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Potentially Toxic Element-Induced Ecological Risk Assessment of Kilitbahir Port, Çanakkale, Türkiye

Kilitbahir Limanı'nın (Çanakkale, Türkiye) Toksik Element Kaynaklı Potansiyel Ekolojik Risk Değerlendirmesi

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Abstract: This study discusses the results of ecological risk analysis of sediments taken from Kilitbahir Port, one of the most active ports along the Çanakkale Strait (Dardanelles). ICP-MS analyses of the collected samples revealed moderate enrichment in Mo, Cu, and Zn in relation to anthropogenic activities in the studied sediments. The compatibility of the geoaccumulation and enrichment factor data indicates that the pollution is anthropogenic. No significant toxic risk was detected, although Mo is the most enriched potentially toxic element. The ecological risk determined in terms of Hg and Cd is likely to be related to oil and fuel leaks caused by marine vessels passing to/from the Kilitbahir port and road traffic moving over the study area.

Keywords: Çanakkale, ecological risk, Kilitbahir Port, potentially toxic element.

Öz: *Bu çalışmada Çanakkale Boğazı boyunca en aktif limanlardan biri olan Kilitbahir Limanı'ndan alınan sedimanların ekolojik risk analizi sonuçları tartışılmaktadır. Liman ve çevresinden alınan numunelerden elde edilen ICP-MS analiz sonuçlarına göre Mo, Cu ve Zn'de orta düzeyde zenginleşme olmasının nedeninin antropojenik aktivitelerle ilişkili olduğu ortaya konulmuştur. Jeoakümülasyon ve zenginleştirme faktörü verilerininde uyumluluğu, kirliliğin antropojenik olduğunu göstermektedir. Çalışma alanında önemli bir toksik risk tespit edilmemiş olmasına ragmen Mo potansiyel toksik element olarak en çok zenginleşmiş elementtir. Çalışmada belirlenmiş olan Hg ve Cd türündeki ekolojik riskin ise Kilitbahir limanına/limanından geçen deniz araçlarının neden olduğu yağ ve yakıt sızıntıları ile çalışma alanındaki karayolu trafiği ile ilgili olması muhtemeldir.*

Anahtar Kelimeler: *Çanakkale, ekolojik risk, Kilitbahir Limanı, toksik element potansiyeli.*

INTRODUCTION

When agricultural activities do not adequately meet the nutritional demands of the rapidly increasing population, the desire to obtain more products encourages the use of fertilizers rich in chemicals, such as metals, as well as organic matter. In addition, pesticides used to combat pests mix with irrigation waters and soil, and from there into groundwater and surface waters, thus creating toxic effects on water quality as well as soil health (Acquavita et al., 2021; Chen et al., 2021). Especially in cities with rivers flowing through them, urban wastes lead to degradation in water and sediment quality (Özkan et al., 2022).

On the other hand, pollution in water resources is not limited to these agents. Industrial wastes and pollutants from the chimneys of thermal power plants also lead to the pollution of living matter

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by toxic elements. In addition to those mentioned, coasts contain susceptible ecosystems, such as seagrasses, mangroves, lagoons, and coral reefs, where polluted water and sediments mixed with the rivers accumulate (Botello et al., 2018). Especially in the low coastal plains where summer residences are concentrated, tourism and population pressure make the ecosystems adjacent to wetlands, such as beaches, hinterland agricultural lands, dunes, lagoons, and salt marshes unusable over time. In addition to these factors, the coasts and ports that carry the load of maritime traffic are constantly faced with the pressure caused by the transportation of heavy vessels, cargo transportation, and fishing activities (Duodu et al., 2017).

This study is an ecological risk analysis study conducted to investigate the extent of potentially toxic element-induced pollution in ports. The Çanakkale Strait (Dardanelles) carries pollutants from all sources mentioned above. Among them, the Çanakkale Strait forms a key point in the transportation network between the Aegean Sea and the Sea of Marmara, and thereafter the Black Sea as well (Ilgar, 2015).

The existence of metal-induced ecological risks on the shores of the Çanakkale Strait has been found by studies conducted in recent years. According to Demir and Akkuş (2018), heavy metal pollution in Kepez (Çanakkale) harbor on the east coast of the Çanakkale Strait can be inferred from the protein, superoxide dismutase and catalase levels in the mussel *Mytilus galloprovincialis* gill, hepatopancreas and muscle tissues, and the pollution may vary according to seasons and tissues. Determining the levels of some heavy metals (Pb, Cu, Zn and Fe) in *Ulva rigida* in the Dardanelles in terms of marine pollution, Özden (2013) and Özden and Tunçer (2015) concluded that the pollution did not reach dangerous levels in the samples they took from the western shores. Similar results were also obtained from *M. galloprovincialis* samples found previously by Çayır et al. (2012) near the Kilitbahir Port. Similarly, another study dealing with *Ulva rigida* samples and sea water reported an increase in metal accumulation in these macroalgae in spring and winter months, but an increase in Pb concentration in strait waters in all seasons (Ustunada et al., 2011).

Oil and detergent pollution on the shores of the Çanakkale Strait also poses a significant risk. Güven and Ilgar (2002) revealed oil and detergent pollution on the shoreline of the Çanakkale Strait between 1996-1997. Accordingly, in the water and sediment samples taken from the Gelibolu, Lapseki and Çanakkale stations, they concluded that the amount of oil and detergent pollution on the shoreline of the Çanakkale Strait was higher than the amount of oil and detergent pollution on the shipping route. However, it was later revealed by Ilgar et al. (2007) that there was no intense oil pollution in the Çanakkale Strait.

One of the sources of pollution reaching the waters of the Çanakkale Strait is the streams that mix with the sea waters. Recent studies reveal an intense Cd and Ni accumulation in the eutrophicated Sarıçay stream sediments (Koçum and Dursun, 2007; Akarsu, 2021; Akarsu et al., 2022), although many toxic metals are retained in the Atikhisar Dam, built on the Sarıçay (Fural et al., 2021a). The stress and negative effects on macroinvertebrates caused by the deterioration of the water quality of this stream have also been reported (Kaya et al., 2014); polluted wastes carrying domestic and industrial wastes are also known.

MATERIALS and METHODS

Study Area

The study area is the Kilitbahir Port, located on the western shore of the Çanakkale Strait which stretch between the Gelibolu and Biga peninsulas, providing a connection between the Aegean Sea and the Black Sea. Its average water depth is 60 meters. The narrowest part of the strait is 1200 m and the widest part is 8275 m (Ilgar, 2008). Kilitbahir Castle and Kilitbahir village are located just behind the port. Due to the historical importance and spiritual and cultural values of the Gelibolu Peninsula in terms of religious tourism, a large number of tourists and excursionists visit Kilitbahir, especially in summer. This interest significantly increases the maritime traffic in the port. Due to the presence of potential polluting sources, Kilitbahir Port is potentially important in terms of ecological risks. On the shores of the Çanakkale Strait, where there is active international traffic, the narrow area between Çanakkale and Kilitbahir is one of the places where ships are most stranded or run aground (Kılıç and Sanal, 2015), due to the currents.

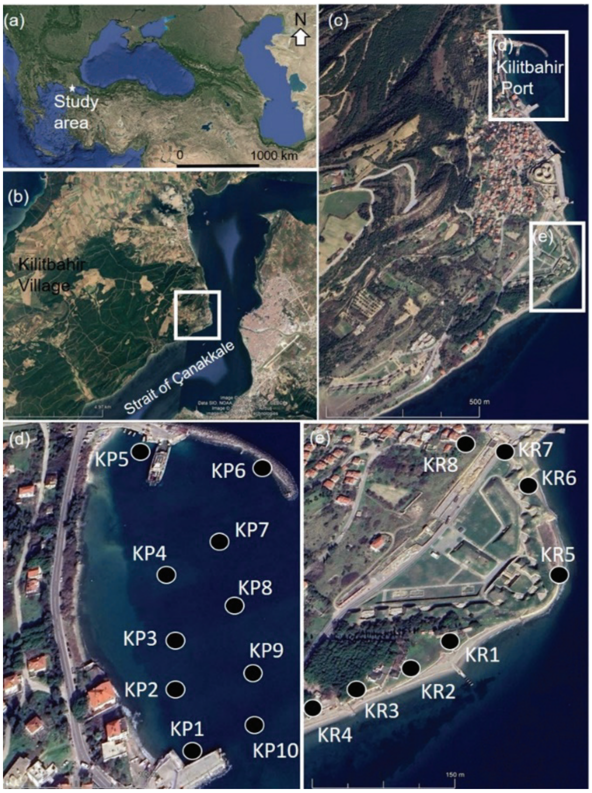

Figure 1. a. b. c) Location of study area and **d. e)** sediment (KP) & bedrock (KR) sampling sites on Google Earth Image (Image date 02/17/2022, last access: 12.16.2022).

Sampling and Analyses

Analytical methods used in regional ecological risk studies from potentially toxic elements (PTE) in aquatic environments (Fural and Kükrer, 2021b) were applied in this study. For the ecological risk analysis, sediment samples (coded as KP1-KP10) were taken from ten different points in Kilitbahir Port on 22.04.2021 using a Van Veen grab sediment sampler (Figure 1d). In order to calculate the background values of the metals, eight bedrock samples (KR1-KR8) were collected from different lithological units around the port area (Figure 1e). The elemental concentration of the port sediments and rock samples was measured by ICP-MS at the Bureau Veritas laboratory in Canada.

Enrichment factor *(EF)*

The enrichment factor was calculated to identify the natural and anthropogenic sources of the elements. While calculating EF, Al, one of the main components of the earth's crust, was used as a reference element (Zhang et al., 2007) in this study. EF is calculated using the following formula:

$$EF = \frac{(C_i/C_{ref})_{sample}}{(B_i/B_{ref})_{background}} \quad (1)$$

Here, C_i is the element concentration, C_{re}f the reference element concentration, B_i the element regional background value, and B_{ref} is the reference element background value. EF findings were evaluated considering the following ranges (Sutherland, 2000); EF < 2 deficiency to minimal enrichment, EF = 2 – 5 moderate enrichment, EF = 5 – 20 significant enrichment, EF = 20 – 40 very high enrichment, and EF ≥ 40 extremely high enrichment.

Geoaccumulation index (I_{geo})

The geoaccumulation index (I_{geo}) used to determine the anthropogenic effect on the metal concentration in the sediment was calculated according to the formula below:

$$I_{geo} = \log_2 \frac{Cm}{(Bm*1.5)} \quad (2)$$

Here, Cm is the element concentration, Bm is the background value of the element with a constant coefficient of 1.5, and the data obtained are accepted as pollution indicators according to the following value ranges (Müller, 1969); ($I_{geo} \leq 0$) unpolluted, ($0 < I_{geo} < 1$) unpolluted to moderately polluted, ($1 < I_{geo} < 2$) moderately polluted, ($2 < I_{geo} < 3$) moderately to strongly polluted, ($3 < I_{geo} < 4$) strongly polluted, ($4 < I_{geo} < 5$) strongly to very strongly polluted, and ($5 \leq I_{geo}$) very strongly polluted.

Toxic risk index (TRI)

TRI is used to determine the toxic risk levels of elements (Zhang et al., 2016). The following formula is used to determine the individual toxic risk coefficient (TRIi) of the element:

$$\mathbf{TRI_i} = \sqrt{\frac{((C_i/TEL)^2 + (C_i/PEL)^2)}{2}} \quad (3)$$

Where C_i is the element concentration, TEL is the threshold effect level and PEL is the probable effect level. TEL and PEL are threshold values calculated according to the limits of the toxic effects of the elements in the sediment (MacDonald et al., 1997; MacDonald et al., 2000). TRI is calculated according to the following formula:

$$\mathbf{TRI} = \sum_{i=1}^{n} \mathbf{TRI_i} \quad (3.4)$$

Here, TRIi is the toxic risk coefficient of an element, i is the element concentration, n is the number of elements used in the analysis, and TRI is the integrated toxic risk value. TRI data is interpreted as TRI ≤ 5 no toxic risk, 5 < TRI ≤ 10 low toxic risk, 10 < TRI ≤ 15 moderate risk, 15 < TRI ≤ 20 considerable toxic risk, and TRI > 20 very high toxic risk (Zhang et al., 2016).

Modified ecological risk analysis (mER)

Modified ecological risk analysis (mER) is used to determine the individual ecological risk levels of the elements. By summing the mER values, the mPER data, which is an indicator of total potential ecological risk, is obtained (Hakanson, 1980; Brady et al., 2015). The mER is calculated according to the following formula:

$$mER = EF \times Tri \quad (4)$$

Here, EF represents the enrichment factor and Tri represents the toxic risk coefficient of the elements. The analysis findings are interpreted as; mER < 40 low ecological risk, 40 ≤ mER < 80 moderate ecological risk, 80 ≤ mER < 160 significant ecological risk, 160 ≤ mER < 320 high ecological risk, and mER ≥ 320 very high ecological risk (Hakanson, 1980).

mPER, which is the sum of the mER values of the elements, is calculated according to the following formula:

$$mPER = \sum_{i=1}^{n} mER \quad (5)$$

The following value ranges are taken into account in the interpretation of mPER data: mPER <150 low ecological risk, 150 ≤ mPER <300 moderate ecological risk, 300 ≤ mPER <600 significant ecological risk, and mPER ≥ 600 very high ecological risk (Hakanson, 1980). The spatial distribution of mPER was analyzed using the Kriging interpolation method in ArcMap 10.8 software.

RESULTS and DISCUSSION

Source Identification of Potentially Toxic Elements

The enrichment factor and geoaccumulation index were used for source identification of potentially toxic elements.

Enrichment factor (EF)

EF values are listed in decreasing order as follows; Mo (3.93) > Cu (2.50) > Zn > (2.35) > Tl (1.83) > Cd (1.61) > Pb (1.57) > Cr (0.89) > Ni (0.81) > Fe (0.73) > Co (0.69) > As (0.57) > Hg (0.54) > Mn (0.27). Mo, Cu, and Zn were moderately enriched compared to the average data, while other elements were not enriched (Table 1). When evaluated based on the sampling point; Cu is moderately enriched at sampling points 3, 4, 5, 6, and 9. Pb was moderately enriched at sampling points 4 and 9. Zn was moderately enriched at sampling points 3, 4, 5, 6, and 9. Ni, Mn, Fe, and As were enriched at very low levels at all sampling points. Cd and Tl were moderately enriched at sampling points 4 and 5. Mo was enriched in greater amounts and at more sampling points than all the other potentially toxic elements examined in the study. Mo was significantly enriched at sampling point 1, and moderately enriched at other sampling points.

In terms of EF values, Ni, Mn, Fe, As, Cr, Hg, and Co were determined to be in the range of deficiency to minimal enrichment. Cd was moderately enriched at the southern parts of the northern breakwater and at sampling points 4 and 5 along the highway. Low enrichment was detected at other sampling points. Cu was moderately enriched at sampling points 3, 4, 5, 6, and 9. The sampling points where Cu was moderately enriched show a linear distribution throughout the settlement, the highway, and the northern breakwater.

Mo, reaching the maximum at sampling point 1, is the most enriched potentially toxic element in the studied sediments. The sampling point is one of the waiting points for ferryboats arriving at the port.

Table 1. Enrichment Factor values

Sampling site	Cu	Pb	Zn	Ni	Mn	Fe	As	Cd	Cr	Hg	Co	Tl	Mo
KP 1	1.56	1.10	1.51	0.84	0.22	0.69	0.51	1.33	0.90	0.49	0.75	1.53	**5.42**
KP 2	1.57	1.30	1.90	0.80	0.31	0.77	0.52	1.29	0.89	0.46	0.67	1.93	**2.98**
KP 3	**2.15**	1.50	**2.38**	0.78	0.21	0.65	0.51	1.47	0.93	0.47	0.64	1.96	**3.95**
KP 4	**4.26**	**2.64**	**3.41**	0.80	0.38	0.76	0.94	**2.34**	0.96	1.13	0.68	**2.34**	**2.88**
KP 5	**4.46**	1.68	**3.78**	0.95	0.39	0.94	0.62	**2.08**	0.99	0.53	0.76	**2.50**	**3.93**
KP 6	**2.14**	1.20	**2.44**	0.73	0.16	0.60	0.33	1.88	0.83	0.33	0.60	1.53	**2.73**
KP 7	1.66	1.35	1.81	0.82	0.26	0.73	0.62	1.07	0.87	0.51	0.73	1.61	**4.90**
KP 8	1.79	1.02	1.66	0.71	0.17	0.57	0.47	1.50	0.82	0.54	0.58	1.69	**3.72**
KP 9	**3.65**	2.47	**2.96**	0.81	0.29	0.79	0.61	1.93	0.83	0.54	0.73	1.61	**3.90**
KP 10	1.77	1.42	1.68	0.90	0.26	0.76	0.51	1.22	0.89	0.35	0.76	1.61	**4.89**
Average	**2.50**	1.57	**2.35**	0.81	0.27	0.73	0.57	1.61	0.89	0.54	0.69	1.83	**3.93**

(Bold numbers show enrichment).

For this reason, the source of the mentioned enrichment may be oil and fuel leaks from ferries. It is known that the presence of Mo in sediments can be caused by steel, catalysts, paints, and lubricants (Rogan Šmuc et al., 2018). On the other hand, the sources of Mo can be diverse, such as industrial waste, urban sewage, agricultural pollution, and pollutants (Ashayeri and Keshavarzi, 2019). However, compared with an extreme example, it should be noted that the determined EF values approach the EF values in Aliağa Bay at Izmir, where significant Mo enrichment is observed and the petrochemical industry is concentrated (Palas, 2020).

Geoaccumulation index (I_{geo})

According to the I_{geo} average data of the surface sediments of Kilitbahir Port, they are; Cu (0.51) > Zn (0.45) > Cd (-0.04) > Pb (-0.14) > Al (-0.69) > Cr (-0.88) > Ni (-1.03) > Fe (-1.17) > As (-1.56) > Hg (-1.65) > Mn (-2.66). These results can be compared with the ICP-AES analysis of the samples taken from the soils around Kilitbahir in the immediate vicinity of the port. Baba and Deniz (2004) determined the metal concentrations (ppm) in Kilitbahir soils as follows; Mn (515) > Sr (170) > Ba (90) > Ni (64) > Cr (34) > V (24) > Cu (16) > Pb = Co (10) > As (8) > Cd <0.5). This indicates that the metal content of the local soils is higher than the values in this study. However, the order of the Igeo averages of the Kilitbahir Port sediments may differ to some degree.

Findings from the average data show that Cu and Zn are exposed to low anthropogenic effects and that these potentially toxic elements cause little pollution in the port sediments (Table 2). When evaluated according to the sampling points, Cu is uncontaminated at the 2nd sampling point and less polluted at the other sampling points. Pb is at slightly polluted levels at sampling points 3, 6, and 9, and at uncontaminated levels at other sampling points. Zn is uncontaminated at sampling point 2 and slightly contaminated at other sampling points. Cd is slightly polluted at sampling points 1, 6 and 8, and uncontaminated at other sampling points. There is no contamination at any sampling point for Ni, Mn, Fe, As, Cr, Al and Hg. I_{geo} and enrichment factor findings are consistent with each other (Figure 2).

Table 2. Geoaccumulation index values

Sampling site	Cu	Pb	Zn	Ni	Mn	Fe	As	Cd	Cr	Al	Hg
KP 1	**0.45**	-0.06	**0.37**	-0.48	-2.39	-0.73	-1.15	**0.22**	-0.37	-0.19	-1.23
KP 2	-0.30	-0.57	-0.05	-1.30	-2.63	-1.33	-1.88	-0.58	-1.13	-0.95	-2.06
KP 3	**0.55**	**0.03**	**0.67**	-0.95	-2.83	-1.19	-1.52	0.00	-0.68	-0.55	-1.64
KP 4	**0.60**	-0.09	**0.25**	-1.85	-2.90	-1.89	-1.58	-0.26	-1.57	-1.49	-1.32
KP 5	**0.83**	-0.57	**0.57**	-1.43	-2.69	-1.41	-2.01	-0.26	-1.35	-1.32	-2.23
KP 6	**1.07**	**0.23**	**1.23**	-0.51	-2.64	-0.76	-1.62	**0.87**	-0.32	-0.03	-1.64
KP 7	**0.04**	-0.25	**0.14**	-1.00	-2.65	-1.14	-1.37	-0.58	-0.90	-0.68	-1.64
KP 8	**0.67**	-0.14	**0.54**	-0.70	-2.69	-0.97	-1.26	**0.42**	-0.47	-0.17	-1.06
KP 9	**0.92**	**0.35**	**0.59**	-1.29	-2.73	-1.28	-1.65	0.00	-1.22	-0.95	-1.64
KP 10	**0.27**	-0.05	**0.17**	-0.74	-2.47	-0.95	-1.52	-0.26	-0.73	-0.55	-2.06
Average	0.51	-0.11	**0.45**	-1.03	-2.66	-1.17	-1.56	-0.04	-0.88	-0.69	-1.65

(Bold numbers show areas of anthropogenic pollution).

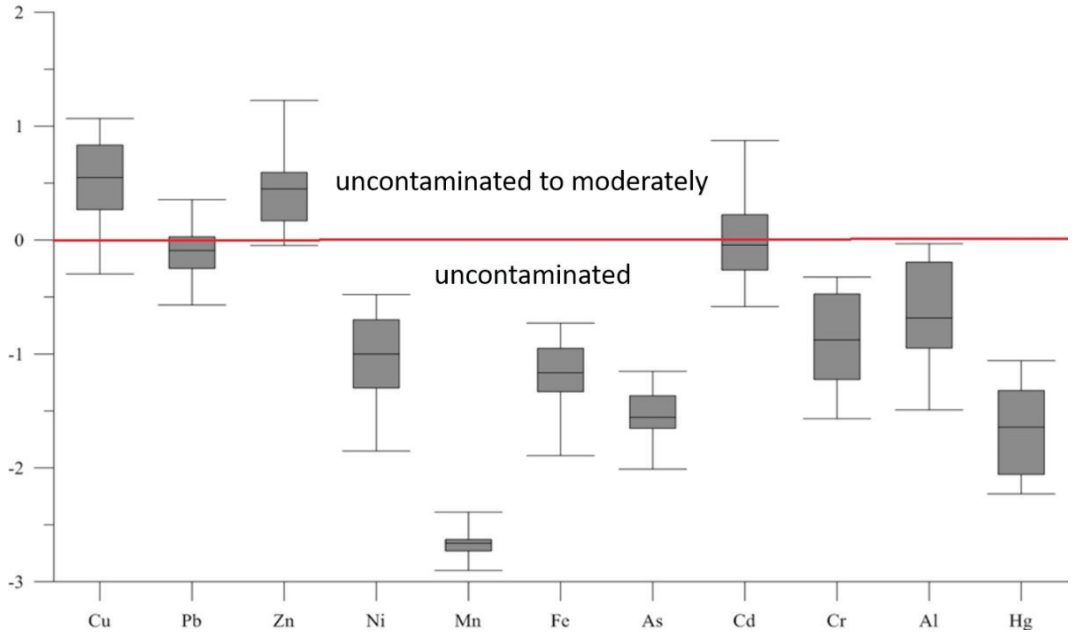

Figure 2. Geoaccumulation index box whisker diagram.

Table 3. Toxic risk index values.

Sampling site	Cu	Pb	Zn	Ni	As	Cd	Cr	Hg	TRI (TEC)
KP 1	0.23	0.15	0.12	0.87	0.44	0.05	0.33	0.06	2.26
KP 2	0.14	0.11	0.09	0.50	0.26	0.03	0.19	0.04	1.35
KP 3	0.25	0.16	0.15	0.63	0.34	0.04	0.27	0.05	1.88
KP 4	0.26	0.15	0.11	0.34	0.32	0.04	0.14	0.06	1.42
KP 5	0.30	0.11	0.14	0.45	0.24	0.04	0.17	0.03	1.47
KP 6	0.36	0.18	0.22	0.85	0.32	0.08	0.34	0.05	2.39
KP 7	0.18	0.13	0.10	0.61	0.38	0.03	0.23	0.05	1.70
KP 8	0.27	0.14	0.13	0.75	0.41	0.06	0.31	0.07	2.14
KP 9	0.32	0.20	0.14	0.50	0.31	0.04	0.18	0.05	1.74
KP 10	0.20	0.15	0.10	0.73	0.34	0.04	0.26	0.04	1.86
Average	0.25	0.15	0.13	0.62	0.34	0.04	0.24	0.05	1.82

Ecological Risk Assessment

The ecological risk level in the surface sediments of Kilitbahir Harbor was analyzed using the toxic risk index, modified ecological risk index, and the modified potential ecological risk index.

Toxic risk index (TRI)

TRI values shown in Table 3 reveal that there is no toxic risk in the harbor sediments. The order of the elements responsible for toxic risk according to the average data is Ni (0.62) > As (0.34) > Cu (0.25) > Cr (0.24) > Pb (0.15) > Zn (0.13) > Hg (0.05) > Cd (0.04). The highest toxic risk with a value of 2.26 was determined at sampling point 1, while the lowest toxic risk, with the value of 1.35, was determined at sampling point 2. When the spatial distribution of the toxic risk is examined, it is seen that higher TRI values are reached in the southern parts of the northern breakwater and the mouth of the harbor.

Modified ecological risk analysis (mER)

According to mER data, the order of the elements responsible for ecological risk is Cd (48.34) > Hg (21.41) > Tl (18.30) > Cu (12.50) > Pb (7.84) > As (5.66) > Ni (4.07) > Co (3.45) > Zn (2.35) > Cr (1.78) > Mn (0.27). Average data indicate that Cd poses a moderate ecological risk, while other elements pose a low ecological risk (Table 4). When evaluated on the basis of the sampling point, Cd created a moderate ecologic risk, except for sampling points 2, 7 and 10, where a low ecological risk level occurs. Hg created a moderate ecological risk only at sampling point 4 and did not cause an ecological risk at the other sampling points. Studies have shown that Cd and Hg are an ecological risk indicator frequently encountered in ports associated with ship waste (Jahan and Strezov, 2018; Choi et al., 2020).

Modified potential ecological risk index (mPER)

The liability ratios of potential toxic elements from potential ecological risk hazards are listed as follows; Cd (38.37%) > Hg (16.99%) > Tl (14.52%) > Cu (9.92%) > Pb (6.62%) > As (4.49) > Ni (3.23%) > Co (2.73) > Zn (1.86) > Cr (1.41) > Mn (0.21) (Figure 3). Average potential ecological risk data indicate low potential ecological risk throughout the port. However, moderate potential ecological risk was identified at sampling points 4 and 5. According to the spatial analysis data, the sampling point 4 is located close to the highway. The sampling point 5 is at the northern breakwater where the ferries stop. Therefore, the probable cause of the ecological risk level detected at sampling point 4 could be road traffic, and the oil and fuel leaks from ferries at sampling point 5 may have caused an increase in ecological risk (Figure 4).

Table 4. Modified Ecological Risk and Modified Potential Ecological Risk Values.

Sampling site	Cu	Pb	Zn	Ni	Mn	As	Cd	Cr	Hg	Co	TI	PER
KP 1	7.79	5.49	1.51	4.20	0.22	5.14	***40.04***	1.79	19.53	3.73	15.25	104.69
KP 2	7.84	6.49	1.90	4.01	0.31	5.23	38.57	1.78	18.51	3.36	19.29	107.30
KP 3	10.73	7.49	2.38	3.88	0.21	5.12	***44.02***	1.86	18.78	3.22	19.57	117.25
KP 4	21.30	13.19	3.41	3.98	0.38	9.38	***70.31***	1.92	***45.00***	3.41	23.44	***195.71***
KP 5	22.28	8.41	3.78	4.73	0.39	6.20	***62.50***	1.98	21.33	3.79	25.00	***160.39***
KP 6	10.72	6.01	2.44	3.67	0.16	3.33	***56.25***	1.65	13.09	3.02	15.34	115.68
KP 7	8.28	6.76	1.81	4.11	0.26	6.23	32.14	1.74	20.57	3.65	16.07	101.63
KP 8	8.94	5.11	1.66	3.55	0.17	4.71	***45.00***	1.64	21.60	2.90	16.88	112.15
KP 9	18.27	12.33	2.96	4.04	0.29	6.13	***57.86***	1.67	21.60	3.65	16.07	144.88
KP 10	8.83	7.10	1.68	4.50	0.26	5.12	36.68	1.78	14.09	3.78	16.07	99.89
Average	12.50	7.84	2.35	4.07	0.27	5.66	48.34	1.78	21.41	3.45	18.30	125.96

(Bold numbers show ecological risk).

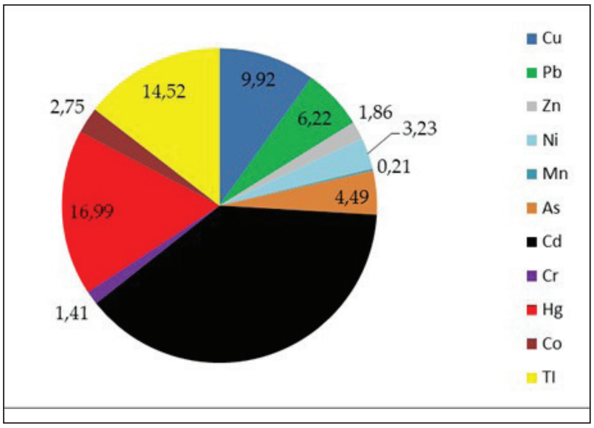

Figure 3. Responsibility ratios of PTEs for potential ecological risk (%).

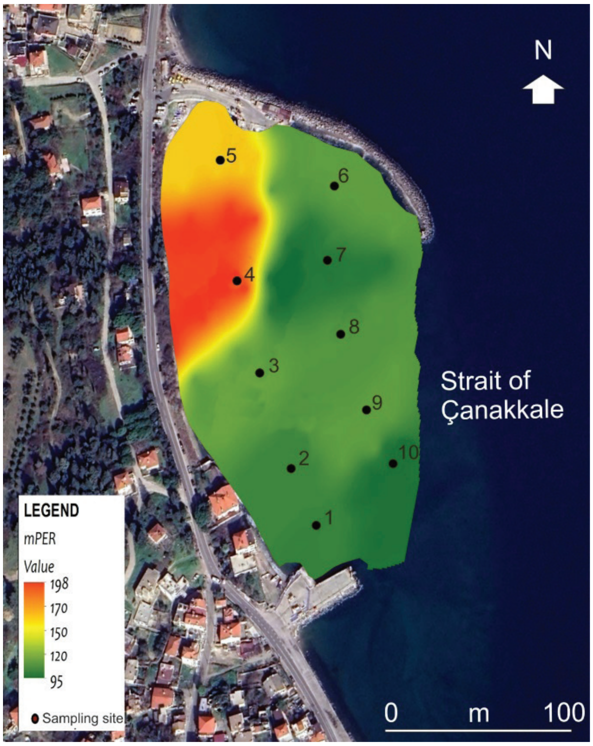

Figure 4. Spatial distribution of potential ecological risk.

CONCLUSIONS

The compatibility between geoaccumulation and enrichment factor data explains the moderate enrichment of Mo, Cu and Zn associated with anthropogenic activities in the Kilitbahir Port sediments. Although no toxic risk was detected in the port sediments, it can be stated that Mo is the most enriched potential toxic element in the port. This enrichment reaches its highest value at the holding point of ferries arriving at the port and must be related to oil and fuel leaks from ferries.

There is an ecological risk in harbor sediments, especially in terms of Cd, and to a lesser extent, Hg. It can be said that there is a medium-low ecological risk in all samples. However, attention should be paid to the ecological risk in terms of Cr, Cu, Ni, Zn and Tl near the ferry waiting and mooring area in the port.

GENİŞLETİLMİŞ ÖZET

Çanakkale Boğazı'nın batı kıyısında yer alan Kilitbahir Limanı konumu gereği Gelibolu Yarımadası'ndaki nüfus, turizm, karayolu trafiği ve hepsinden önemlisi deniz yolu ulaşımından kaynaklanan ekolojik risklerle karşı karşıyadır. Bu çalışmada boğazdan geçiş yapan deniz araçları ve özellikle Çanakkale-Kilitbahir arasındaki boğaz hattında faaliyet gösteren feribotlar ile diğer deniz araçlarının liman sedimentlerinde bir ekolojik risk oluşturma potansiyeli ele alınmıştır. Hesaplamaların güvenirliği açısından liman çevresindeki 8 anakaya örneğinden yapılan ardalan hesaplamaları ile antropojenik ve litolojik kökenli metal kaynakları ayırtlanmıştır.

2021 yılı Nisan ayında Van Veen grab sediment örnekleyici kepçe ile alınan 10 sediment örneğinin Bureau Veritas Laboratuvarlarında (Kanada) yapılan ICP-MS analizlerinin sonuçlarından zenginleşme faktörü, jeoakümülasyon indeksi, toksik risk indeksi ve modifiye ekolojik risk hesaplamaları yapıldı. Analiz sonuçlarına göre Kilitbahir Limanı sedimentlerinde antropojenik kaynaklı olarak Mo, Cu ve Zn'de orta düzeyde zenginleşme söz konusudur ve zenginleşme faktörü verileri jeoakümülasyon indisi sonuçları ile *tutarlıdır. Ni, Mn, Fe ve As bakımından çok düşük düzeyde zenginleşme, Cd ve Tl bakımında ise iki istasyonda orta düzeyde zenginleşme belirlenmiştir. Jeoakümülasyon indeksi hesaplamalarına göre Cu, Pb, Zn ve Cd değerlerinden kaynaklı düşük seviyede de olsa kirlilik söz konusudur.*

Sonuç olarak Kilitbahir Limanı'nda önemli bir toksik risk tespit edilmemiş olmakla birlikte, Mo en çok zenginleşmiş potansiyel toksik elementi oluşturur. Ayrıca bir istasyonda Hg ve 7 istasyonda Cd bakımından da orta düzeyde ekolojik risk söz konusudur. Bu veriler Kilitbahir limanında faaliyet gösteren ve boğazdan transit geçen deniz araçlarının neden olduğu yağ ve yakıt sızıntıları yanı sıra çalışma alanındaki karayolu trafiği ve nüfus baskısının ekolojik risk oluşturduğuna işaret etmektedir.

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