cr	Pb
B1	4.95**	0.90	0.30	0.74	9.33***	1.40*	1.18*	2.62*
B2	10.38***	0.74	0.26	0.81	12.00***	1.37*	1.16*	3.05**
B3	4.99**	0.81	0.41	0.74	10.67***	1.52*	1.24*	2.62*
B4	3.88**	0.61	0.41	0.75	12.33***	1.30*	0.98	3.41*
B5	1.43*	0.47	0.29	0.76	6.00**	1.30*	0.93	2.11*
B6	1.66*	0.58	0.38	0.84	9.33***	1.26*	1.08*	2.96*
B7	1.36*	0.65	0.41	0.89	9.33***	1.40*	1.10*	2.77*
B8	1.26*	0.64	0.34	0.76	9.00***	1.50*	1.11*	2.73*
B9	1.30*	0.41	0.48	0.79	9.67***	1.44*	1.01*	2.64*
B10	1.72*	0.46	0.58	1.02*	8.67***	1.66*	1.15*	2.71*
B11	1.40*	0.40	0.58	0.88	10.00***	1.51*	1.05*	3.21**
B12	7.72***	0.41	0.59	0.79	3.67**	1.58*	1.00*	1.75*
B13	0.77	0.30	0.41	0.42	5.67**	1.03*	0.73	1.84*

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B14	1.16*	0.35	0.58	0.62	11.00***	1.73*	0.94	3.71**
B15	1.66*	0.35	0.61	0.99	0.67	2.59*	1.23*	1.62*
B16	1.78*	0.47	0.45	1.13*	14.67***	2.21*	1.34*	4.34**
B17	1.00	0.27	0.57	0.84	8.33***	1.18*	0.81	2.99*
B18	1.03*	0.22	0.66	0.66	6.67***	1.19*	0.75	2.34*
B19	0.95	0.26	0.30	0.98	7.33***	1.24*	0.91	2.35*
B20	0.99	0.22	0.31	0.50	6.33***	0.95	0.54	2.20*
B21	0.88	0.18	0.26	0.59	7.33***	0.97	0.55	2.19*
B22	0.59	0.19	0.33	0.47	13.00***	1.31*	0.62	3.72**

*Moderate pollution, **high pollution, ***very high pollution

Table 9. *Heavy metal relationship between sediment samples and plant samples in Region A*

Correlations		Plants								
		Total metals	**Zn**	**Fe**	**Mn**	**Cu**	**Cd**	**Co**	**Cr**	**Pb**
Sediment	Pearson correlation	.569**	-.333	.333	.376	-.913	.183	-.667	-.659	-.340
	Sig. (2-tailed)	.001	.497	.497	.624	.071	.718	.174	.341	.660
	N	32	4	4	4	4	4	4	4	4

Table 10. *Heavy metal relationship between sediment samples and plant samples in Region B*

Correlations		Plants								
		Total metals	**Zn**	**Fe**	**Mn**	**Cu**	**Cd**	**Co**	**Cr**	**Pb**
Sediment	Pearson correlation	.920**	-.345	.554	.482	.822	.186	-.408	.333	-.183
	Sig. (2-tailed)	.000	.655	.446	.562	.178	.282	.239	.497	.718
	N	32	4	4	4	4	4	4	4	4

Discussion

The discussion section provides a comprehensive analysis and interpretation of the study’s findings, drawing on relevant literature to contextualize the results and highlight their broader implications. The heavy metal contamination observed in the Boğaziçi Tuzla Lagoon sediment and plants is a significant concern, with potential ecological and human health consequences. The elevated levels of heavy metals, particularly cadmium, lead, copper, and zinc, as indicated by the geoaccumulation index, contamination factor, and potential ecological risk index, suggest that the lagoon is experiencing substantial pollution (Beraldi et al., 2019; Yahaya et al., 2022). The predominance of cadmium as the primary ecological risk factor is particularly worrying, as this metal is classified as carcinogenic and mutagenic.

The accumulation of these toxic metals in the lagoon’s sediment is likely attributed to a range of anthropogenic activities, including industrial, agricultural, and sewage discharges, as well as atmospheric deposition (Oyeyiola et al., 2013; Olivier Togbé et al., 2022; Ontiveros-Cuadras et al., 2024). Seasonal variations in metal concentrations, with higher levels often observed during the dry season, suggest that reduced water flow and increased evaporation may exacerbate the pollution levels. (Iqbal et al., 2022; Sebastiá et al., 2013).

To mitigate the heavy metal pollution in the Boğaziçi Tuzla Lagoon, a comprehensive management plan should be implemented, incorporating a range of strategies, such as

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effluent treatment, sediment remediation, and the enforcement of environmental regulations. Regular monitoring of water quality, sediment, and biota should also be conducted to assess the effectiveness of these measures and to detect any emerging pollution threats.

The spatial distribution of heavy metal pollution in the Boğaziçi Tuzla Lagoon, with higher concentrations observed in certain regions, may be attributed to localized sources of contamination, such as industrial discharges or agricultural runoff. It is important to identify and control these point sources of pollution to reduce the overall heavy metal load in the lagoon. The sequence of total heavy metal concentrations in Boğaziçi Tuzla Lagoon sediment was measured as Fe > Mn > Zn > Cr > Co > Pb > Cu > Cd. Specifically, the geoaccumulation index values, which provide insights into the level of metal enrichment above background levels, followed distinct patterns across the lagoon's regions.

The heavy metal contamination observed in the Boğaziçi Tuzla Lagoon is a significant environmental concern that requires comprehensive mitigation efforts. The elevated levels of toxic metals, particularly cadmium, lead, copper, and zinc, as indicated by the geoaccumulation index, contamination factor, and potential ecological risk index, pose substantial risks to the lagoon's ecological health and the well-being of the surrounding communities.

The increasing supply of housing stock in the vicinity of the lagoon area, coupled with its growing importance as a tourism destination, has put serious pressure on the Boğaziçi-Tuzla Lagoon and its ecosystem. Research shows that there are very few studies on the water quality, sediment, heavy metal concentration and plant samples of the lagoon area.

Heavy metal concentrations and evaluations in sediment

The results of sediment analyses of Zn, Fe, Mn, Cu, Cd, Co, Cr and Pb obtained from Boğaziçi-Tuzla Lagoon and the results of some other studies are not comparatively examined in this section. As a result of sediment analyses, the average metal concentration order in Boğaziçi-Tuzla Lagoon was measured as Fe > Mn > Zn > Cr > Co > Pb > Cu > Cd. According to the results obtained, Cr values are in parallel with previous studies. According to the Canadian Sediment Quality Guidelines (CSQGs, 2001), (Cr: 37.30 mg kg^{-1}) is above the limit value of 66.84 mg kg^{-1}, which is the total average value of Regions A and B. The reason for this is thought to be the domestic wastewater discharge entering the lagoon (Döndü et al., 2024).

According to the results obtained, Cd values are in parallel with previous studies. According to the Canadian Sediment Quality Guidelines (CSQGs, 2001), the total average value of Cd:0.60 mg kg^{-1} for Regions A and B is above the limit value of 2.30 mg kg^{-1}. The reason for this is thought to be groundwater and domestic wastewater entering the lagoon area (Döndü et al., 2024).

According to the results obtained, Pb values are in parallel with previous studies. According to the Canadian Sediment Quality Guidelines (CSQGs, 2001) (Pb: 35.00 mg kg^{-1}), the total average value of 40.17 mg kg^{-1} in Regions A and B is close to the limit value.

According to the results obtained, Zn values are in parallel with previous studies. When a comparison is made according to the Canadian Sediment Quality Guidelines (CSQGs, 2001) (Zn: 123.00 mg kg^{-1}), the total average value of A and B Regions, which we obtained, is close to the limit value of 169.31 mg kg^{-1}.

According to the results obtained, Cu values are in parallel with previous studies. When a comparison is made according to the Canadian Sediment Quality Guidelines

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(CSQGs, 2001) (Cu: 35.00 mg kg^{-1}), the total average value of A and B Regions, which we obtained, is close to the limit value of 31.92 mg kg^{-1}.

According to the results obtained, Mn values were found below the values obtained in previous studies. It is thought that this is due to the contact of manganese minerals with water in an oxygen-free environment or the activity of bacteria (Döndü et al., 2024). According to the results obtained, Co values are in parallel with the previous studies. In our study, Fe values were measured in the range of 2000-38400 mg kg^{-1}.

Metal concentrations in plant samples

Salicornia europaea, *Dittrichia viscosa*, *Halocnemum strobilaceum* and *M. nodiflorum* samples were taken from the stations determined in Regions A and B throughout the study in Boğaziçi-Tuzla Lagoon and heavy metal analyses were performed.

According to the measurement results obtained, the average concentration of Cd in *S. europaea* was 0.25 mg kg^{-1}, the average concentration of Pb was 1.15 mg kg^{-1}, the average concentration of Cu was 3.85 mg kg^{-1}, the average concentration of Fe was 487 mg kg^{-1}, the average concentration of Mn was 21.65 mg kg^{-1}, the average concentration of Zn was 91.25 mg kg^{-1}, the average concentration of Co was 0.35 mg kg^{-1} and the average concentration of Cr was 1.25 mg kg^{-1}. *S. europaea* concentration order was determined as Fe > Zn > Mn > Cu > Cr > Pb > Co > Cd. Pirasteh-Anosheh et al. (2013) measured Cd mean concentration as 0.22 mg kg^{-1}, Pb mean concentration as 19.16 mg kg^{-1}, Cu mean concentration as 9.62 mg kg^{-1}, Zn mean concentration as 28.16 mg kg^{-1}, Co mean concentration as 2.30 mg kg^{-1} and Cr mean concentration as 7.14 mg kg^{-1} in *S. europaea* (acceptable values for *S. europea* are mg kg^{-1}: Cd:3, Co:30, Cr:300, Cu:150, Pb:250 and Zn:500). Milic et al. (2012) determined Cu concentration as 2.3 mg kg^{-1}, Fe concentration as 73.5 mg kg^{-1}, Mn concentration as 41.5 mg kg^{-1}, and Zn concentration as 8.9 mg kg^{-1} in *S. europaea*. Döndü (2020) determined Cd average concentration as 0.31 mg kg^{-1}, Pb average concentration as 0.24 mg kg^{-1}, Cu average concentration as 11.62 mg kg^{-1}, Fe average concentration as 5.65 mg kg^{-1}, Mn average concentration as 8.66 mg kg^{-1}, Zn average concentration as 1.06 mg kg^{-1} and Hg average concentration as 10.05 mg kg^{-1} in *S. Europaea* (Döndü, 2020).

Dittrichia viscosa grows in polluted areas of the Mediterranean region such as mining areas and roadsides. Various studies have indicated that some heavy metal levels in *D. viscosa* are in the phytotoxic range (Baycu et al., 2015). According to the measurement results obtained, Cd mean concentration in *D. viscosa* was 0.35 mg kg^{-1}, Pb mean concentration 1.35 mg kg^{-1}, Cu mean concentration 1.75 mg kg^{-1}, Fe mean concentration 112.75 mg kg^{-1}, Mn mean concentration 16.70 mg kg^{-1}, Zn mean concentration 32.35 mg kg^{-1}, Co mean concentration 0.15 mg kg^{-1} and Cr mean concentration 0.50 mg kg^{-1}. *D. viscosa* concentration order was determined as Fe > Zn > Mn > Cu > Pb > Cr > Cd > Co. (2021) measured the average Pb concentration as 0.30 mg kg^{-1}, Cd concentration as 0.41 mg kg^{-1} and Cu concentration as 13.56 mg kg^{-1}.

According to the measurement results obtained, the average concentration of Cd in *H. strobilaceum* was 0.25 mg kg^{-1}, the average concentration of Pb was 1.45 mg kg^{-1}, the average concentration of Cu was 7.90 mg kg^{-1}, the average concentration of Fe was 216.50 mg kg^{-1}, the average concentration of Mn was 18.35 mg kg^{-1}, the average concentration of Zn was 36.25 mg kg^{-1}, the average concentration of Co was 0.25 mg kg^{-1} and the average concentration of Cr was 0.70 mg kg^{-1}. *H. strobilaceum* concentration order

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was determined as Fe > Zn > Mn > Cu > Pb > Cr > Cd = Co. Cd average concentration as 1.72 mg kg^{-1}, Pb average concentration as 5.45 mg kg^{-1}, Fe average concentration as 21.85 mg kg^{-1} and Co average concentration as 1.33 mg kg^{-1} were determined in Nile Delta coast (El-Amier et al., 2021b).

According to the measurement results obtained, the average concentration of Cd in *M. nodiflorum* was 0.30 mg kg^{-1}, the average concentration of Pb was 1.05 mg kg^{-1}, the average concentration of Cu was 6.90 mg kg^{-1}, the average concentration of Fe was 133.40 mg kg^{-1}, the average concentration of Mn was 7.90 mg kg^{-1}, the average concentration of Zn was 12.00 mg kg^{-1}, the average concentration of Co was 2.30 mg kg^{-1} and the average concentration of Cr was 0.55 mg kg^{-1}. *M. nodiflorum* concentration order was determined as Fe > Zn > Mn > Cu > Pb > Cr > Cd > Co.

Conclusion

In the study we conducted in Boğaziçi-Tuzla Lagoon, it was concluded that the region is seriously affected by environmental factors. Sustainable Lagoon Management should focus on implementing best practices that promote ecological balance while allowing for responsible recreational use. By prioritizing education and engagement, communities can empower individuals to take an active role in protecting their local lagoons, fostering a sense of stewardship that benefits both the environment and public well-being. Incorporating innovative technologies and sustainable practices, such as eco-friendly infrastructure and habitat restoration projects, can further enhance the resilience of lagoon systems against climate change impacts. Investing in research and data collection will also be essential for understanding the specific dynamics of each lagoon ecosystem, allowing for tailored management approaches that reflect local conditions and challenges. These collaborative efforts not only promote biodiversity but also create economic opportunities for local communities, ensuring that conservation initiatives are both ecologically sound and socially equitable. Such community involvement fosters a sense of ownership and responsibility, encouraging sustainable practices that can be passed down through generations while simultaneously empowering residents to advocate for their environment.

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