Mar. Sci. Tech. Bull. (2024) 13(3): 175-182
e–ISSN: 2147–9666
info@masteb.com

dergipark.org.tr/en/pub/masteb
www.masteb.com
DOI: 10.33714/masteb.1514540

Marine Science and Technology Bulletin

PRENSİP
https://prensip.gen.tr/

RESEARCH ARTICLE

Heavy metal distributions of macroalgal species from the Mersin inner bay, Türkiye

Özgür Özbay[1 *] • İsmail Akçay[1]

[1] *Mersin University, Faculty of Fisheries, Mersin, Türkiye*

ARTICLE INFO

Article History:
Received: 11.07.2024
Received in revised form: 05.08.2024
Accepted: 15.08.2024
Available online: 30.09.2024

Keywords:
Trace elements
Bioaccumulation
Marine organisms
Health risk assessment
Mediterranean Sea

ABSTRACT

The bio-accumulation of heavy metals in macroalgae poses significant risks to marine ecosystems and human health. In this study, heavy metal distributions of macroalgae and potential health risk assessment in the Mersin inner Bay were determined from macroalgae (*Stypopodium schimperi*, *Padina pavonica*, *Laurencia obtusa*, *Dictyota* sp., *Sargassum vulgare*, *Jania rubens*, *Halopithys* sp., *Osmundea* sp., *Halopithys incurve*, *Ulva intestinalis*, *Entromorpha flexuosa*, *Ulva linza*) samples collected between February and September 2021. The levels of heavy metals were found as 1.24-5.93 g/kg for aluminum, 0.61-5.26 g/kg for iron, 1.17-7.61 mg/kg for cobalt, 0.03-0.21 mg/kg for cadmium, 4.26-43.10 mg/kg for chromium, 0.28-437.52 mg/kg for cupper, 17.90-139.08 mg/kg for manganese, 2.78-79.25 mg/kg for nickel, 0.75-3.49 mg/kg for lead and 1.71-70.34 mg/kg for zinc, respectively. The potential risk assessment of macroalgal species using the calculated total cancer risk (TCR) suggested high carcinogenic risk from the carcinogenic chromium, copper and nickel (TCR>1.00E-04).

Please cite this paper as follows:

Özbay, Ö., & Akçay, İ. (2024). Heavy metal distributions of macroalgal species from the Mersin inner bay, Türkiye. *Marine Science and Technology Bulletin*, *13*(3), 175-182. https://doi.org/10.33714/masteb.1514540

Introduction

Coastal marine regions are adversely affected by human-induced pressures. The development of cities along the coasts and industrialization are the main causes of anthropogenic contaminants in these ecosystems (Bouri et al., 2021; Rahhou et al., 2023). Heavy metals, one of the certain kinds of contaminants, are naturally available in aquatic ecosystems. In order to assess heavy metal pollution in aquatic ecosystems, it is important to distinguish between anthropogenic heavy metal pollution and background levels (Akcali & Kucuksezgin, 2011). It is well known that anthropogenic and non-anthropogenic inputs into the aquatic environments will eventually accumulate in water column, sediments and organisms (Bibak et al., 2020).

* Corresponding author
E-mail address: ozgurozbay@mersin.edu.tr (Ö. Özbay)

Heavy metals that accumulate in marine organisms are strongly link to metal contamination (Alkan et al., 2016; Jeong & Ra, 2022). Many marine organisms are widely used for bio-monitoring studies to assess the degree of contamination due to anthropogenic pressures (Akcali & Kucuksezgin, 2011; Hao et al., 2019; Rakib et al., 2021; Jeong & Ra, 2022). Additionally, bio-monitoring studies are of critical importance since some marine organisms are used as food resources for humans due to their high content of polysaccharides, polyunsaturated fatty acids, minerals and vitamins (Jeong & Ra, 2022). It was estimated that there are 150 macroalgal species which are consumed as human food (Barrow, 2007; Mohamed & Hasan, 2023).

Mersin Bay is located at the Northeastern (NE) Mediterranean (Figure 1). Previous studies showed the development of eutrophication and sedimentary heavy metal pollution in the Mersin inner bay due to anthropogenic pressures (Akcay et al., 2022; Özbay & Akçay, 2023; Akçay, 2023; Özbay, 2024). However, only a few studies have been conducted on the distributions of heavy metals in the most common macroalgal species along the coastal areas of the Mersin Bay (Alp et al., 2012; Börekçi et al., 2021). Therefore, this study focuses on the heavy metal levels of the collected macroalgal species in the Mersin Bay.

Heavy metal pollution poses a significant threat to macroalgae and the broader marine environment. By understanding the sources and effects of heavy metals, and implementing effective monitoring and mitigation strategies, it is possible to protect marine ecosystems for ensuring the health and sustainability of our seas. The main objective of this study was to determine concentrations of heavy metals in the macroalgae samples collected from the Mersin Bay, located at the NE Mediterranean Sea. Due to the adverse health effects of heavy metals for humans (Doshi et al., 2008; Cheng et al., 2019), assessment of potential health risk due to consumption of the collected species as human food was also determined in the present study.

Material and Methods

In order to determine distributions of heavy metals [aluminum (Al), iron (Fe), cobalt (Co), cadmium (Cd), chromium (Cr), cupper (Cu), manganese (Mn), nickel (Ni), lead (Pb), zinc (Zn)] for the collected macroalgal species, 6 stations were visited along the coastal regions of the Mersin inner Bay (Figure 1). The list of macroalgal species was presented in Table 1.

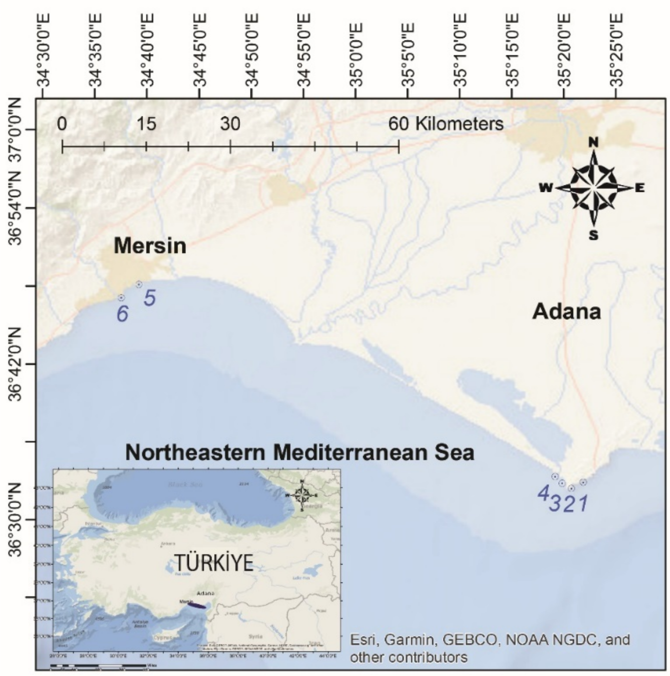

Figure 1. Study area

Table 1. The macroalgal species collected from the Mersin inner bay

Station	Macroalgae
1	*Stypopodium schimperi*
	Padina pavonica
	Laurencia obtusa
2	*Dictyota* sp.
	Sargassum vulgare
	Jania rubens
3	*Halopithys* sp.
4	*Osmundea* sp.
	Halopithys incurva
5	*Ulva intestinalis*
6	*Entromorpha flexuosa*
	Ulva linza

Macroalgal species, obtained between February and September 2021, were collected by hand and washed by seawater. The obtained samples were put in the polyethylene bags and stored at −20°C till the analysis of heavy metals. In the laboratory, the collected macroalgae samples were dried and homogenized. Then, concentrations of heavy metals were by using Inductively Coupled Plasma Mass Spectrometer (ICP-MS -AGILENT 7850 Model) according to method described by the study of Alp et al. (2012).

Health risk of heavy metals was assessed by the calculation of Hazard Quotient through ingestion pathway ($HQ_{ing.}$) and Total Cancer Risk (TCR) (USEPA, 2002, 2014; Magni et al., 2021; Özbay & Akçay, 2023).

Results and Discussion

Macroalgal species are good bio-indicators for the assessment of heavy metal pollution due to their high capacity for bioaccumulation (Akcali & Kucuksezgin, 2011; Hao et al., 2019; Rakib et al., 2021; Jeong & Ra, 2022; El-Mahrouk et al., 2023). There were some studies carried out to determine heavy metals contents in macroalgae of the Mediterranean coasts. However, studies performed in the Mersin inner Bay are very limited. Previous studies performed in the study region showed that concentrations of heavy metals displayed spatio-temporal variability (Alp et al., 2012; Börekçi et al., 2021). The heavy metal concentrations of the collected macroalgae samples varied between 1.24-5.93 g/kg for Al, 0.61-5.26 g/kg for Fe, 1.17-7.61 mg/kg for Co, 0.03-0.21 mg/kg for Cd, 4.26-43.10 mg/kg for Cr, 0.28-437.52 mg/kg for Cu, 17.90-139.08 mg/kg for Mn, 2.78-79.25 mg/kg for Ni, 0.75-3.49 mg/kg for Pb and 1.71-70.34 mg/kg for Zn, respectively (Table 2). It should be noted that maximum concentrations of heavy metals Co, Cr, Fe, Mn and Ni were recorded in the eastern section of the Mersin Bay for the macroalgae *Stypopodium schimperi* whilst the Cd, Cu and Zn contents were higher for the macroalgae *Halopithys incurva*, strongly suggested high bioaccumulation capacity of these macroalgal species for heavy metals.

Previous studies showed heavy metal pollution in sediments and macroalgae of the Mersin inner bay due to natural processes and anthropogenic pressures (Yalçın et al., 2013; Özbay & Akçay, 2023; Özbay, 2024; Akçay, 2023, 2024). The Ni enrichment in the Mersin inner bay is probably due to natural weathering and erosion of rocks (Yalcın et al., 2013; Akçay, 2024). It was also reported that large Cr mineral deposits and the use of pesticide and fertilizer with high Cr, Ni and Mn contents in the study region enhanced heavy metals pollution in the coastal sites of the Mersin Bay (Tuncel et al., 2007; Alp et al., 2012; Özbay, 2024). All these natural and human-induced pressures increased the concentration of heavy metals in the collected macroalgal samples from the Mersin inner bay. Furthermore, comparison of heavy metal concentrations in macroalgae along different coastal regions in the Mediterranean Sea showed that the concentrations of heavy metals Al, Cr, Cu, Fe and Mn were higher along the coastal areas of the Mersin Bay (Table 2). In the recent studies performed in the Mersin Bay also showed that the macroalgae species has high metal contents due to anthropogenic inputs (Alp et al., 2012; Börekçi et al., 2021).

It was reported that there are 150 macroalgal species which are consumed as food resources for humans due to their high content of polysaccharides, polyunsaturated fatty acids, minerals and vitamins (Barrow, 2007; Jeong & Ra, 2022; Mohamed & Hasan, 2023). Furthermore, about 15–20 edible algae strains are marketed for food consumption in Europe (Polat & Ozogul, 2013; Ozgun & Turan, 2015). Previous studies indicated that though some macroalgal species, (*Ulva* sp., *Entromorpha* sp., *Laurencia obtusa*) are edible, *Padina pavonica* species are non-edible (Çolakoğlu & Ak, 2017; Caf et al., 2019; Tuzen et al., 2009). The studied macroalgal species collected from the Mersin inner bay is of great importance for their edibility. In the present study, therefore, health risk assessment of heavy metals for the collected macroalgae samples was determined by the calculation of $HQ_{ing.}$ and TCR. The calculated $HQ_{ing.}$ values, less than 1 indicated non-carcinogenic risk (safe for human health), while the values, greater than 1, showed carcinogenic risk. For the TCR values, a TCR value, less than 1.00E-06, indicates no significant health hazards, but a TCR value, higher than 1.00E-04, indicates high carcinogenic risk. A TCR values, varied between 1.00E-06 and 1.00E-04, suggests tolerable carcinogenic risk (Magni et al., 2021; Özbay & Akçay, 2023). The calculated values were presented in Table 3. The study findings showed that though all the calculated $HQ_{ing.}$ values were less than 1, the calculated TCR values ranged from 7.64E-09 for adults to 9.51E-03 for children (Table 3). The high values calculated for the heavy metals Cu and Ni for adults, and Cr, Cu and Ni for children (TCR>1.00E-04) strongly suggested high carcinogenic risk for adults and children. In a recent study, Akçay (2024) reported health hazards for Cr and Ni by studying heavy metals content of *Enteromorpha* sp. in the Mersin inner Bay. Therefore, all these findings suggested that the consumption of these macroalgae species from the coastal regions as human food or animal feed may cause health hazards.

Human-induced metal contamination has been experienced in the Mersin Bay with levels and sources potentially changing over time. This study revealed that regular monitoring is necessary to track these changes and assess the effectiveness of mitigation measures. Establishing a regular monitoring schedule, comparing current data with historical records, and implementing recommended measures based on the findings ensure ongoing protection of the marine environment.

Table 2. Heavy metal contents in macroalgae from the Mersin inner bay (mg/kg)

Region	Macroalgae	Al*	Fe*	Co	Cd	Cr	Cu	Mn	Ni	Pb	Zn	Reference
Mersin Bay coastal regions, Türkiye	*Stypopodium schimperi*	5.92	5.26	7.61	0.11	43.10	303.52	139.08	79.25	1.57	30.66	This study
	Padina pavonica	3.86	2.84	3.21	0.10	16.62	5.34	89.07	33.58	2.88	12.82	
	Laurencia obtusa	3.26	2.75	2.52	0.14	16.81	4.35	82.76	13.70	2.27	8.93	
	Dictyota sp.	3.19	1.45	2.04	0.07	10.35	4.19	62.12	5.30	1.68	6.16	
	Sargassum vulgare	1.34	0.61	1.32	0.04	4.26	2.05	17.90	4.48	0.75	4.85	
	Jania rubens	1.24	0.77	1.17	0.04	5.30	0.28	28.22	2.78	1.13	1.71	
	Halopithys sp.	1.69	0.87	1.49	0.03	4.95	18.96	58.33	4.92	1.39	6.40	
	Osmundea sp.	3.40	2.15	2.12	0.14	14.30	3.01	51.72	9.09	1.77	7.98	
	Halopithys incurva	4.67	3.87	4.29	0.21	14.93	437.52	98.79	21.29	3.28	70.34	
	Ulva intestinalis	4.28	1.95	1.72	0.13	12.94	5.30	45.23	12.81	2.16	22.92	
	Entromorpha flexuosa	5.93	3.09	3.06	0.14	20.19	6.38	50.11	19.90	1.53	15.92	
	Ulva linza	5.44	2.70	2.46	0.15	17.25	8.36	64.39	20.70	3.49	59.80	
South Adriatic Sea, Italy	*Ulva lactuca*	-	0.34	-	0.20	-	12.07	-	-	0.84	127.27	Storelli et al. (2001)
	Entromorpha prolifera	-	0.39	-	0.72	-	10.33	-	-	1.15	58.79	
Eastern Aegean coastal regions, Türkiye	*Ulva* sp.	-	0.128-0.308	-	0.015-0.057	0.78 -4.78	6.49-13.90	-	-	0.001-0.006	-	Akcali and Kucuksezgin (2011)
	Enterophmorpha sp.	-	0.205-0.440	-	0.013 -0.044	3.15 -9.63	4.43-13.20	-	-	0.001-0.010	-	
	Padina pavonica	-	0.039-0.299	-	0.018-0.148	0.73 -3.19	3.73 - 8.22	-	-	0.001-0.005	-	
Mediterranean Sea, Mersin, Türkiye	*Ulva* sp.	0.05	0.20	-	0.03	3.07	1.02	7.84	7.58	0.81	4.59	Alp et al. (2012)
	Enterophmorpha sp.	0.18	0.65	-	0.03	4.02	1.65	14.62	16.77	1.04	6.42	
Mediterranean Sea, Egypt	*Entromorpha prolifera*	-	0.86	4.60	0.09	1.02	4.09	15.55	5.70	5.61	102.82	El Zokm et al. (2021)
	Ulva linza	-	1.54	7.83	1.04	0.85	0.28	23.34	9.16	10.82	88.19	
	Jania rubens	-	1.36	29.30	3.10	0.84	3.30	56.25	30.00	35.60	48.80	
	Sargassum vulgare	-	0.26	6.70	1.85	1.64	18.00	15.00	14.80	9.00	129.05	
	Padina pavonica	-	0.94	10.52	1.35	0.95	6.68	89.65	12.64	13.36	109.79	
Mediterranean Sea, Mersin, Türkiye	*Ulva rigada*	0.66-1.65	-	-	-	95.96-195.65	-	88.61-224.08	-	-	-	Börekçi et al. (2021)
Mediterranean Sea, Morocco	*Ulva lactuca*	-	0.12-0.42	-	-	0.90-1.00	1.90-7.40	25.50-164	4.00-4.50	2.70-4.80	8.52-10.20	Rahhou et al. (2023)

Note: *The units of Al and Fe concentrations are g/kg

Table 3. Health risk assessment for the macroalgae from the Mersin inner Bay

$HQ_{ing.}$		ADULT										CHILD								
Station	Macroalgae	Co	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn		Co	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn
1	*Stypopodium schimperi*	3.04E-02	1.32E-04	1.72E-02	1.82E-02	9.01E-03	1.19E-03	4.75E-03	1.34E-02	1.23E-04		3.24E-01	1.41E-03	1.84E-01	1.94E-01	9.61E-02	1.27E-02	5.07E-02	1.43E-01	1.31E-03
1	*Padina pavonica*	1.28E-02	1.20E-04	6.64E-03	3.20E-04	4.86E-03	7.63E-04	2.01E-03	2.47E-02	5.12E-05		1.37E-01	1.28E-03	7.08E-02	3.41E-03	5.19E-02	8.13E-03	2.15E-02	2.63E-01	5.46E-04
1	*Laurencia obtusa*	1.01E-02	1.68E-04	6.72E-03	2.61E-04	4.71E-03	7.09E-04	8.21E-04	1.94E-02	3.57E-05		1.07E-01	1.79E-03	7.16E-02	2.78E-03	5.02E-02	7.56E-03	8.76E-03	2.07E-01	3.81E-04
2	*Dictyota* sp.	8.15E-03	8.39E-05	4.14E-03	2.51E-04	2.48E-03	5.32E-04	3.18E-04	1.44E-02	2.46E-05		8.69E-02	8.95E-04	4.41E-02	2.68E-03	2.65E-02	5.67E-03	3.39E-03	1.53E-01	2.63E-04
2	*Sargassum vulgare*	5.27E-03	4.79E-05	1.70E-03	1.23E-04	1.04E-03	1.53E-04	2.68E-04	6.42E-03	1.94E-05		5.63E-02	5.11E-04	1.82E-02	1.31E-03	1.11E-02	1.63E-03	2.86E-03	6.85E-02	2.07E-04
2	*Jania rubens*	4.67E-03	4.79E-05	2.12E-03	1.68E-05	1.32E-03	2.42E-04	1.67E-04	9.67E-03	6.83E-06		4.99E-02	5.11E-04	2.26E-02	1.79E-04	1.41E-02	2.58E-03	1.78E-03	1.03E-01	7.29E-05
3	*Halopithys* sp.	5.95E-03	3.60E-05	1.98E-03	1.14E-03	1.49E-03	4.99E-04	2.95E-04	1.19E-02	2.56E-05		6.35E-02	3.84E-04	2.11E-02	1.21E-02	1.59E-02	5.33E-03	3.15E-03	1.27E-01	2.73E-04
4	*Osmundea* sp.	8.47E-03	1.68E-04	5.71E-03	1.80E-04	3.68E-03	4.43E-04	5.45E-04	1.52E-02	3.19E-05		9.04E-02	1.79E-03	6.09E-02	1.92E-03	3.93E-02	4.72E-03	5.81E-03	1.62E-01	3.40E-04
4	*Halopithys incurva*	1.71E-02	2.52E-04	5.97E-03	2.62E-02	6.63E-03	8.46E-04	1.28E-03	2.81E-02	2.81E-04		1.83E-01	2.68E-03	6.36E-02	2.80E-01	7.07E-02	9.02E-03	1.36E-02	3.00E-01	3.00E-03
5	*Ulva intestinalis*	6.87E-03	1.56E-04	5.17E-03	3.18E-04	3.34E-03	3.87E-04	7.68E-04	1.85E-02	9.16E-05		7.33E-02	1.66E-03	5.51E-02	3.39E-03	3.56E-02	4.13E-03	8.19E-03	1.97E-01	9.77E-04
6	*Entromorpha flexuosa*	1.22E-02	1.68E-04	8.07E-03	3.82E-04	5.29E-03	4.29E-04	1.19E-03	1.31E-02	6.36E-05		1.30E-01	1.79E-03	8.60E-02	4.08E-03	5.64E-02	4.58E-03	1.27E-02	1.40E-01	6.78E-04
6	*Ulva linza*	9.83E-03	1.80E-04	6.89E-03	5.01E-04	4.62E-03	5.51E-04	1.24E-03	2.99E-02	2.39E-04		1.05E-01	1.92E-03	7.35E-02	5.34E-03	4.93E-02	5.88E-03	1.32E-02	3.19E-01	2.55E-03

TCR		ADULT										CHILD								
Station	Macroalgae	Co	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn		Co	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn
1	*Stypopodium schimperi*		6.61E-08	2.59E-05	6.18E-04			1.61E-04	1.60E-08				7.05E-07	2.76E-04	6.60E-03			1.72E-03	1.71E-07	
1	*Padina pavonica*		6.01E-08	9.98E-06	1.09E-05			6.84E-05	2.93E-08				6.41E-07	1.06E-04	1.16E-04			7.30E-04	3.13E-07	
1	*Laurencia obtusa*		8.41E-08	1.01E-05	8.86E-06			2.79E-05	2.31E-08				8.97E-07	1.08E-04	9.45E-05			2.98E-04	2.47E-07	
2	*Dictyota sp.*		4.20E-08	6.22E-06	8.54E-06			1.08E-05	1.71E-08				4.48E-07	6.63E-05	9.11E-05			1.15E-04	1.83E-07	
2	*Sargassum vulgare*		2.40E-08	2.56E-06	4.18E-06			9.13E-06	7.64E-09				2.56E-07	2.73E-05	4.46E-05			9.74E-05	8.15E-08	
2	*Jania rubens*		2.40E-08	3.18E-06	5.71E-07			5.66E-06	1.15E-08				2.56E-07	3.39E-05	6.09E-06			6.04E-05	1.23E-07	
3	*Halopithys sp.*		1.80E-08	2.97E-06	3.86E-05			1.00E-05	1.42E-08				1.92E-07	3.17E-05	4.12E-04			1.07E-04	1.51E-07	
4	*Osmundea sp.*		8.41E-08	8.59E-06	6.13E-06			1.85E-05	1.80E-08				8.97E-07	9.16E-05	6.54E-05			1.98E-04	1.92E-07	
4	*Halopithys incurva*		1.26E-07	8.97E-06	8.92E-04			4.34E-05	3.34E-08				1.35E-06	9.56E-05	9.51E-03			4.63E-04	3.56E-07	
5	*Ulva intestinalis*		7.81E-08	7.77E-06	1.08E-05			2.61E-05	2.20E-08				8.33E-07	8.29E-05	1.15E-04			2.78E-04	2.35E-07	
6	*Entromorpha flexuosa*		8.41E-08	1.21E-05	1.30E-05			4.05E-05	1.56E-08				8.97E-07	1.29E-04	1.39E-04			4.33E-04	1.66E-07	
6	*Ulva linza*		9.01E-08	1.04E-05	1.70E-05			4.22E-05	3.56E-08				9.61E-07	1.10E-04	1.82E-04			4.50E-04	3.79E-07	

$HQ_{ing.}$< 1; non-carcinogenic risk | HQ_{ing}≥ 1; potential carcinogenic | TCR<1.00E-06; No significant health hazards | 1.00E-06 <TCR< 1.00E-04; Acceptable carcinogenic risk | TCR>1.00E-04; High risk of carcinogenesis

Conclusion

In the present study, heavy metal distributions of macroalgae and potential health risk assessment along the coastal regions of the Mersin Bay were determined. The finding of this study showed that the concentrations of Al, Cr, Cu, Fe and Mn were higher in macroalgal species in the Mersin Bay, showing high bioaccumulation of these heavy metals. Furthermore, the high TCR values for the adults and children living in the study region showed potential carcinogenic risk from the carcinogenic Cr, Cu and Ni. Continuous bio-monitoring and proactive measures based on these studies are essential for safeguarding marine ecosystems and human health from the adverse effects of metal pollution.

Compliance With Ethical Standards

Authors' Contributions

ÖÖ: Writing – original draft, Formal analysis, Writing – review and editing

İA: Writing – original draft, Formal analysis, Writing – review and editing

All authors read and approved the final manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required.

Funding

Not applicable.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

References

Akcali, I., & Kucuksezgin, F. (2011). A biomonitoring study: heavy metals in macroalgae from eastern Aegean coastal areas. *Marine Pollution Bulletin*, *62*(3), 637-645. https://doi.org/10.1016/j.marpolbul.2010.12.021

Akcay, I., Tugrul, S., & Ozhan, K. (2022). Effects of river inputs on particulate organic matter composition and distributions in surface waters and sediments of the Mersin Bay, Northeastern Mediterranean Sea. *Regional Studies in Marine Science*, *52*, 102316. https://doi.org/10.1016/j.rsma.2022.102316

Akçay, İ. (2023). Comparison of diffusive and total nutrient fluxes from the sediment of Mersin Bay, northeastern Mediterranean Sea. *Journal of Water Chemistry and Technology*, *45*(2), 176-180. https://doi.org/10.3103/S1063455X23020042

Akçay, İ. (2024). Environmental risk assessment and bioaccumulation of heavy metals in sediments and macroalgae (*Enteromorpha* sp.) along the Mersin coast (Türkiye), northeastern Mediterranean Sea. *Regional Studies in Marine Science*, *77*, 103673. https://doi.org/10.1016/j.rsma.2024.103673

Alkan, N., Alkan, A., Gedik, K., & Fisher, A. (2016). Assessment of metal concentrations in commercially important fish species in Black Sea. *Toxicology and Industrial Health*, *32*(3), 447-456. https://doi.org/10.1177/0748233713502840

Alp, M. T., Ozbay, O., & Sungur, M. (2012). Determination of heavy metal levels in sediment and macroalgae (*Ulva* sp. and *Enteromorpha* sp.) on the Mersin coast. *Ekoloji*, *21*, 47-55.

Barrow, C. J. (2007). Marine by-products as functional food ingredients. *Food Technology International*, 1-5.

Bibak, M., Sattari, M., Tahmasebi, S., Agharokh, A., & Namin, J. I. (2020). Marine macro-algae as a bio-indicator of heavy metal pollution in the marine environments, Persian Gulf. Indian Journal of Geo Marine Sciences, *49*(03), 357-363.

Börekçi, N. S., Bakan, M., Peksezer, B., Alp, M. T., & Deniz, A. (2021). Determination of effects of seasonal and sampling area on *Ulva rigida*'s elemental composition. *Advanced Underwater Sciences*, *1*(1), 01-07.

Bouri, I., Rouane-Hacene, O., & Boutiba, Z. (2021). Ecological diagnosis of the marine environment of the Algerian West Coast using benthic macroalgae. *Ukrainian Journal of Ecology*, *11*(8), 13-20. https://doi.org/10.15421/2021_262

Caf, F., Şen Özdemir, N., Yılmaz, Ö., Durucan, F., & Ak, İ. (2019). Fatty acid and lipophilic vitamin composition of seaweeds from Antalya and Çanakkale (Turkey). *Grasas Aceites*, *70*(3), e312. https://doi.org/10.3989/gya.0704182

Cheng, S. Y., Show, P. L., Lau, B. F., Chang, J. S., & Ling, T. C. (2019). New prospects for modified algae in heavy metal adsorption. *Trends in Biotechnology*, *37*(11), 1255-1268. https://doi.org/10.1016/j.tibtech.2019.04.007

Çolakoğlu, F., & Ak, İ. (2017). Evaluation of seaweed resources as functional food in Turkey. *Proceedings of the Jubilee International Scientific Conference Bulgaria of Regions 2017 Sustainable Regional Development Perspectives*, Bulgaria, pp. 246-255.

Doshi, H., Seth, C., Ray, A., & Kothari, I. L. (2008). Bioaccumulation of heavy metals by green algae. *Current Microbiology*, *56*(3), 246-255. https://doi.org/10.1007/s00284-007-9070-z

El Zokm, G. M., Ismail, M. M., & El-Said, G. F. (2021). Halogen content relative to the chemical and biochemical composition of fifteen marine macro and micro algae: nutritional value, energy supply, antioxidant potency, and health risk assessment. *Environmental Science and Pollution Research*, *28*(12), 14893-14908. https://doi.org/10.1007/s11356-020-11596-0

El-Mahrouk, M. E., Dewir, Y. H., Hafez, Y. M., El-Banna, A., Moghanm, F. S., El-Ramady, H., Mahmood, Q., Elbehiry, F., & Brevik, E. C. (2023). Assessment of bioaccumulation of heavy metals and their ecological risk in Sea Lettuce (*Ulva* spp.) along the coast Alexandria, Egypt: Implications for Sustainable Management. *Sustainability*, *15*(5), 4404. https://doi.org/10.3390/su15054404

Hao, Z., Chen, L., Wang, C., Zou, X., Zheng, F., Feng, W., Zhang, D., & Peng, L. (2019). Heavy metal distribution and bioaccumulation ability in marine organisms from coastal regions of Hainan and Zhoushan, China. *Chemosphere*, *226*, 340-350. https://doi.org/10.1016/j.chemosphere.2019.03.132

Jeong, H., & Ra, K. (2022). Seagrass and green macroalgae *Halimeda* as biomonitoring tools for metal contamination in Chuuk, Micronesia: Pollution assessment and bioaccumulation. *Marine Pollution Bulletin*, *178*, 113625. https://doi.org/10.1016/j.marpolbul.2022.113625

Magni, L. F., Castro, L. N., & Rendina, A. E. (2021). Evaluation of heavy metal contamination levels in river sediments and their risk to human health in urban areas: A case study in the Matanza-Riachuelo Basin, Argentina. *Environmental Research*, *197*, 110979. https://doi.org/10.1016/j.envres.2021.110979

Mohamed, W. F., & Hasan, H. M. A. (2023). Study the accumulation of minerals and heavy metals in Ulva algae, Cladophora, *Polysiphonia* and *Laurencia* algae samples at eastern north region of Libya coast. *GSC Biological and Pharmaceutical Sciences*, *23*(3), 147-152. https://doi.org/10.30574/gscbps.2023.23.3.0202

Özbay, Ö. (2024). Assessment of heavy metal pollution in coastal surface sediments of the Mersin Bay, Northeastern Mediterranean Sea. *International Journal of Environmental Science and Technology*, *21*(1), 875-884. https://doi.org/10.1007/s13762-023-05196-x

Özbay, Ö., & Akçay, İ. (2023). Metal pollution status and health risk assessment of beach sediments along the Mersin coast, Turkey. *Oceanological and Hydrobiological Studies*, *52*(4), 461-470. https://doi.org/10.26881/oahs-2023.4.07

Ozgun, S., & Turan, F. (2015). Biochemical composition of some brown algae from Iskenderun Bay, the northeastern Mediterranean coast of Turkey. *Journal of Black Sea/Mediterranean Environment*, *21*(2), 125-134.

Polat, S., & Ozogul, Y. (2013). Seasonal proximate and fatty acid variations of some seaweeds from the northeastern Mediterranean coast. *Oceanologia*, *55*(2), 375-391. https://doi.org/10.5697/oc.55-2.375

Rahhou, A., Layachi, M., Akodad, M., El Ouamari, N., Rezzoum, N. E., Skalli, A., Oudra, B., El Bakali, M., Kolar, M., Imperl, J., Petrova, P., Moumen, A., & Baghour, M. (2023). The bioremediation potential of *Ulva lactuca* (chlorophyta) causing green tide in Marchica Lagoon (NE Morocco, Mediterranean Sea): Biomass, heavy metals, and health risk assessment. *Water*, *15*(7), 1310. https://doi.org/10.3390/w15071310

Rakib, M. R. J., Jolly, Y. N., Dioses-Salinas, D. C., Pizarro-Ortega, C. I., De-la-Torre, G. E., Khandaker, M. U., Alsubaie, A., Almalki, A. S., & Bradley, D. A. (2021). Macroalgae in biomonitoring of metal pollution in the Bay of Bengal coastal waters of Cox's Bazar and surrounding areas. *Scientific Reports*, *11*(1), 20999. https://doi.org/10.1038/s41598-021-99750-7

Storelli, M. M., Storelli, A., & Marcotrigiano, G. O. (2001). Heavy metals in the aquatic environment of the Southern Adriatic Sea, Italy: macroalgae, sediments and benthic species. *Environment International*, *26*(7-8), 505-509. https://doi.org/10.1016/s0160-4120(01)00034-4

Tuncel, S. G., Tugrul, S., & Topal, T. (2007). A case study on trace metals in surface sediments and dissolved inorganic nutrients in surface water of Ölüdeniz Lagoon-Mediterranean, Turkey. *Water Research*, *41*(2), 365-372. https://doi.org/10.1016/j.watres.2006.10.001

Tuzen, M., Verep, B., Ogretmen, A. O., & Soylak, M. (2009). Trace element content in marine algae species from the Black Sea, Turkey. *Environmental Monitoring and Assessment*, *151*, 363-368. https://doi.org/10.1007/s10661-008-0277-7

USEPA. (2002). *Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites*. U.S. Environmental Protection Agency, Office of Emergency and Remedial Response, Washington DC.

USEPA. (2014). *Human Health Evaluation Manual, Supplemental Guidance: Update of Standard Default Exposure Factors–OSWER Directive 9200.1-120*. US Environmental Protection Agency, Washington, D.C.

Yalçın, M., Cevik, O., & Karaman, M. (2013). Use of multivariate statistics methods to determine grain size, heavy metal distribution and origins of heavy metals in Mersin Bay (Eastern Mediterranean) coastal sediments. *Asian Journal of Chemistry*, *25*(5), 2696-2702. https://doi.org/10.14233/ajchem.2013.13683