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ARAŞTIRMA MAKALESİ RESEARCH PAPER

Ecological and Health Risk Assessment in Surface Sediments of the Berdan River Basin (Mersin-Türkiye)

İsmail AKÇAY* **Özgür ÖZBAY**
Mersin University, Faculty of Fisheries, Yenişehir-Mersin, Türkiye

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*: https://orcid.org/0000-0001-8738-8359
: https://orcid.org/0000-0001-7837-350X

***Corresponding author:**
İsmail AKÇAY
Mersin University, Faculty of Fisheries, Yenişehir-Mersin, Türkiye
: iakcay@mersin.edu.tr

Abstract: Berdan River (Tarsus-Mersin) is one of the major rivers flowing into the coastal region of Northeastern (NE) Mediterranean Sea. Determination of water and sediment quality is of great importance for the sustainable management of streams and rivers. In this study, it was aimed to determine metal ((Fe), Manganese (Mn), Chromium (Cr), Nickel (Ni) Zinc (Zn), Cadmium (Cd) and Lead (Pb)) pollution status of sediments in Berdan River caused by human activities by using Enrichment Factor (EF), Geoaccumulation Index (Igeo), Contamination Factor (CF) and Pollution Load Index (PLI). Furthermore, the potential health risk assessment was determined as the non-carcinogenic and carcinogenic risk for children and adults by using chronic daily intake (CDI), hazard quotients (HQ), hazard index (HI), cancer risk (CR), and total lifetime cancer risk (LCR). High values of metal pollution indices showed that while Ni and Cd pollution were determined at all sampling points of the Berdan River Basin, there was a regional pollution of Pb and Zn caused by anthropogenic pressures due to industrial and agricultural activities as well as domestic wastewater and atmospheric inputs into the Berdan River. Health risk assessment showed that all the calculated HI values were greater than 1 for the metal Pb suggesting "potential carcinogenic risk" for children. For the adults, the calculated TLRC values indicated "high carcinogenic risk" from the carcinogenic Ni (TLCR: 3.45E-04 - 5.08E-04) whilst for the children, the calculated TLRC values indicated "high carcinogenic risk" from the carcinogenic Cr (TLCR: 2.56E-04 - 5.85E-04) and Ni (TLCR: 3.13E-03 - 4.61E-03). All these findings indicated significant health hazards for the children and adults living in the study area from the carcinogenic lead, chromium and nickel.

Keywords: Berdan river, health risk, potential ecological risk, sediments.

Berdan Nehri Yüzey Sedimanlarında Ekolojik ve Sağlık Riski Değerlendirmesi (Mersin-Türkiye)

***Sorumlu yazar:**
İsmail AKÇAY
Mersin Üniversitesi Su Ürünleri Fakültesi, Yenişehir-Mersin, Türkiye
: iakcay@mersin.edu.tr

Öz: Berdan Nehri (Tarsus-Mersin), Kuzeydoğu Akdeniz sığ kıyısal alanına dökülen başlıca nehirlerden biridir. Akarsu ve akarsuların sürdürülebilir yönetimi için su ve sediman kalitesinin belirlenmesi oldukça büyük bir öneme sahiptir. Bu çalışmada, Zenginleşme Faktörü (EF), Jeoakümülasyon İndeksi (Igeo), Kirlilik Faktörü (CF) ve Kirlilik Yük İndeksi (PLI) kullanılarak Berdan nehri sedimanlarının metal ((Fe), Manganez (Mn), Krom (Cr), Nikel (Ni) Çinko (Zn), Kadmiyum (Cd) ve Kurşun (Pb)) kirlilik durumunun belirlenmesi amaçlanmıştır. Ayrıca, Kronik Günlük Alım (CDI), Tehlike Katsayıları (HQ), Tehlike İndeksi (HI), Kanser Riski (CR) ve Yaşam Boyu Kanser Riski (TLCR) kullanılarak çocuklar ve yetişkinler için potansiyel sağlık risk değerlendirmesi yapılmıştır. Hesaplanan yüksek metal kirlilik indeks değerleri, Berdan Nehri Havzası'nın tüm örnekleme noktalarında Ni ve Cd kirliliğini gösterirken, evsel atık suların ve atmosferik girdilerin yanı sıra endüstriyel ve tarımsal faaliyetlerden kaynaklanan antropojenik baskılardan kaynaklanan bölgesel bir Pb ve Zn kirliliğinin de mevcut olduğunu göstermiştir. Sağlık riski değerlendirmesi, çocuklarda Pb için hesaplanan tüm HI değerlerinin 1'den büyük olduğunu göstermiştir. Bu da çocuklar için, potansiyel kanser riski olduğunu gösteriyor. Yetişkinler için hesaplanan TLRC değerleri, Ni için (TLCR: 3.45E-04 - 5.08E-04) yüksek kanser riskini belirtirken, çocuklar için hesaplanan TLRC değerleri, Cr (TLCR: 2.56E-04 - 5.85E-04) ve Ni (TLCR: 3.13E-03 - 4.61E-03) için yüksek kanser riskini göstermiştir. Tüm bu bulgular, kanserojen kurşun, krom ve nikelin çalışma alanında yaşayan çocuklar ve yetişkinler için önemli sağlık tehlikelerine işaret etmektedir.

Anahtar kelimeler: Berdan nehri, ekolojik risk; sağlık riski, sediman.

INTRODUCTION

Heavy metal pollution in sediments is a worldwide problem and many studies have been conducted on the heavy metal pollution in river and estuary sediments (Andem et al., 2015; Caridi et al., 2016; Copaja et al., 2016; Krika & Krika, 2017; Ma et al., 2015; Ogbeibu et al., 2014; Olivares-Rieumont et al., 2005; Rani et al., 2021; Sakan et al., 2009; Sutherland, 2000; Tomlinson et al., 1980; Ustaoğlu & Islam, 2020; Ustaoğlu & Tepe, 2019; Yabanlı et al., 2022). Heavy metals entered into the aquatic environments either naturally such as the erosion of rocks or as a result of anthropogenic activities that are accumulated in the sediment (Ma et al., 2015; Mandour et al., 2021; Ogbeibu et al., 2014). The characteristics of sediment, the amount of organic matter and clay, and the mineral content affect the burial and accumulation of heavy metals in sediments (Bagheri et al., 2011; Vertacnik et al., 1995). Therefore, heavy metal analysis in sediments provides information about the pollution status of the aquatic environments (Andem et al., 2015; Rauf et al., 2009).

Metal pollution has critical importance for aquatic biota. In the aquatic environments, it is critical to understand metal bioaccumulation or biomagnification within food webs (Karadede-Akin & Ünlü, 2007). Since heavy metals are toxic substances accumulating in the food chain with the increasing concentrations, non-biodegradable metals may pose a health risk to people by consuming aquatic organisms due to bioaccumulation in the food web (Akkan & Mutlu, 2022; Boran & Altınok, 2010). In a recent study, it was reported that heavy metal copper can be associated with the toxic effect on biota (Boran & Gedik, 2013). Pollution of rivers not only poses a risk to aquatic organisms, but also poses a risk to human health (Ustaoğlu & Tepe, 2019). Heavy metals accumulated in sediments can release into the overlying water over time and reach humans by benthic organisms via food chain (Ogbeibu et al., 2014). Heavy metals also enter the human body air, ingestion and skin contact. It is well known that heavy metals accumulated in the human body can cause many health problems such as chronic kidney diseases and cancers (Al-Kahtany & El-Sorogy, 2023).

Assessment of water and sediment quality is of great importance for the sustainable management of rivers (Ogbeibu et al., 2014). Furthermore, it is important to investigate sediment heavy metal pollution along the river basins for the determination of anthropogenic and natural impacts on the pollution of coastal surface sediments (Saddik et al., 2019). Ozbay et al., (2013) carried out one study in Berdan River sediments and determined concentrations of Iron (Fe), Manganese (Mn), Chromium (Cr), Nickel (Ni), Zinc (Zn), Cadmium (Cd) and Lead (Pb). In this study, the sediment heavy metal pollution status and potential health risk assessment of Berdan River Basin were determined.

MATERIAL AND METHOD

Sampling and analysis: The Berdan River, which passes through the Tarsus district of Mersin, is one of the important rivers of the region and is 124 km long and its waters are originated from precipitation (snow and rain) (Ozbay et al., 2013). The Berdan Dam waters are the main source of drinking water for the Mersin and Tarsus cities. The factories constructed along the Berdan River Basin are an oil factory, a dye plant, an industrial machine factory), a glass wool plant and a textile mill (Ergene et al., 2007). The study of Ozbay et al. (2013) was carried out seasonally at 6 stations in the area of approximately 40 km from the Berdan Dam exit to the sampling point where it flows into the coastal site of the NE Mediterranean Sea between December 2008 and November 2009. The sampling points are presented in Figure 1.

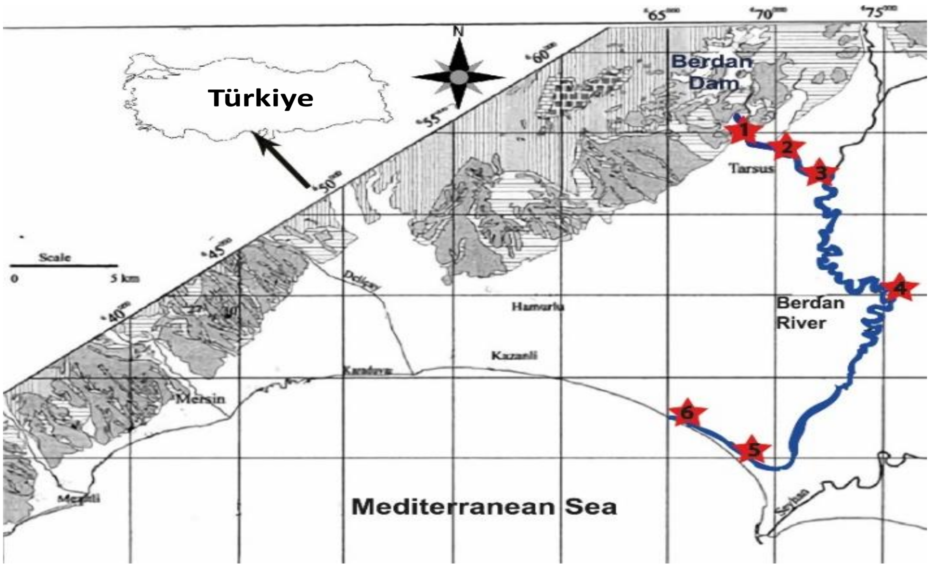

Figure 1. Study region and the sampling locations.

For metal (Iron (Fe), Manganese (Mn), Chromium (Cr), Nickel (Ni) Zinc (Zn), Cadmium (Cd) and Lead (Pb)) analysis, surface sediments were collected by using Ekman Grab from the selected stations where discharge rates were low. The samples were transported to the laboratory in polyethylene bags in an ice box and stored in the freezer (at -20˚C) till analysis. After the sediment samples were dried in an oven at 105 ˚C, they were sieved through a 2 mm sieve to homogenize the samples. The samples were analyzed according to the EPA 3051 method. About 1 g of sediment sample was digested by 10 ml of concentrated HNO_3 (Merck). Then, the sediment samples were combusted by using microwave oven. The digested sediment samples were diluted and filtered through blue quantitative filter papers for the measurements of heavy metals (USEPA, 1994). The digested sediment samples were analyzed by using Agilent 7500ce model Inductively Coupled Plasma Mass Spectrometry (ICP-MS). Detection limits were 0.101 µg/l for Fe, 0.027 µg/l for Mn, 0.011 µg/l for Cr, 0.200 µg/l for Ni, 0.176 µg/l for Zn, 0.006 µg/l for Cd and 0.012 µg/l for Pb, respectively.

Classification of metal pollution and health risk assessment: In this study, the sediment heavy metal pollution status of Berdan River Basin was determined using the pollution indices Enrichment Factor (EF), Geoaccumulation Index (Igeo), Contamination Factor (CF) and Pollution Load Index (PLI) based on the metal concentration values obtained by Ozbay et al., (2013).

EF is calculated by the following equation (Abrahim & Parker, 2008; Şimşek et al., 2022; Tepe et al., 2022):

$$\text{EF}=\frac{M_{sx}/M_{sFe}}{M_{bx}/M_{bFe}}$$

where M_{sx}: the measured metal concentration, M_{sFe}: the measured iron concentration, M_{bx}: the metal concentrations in the earth's crust and M_{bFe}: the iron concentrations in the earth's crust.

Igeo is calculated by the following equation (Caridi et al., 2016; Şimşek et al., 2022; Tepe et al., 2022):

$$\text{Igeo}=\log_2\left(\frac{M_{sx}}{1.5 \text{ x } M_{bx}}\right)$$

where M_{sx}: the measured metal concentration and M_{bx}: the metal concentrations in the earth's crust.

CF values are calculated by the ratio of the measured metal concentration (M_{sx}) to the metal concentration (M_{bx}) in the earth's crust (Martínez-Guijarro et al., 2019; Şimşek et al., 2022; Tepe et al., 2022).

$$\text{CF}=\frac{M_{sx}}{M_{bx}}$$

PLI is used for the assessment of overall metal pollution in sediments and is calculated by the following formula (Saddik et al., 2019):

$$\text{PLI}=(CF_1 x CF_2 x CF_3 \text{ x} \dots \text{x } CF_n)^{1/n}$$

Chronic daily intake, hazard quotients, hazard index, cancer risk and total lifetime cancer risk were used to determine potential health risk assessment for dermal contact and ingestion pathways. These indices were calculated by using the formulas presented in Table 1 (Al-Kahtany & El-Sorogy, 2023; Magni et al., 2021; Pavilonis et al., 2017; USEPA, 2002). Reference dose and cancer slope factor values of the studied heavy metals used for the calculations were depicted in Table 2.

Table 1. Calculation of chronic daily intake (CDI), hazard quotients (HQ), hazard index (HI), cancer risk (CR), and total lifetime cancer risk (TLCR).

Non-Carcinogenic	Carcinogenic	Parameter*	Adult	Child	
$CDI_{ing.} = (HMs \text{ x } IngR \text{ x } EF \text{ x } ED/BW \text{ x } AT) \text{ x } CF$ **(mg/kg/day)**		ED (Exposure Duration)(years)	24	6	
		EF (Exposure Frequency)(days/years)	350		
		BW (Body Weight) (kg)	70	15	
$CDI_{der.} = (HMs \text{ x } SA \text{ x} AFs \text{ x} ABS \text{ x } EF \text{ x } ED/BW \text{ x } AT) \text{ x } CF$ **(mg/kg/day)**		AT (Average Time)(years) (365 x ED)	8760	2190	
		IngR (Ingestion Rate)(mg/day)	100	200	*USEPA (2002)
		SA (Skin Surface Area Exposed)(cm^2)	5700	2800	
$HQ_{ing.} = \frac{CDI_{ing.}}{RfD_{ing.}}$	$CR_{ing.} = CDI_{ing.} \text{ x } CSF_{ing.}$	AF_s (Skin-soil adherence factor)(mg/cm^2)	0.07	0.2	
$HQ_{der.} = \frac{CDI_{der.}}{RfD_{der.}}$	$CR_{der.} = CDI_{der.} \text{ x } CSF_{der.}$	CF (Conversion Factor)(kg/mg)	1.00E-06		
$HI = \sum HQ = HQ_{ing.} + HQ_{der.}$	$TLCR = \sum CR = CR_{ing.} + CR_{der.}$	ABS (Absorption Factor Dermal)(unitless)	0.001		
		HM_s (Heavy Metals Sediment)(mg/kg)	Table 3		
TLCR<1.00E-06; No significant health hazards		HI < 1; non-carcinogenic risk			
1.00E-06 <TLCR< 1.00E-04; Acceptable carcinogenic risk		HI≥ 1; potential carcinogenic			
TLCR<1.00E-04; High risk of carcinogenesis					

Statistical analysis: In this study, statistical analysis (the Pearson's correlation) of the ecological and health risk indices calculated for the Berdan River sediments was performed by using IBM SPSS Statistics 26 software.

Table 2. Reference dose (RfD) and cancer slope factor (CSF) values of heavy metals

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

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

RESULTS

Concentrations of heavy metals in sediments of the Berdan River were determined seasonally between December 2008 and November 2009. By using surface sediment metal concentrations by the study of Ozbay et al., (2013) and earth's crust metal values (Krauskopf,1979) (Table 3), metal pollution indices EF, Igeo, CF and PLI were calculated (Figure 2-8).

According to calculated metal pollution indices, surface sediments were not contaminated by the metals Fe, Cr and Mn suggested that Berdan River was not affected by the pollution of these metals (Figure 2-8).

Table 3. Sediment heavy metal concentrations in Berdan River (Ozbay et al., 2013) and earth's crust metal concentrations Krauskopf, 1979).

Station		Fe (g/kg)	Cr (mg/kg)	Mn (mg/kg)	Ni (mg/kg)	Zn (mg/kg)	Cd (mg/kg)	Pb (mg/kg)
1	Mean	16.46	50.17	259.12	134.75	44.77	4.74	11.49
	Std. Dev.	± 8.39	± 24.37	± 37.49	± 75.80	± 33.61	± 0.40	± 5.76
	Min.	10.98	28.18	225.91	86.39	0.00	4.32	3.04
	Max.	30.93	84.89	307.51	246.68	77.56	5.16	15.48
2	Mean	14.27	35.95	345.91	148.15	31.88	4.44	18.08
	Std. Dev.	± 2.52	± 14.04	± 91.45	± 73.83	± 24.60	± 0.13	± 9.61
	Min.	12.21	21.46	277.17	80.09	0.00	4.25	4.35
	Max.	18.47	52.76	473.34	252.92	58.09	4.53	26.25
3	Mean	20.88	64.80	393.56	176.89	81.23	4.66	18.09
	Std. Dev.	± 5.23	± 14.48	± 61.84	± 68.23	± 61.69	± 0.36	± 12.83
	Min.	12.34	48.90	305.11	129.55	0.00	4.28	3.31
	Max.	26.38	80.43	449.29	277.94	147.41	5.14	26.40
4	Mean	21.16	68.24	505.18	198.28	46.12	4.51	15.10
	Std. Dev.	± 5.85	± 17.35	± 111.23	± 87.68	± 32.29	± 0.15	± 8.24
	Min.	13.69	52.00	342.60	142.54	0.00	4.29	3.51
	Max.	29.11	91.55	593.17	327.44	70.42	4.61	23.02
5	Mean	24.59	82.35	444.16	175.72	53.65	4.52	15.84
	Std. Dev.	± 10.75	± 42.04	± 162.30	± 15.41	± 46.10	± 0.20	± 8.66
	Min.	8.77	34.58	235.30	153.88	0.00	4.26	4.40
	Max.	35.88	120.35	612.11	186.88	92.54	4.69	22.57
6	Mean	13.77	45.32	316.45	172.29	15.90	4.38	10.90
	Std. Dev.	± 4.77	± 12.87	± 98.98	± 54.39	± 18.73	± 0.10	± 5.15
	Min.	7.58	28.43	234.53	124.30	0.00	4.27	4.73
	Max.	20.35	56.27	436.75	247.76	36.35	4.48	15.74
Earth's Crust		47	100	850	80	90	0,3	20

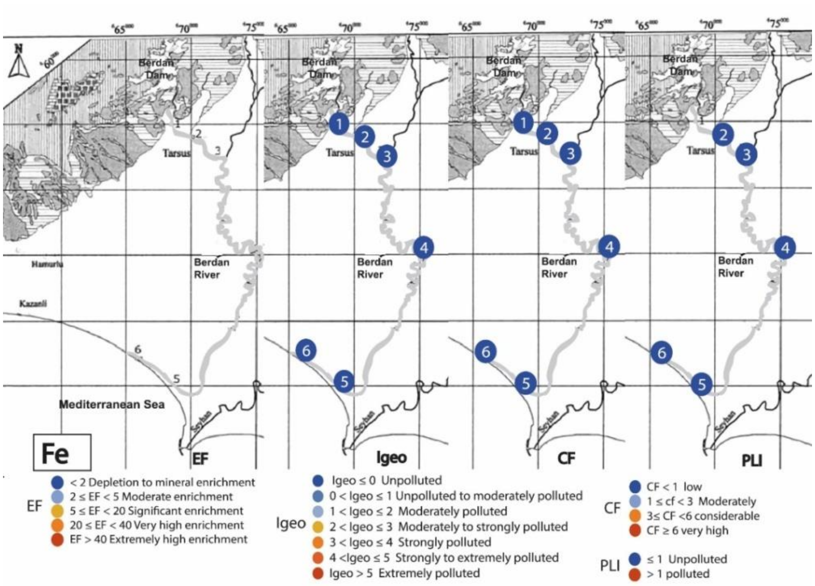

Figure 2. Fe pollution status of surface sediments in the Berdan River Basin.

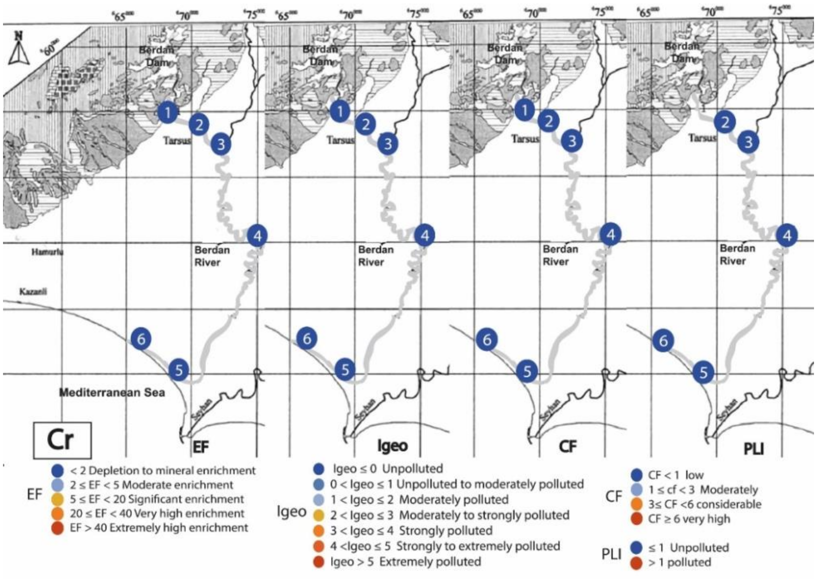

Figure 3. Cr pollution status of surface sediments in the Berdan River Basin.

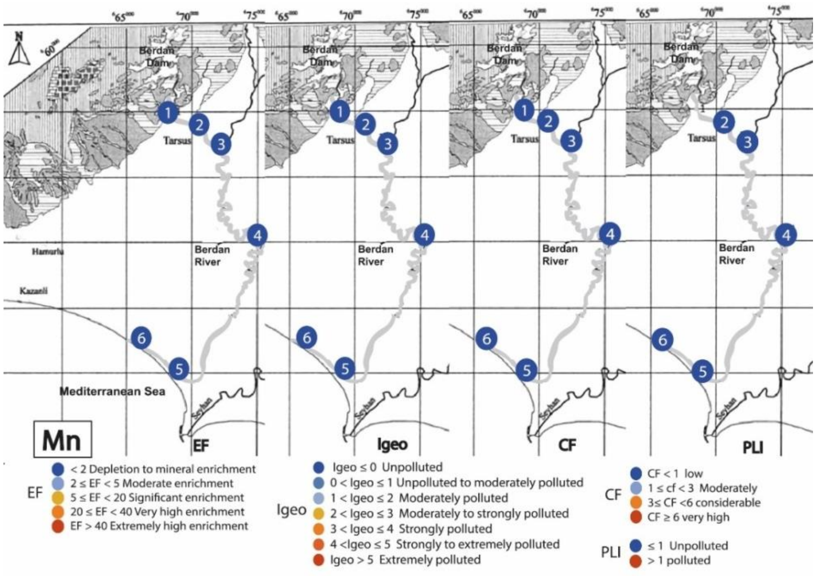

Figure 4. Mn pollution status of surface sediments in the Berdan River Basin.

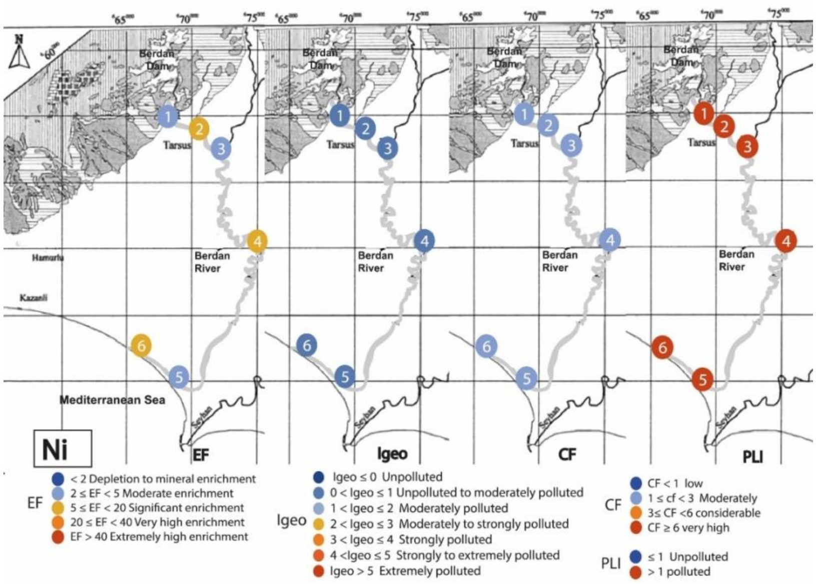

Figure 5. Ni pollution status of surface sediments in the Berdan River Basin.

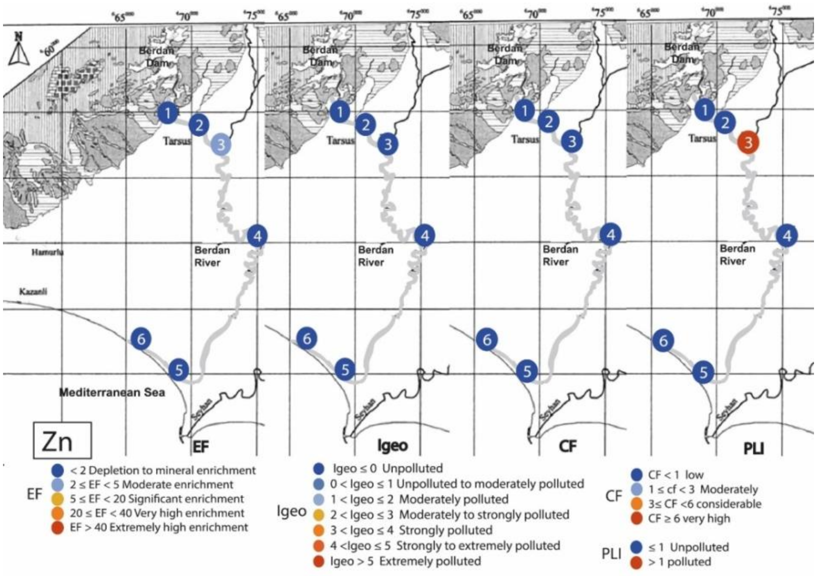

Figure 6. Zn pollution status of surface sediments in the Berdan River Basin.

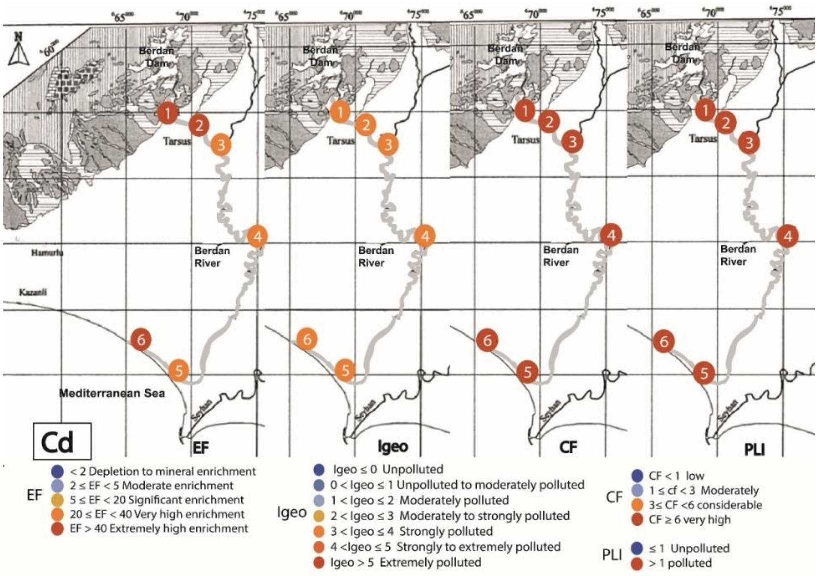

Figure 7. Cd pollution status of surface sediments in the Berdan River Basin.

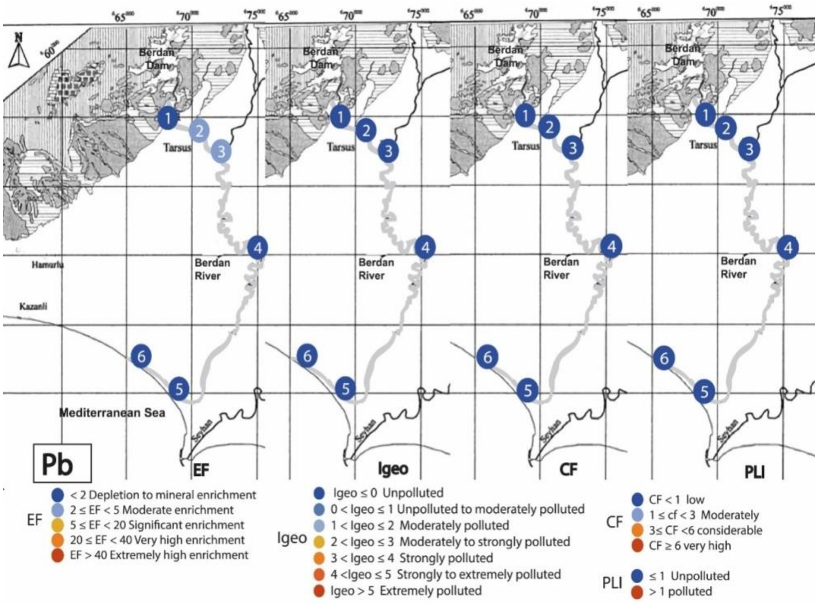

Figure 8. Pb pollution status of surface sediments in the Berdan River Basin.

For the assessment of sediment Ni pollution, Igeo values showed that all stations were Unpolluted to moderately polluted whilst CF classification showed all stations were Moderately contaminated. Furthermore, EF values suggested station 1, 3 and 5 were classified as Moderate enrichment and classification of station 2, 4 and 6 was determined as Significant enrichment. According to the PLI values, it was determined as sediments obtained from the all stations were polluted by Ni suggesting the anthropogenic Ni pollution in the Berdan River (Figure 5). For the assessment of sediment Zn pollution, EF values suggested Moderate enrichment and PLI values suggested Zn pollution at station 3 indicating a local Zn pollution in this region (Figure 6). The calculated EF values suggested Cd pollution status was classified as Extremely high enrichment in stations 1, 2 and 6 whilst stations 3, 4 and 5 were classified as Very high enrichment. According to other pollution indices, it was determined as Strongly polluted by Igeo classification, very high in CF classification, and polluted by PLI classification, respectively, in the Berdan River Basin (Figure 7). According to EF calculations of Pb, stations 2 and 3 were classified as Moderate enrichment. According to other pollution indices, however, all stations were determined as unpolluted/uncontaminated by Pb (Figure 8).

In this study, it was determined that whether the Berdan River surface sediments was affected by human activities, or not. It has been determined that according to all pollution indices there was an apparent pollution of surface sediments by Ni and Cd at all sampling points of the river. CF and PLI indices show uncontaminated by Pb at all stations, while EF showed that there was a regional pollution at stations 2 and 3. It was assumed that the sources of Pb are paint factories, car exhaust fumes, phosphate fertilizers and domestic wastes since Pb enrichment in the Manoa River has been determined as car-related municipal wastewater discharges (Sutherland, 2000). EF is used to quantify anthropogenic effects and showed actual pollution (Sakan et al., 2009). EF and PLI index values showed that only at station, there was an apparent Zn pollution, whilst there was no Zn pollution according to Igeo and CF indices.

Köleli and Kantar, (2005) stated that the high Cd level in the soil is caused by composite fertilizers and phosphate fertilizers with high Cd content. Furthermore, Köleli et al., (2010) showed the increase in the amount of barn manure increased the Cd level in the soil. Krika and Krika, (2017) reported that the Cd pollution in the Nile River was caused by domestic and agricultural wastewater discharges. Çevik et al., (2009) stated that Cd, showing metal pollution according to EF and Igeo indices in Seyhan Dam Lake, is caused by fertilizers and pesticides. Sutherland, (2000) stated that Cd is caused by phosphate fertilizers, batteries, pesticides, diesel oils and household wastes while Ni pollutants are caused by phosphate fertilizers, batteries, vehicle exhausts, diesel fuels. Sakan et al., (2009) reported that the high Ni level in the Tisza River is due to the natural rock structure. Ma et al., (2017) attributed metal pollution in the Daliao River and delta sediment to the influx of industrial and sewage effluents both from natural sources and anthropogenic inputs. Although the rocks of the Tarsus region are rich in Cr and Ni (Kurt et al., 2014), there is no risk of sediment Cr pollution, while there is a potential Ni pollution recorded in this study. Kumbur and Vural, (1989) and Ergene et al., (2007) also showed the heavy metal pollution at downstream of the Berdan River while Ozbay et al., (2013) stated that there is a high level of heavy metal accumulation in the sediments. According to the pollution indices calculated in this study, it is clearly shown that the Berdan River has a risk of metal pollution, specifically Ni and Cd pollution, caused by anthropogenic impacts as industrial activities, agricultural fertilization and spraying, domestic wastewater and atmospheric inputs.

The study results were compared with the previously reported results performed in different rivers in Türkiye showed metal pollution due to natural and human-induced pressures. Akarsu et al. (2022) showed that a moderate risk for Cd, but a very high risk for Ni and Pb in Sarıçay River sediments whilst Borcka Dam Lake sediments were highly contaminated by As, Cu, Pb and Zn (Gedik et al., 2018). Similarly, the EF values calculated for the Çoruh river sediments showed significant enrichment for Cu and Zn and very high enrichment for Cd and Ni (Akkan & Mutlu, 2022). It was reported that the ecological risk assessment indices calculated for the Tigris River sediments showed local pollution for the metals Cu, Co, Zn and Pb which might result in harmful effects on sediment-dwelling organisms (Varol, 2011). The results of this study showed similar metal pollution status determined in the Berdan River Basin. While Ni and Cd pollution were determined at all sampling points of the Berdan River Basin, there was a regional pollution of Pb and Zn caused by anthropogenic pressures.

The results of CDI, HQ, HI, CR and TLCR from ingestion and dermal contact pathways on children and adults were presented in Table 4. Based on the study findings, the carcinogenic risks for Cr, Pb, Cd and Ni were determined in the Berdan River Basin. A HI value less than 1 indicates non-carcinogenic risk, but a HI value greater than 1 indicates potential carcinogenic risk in humans (Magni et al., 2021). In this study, the calculated HI values ranged from 7.41E-05 for adults to 1.65E+00 for children. For the children, with the exception of one station (Station

6), all the calculated HI values were greater than 1 for the metal Pb suggesting "potential carcinogenic risk" for children in the region (Table 4). A TLCR value less than 1.00E-06 indicates no significant health hazards while a TLCR/CR value higher 1.00E-04 indicates high carcinogenic risk. A TLCR value between 1.00E-06 and 1.00E-04 indicates acceptable or tolerable carcinogenic risk (Magni et al., 2021). For the children, TLCR values calculated from the measured heavy metal contents ranged between 1.19E-6 and 4.61E-3 through the ingestion and dermal pathways whilst for the adults, TLCR values ranged from 1.27E-7 to 5.08E-4 through the ingestion and dermal pathways. For the adults, the calculated TLRC values indicated "high carcinogenic risk" from the carcinogenic Ni (TLCR: 3.45E-04 - 5.08E-04), "tolerable carcinogenic risk" from the metals Cd (TLCR: 3.49E-06 - 3.77E-06) and Cr (TLCR: 2.86E-05 - 6.54E-05), and "no significant health hazards" for the metal Pb (TLCR: 1.27E-07 - 2.11E-07). For the children, however, the calculated TLRC values indicated "high carcinogenic risk" from the carcinogenic Cr (TLCR: 2.56E-04 - 5.85E-04) and Ni (TLCR: 3.13E-03 - 4.61E-03), and "tolerable carcinogenic risk" from the metals Cd (TLCR: 3.12E-05 - 3.38E-05) and Pb (TLCR: 1.19E-06 - 1.97E-06). These findings strongly suggested that though Cd and Ni pollution were determined at all sampling points of the Berdan River Basin, significant health hazards were assessed for both children and adult from the carcinogenic Pb, Cr and Ni. The Pearson's correlation showed strong and positive correlations between ecological and health risk indices (Figure 9), strongly suggesting that the metal pollution in the Berdan River sediments resulted in ecological and potential health risk. Similar results were obtained from different regions where heavy metal pollution was experienced (Al-Kahtany & El-Sorogy, 2023; Magni et al., 2021; Pavilonis et al., 2017). However, since the Berdan River is used for drinking water needs, agricultural irrigation and electricity production (Ozbay et al., 2013), it should be considered that further metal accumulation/pollution of the Berdan River Basin may enhance significant health hazards that is critical importance for the humans living in the region.

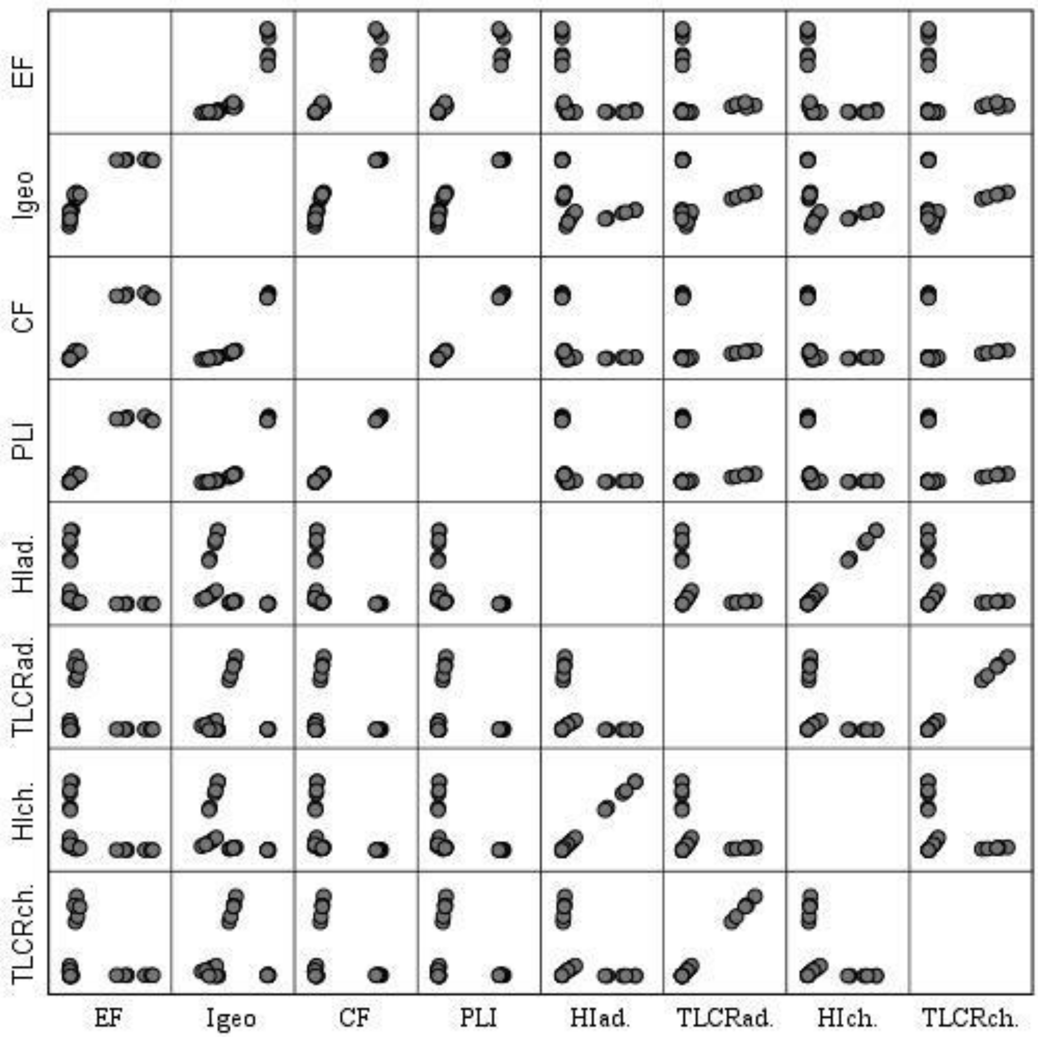

Figure 9. Correlations between the values of calculated indices for the ecological and potential health risk assessment.

Table 4. The results of HI and TLCR from ingestion and dermal contact pathways on children and adults calculated for the Berdan River Basin.

			ADULT							CHILD						
		st.	Fe	Cr	Mn	Ni	Zn	Cd	Pb	Fe	Cr	Mn	Ni	Zn	Cd	Pb
	$CDI_{ing.}$	1	2.25E-02	6.87E-05	3.55E-04	1.85E-04	6.13E-05	6.50E-06	1.57E-05	2.10E-01	6.41E-04	3.31E-03	1.72E-03	5.72E-04	6.06E-05	1.47E-04
		2	1.95E-02	4.93E-05	4.74E-04	2.03E-04	4.37E-05	6.09E-06	2.48E-05	1.82E-01	4.60E-04	4.42E-03	1.89E-03	4.08E-04	5.68E-05	2.31E-04
		3	2.86E-02	8.88E-05	5.39E-04	2.42E-04	1.11E-04	6.38E-06	2.48E-05	2.67E-01	8.29E-04	5.03E-03	2.26E-03	1.04E-03	5.95E-05	2.31E-04
		4	2.90E-02	9.35E-05	6.92E-04	2.72E-04	6.32E-05	6.18E-06	2.07E-05	2.71E-01	8.72E-04	6.46E-03	2.54E-03	5.90E-04	5.77E-05	1.93E-04
		5	3.37E-02	1.13E-04	6.08E-04	2.41E-04	7.35E-05	6.20E-06	2.17E-05	3.14E-01	1.05E-03	5.68E-03	2.25E-03	6.86E-04	5.78E-05	2.02E-04
		6	1.89E-02	6.21E-05	4.33E-04	2.36E-04	2.18E-05	6.00E-06	1.49E-05	1.76E-01	5.79E-04	4.05E-03	2.20E-03	2.03E-04	5.60E-05	1.39E-04
	$CDI_{der.}$	1	9.00E-05	2.74E-07	1.42E-06	7.37E-07	2.45E-07	2.59E-08	6.28E-08	5.89E-04	1.80E-06	9.28E-06	4.82E-06	1.60E-06	1.70E-07	4.11E-07
		2	7.80E-05	1.97E-07	1.89E-06	8.10E-07	1.74E-07	2.43E-08	9.88E-08	5.11E-04	1.29E-06	1.24E-05	5.30E-06	1.14E-06	1.59E-07	6.47E-07
		3	1.14E-04	3.54E-07	2.15E-06	9.67E-07	4.44E-07	2.54E-08	9.88E-08	7.47E-04	2.32E-06	1.41E-05	6.33E-06	2.91E-06	1.67E-07	6.47E-07
		4	1.16E-04	3.73E-07	2.76E-06	1.08E-06	2.52E-07	2.47E-08	8.25E-08	7.58E-04	2.44E-06	1.81E-05	7.10E-06	1.65E-06	1.62E-07	5.40E-07
		5	1.34E-04	4.50E-07	2.43E-06	9.60E-07	2.93E-07	2.47E-08	8.66E-08	8.80E-04	2.95E-06	1.59E-05	6.29E-06	1.92E-06	1.62E-07	5.67E-07
		6	7.53E-05	2.48E-07	1.73E-06	9.42E-07	8.69E-08	2.39E-08	5.96E-08	4.93E-04	1.62E-06	1.13E-05	6.17E-06	5.69E-07	1.57E-07	3.90E-07
Non-carcinogenic	$HQ_{ing.}$	1	3.22E-02	2.29E-02	2.54E-03	9.23E-03	2.04E-04	6.50E-03	1.12E-01	3.01E-01	2.14E-01	2.37E-02	8.61E-02	1.91E-03	6.06E-02	1.05E+00
		2	2.79E-02	1.64E-02	3.38E-03	1.01E-02	1.46E-04	6.09E-03	1.77E-01	2.61E-01	1.53E-01	3.16E-02	9.47E-02	1.36E-03	5.68E-02	1.65E+00
		3	4.09E-02	2.96E-02	3.85E-03	1.21E-02	3.71E-04	6.38E-03	1.77E-01	3.81E-01	2.76E-01	3.59E-02	1.13E-01	3.46E-03	5.95E-02	1.65E+00
		4	4.14E-02	3.12E-02	4.94E-03	1.36E-02	2.11E-04	6.18E-03	1.48E-01	3.86E-01	2.91E-01	4.61E-02	1.27E-01	1.97E-03	5.77E-02	1.38E+00
		5	4.81E-02	3.76E-02	4.35E-03	1.20E-02	2.45E-04	6.20E-03	1.55E-01	4.49E-01	3.51E-01	4.06E-02	1.12E-01	2.29E-03	5.78E-02	1.45E+00
		6	2.69E-02	2.07E-02	3.10E-03	1.18E-02	7.26E-05	6.00E-03	1.07E-01	2.52E-01	1.93E-01	2.89E-02	1.10E-01	6.78E-04	5.60E-02	9.95E-01
	$HQ_{der.}$	1	1.29E-04	9.14E-05	2.53E-04	1.36E-04	4.08E-06	1.04E-03	1.20E-04	8.42E-04	5.99E-04	1.66E-03	8.93E-04	2.67E-05	6.79E-03	7.85E-04
		2	1.11E-04	6.55E-05	3.38E-04	1.50E-04	2.90E-06	9.71E-04	1.89E-04	7.30E-04	4.29E-04	2.21E-03	9.82E-04	1.90E-05	6.36E-03	1.23E-03
		3	1.63E-04	1.18E-04	3.84E-04	1.79E-04	7.40E-06	1.02E-03	1.89E-04	1.07E-03	7.73E-04	2.52E-03	1.17E-03	4.85E-05	6.67E-03	1.24E-03
		4	1.65E-04	1.24E-04	4.93E-04	2.01E-04	4.20E-06	9.87E-04	1.57E-04	1.08E-03	8.14E-04	3.23E-03	1.31E-03	2.75E-05	6.46E-03	1.03E-03
		5	1.92E-04	1.50E-04	4.34E-04	1.78E-04	4.89E-06	9.89E-04	1.65E-04	1.26E-03	9.83E-04	2.84E-03	1.16E-03	3.20E-05	6.48E-03	1.08E-03
		6	1.08E-04	8.26E-05	3.09E-04	1.74E-04	1.45E-06	9.58E-04	1.14E-04	7.04E-04	5.41E-04	2.02E-03	1.14E-03	9.49E-06	6.27E-03	7.45E-04
	HI	1	3.23E-02	2.30E-02	2.79E-03	9.37E-03	2.09E-04	7.54E-03	1.13E-01	3.01E-01	2.14E-01	2.53E-02	8.70E-02	1.93E-03	6.74E-02	1.05E+00
		2	2.80E-02	1.65E-02	3.72E-03	1.03E-02	1.48E-04	7.06E-03	1.77E-01	2.61E-01	1.54E-01	3.38E-02	9.57E-02	1.38E-03	6.32E-02	1.65E+00
		3	4.10E-02	2.97E-02	4.23E-03	1.23E-02	3.78E-04	7.40E-03	1.77E-01	3.82E-01	2.77E-01	3.85E-02	1.14E-01	3.51E-03	6.62E-02	1.65E+00
		4	4.16E-02	3.13E-02	5.44E-03	1.38E-02	2.15E-04	7.17E-03	1.48E-01	3.88E-01	2.92E-01	4.94E-02	1.28E-01	1.99E-03	6.42E-02	1.38E+00
		5	4.83E-02	3.78E-02	4.78E-03	1.22E-02	2.50E-04	7.18E-03	1.55E-01	4.50E-01	3.52E-01	4.34E-02	1.13E-01	2.32E-03	6.43E-02	1.45E+00
		6	2.71E-02	2.08E-02	3.41E-03	1.20E-02	7.41E-05	6.96E-03	1.07E-01	2.52E-01	1.94E-01	3.09E-02	1.11E-01	6.87E-04	6.23E-02	9.96E-01
Carcinogenic	$CR_{ing.}$	1	-	3.44E-05	-	3.14E-04	-	3.26E-06	1.34E-07	-	3.21E-04	-	2.93E-03	-	3.04E-05	1.25E-06
		2	-	2.46E-05	-	3.45E-04	-	3.05E-06	2.10E-07	-	2.30E-04	-	3.22E-03	-	2.85E-05	1.96E-06
		3	-	4.44E-05	-	4.12E-04	-	3.20E-06	2.11E-07	-	4.14E-04	-	3.84E-03	-	2.98E-05	1.97E-06
		4	-	4.67E-05	-	4.62E-04	-	3.10E-06	1.76E-07	-	4.36E-04	-	4.31E-03	-	2.89E-05	1.64E-06
		5	-	5.64E-05	-	4.09E-04	-	3.10E-06	1.84E-07	-	5.26E-04	-	3.82E-03	-	2.90E-05	1.72E-06
		6	-	3.10E-05	-	4.01E-04	-	3.01E-06	1.27E-07	-	2.90E-04	-	3.74E-03	-	2.81E-05	1.18E-06
	$CR_{der.}$	1	-	5.48E-06	-	3.13E-05	-	5.19E-07	5.34E-10	-	3.59E-05	-	2.05E-04	-	3.40E-06	3.50E-09
		2	-	3.93E-06	-	3.44E-05	-	4.86E-07	8.40E-10	-	2.57E-05	-	2.25E-04	-	3.18E-06	5.50E-09
		3	-	7.08E-06	-	4.11E-05	-	5.09E-07	8.40E-10	-	4.64E-05	-	2.69E-04	-	3.33E-06	5.50E-09
		4	-	7.46E-06	-	4.61E-05	-	4.93E-07	7.01E-10	-	4.89E-05	-	3.02E-04	-	3.23E-06	4.59E-09
		5	-	9.00E-06	-	4.08E-05	-	4.94E-07	7.36E-10	-	5.90E-05	-	2.67E-04	-	3.24E-06	4.82E-09
		6	-	4.95E-06	-	4.00E-05	-	4.79E-07	5.06E-10	-	3.24E-05	-	2.62E-04	-	3.14E-06	3.32E-09
	TLCR	1	-	3.98E-05	-	3.45E-04	-	3.77E-06	1.34E-07	-	3.57E-04	-	3.13E-03	-	3.38E-05	1.25E-06
		2	-	2.86E-05	-	3.79E-04	-	3.53E-06	2.11E-07	-	2.56E-04	-	3.45E-03	-	3.16E-05	1.97E-06
		3	-	5.15E-05	-	4.53E-04	-	3.70E-06	2.11E-07	-	4.61E-04	-	4.11E-03	-	3.32E-05	1.97E-06
		4	-	5.42E-05	-	5.08E-04	-	3.59E-06	1.76E-07	-	4.85E-04	-	4.61E-03	-	3.21E-05	1.65E-06
		5	-	6.54E-05	-	4.50E-04	-	3.60E-06	1.85E-07	-	5.85E-04	-	4.09E-03	-	3.22E-05	1.73E-06
		6	-	3.60E-05	-	4.41E-04	-	3.49E-06	1.27E-07	-	3.22E-04	-	4.01E-03	-	3.12E-05	1.19E-06

CONCLUSION

The metal pollutants released into streams and rivers accumulate in the sediment. The characteristics of sediments with the organic matter, clay and mineral contents affect the accumulation and long term burial of heavy metals in the sediment. By using the heavy metal values measured in the Berdan River sediments, various metal pollution indices were calculated. Study findings indicated that the river sediments were polluted by Cd and Ni. It is shown that the sources of pollution of the Berdan River are the industrial and domestic discharges in the region originated from the uncontrolled and intensively used fertilizers and agricultural pesticides. This study also showed significant health hazards for both children and adults from the carcinogenic Pb, Cr and Ni. Furthermore, since the Berdan River is used for drinking water needs, agricultural irrigation and electricity production, it is necessary to monitor organic and inorganic matter pollution of the Berdan River.

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