Montes Taurus J. Pure Appl. Math. 6 (3), 532–539, 2024

Montes Taurus Journal of Pure and Applied Mathematics

https://www.mtjpamjournal.com

MTJPAM
ISSN: 2687-4814

Index calculations in Kiris (Antalya) beach sediments

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Abstract

Kiris coastline, located in the west of Antalya, is one of the important tourism regions. Rocks of different ages and characteristics of the region are observed in the sediments of the coastline. The aim of the study is to determine the anomaly areas of Kiris beach sediments by calculating different indices such as contamination factor (C_f), degree of contamination (C_d), modified contamination degree (mC_d), pollution load index (PLI) and enrichment factor (EF). The beach sediments taken systematically along the beach were chemically analyzed by X-ray fluorescence spectroscopy (XRF). In this context, accumulation index degrees were determined in the study area and anomaly areas caused by natural and anthropogenic effects were determined.

Keywords: Beach sediments, heavy metals, contamination factor (C_f), degree of contamination (C_d), modified contamination degree (mC_d), pollution load index (PLI), enrichment factor (EF)

2020 MSC: 90C08, 62P12

1. Introduction

The allure of pristine and unspoiled beaches is a universal phenomenon that draws individuals from across the globe (*cf.* [1, 10, 17, 20, 21, 23]). The preservation of these environments is imperative for the utilization of future generations. The Kiris (Antalya) beach, the subject of this study, is noteworthy for its natural beauty and the quality of its sea. Scientific research on beaches has gained importance for the protection of these areas from anthropogenic factors. A wide array of scientific disciplines are represented in the studies conducted on beaches. These include, but are not limited to, radionuclide studies, environmental studies, beach sediment studies, and index calculations (*cf.* [18, 22, 24]). Index studies on beach sediments are also among the most significant scientific studies. A thorough analysis of the geological characteristics of the study area and its immediate surroundings reveals that the region is composed of units of oceanic crustal origin (*cf.* [16]). These rocks are primarily found in the slope and basin environments of the Antalya Nappes. The ultramafic rocks, which are the dominant rocks in the vicinity of the study area, manifest as light-dark colored, hard, and massive-appearing units. In certain regions, pyroxenites manifest as dykes. Black-colored gabbro and diorite cut the ultramafic rocks. Pillow basalts have been observed in the uppermost levels (*cf.* [19]). A preliminary investigation revealed that, with the exception of a single prior study, no additional

†*Article ID:* MTJPAM-D-24-00236

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Received:31 December 2024, Accepted:18 April 2025, Published:7 August 2025

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analogous studies have been conducted within the study area. A study in the literature examined the Igeo index and the presence of Cr, Sn, Cl, and Br, which were observed in excess in certain locations (*cf.* [8]). However, there are no studies on pollution factor (C_f), pollution grade (C_d), modified contamination degree (mC_d), pollution load index (PLI) and enrichment factor (EF). In the light of this, this study aims to calculate the above-mentioned indices of beach sediments in the study area and determine their limit values. This scientific study is original and based on field studies, laboratory analysis and calculation application.

2. Material and method

The index calculations were based on the systematic sampling of Kiris beach sediments at 100-meter intervals, with each interval separated by 10 centimeters. The samples were then dried under both normal and laboratory conditions for a period of seven days. Subsequent to the drying of the samples in an drying oven, the heat losses were determined. Subsequently, the samples were homogenized, and their contents were extracted by means of chemical analysis (XRF). The contamination factor (C_f), degree of contamination (C_d), modified contamination degree (mC_d), and pollution load index (PLI) were subsequently calculated for the obtained data.

In the context of heavy metal calculations, the contamination factor is determined with the objective of facilitating its application and ensuring the acquisition of reliable and precise data concerning the investigation area. The formula employed to calculate the contamination factor is presented below (*cf.* [9]):

$$C_f = \frac{C_{\text{sample}}}{C_{\text{background}}}. \tag{2.1}$$

where C_{sample} represents the concentration of the metal measured in the sediment, while $C_{\text{background}}$ represents the reference value of that metal measured before industrialization. The calculated C_f value is examined in four separate pollution classes (see, for details, *cf.* [9]). The established limit values for this classification are delineated in Table 1.

Degree of Contamination	C_f **Value**
Low Contamination	$C_f < 1$
Medium Contamination	$1 \leq C_f < 3$
High Contamination	$3 \leq C_f < 6$
Very High Contamination	$C_f \geq 6$

Table 1. Contamination factor classification (*cf.* [9])

The degree of contamination (C_d) is a measure of the extent to which a sediment sample is contaminated by anthropogenic metals. This method facilitates the comparison of metal concentrations across sample locations by interpreting a single value (*cf.* [9]). The contamination levels of the locations across the study area are determined and calculated by the following formula:

$$C_d = \sum_{i=1}^{n} C_f^i \tag{2.2}$$

where C_f^i denotes the contamination level of i-th element (or pollutant) (see, for details, [9]).

The contamination levels observed in this study are presented in Table 2.

Degree of Contamination	C_d **Value**
Low Degree of Contamination	$C_d < 8$
Medium Degree of Contamination	$8 \leq C_d < 16$
High Degree of Contamination	$16 \leq C_d < 32$
Low Degree of Contamination	$C_d < 8$

Table 2. Contamination degree (C_d) classification (*cf.* [9])

The modified contamination degree (mC_d) was developed to address the variability in contaminant quantities within the formula (*cf.* [2]). The formula for the modified contamination degree is as follows:

$$mC_d = \frac{\sum_{i=1}^{n} C_f^i}{n}. \tag{2.3}$$

where n denotes the number of C_f entering the process (see, for details, [2]). The established limit values can be found in Table 3.

Degree of Contamination	mC_d **Classification**
Very low degree of contamination	$mC_d < 1.5$
Low degree of contamination	$1.5 \leq mC_d < 2$
Medium degree of contamination	$2 \leq mC_d < 4$
High degree of contamination	$4 \leq mC_d < 8$
Very high degree of contamination	$8 \leq mC_d < 16$
Extremely high degree of contamination	$16 \leq mC_d < 32$
Ultra high degree of contamination	$mC_d \geq 32$

Table 3. Modified contamination degree (*cf.* [2])

The pollution load index (PLI) is derived by calculating the contamination factors (C_f) for each metal. The formula for the pollution load index (PLI) is as follows (*cf.* [5]):

$$\text{PLI} = \sqrt[n]{Cf_1 \times Cf_2 \times Cf_3 \times \cdots \times Cf_n} \tag{2.4}$$

where $\times$ denotes the classical multiplication.

According to the formula (2.4), C_f is the calculated contamination factor of the metal, and n is the number of samples analyzed. The contamination load index classification is shown in Table 4. According to Chakravarty and Patgiri [5], if the Pollution Load Index (PLI) value obtained is greater than 1, there is contamination, and if the PLI value is less than 1, there is no contamination.

Pollution Degree	**PLI Classification**
No pollution	PLI < 1
Pollution present	PLI ≥ 1

Table 4. Pollution load index classification (PLI) (*cf.* [5])

The enrichment factor (EF) is calculated using the equation described by Buat-Menard and Chessele [4]. The calculated EF value is then subjected to analysis by Sutherland and Tolosa [15] in five different pollution classes as indicated in Table 5. According to the following formula, EF is defined as the enrichment factor.

$$EF = \frac{\left(\frac{C_x}{Fe_x}\right)}{\left(\frac{C_b}{Fe_b}\right)}. \tag{2.5}$$

In the above formula, C_x indicates the concentration of the relevant metal in the sample and Fe_x indicates the concentration of iron in the sample. The average shale concentrations of metal and iron to be analyzed in the sample are represented by C_b and Fe_b, respectively. The range of EF values corresponding to metals originating from natural erosion processes, i.e. metals of crustal origin, is defined as $0.5 \leq EF \leq 1.5$. On the other hand, if the EF value is

greater than 1.5, the metals are not of crustal origin. Instead, we can say that these trace elements are derived from point or non-point sources of pollution, i.e. anthropogenic sources (*cf.* [4, 11]).

Degree of Contamination	EF **Value**
Low Enrichment	$EF < 2$
Moderate Enrichment	$2 \leq EF < 5$
High Enrichment	$5 \leq EF < 20$
Very High Enrichment	$20 \leq EF < 40$
Extreme Enrichment	$EF \geq 40$

Table 5. Enrichment factor (EF) classification (*cf.* [14])

3. Result

It has been determined that the contamination factor (C_f), degree of contamination (C_d), modified degree of contamination (mC_d), pollution load index (PLI) values, and enrichment factor (Ef) calculated from the chemical constituents of Kiris beach sediments offer clear insight into the effects of the natural ultrabasic rocks in the area.

The contamination factor (C_f) formula indicates the concentration value of the metal measured in the sediment, with $C_{\text{background}}$ representing the reference value of that metal measured prior to industrialization (*cf.* [9]). The calculated C_f value is then subjected to analysis in four distinct pollution classes according to Hakanson [9]. With respect to the contamination factor (C_f) for Ti, Cr, Cu, Ni, Zn, Fe, and Mn, it is particularly noteworthy that IGK 14 (Zn), 27 (Fe), 29 (Cu), 31 (Cr), and 35 (Ni) have been identified as locations exhibiting the highest anomalies (Table 6). Notably, the average contamination factor for all locations exceeds the lower limit of 1, a finding that merits further investigation.

The degree of contamination (C_d) is calculated as the sum of the eight contaminants identified by Hakanson [9]. The application of this method is contingent upon the inclusion of all seven metals enumerated in Hakanson's study [9]. Notably, IGK 31 has been identified as the location with the highest anomaly in terms of the degree of contamination (C_d) (Table 6). However, it is noteworthy that the average contamination factor for all locations exceeds the lower limit of 8.

The Modified contamination degree (mC_d) has been emphasized in the calculation of various contaminants by entering the appropriate values into the formula (*cf.* [2]). The modified contamination degree (mC_d) is noteworthy as the location with the highest anomaly in IGK 31 as in the other indices (Table 6). However, the mean of all locations falls below the threshold of very low contamination.

The pollution load index (PLI) is a metric used to compare the pollution values of different study sites and to determine variations between locations (*cf.* [9]). The index's primary function is to facilitate the comparison of the consequences of anthropogenic metal pollution across diverse regions. A notable advantage of the index is its comprehensibility, which renders it accessible to a wide audience. This index is frequently employed to compare the pollution status of different locations, as it consolidates all the metals analyzed into a single metric. As illustrated in Table 4, if the PLI value obtained is greater than 1, it indicates the presence of pollution, and if it is less than 1, it indicates the absence of pollution (*cf.* [5]). In terms of the pollution load index (PLI), IGK 31 is identified as the location with the highest anomaly (Table 6). However, it is noteworthy that the average of all locations is above the lower limit of 1.

The enrichment factor (EF) is a common calculation method used to estimate the impact of anthropogenic heavy metals in sediment (*cf.* [7, 13]). To calculate the enrichment factor, the measured heavy metal content is normalized to a reference metal such as Fe or Al (*cf.* [12]). Deely and Fergusson [6] recommended Fe as an acceptable normalization element to use in the calculation of the enrichment factor because they considered that the Fe distribution was not correlated with other heavy metals (*cf.* [2]). The utilization of EF values in lieu of elemental concentrations is predicated on the assumption that iron (Fe) serves as the reference element, thereby obviating the impact of substantial

variations in grain size, carbonate dilution, and mineral content. The utilization of conservative elements, including Mn, Ti, Al, Ca, and Fe, is crucial in reducing metal variability caused by variations in grain size and mineralogy. These elements facilitate the identification of metal anomalies and ensure the geochemical normalization of heavy metals. Al is the most abundant element in the crust, while Fe is the most abundant element in the structure of clay minerals (*cf.* [11]). In regard to the enrichment factor (EF), IGK 31 (Cr) and IGK 29 (Cu, Zn, Mn) have been identified as the locations exhibiting the highest anomalies (Table 7). However, the mean contamination factor for all locations is below the lower limit of 2, with the exception of Mn, which registered at 2.77. The natural environment has been identified as the cause of anomalies below 1.5, while anthropogenic influence has been implicated in cases above 1.5.

Locations	**Ti**	**Cr**	**Cu**	**Ni**	**Zn**	**Fe**	**Mn**			
				C_f				C_d	mC_d	**PLI**
IGK-1	1,16	3,70	2,16	0,00	1,93	1,01	2,79	12,76	1,16	1,92
IGK-2	1,72	0,00	2,08	1,74	1,92	1,33	3,21	12,00	1,09	1,93
IGK-3	1,48	0,00	2,06	1,81	2,03	1,17	3,18	11,73	1,07	1,86
IGK-4	1,58	0,00	0,00	1,70	1,99	1,25	3,01	9,52	0,87	1,82
IGK-5	1,26	2,46	2,28	1,45	0,00	1,01	3,58	12,04	1,09	1,83
IGK-6	1,12	3,50	0,00	1,38	1,63	0,92	2,58	11,13	1,01	1,66
IGK-7	1,17	2,35	0,00	0,00	1,70	0,96	2,84	9,01	0,82	1,66
IGK-8	1,23	2,43	1,78	0,00	1,64	1,01	2,93	11,03	1,00	1,72
IGK-9	1,12	3,31	2,12	0,00	1,57	0,90	2,47	11,48	1,04	1,73
IGK-10	1,98	0,00	2,12	2,03	2,16	1,68	4,18	14,14	1,29	2,25
IGK-11	1,83	0,00	2,18	1,76	2,19	1,39	3,79	13,13	1,19	2,08
IGK-12	1,65	0,00	2,16	1,83	2,12	1,47	4,16	13,38	1,22	2,09
IGK-13	1,90	4,92	0,00	1,79	2,39	1,68	4,12	16,80	1,53	2,55
IGK-14	1,96	4,21	2,62	1,94	**2,74**	**1,79**	5,00	20,26	1,84	2,69
IGK-15	1,44	2,48	1,97	1,60	1,84	1,33	5,04	15,70	1,43	2,02
IGK-16	1,54	2,10	1,89	1,51	2,04	1,31	3,48	13,88	1,26	1,89
IGK-17	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-
IGK-18	1,32	2,12	1,61	1,58	1,71	1,14	2,94	12,42	1,13	1,70
IGK-19	1,73	1,69	1,62	1,60	2,06	1,42	4,96	15,07	1,37	1,96
IGK-20	1,81	3,26	2,04	1,79	1,81	1,51	3,68	15,90	1,45	2,16
IGK-21	1,36	2,31	1,68	1,51	1,69	1,12	3,15	12,82	1,17	1,74
IGK-22	1,62	1,44	1,95	1,64	2,08	1,37	3,40	13,50	1,23	1,84
IGK-23	1,74	1,85	1,76	1,89	2,39	1,37	3,71	14,71	1,34	2,00
IGK-24	1,86	4,30	2,36	2,11	2,28	1,62	3,78	18,31	1,66	2,47
IGK-25	1,63	2,15	2,32	1,90	2,04	1,36	3,34	14,75	1,34	2,03
IGK-26	1,72	2,63	2,10	1,91	2,04	1,48	3,31	15,20	1,38	2,10
IGK-27	**2,06**	0,00	2,20	2,06	2,37	1,67	5,16	15,52	1,41	2,40
IGK-28	1,96	1,63	2,34	2,11	2,42	1,63	4,62	16,72	1,52	2,25
IGK-29	2,00	2,32	**2,68**	1,98	2,23	1,11	4,65	16,97	1,54	2,24
IGK-30	2,02	6,48	1,96	1,90	2,08	1,69	4,25	20,37	1,85	2,56
IGK-31	1,88	**7,03**	2,08	2,16	2,14	1,69	**5,21**	**22,20**	**2,02**	**2,73**
IGK-32	1,95	1,76	2,24	1,94	1,92	1,61	4,04	15,45	1,40	2,11
IGK-33	1,84	0,00	2,18	1,95	2,07	1,47	3,75	13,25	1,20	2,11
IGK-34	1,71	0,00	2,00	1,60	2,21	1,44	3,73	12,70	1,15	2,01
IGK-35	1,97	4,57	1,84	**2,24**	1,99	1,65	4,01	18,26	1,66	2,42
Mean	**1,66**	**2,26**	**1,83**	**1,60**	**1,98**	**1,37**	**3,77**	**14,47**	**1,32**	**2,07**

Table 6. Pollution indices of Kiris beach samples

Locations	Ti	Cr	Cu	Ni	Zn	Fe	Mn
				EF			
IGK-1	1,15	3,65	2,13	0,00	1,90	1,00	2,75
IGK-2	1,29	0,00	1,56	1,30	1,44	1,00	2,41
IGK-3	1,26	0,00	1,76	1,55	1,73	1,00	2,71
IGK-4	1,26	0,00	0,00	1,36	1,60	1,00	2,42
IGK-5	1,24	2,42	2,25	1,43	0,00	1,00	3,52
IGK-6	1,21	3,79	0,00	1,49	1,77	1,00	2,79
IGK-7	1,22	2,45	0,00	0,00	1,77	1,00	2,95
IGK-8	1,21	2,39	1,75	0,00	1,62	1,00	2,89
IGK-9	1,24	3,69	2,36	0,00	1,74	1,00	2,75
IGK-10	1,18	0,00	1,26	1,20	1,28	1,00	2,48
IGK-11	1,32	0,00	1,57	1,27	1,58	1,00	2,73
IGK-12	1,12	0,00	1,47	1,24	1,45	1,00	2,84
IGK-13	1,13	2,92	0,00	1,06	1,42	1,00	2,45
IGK-14	1,09	2,35	1,46	1,08	1,53	1,00	2,79
IGK-15	1,09	1,87	1,49	1,21	1,39	1,00	3,79
IGK-16	1,17	1,60	1,44	1,15	1,55	1,00	2,65
IGK-17	1,17	1,53	1,47	1,15	1,39	1,00	2,69
IGK-18	1,16	1,86	1,42	1,38	1,50	1,00	2,58
IGK-19	1,22	1,19	1,14	1,13	1,45	1,00	3,50
IGK-20	1,20	2,16	1,35	1,18	1,20	1,00	2,44
IGK-21	1,21	2,06	1,49	1,35	1,50	1,00	2,81
IGK-22	1,18	1,05	1,42	1,19	1,51	1,00	2,48
IGK-23	1,27	1,35	1,29	1,38	1,74	1,00	2,70
IGK-24	1,14	2,65	1,45	1,30	1,40	1,00	2,33
IGK-25	1,20	1,58	1,70	1,40	1,50	1,00	2,45
IGK-26	1,16	1,78	1,42	1,29	1,38	1,00	2,23
IGK-27	1,23	0,00	1,32	1,23	1,42	1,00	3,09
IGK-28	1,20	1,00	1,43	1,29	1,48	1,00	2,83
IGK-29	**1,81**	2,09	**2,42**	**1,78**	**2,01**	1,00	**4,19**
IGK-30	1,20	3,84	1,16	1,13	1,23	1,00	2,52
IGK-31	1,11	**4,16**	1,23	1,28	1,27	1,00	3,09
IGK-32	1,21	1,09	1,39	1,20	1,19	1,00	2,50
IGK-33	1,25	0,00	1,49	1,33	1,41	1,00	2,56
IGK-34	1,18	0,00	1,38	1,11	1,53	1,00	2,58
IGK-35	1,19	2,78	1,12	1,36	1,21	1,00	2,44
Mean	1,21	1,69	1,36	1,14	1,46	1,00	**2,77**

Table 7. Enrichment factor (E_f) results for Kiris Beach samples

The geochemical investigations undertaken in the study area for Cr, Cl, Br, and Sn revealed anomalies in analogous locations (IGK 14, 16, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36). The results of these studies indicated that natural and anthropogenic impacts produced analogous outcomes (*cf.* [8]).

4. Conclusion

The contamination factor (C_f), degree of contamination (C_d), modified degree of contamination (mC_d), pollution load index (PLI) values and enrichment factor (EF) calculated from the chemical composition of the sediments of the Kiris coast exhibited anomalous values. The values calculated based on chemical analyses clearly identified the influence of anthropogenic and natural ultrabasic rocks. Preliminary analyses indicate that the coastline is subject

to the deleterious effects of natural ultrabasic rocks and anthropogenic influence. Consequently, the implementation of comprehensive scientific remedial and environmental measures is imperative to address the heavy metal anomaly observed in the coastal zone.

Acknowledgments

This paper is dedicated to Professor Yilmaz Simsek on the occasion of his 60th anniversary.

This study is based on a part of a master thesis of the first author (I. Gokdal) prepared at Akdeniz University, Institute of Science and Technology.

Author Contributions: The authors contributed equally to this work.

Conflict of Interest: The authors declare no conflict of interest.

Funding (Financial Disclosure): This paper was supported by the Scientific Research Projects Coordination Office with the code number FYL-2018-4090.

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How to cite this article: I. Gokdal, M. G. Yalcin and E. C. Ozcelik, *Index calculations in Kiris (Antalya) beach sediments*, Montes Taurus J. Pure Appl. Math. **6 (3)**, 532–539, 2024; Article ID: MTJPAM-D-24-00236.