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Metal pollution status and health risk assessment of beach sediments along the Mersin coast, Turkey

by

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Abstract

In the present study, the ecological risk assessment of metal contamination in beach sediments along the Mersin coast was determined using the metal contents of beach sediments in Mersin, Kızkalesi, Susanoğlu and Taşucu region obtained between 2006 and 2009. Furthermore, the potential health risk assessment for ingestion and dermal contact pathways of adults and children was determined. Ecological risk assessment of heavy metals showed that there is no pollution in the beach sediments for the metals Cu, Pb and Zn for the all studied coasts. However, the high ecological risk indices calculated in this study strongly suggested an apparent Cd, Cr and Ni pollution in the studied beach sediments due to natural and anthropogenic contamination. Study findings indicated the HI values were greater than 1 for the metal Cr. The TCR values were higher than 1.00E-04 for the metals Cr and Ni calculated for adults, and for the metal Cu, Cr and Ni calculated for children, respectively. All these findings showed that there is a high carcinogenic risk for adults and children resident in the Mersin province from carcinogenic Cr and Ni whilst the studied coasts have additional health risks to children from carcinogenic Cu.

Key words: Sediment, metal pollution assessment, health risk assessment, Mersin Bay, Mediterranean Sea

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1. Introduction

Heavy metal contamination in the soils and sediments is a worldwide problem due to its ubiquity, trace-level toxicity, bioaccumulation and persistence (Buccolieri et al. 2004; Buccolieri et al. 2006; El-Sorogy et al. 2016; Jia et al. 2018). Heavy metals enter the human body through the gastrointestinal tract, skin and via the air (Pan et al. 2019; Witkowska et al. 2021). Excessive intake of heavy metals in the human body can cause many health problems such as neurological, cardiovascular, and chronic kidney diseases, tumours, and even cancers (Pan et al. 2019; Al-Kahtany & El-Sorogy 2023 and references therein).

Beaches are one of the most important assets for coastal tourism in Turkey (Birdir et al. 2013). The Mersin province is located on the eastern Mediterranean coast of Turkey (latitude 36°48′0″N, longitude 34°38′0″E) with a surface area of 15,853 km^2 and it has 321 km coastline and flatland along the coast (Figure 1) (Birdir et al. 2013; Limoncu et al. 2020). According to census data, Mersin's population was 1,891,145 in 2021. The Mersin coastline has experienced rapid development and one of the most distinctive features of the Mersin city is its bathing facilities and beaches (Ünal & Birdir 2007; Birdir et al. 2013). Many studies have been carried out to determine heavy metal contamination in beach sediments along the northeastern Mediterranean coast using multiple indices such as enrichment factor (Çevik 2009; Yalcın & İlhan 2008; Yalcın 2009; Yalcın et al. 2013; Yalcın et al. 2020). However, no study has been performed to determine the potential health risk assessment of beach sediments along the Mersin coast located on the northeastern Mediterranean Sea that has assets for coastal tourism in Turkey.

The main objective of this study is, therefore, to determine metal pollution status and health risk posed by beach sediments for adults and children along the Mersin Coast used by large numbers for coastal tourism.

2. Materials and methods

2.1. Study area and data collection

The mean metal concentrations and their spatial variations in beach sediments of the Mersin, Kızkalesi, Susanoğlu and Taşucu regions were reported in studies by Yalcın & İlhan (2008), Çevik (2009), Yalcın (2009), Yalcın et al. (2013), Yalcın et al. (2020) (Table 1). In this study, however, the ecological and health risk posed by beach sediments along the Mersin province were evaluated for the first time. The studied coasts are located in Mersin Bay, which is 43 km wide, east of the Seyhan River Delta, and narrows down to 8.4 km near the Göksu River Delta in the west (Okyar et al. 2013). Four regions were selected for this study – namely, Mersin, Kızkalesi, Susanoğlu and Taşucu (Figure 1).

2.2. Ecological and health risk assessment of beach sediments

In the present study, the ecological risk assessment of metal contamination in beach sediments along the Mersin coast was determined by Enrichment Factor (EF) (Sakan et al. 2009), Geoaccumulation index (Igeo) (Müller 1981) and contamination factor (CF) (Hakanson 1980), from data previously reported in studies by Yalcın & İlhan (2008), Çevik (2009), Yalcın (2009), Yalcın et al. (2013), Yalcın et al. (2020). The calculations and the formulas are presented in Table 2.

The potential health risk assessment for ingestion and dermal contact pathways of the adults and children was determined based on chronic daily intake (CDI), hazard quotients (HQ), hazard index (HI), cancer risk (CR), and total cancer risk (TCR) (USEPA 2002; Pavilonis et al. 2017; Magni et al. 2021; Abbasi et al. 2022; Al-Kahtany & El-Sorogy 2023) (Table 3-4). Moreover, statistical analyses of the calculated ecological and health risk indices from the obtained data sets were performed via Microsoft Excel 2016 and IBM SPSS Statistics 26 software.

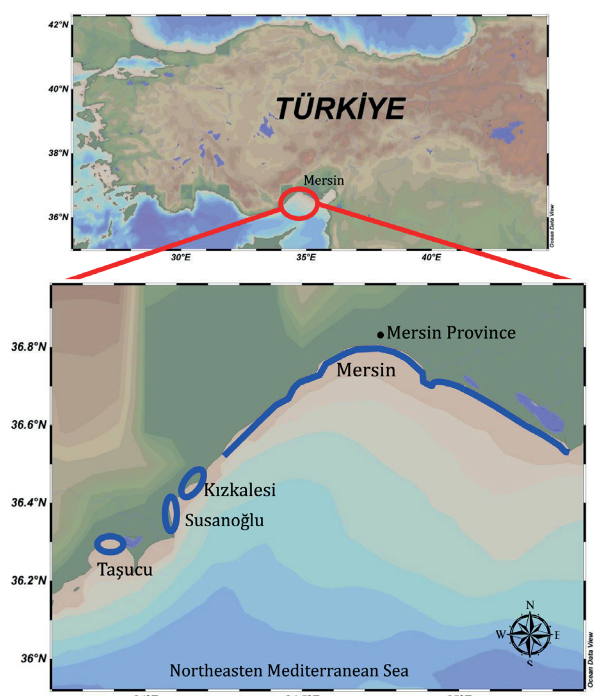

Figure 1

The location of Mersin province and the study area

Table 1

Mean metal concentrations of beach sediments obtained in the 2006–2009 period, sampling sites and references (sampling sites were shown on Figure 1)

Region/Location	# of stations visited	Heavy Metals (HM) (Mean)(mg kg^{-1})								Reference
		Cd	Cu	Pb	Zn	Cr	Ni	Mn	Fe	
Mersin (Karataş-Kızkalesi)	60	0.21	15.85	10.23	52.55	1512.41	279.09	766.60	34078.00	Yalcın et al. (2013) Çevik (2009)
Kızkalesi	20	4.21	10.13	4.55	19.75	554.00	186.80	586.00	18803.00	Yalcın & İlhan (2008)
Susanoğlu	33	4.32	12.81	5.51	17.80	428.06	145.52	333.85	13909.09	Yalcın (2009)
Taşucu	33	4.45	7.50	3.39	13.52	349.61	99.09	230.42	5900.00	Yalcın et al. (2020)

Table 2

Ecological assessment of metal pollution in sediments

Enrichment factor (EF)[a]	Geoaccumulation index (Igeo)[b]
$EF = \dfrac{\left(\dfrac{HM_x}{HM_{Fe}}\right)_{Sample}}{\left(\dfrac{HM_{xs}}{HM_{Fe}}\right)_{shale}}$	$I_{geo} = log_2\left(\dfrac{HM_x}{1.5 \times HM_{xs}}\right)$
EF classification Degree of enrichment	**Igeo value Class Designation of sediment quality**
< 2 Depletion to mineral enrichment	Igeo ≤ 0 Unpolluted
2 ≤ EF < 5 Moderate	0 < Igeo ≤ 1 Unpolluted - moderately polluted
5 ≤ EF < 20 Significant	1 < Igeo ≤ 2 Moderately polluted
20 ≤ EF < 40 Very high	2 < Igeo ≤ 3 Moderately - strongly polluted
EF > 40 Extremely high	3 < Igeo ≤ 4 Strongly polluted
	4 <Igeo ≤ 5 Strongly - extremely polluted
	Igeo > 5 Extremely polluted
Contamination factor (CF)[c]	**CF classification**
$CF = \dfrac{HM_x}{HM_{xs}}$	CF < 1 Low
	1 ≤ CF < 3 Moderately
	3≤ CF <6 Considerable
	CF ≥ 6 Very high

HM_x – the measured metal concentration, HM_{Fe} – the iron concentrations, HM_{xs} – the metal concentrations in the shale; Shale values were taken from Krauskopf (1979).

[a]Sakan et al. (2009)

[b]Müller (1981)

[c]Hakanson (1980)

Table 3

Calculation of chronic daily intake (CDI), hazard quotients (HQ), hazard index (HI), cancer risk (CR), and total lifetime cancer risk (TCR) (USEPA 2002; Pavilonis et al. 2017; Magni et al. 2021; Abbasi et al. 2022; Al-Kahtany & El-Sorogy 2023)

Non-Carcinogenic	Carcinogenic	Parameter*	Unit	Adult	Child
		ED (Exposure Duration)	years	24	6
		EF (Exposure Frequency)	days years^{-1}	350	
	TCR < 1.00E-06 No significant health hazards	BW (Body Weight)	kg	70	15
HI < 1 non-carcinogenic risk		AT (Average Time)	years (365 x ED)	8760	2190
	TCR < 1.00E-06 No significant health hazards	IngR (Ingestion Rate)	mg day^{-1}	100	200
HI < 1 non-carcinogenic risk		SA (Skin Surface Area Exposed)	cm^2	5700	2800
	TCR < 1.00E-04 High risk of carcinogenesis	AFs (Skin-soil adherence factor)	mg cm^{-2}	0.07	0.2
		CF (Conversion Factor)	kg mg^{-1}	1.00E-06	
		ABS (Absorption Factor Dermal)	-	0.001	
		HM (Heavy Metals Sediment)	mg kg^{-1}	Table 1	

* USEPA (2002)

Table 4

Reference dose (RfD) and cancer slope factor (CSF) values of heavy metals

HM	Non-Carcinogenic		Carcinogenic	
	$RfD_{ing.}$ (Reference Dose Ingestion)	$RfD_{der.}$ (Reference Dose Dermal)	$CSF_{ing.}$ (Cancer Slope Factor Ingestion)	$CSF_{der.}$ (Cancer Slope Factor Dermal)
	mg kg^{-1} day^{-1}			
Cd[a]	1.00E-03	2.50E-05	5.01E-01	2.00E+01
Cu[b]	2.00E-02	5.40E-03	1.70E+00	4.25E+01
Pb[a]	1.40E-04	5.24E-04	8.50E-03	8.50E-03
Zn[a]	3.00E-01	6.00E-02	-	-
Cr[a]	3.00E-03	3.00E-03	5.01E-01	2.00E+01
Ni[a]	2.00E-02	5.40E-03	1.70E+00	4.25E+01
Mn[c]	1.40E-01	5.60E-03	-	-
Fe[d]	7.00E-01	7.00E-01	-	-

[a]Magni et al. (2021), [b]Pan et al. (2019), [c]Pavilonis et al. (2017), [d]Al-Kahtany & El-Sorogy (2023)

3. Results

3.1. Ecological Risk Assessment

Heavy metal concentrations, along with their spatial variations, have been extensively reported in previous studies along the Mersin coast (Çevik 2009; Yalcın & İlhan 2008; Yalcın 2009; Yalcın et al. 2013, Yalcın et al. 2020). This study, however, marks the first attempt to assess both the ecological and health risk of beach sediments along the Mersin coast, a major asset for coastal tourism in Turkey (Table 5 and Table 6). The study findings indicated that the calculated EF values ranged from 0.44 for the metal Cu in Mersin to 118.2 for the metal Cd in Taşucu. According to metal pollution assessment based on EF, the Taşucu and Susanoğlu coasts are classified as "extremely high enrichment" whilst Kızkalesi coast is classified as "very high enrichment" for the metal Cd. Susanoğlu and Kızkalesi beach sediments are significantly enriched by the metal Cr whilst Taşucu and Mersin coast are classified as "very high enrichment". For the metal Ni, Taşucu, Susanoğlu and Kızkalesi beach sediments are classified as "significant enrichment". Mersin and Taşucu beach sediments are moderately enriched by the metal Ni and Mn, respectively (Table 5).

The Igeo values varied between -8.46 and 3.33 whilst the CF values ranged between 0.004 and 15.12 with the maximum values calculated for the metal Cr in Mersin beach sediment and for the metal Cd in the beach sediments of Kızkalesi, Susanoğlu and Taşucu region (Table 5). According to metal pollution assessment based on Igeo, Kızkalesi, Susanoğlu and Taşucu, the beach sediments were classified as "strongly polluted" by the metal Cd. For the metal Cr, Kızkalesi, Susanoğlu and Taşucu beach sediments are "moderately polluted" whilst Mersin beach sediments were classified as "strongly polluted". Mersin beach sediments are also "moderately polluted" by the metal Ni. Similar classification results were also obtained by a metal pollution assessment based on CF. Kızkalesi, Susanoğlu and Taşucu beach sediments and were classified as "very high contamination", "considerable contamination" and "moderate contamination" for the metals Cd, Cr and Ni, respectively. Furthermore, Mersin beach sediments are classified as "very high contamination" by the metal Cr and "considerable contamination" by the metal Ni (Table 5).

Table 5

Assessment of metal pollution in beach sediments along the Mersin coast based on EF, Igeo and CF

HM	Enrichment factor (EF)				Geoaccumulation index (Igeo)				Contamination factor (CF)			
	Mersin	Kızkalesi	Susanoğlu	Taşucu	Mersin	Kızkalesi	Susanoğlu	Taşucu	Mersin	Kızkalesi	Susanoğlu	Taşucu
Cd	0.98	35.08	48.66	118.16	-1.08	3.23	3.26	3.31	0.71	14.03	14.40	14.83
Cu	0.44	0.51	0.87	1.19	-8.46	-2.89	-2.55	-3.32	0.004	0.20	0.26	0.15
Pb	0.71	0.57	0.93	1.35	-1.55	-2.72	-2.45	-3.15	0.51	0.23	0.28	0.17
Zn	0.81	0.55	0.67	1.20	-1.36	-2.77	-2.92	-3.32	0.58	0.22	0.20	0.15
Cr	20.86	13.85	14.46	27.85	3.33	1.89	1.51	1.22	15.12	5.54	4.28	3.50
Ni	4.81	5.84	6.15	9.87	1.22	0.64	0.28	-0.28	3.49	2.34	1.82	1.24
Mn	1.24	1.72	1.33	2.16	-0.73	-1.12	-1.93	-2.47	0.90	0.69	0.40	0.27

3.2. Health Risk Assessment

In this study, health risk assessment of beach sediments was determined along the Mersin coast by using CDI, HQ, HI, CR and TCR from ingestion and dermal contact pathways in children and adults (Table 6). The HI values determined whether adults and children are exposed to carcinogenic or non-carcinogenic risks. A HI value less than 1 indicates non-carcinogenic risk while a HI value greater than 1 indicates a potential carcinogenic effect in humans (USEPA 2002; Magni, et al. 2021; Abbasi et al. 2022). Study findings indicated that HI values ranged from 6.30E-05 for adults to 6.46E+00 for children (Table

Table 6

Health risk assessment of beach sediment along the Mersin coast based on CDI, HQ, HI, CR and TCR from ingestion and dermal contact pathways in children and adults

		HM	Adult				Child			
			Mersin	Kızkalesi	Susanoğlu	Taşucu	Mersin	Kızkalesi	Susanoğlu	Taşucu
$CDI_{ing.}$		Cd	2.91E-07	5.77E-06	5.92E-06	6.10E-06	2.72E-06	5.38E-05	5.52E-05	5.69E-05
		Cu	2.17E-05	1.39E-05	1.75E-05	1.03E-05	2.03E-04	1.30E-04	1.64E-04	9.59E-05
		Pb	1.40E-05	6.23E-06	7.55E-06	4.64E-06	1.31E-04	5.82E-05	7.04E-05	4.33E-05
		Zn	7.20E-05	2.71E-05	2.44E-05	1.85E-05	6.72E-04	2.53E-04	2.28E-04	1.73E-04
		Cr	2.07E-03	7.59E-04	5.86E-04	4.79E-04	1.93E-02	7.08E-03	5.47E-03	4.47E-03
		Ni	3.82E-04	2.56E-04	1.99E-04	1.36E-04	3.57E-03	2.39E-03	1.86E-03	1.27E-03
		Mn	1.05E-03	8.03E-04	4.57E-04	3.16E-04	9.80E-03	7.49E-03	4.27E-03	2.95E-03
		Fe	4.67E-02	2.58E-02	1.91E-02	8.08E-03	4.36E-01	2.40E-01	1.78E-01	7.54E-02
$CDI_{der.}$		Cd	1.16E-09	2.30E-08	2.36E-08	2.43E-08	7.61E-09	1.51E-07	1.55E-07	1.59E-07
		Cu	8.66E-08	5.54E-08	7.00E-08	4.10E-08	5.67E-07	3.63E-07	4.59E-07	2.68E-07
		Pb	5.59E-08	2.49E-08	3.01E-08	1.85E-08	3.66E-07	1.63E-07	1.97E-07	1.21E-07
		Zn	2.87E-07	1.08E-07	9.73E-08	7.39E-08	1.88E-06	7.07E-07	6.37E-07	4.84E-07
		Cr	8.27E-06	3.03E-06	2.34E-06	1.91E-06	5.41E-05	1.98E-05	1.53E-05	1.25E-05
		Ni	1.53E-06	1.02E-06	7.95E-07	5.42E-07	9.99E-06	6.69E-06	5.21E-06	3.55E-06
		Mn	4.19E-06	3.20E-06	1.82E-06	1.26E-06	2.74E-05	2.10E-05	1.20E-05	8.25E-06
		Fe	1.86E-04	1.03E-04	7.60E-05	3.22E-05	1.22E-03	6.73E-04	4.98E-04	2.11E-04
Non-carcinogenic	$HQ_{ing.}$	Cd	2.91E-04	5.77E-03	5.92E-03	6.10E-03	2.72E-03	5.38E-02	5.52E-02	5.69E-02
		Cu	1.09E-03	6.94E-04	8.77E-04	5.14E-04	1.01E-02	6.48E-03	8.19E-03	4.79E-03
		Pb	1.00E-01	4.45E-02	5.39E-02	3.32E-02	9.34E-01	4.16E-01	5.03E-01	3.10E-01
		Zn	2.40E-04	9.02E-05	8.13E-05	6.17E-05	2.24E-03	8.42E-04	7.59E-04	5.76E-04
		Cr	6.91E-01	2.53E-01	1.95E-01	1.60E-01	**6.45E+00**	**2.36E+00**	**1.82E+00**	**1.49E+00**
		Ni	1.91E-02	1.28E-02	9.97E-03	6.79E-03	1.78E-01	1.19E-01	9.30E-02	6.33E-02
		Mn	7.50E-03	5.73E-03	3.27E-03	2.25E-03	7.00E-02	5.35E-02	3.05E-02	2.10E-02
		Cd	6.67E-02	3.68E-02	2.72E-02	1.15E-02	6.22E-01	3.43E-01	2.54E-01	1.08E-01
	$HQ_{der.}$	Cd	4.65E-05	9.20E-04	9.44E-04	9.73E-04	3.05E-04	6.03E-03	6.19E-03	6.37E-03
		Cu	1.60E-05	1.03E-05	1.30E-05	7.59E-06	1.05E-04	6.72E-05	8.49E-05	4.97E-05
		Pb	1.07E-04	4.75E-05	5.75E-05	3.54E-05	6.99E-04	3.11E-04	3.76E-04	2.32E-04
		Zn	4.79E-06	1.80E-06	1.62E-06	1.23E-06	3.14E-05	1.18E-05	1.06E-05	8.07E-06
		Cr	2.76E-03	1.01E-03	7.80E-04	6.37E-04	1.80E-02	6.61E-03	5.11E-03	4.17E-03
		Ni	2.82E-04	1.89E-04	1.47E-04	1.00E-04	1.85E-04	1.24E-04	9.65E-05	6.57E-05
		Mn	7.48E-04	5.72E-04	3.26E-04	2.25E-04	4.90E-03	3.75E-03	2.13E-03	1.47E-03
		Fe	2.66E-04	1.47E-04	1.09E-04	4.61E-05	1.74E-03	9.62E-04	7.11E-04	3.02E-04
	HI	Cd	3.38E-04	6.69E-03	6.86E-03	7.07E-03	3.02E-03	5.99E-02	6.14E-02	6.33E-02
		Cu	1.10E-03	7.04E-04	8.90E-04	5.21E-04	1.02E-02	6.54E-03	8.27E-03	4.84E-03
		Pb	1.00E-01	4.46E-02	5.40E-02	3.32E-02	9.35E-01	4.16E-01	5.04E-01	3.10E-01
		Zn	2.45E-04	9.20E-05	8.29E-05	6.30E-05	2.27E-03	8.53E-04	7.69E-04	5.84E-04
		Cr	6.93E-01	2.54E-01	1.96E-01	1.60E-01	6.46E+00	2.37E+00	1.83E+00	1.49E+00
		Ni	1.94E-02	1.30E-02	1.01E-02	6.89E-03	1.79E-01	1.20E-01	9.31E-02	6.34E-02
		Mn	8.25E-03	6.31E-03	3.59E-03	2.48E-03	7.49E-02	5.73E-02	3.26E-02	2.25E-02
		Fe	6.70E-02	3.69E-02	2.73E-02	1.16E-02	6.24E-01	3.44E-01	2.55E-01	1.08E-01
Carcinogenic	$CR_{ing.}$	Cd	1.46E-07	2.89E-06	2.96E-06	3.05E-06	1.36E-06	2.70E-05	2.77E-05	2.85E-05
		Cu	3.69E-05	2.36E-05	2.98E-05	1.75E-05	3.45E-04	2.20E-04	2.78E-04	1.63E-04
		Pb	1.19E-07	5.30E-08	6.42E-08	3.95E-08	1.11E-06	4.94E-07	5.99E-07	3.68E-07
		Cr	1.04E-03	3.80E-04	2.94E-04	2.40E-04	9.69E-03	3.55E-03	2.74E-03	2.24E-03
		Ni	6.50E-04	4.35E-04	3.39E-04	2.31E-04	6.07E-03	4.06E-03	3.16E-03	2.15E-03
	$CR_{der.}$	Cd	2.33E-08	4.60E-07	4.72E-07	4.86E-07	1.52E-07	3.01E-06	3.09E-06	3.19E-06
		Cu	3.68E-06	2.35E-06	2.98E-06	1.74E-06	2.41E-05	1.54E-05	1.95E-05	1.14E-05
		Pb	4.75E-10	2.11E-10	2.56E-10	1.57E-10	3.11E-09	1.38E-09	1.68E-09	1.03E-09
		Cr	1.65E-04	6.06E-05	4.68E-05	3.82E-05	1.08E-03	3.97E-04	3.06E-04	2.50E-04
		Ni	6.48E-05	4.34E-05	3.38E-05	2.30E-05	4.25E-04	2.84E-04	2.21E-04	1.51E-04
	TCR	c	1.69E-07	3.35E-06	3.44E-06	3.54E-06	1.51E-06	3.00E-05	3.08E-05	3.17E-05
		Cu	4.06E-05	2.59E-05	3.28E-05	1.92E-05	3.69E-04	2.36E-04	2.98E-04	1.74E-04
		Pb	1.20E-07	5.32E-08	6.44E-08	3.96E-08	1.11E-06	4.96E-07	6.00E-07	3.69E-07
		Cr	1.20E-03	4.41E-04	3.41E-04	2.78E-04	1.08E-02	3.95E-03	3.05E-03	2.49E-03
		Ni	7.15E-04	4.78E-04	3.73E-04	2.54E-04	6.49E-03	4.34E-03	3.38E-03	2.30E-03

6). The calculated HI values were consistently higher for the children (range: 5.84E-04-6.46E+00) along the studied coasts compared to the values calculated for the adults (range: 6.30E-05-6.93E-01) suggesting that children were at higher risk. The HI values for the metal Cr were greater than 1 among children along the whole Mersin coast indicating a potential carcinogenic effect in children (Table 6). In this study, TCR values from the beach sediments along the Mersin coast were also calculated and presented (Table 6). A TCR value less than 1.00E-06 indicates no significant health hazards. A TCR value between 1.00E-06 and 1.00E-04 indicates acceptable or tolerable carcinogenic risk, while a TCR value higher 1.00E-04 indicates high carcinogenic risk (USEPA 2002; Magni et al. 2021). The calculated TCR values indicated a high carcinogenic risk for adults and children inhabiting the Mersin province from carcinogenic Cr and Ni. Moreover, the studied coasts have additional health risks to children from carcinogenic Cu (Table 6).

4. Discussion

In this study, ecological and health risk assessments of beach sediments along the economically important Mersin coast were determined and presented in Figure 2. Previous studies showed that heavy metal concentrations in beach sediments along the Mersin coast displayed pronounced spatial variability (Table 1). It is well known that natural contamination and anthropogenic impacts affected the distributions of metals in the beach sediments along the Mersin coast. The peak values were consistently recorded in the beach sediments of the Mersin coast due to natural contamination as basic/ultrabasic rocks outcropped in the region (Yalcın et al. 2013) and weathering/erosion of these rocks (Tuncel et al. 2007). Anthropogenic disturbances also increased the metal levels in beach sediments along the Mersin coast (Alp et al. 2012).

Ecological risk assessment of heavy metals showed that the beach sediments are not polluted by the metals Cu, Pb and Zn for the all studied coasts (Figure 2). However, Cd, Cr and Ni pollution is pronounced in the Kızkalesi, Susanoğlu and Taşucu beach sediment (Table 5). The sources of anthropogenic metal pollution in the coastal regions are generally contaminated rivers, estuaries, domestic and industrial wastewater inputs, vehicle emissions, and agricultural runoff (Ip et al. 2007; Yalcın & İlhan 2008; Saher & Siddiqui 2016; Nour & El-Sorogy 2020; Akçay & Özbay 2022). Study findings indicated that the beach sediments were polluted by the metals Cr and Ni in the Mersin province due probably to contaminated rivers

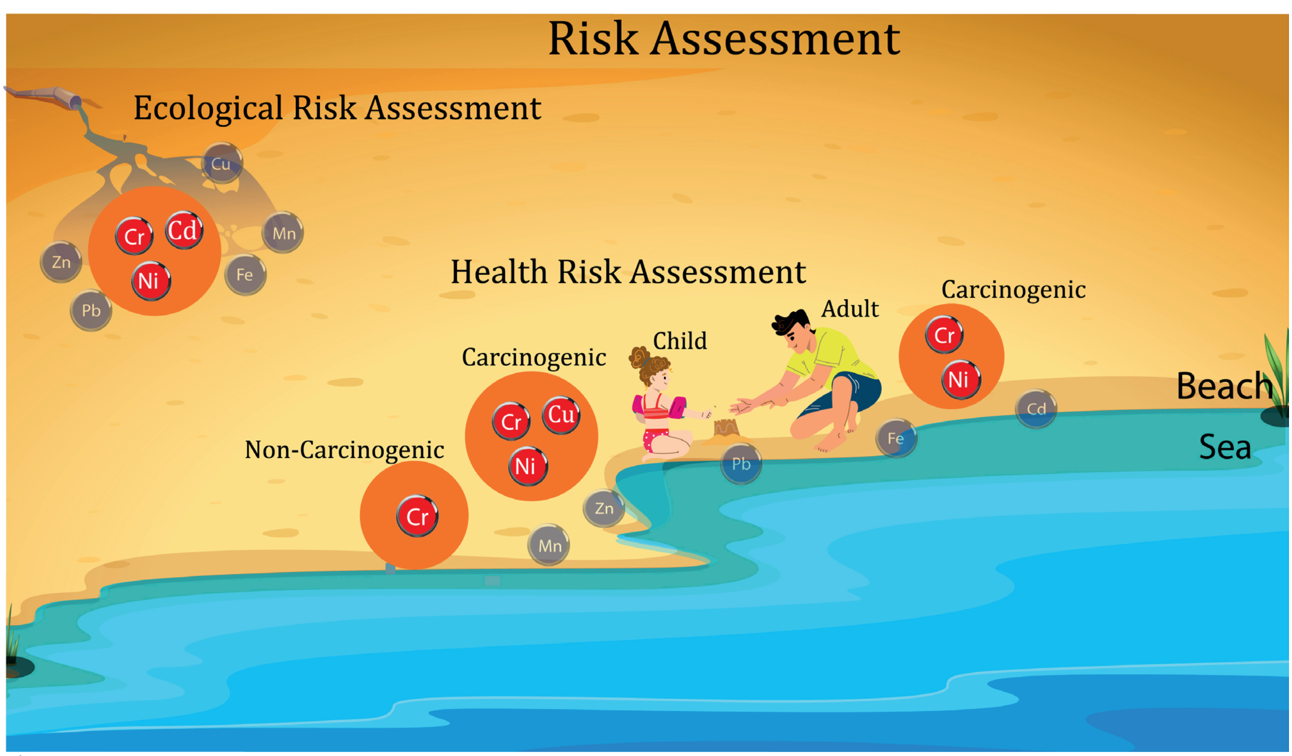

Figure 2

Ecological and health risk assessments of beach sediments along the Mersin coast and wastewater inputs originated from agricultural activities and discharge from mines, also reported by the studies by Çevik et al. (2009) and Özbay et al. (2013). Coastal surface sediments in the Mersin inner Bay were also affected by Cr pollution (Akçay & Özbay 2022). Pearson's correlation indicated strong and positive correlations among both ecological and health risk indices. Furthermore, the correlations between ecological and health risk indices showed that there are strong and positive correlations between Igeo and values of HI and TCR, and between CF and HI values (Figure 3). These correlations strongly suggest that the metal pollution in the coastal beach sediments caused both ecological and health risk in the Mersin Province.

One of the most distinctive features of Mersin city is its bathing facilities and beaches, which are an asset for coastal tourism in Turkey (Ünal & Birdir 2007; Birdir et al. 2013). Mersin province is, therefore, famous for the presence of tourist resorts, marine sports and marine recreational activities. It is critical to assess the health risk posed by beach sediments along the Mersin coast. Some heavy metals can cause health problems such as Cd, Zn, Pb and Hg (Sarkar et al. 2016; Nour et al. 2022). Health risk assessment of beach sediments suggested carcinogenic risk for the adults and children inhabiting the Mersin province from carcinogenic Cr, Ni and Cu (Figure 2). Health risk assessment of beach sediments from different coastal areas reported higher HI values

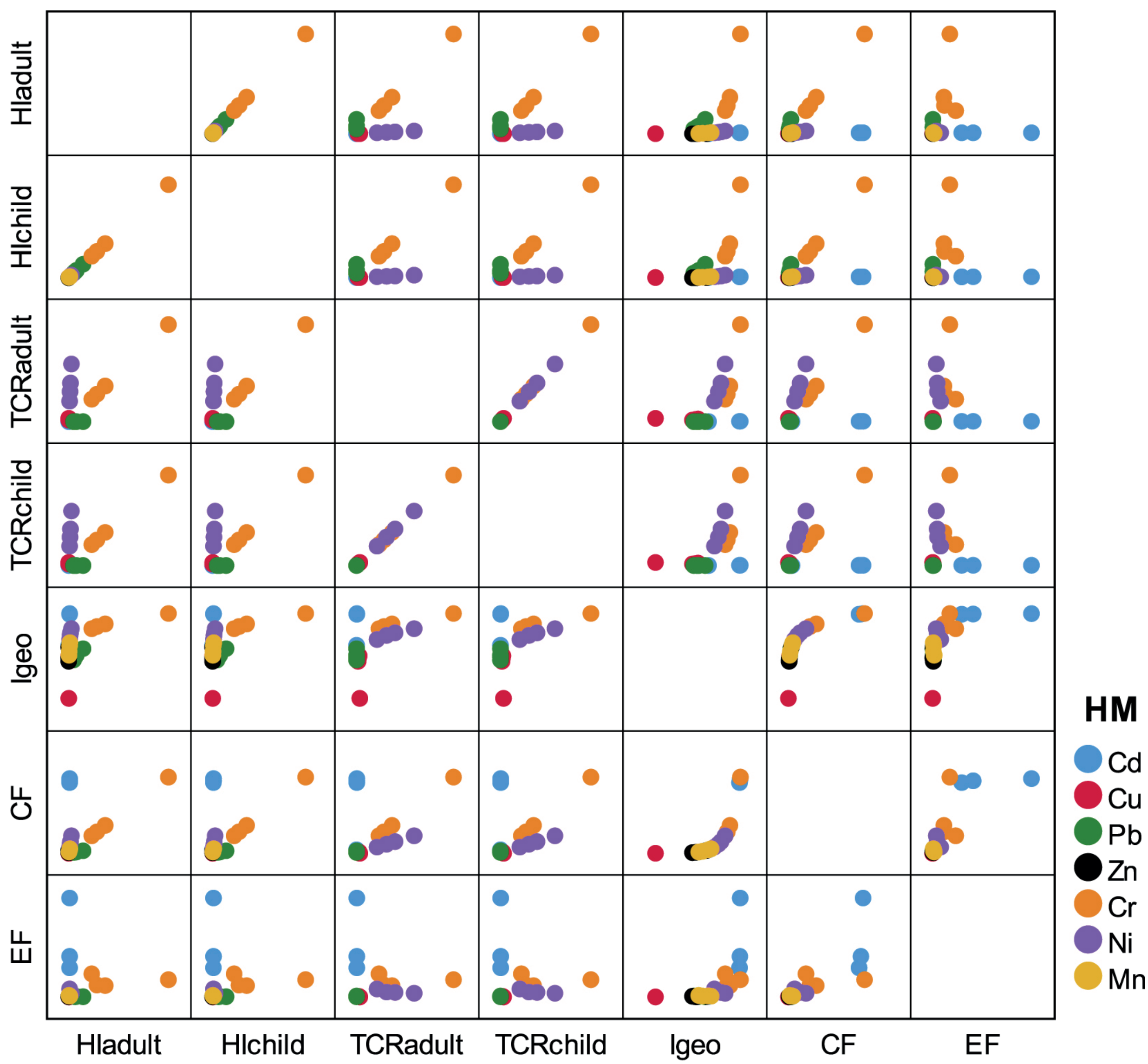

Figure 3

Correlations between the values of indices calculated to evaluate ecological and health risk for children than for adults (Alharbi et al. 2022; Abbasi et al. 2022; Nour et al. 2022; Al-Kahtany & El-Sorogy 2023; Al-Kahtany et al. 2023). However, the potential health risk assessment of these regions differs in terms of the heavy metals and the contamination levels. Low TCR values in beach sediments from the Red Sea and Gulf of Aqaba (Nour et al. 2022), along Ras Abu Ali Island, Saudi Arabia (Al-Kahtany & El-Sorogy 2023) and along the southern Al-Khobar coast, Saudi Arabia (Al-Kahtany et al. 2023) indicated no significant health hazards for adults and children. On the other hand, high TCR values calculated in the urban surface soils of Mediterranean Sea region, on Cyprus, showed a high risk for the adults and children from carcinogenic Cr and Ni (Abbasi et al. 2022). The results of this study were in agreement with the study by Abbasi et al. (2022) also conducted in the eastern Mediterranean suggesting an apparent potential health hazard from carcinogenic Cr and Ni.

5. Conclusions

In this study, the ecological and health risk posed by beach sediments along the Mersin coast was determined. The study findings indicated apparent Cd, Cr and Ni pollution in the Kızkalesi, Susanoğlu and Taşucu beach sediments due to natural and anthropogenic disturbances. In the studied sites, the calculated HI values were consistently higher for children compared to those for adults, suggesting that children were at higher risk. The high TCR values indicated a high carcinogenic risk for adults and children inhabiting Mersin province from carcinogenic Cr and Ni. Moreover, the studied coasts pose additional health risks for children from carcinogenic Cu. Our initial health risk assessment of beach sediments along the Mersin coast will provide critical information for decision-makers to reduce metal contamination of the ecosystem and public health in the Mersin province, an important asset for coastal tourism in Turkey. In order to manage and assess the potential risk of polluted beach sediments, monitoring studies should be carried out.

Conflict of interest

The authors declare that they have no known conflicting financial interests or personal relationships that could have influenced the work reported in this paper.

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