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Geochemical Insights into Environmental Studies: A Global Perspective from Western Iran

Perspetivas geoquímicas nos estudos ambientais: uma perspectiva global do oeste do Irão

Samira Abbasi
Department of Geology,
Khorramshahr University of Marine Science and Technology, Iran
https://orcid.org/0009-0009-3536-131X

Saeid Pourmorad
University of Coimbra, Centre of Studies in Geography and Spatial Planning (CEGOT),
University of Coimbra – Faculty of Arts and Humanities, Portugal
omid2red@gmail.com
http://orcid.org/0000-0002-4465-9400

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Abstract

Environmental pollutions are considered a significant challenge in all human societies. Heavy metals, recognized as fundamental environmental pollutants, enter the environment through human activities and can pose various environmental hazards. In this study, a comprehensive investigation of environmental pollutions in Aligudarz County is considered as a strategic point in Iran and serves as a model for similar studies worldwide. The research utilizes geochemical, mineralogical, and statistical approaches to examine pollutions, providing innovative and quantitative insights into understanding the geochemistry of the environment and the relationship between pollutions and environmental factors. The results indicate that the study area is subject to moderate to severe pollution from toxic elements, including molybdenum, lead, cadmium, and copper. These pollutions are correlated with the geochemical, mineralogical, and environmental analysis of the region, and the information derived from this study contributes to environmental management and protection. Considering the research findings, this research model can serve as a global template for environmental studies, playing a crucial role in enhancing understanding of pollutions and advancing knowledge in this field. Therefore, the current research has a broad impact on fostering innovations and advancing knowledge in pollution management and environmental conservation.

Keywords: Environmental pollutions, Heavy metals, Sedimentary geochemistry, Environmental pollutants, Geochemical Study.

Resumo

A poluição ambiental é um dos grandes desafios das sociedades humanas. Os metais pesados, reconhecidos como grandes poluentes, entram no meio ambiente por ação humana e representam riscos ambientais consideráveis. Neste estudo, apresenta-se uma investigação abrangente sobre a poluição ambiental no condado de Aligudarz, considerado um ponto estratégico no Irão, trabalho este que serve de modelo para estudos semelhantes em todo o mundo. A pesquisa utiliza abordagens geoquímicas, mineralógicas e estatísticas, com vista ao exame do índice de poluição detetado, fornecendo perspetivas inovadoras e quantitativas para a compreensão da geoquímica do meio ambiente. Além disso, procura estabelecer a relação entre a poluição e os fatores ambientais. Os resultados obtidos indicam que a área estudada está sujeita a um índice de poluição que vai de moderado a grave provocado por elementos tóxicos, nomeadamente molibdénio, chumbo, cádmio e cobre.

Essa poluição está correlacionada com as análises geoquímicas, mineralógicas e ambientais da região, pelo que as informações decorrentes deste estudo contribuem para a gestão e proteção ambientais. Considerando os resultados obtidos, o modelo apresentado neste artigo pode inspirar a elaboração de um modelo global para os estudos ambientais, desempenhando um papel decisivo na melhor compreensão dos diferentes tipos de poluição e no avanço do conhecimento neste domínio. Nesse sentido, esta pesquisa tem um grande impacto quer na promoção de medidas inovadoras e no avanço científico na gestão da poluição, quer na conservação ambiental.

Palavras-chave: Poluição ambiental, Metais pesados, Geoquímica sedimentar, Poluentes ambientais, Poluentes geoquímicos.

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1. Introduction

Environmental pollutions are recognized as one of the significant and prominent challenges in all human societies (Gueye et al., 2023). Heavy metals are considered one of the primary environmental pollutants worldwide (Chakraborty et al., 2017). In fact, heavy metals are among the pollutants with high stability and persistence that, unlike organic pollutants, do not undergo decomposition through chemical or biological processes in nature (Mohanty et al., 2023). These metals are naturally essential in small quantities for both the human body and the environment. However, at higher concentrations, primarily introduced by human activities, they pose numerous environmental hazards (Kolesnikova et al., 2023(. Aligudarz County, located in western Iran, possesses a unique geographical position that can contribute to the spread of environmental pollution to distant areas. The strategic location of this region plays a crucial role in the distribution and transmission of pollutants at the regional and even global levels (Mohajjel et al., 2003). A comprehensive and precise study of environmental pollutions in this area can be recognized as an effective and efficient global research model. In addition, this research aims to investigate environmental pollutions in the Aligudarz County area in Iran using geochemical, mineralogical, and statistical approaches. This interdisciplinary and innovative perspective on pollution analysis enables the provision of new insights and effective quantitative and qualitative results in understanding the geochemistry of the environment and the relationship between pollutants and various environmental factors. As a result, this study not only contributes to improve the understanding of environmental pollutions in Aligudarz but also serves as a research model applicable globally. Therefore, the current research plays a significant role in advancing knowledge in the field of environmental studies and fostering innovations related to pollution management.

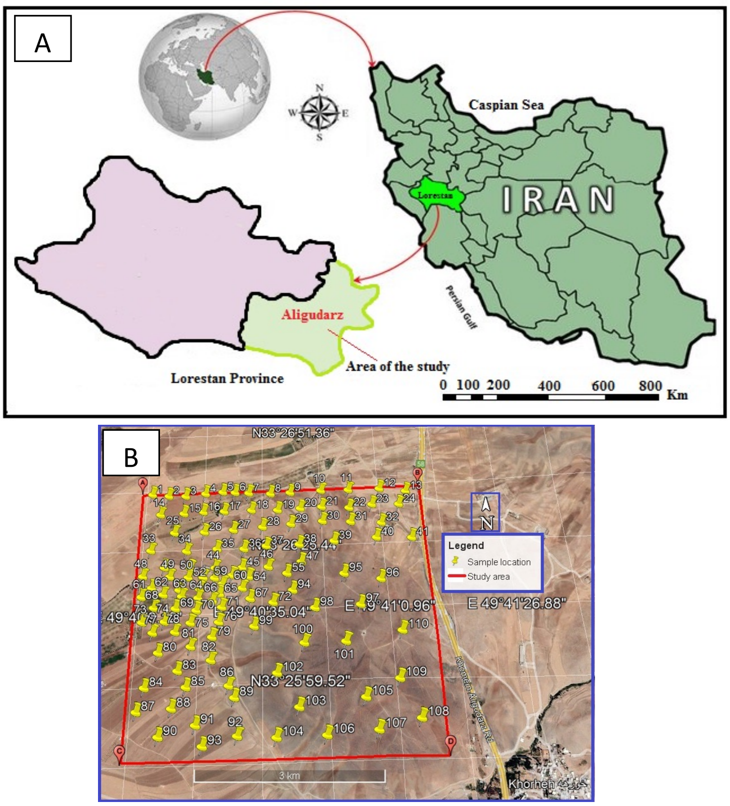

Figure 1
Geographic Location (A) and Sampling Points' Positions (B) in the Study Area.

2. Geological location

The study area is located in the western part of Iran within the boundaries of Aligudarz County, with an approximate geographical position of 49 degrees and 42 minutes east longitude and 33 degrees and 24 minutes north latitude (Dehghani et al., 2022). This county, covering approximately 5,338 square kilometers and having a population of around 145,000 people, is situated in the heart of the Zagros mountain range (Zarasvandi et al., 2019). In terms of climatic characteristics, the region experiences a moderate mountainous climate with cool winters, as indicated by Karimi et al. (2016). The average precipitation in Aligudarz County is variable, ranging from 450 to 800 millimeters per year, and the elevations reach up to 2,000 meters above sea level (Akbari et al. 2023). Aligudarz, positioned at approximately 49 degrees and 42 minutes east longitude and 33 degrees and 24 minutes north latitude, holds a strategic geographical location that has had a significant impact on the development and diversity of natural and cultural resources in the region (Heydari et al., 2024; Porhemmat & Altafi Dadgar, 2023) (Figure 1).

3. Research Methodology

This study comprises two main categories of research: field studies and laboratory experiments. Field studies began after a preliminary review, during which existing data and relevant literature were collected. Using satellite imagery, sites were identified, and subsequent field visits were conducted to gather data. In addition to documenting and studying the sedimentary and geomorphic features of the region, 110 sediment samples (mostly composed of silt, clay, and fine sand) were collected from a depth of 10-20 centimeters below the surface for grain size and geochemical analyses. Geographic coordinates were determined using the Global Positioning System (GPS). Samples were primarily collected from various locations in the floodplain, with a specific focus on the margins of seasonal and perennial water bodies, as they could transport sediment from different sources. Efforts were made to collect mostly dry samples, and naturally moist samples were dried in sunlight to prevent errors in geochemical data. For the analysis of particle size, samples with particle diameters less than 63 microns were processed using the Cilas 1064 laser granulometer wet sieving instrument. Statistical parameters such as mean, median, mode, sorting, elongation, and skewness were calculated using the Sediment Size software. The collected samples underwent analysis at the Institute of Earth Sciences, Iran, using X-ray Diffraction (XRD) and Inductively Coupled Plasma Mass Spectrometry (ICP-MS). Mineralogical analyses were performed using the XRD-7000 X-ray diffractometer. The Perkin Elmer ELAN 6100 DRC-e Inductively Coupled Plasma Mass Spectrometry (ICP-MS) model was employed for accurate measurement of various metallic, non-metallic, and trace elements in the samples. The standard indices have been employed to investigate environmental pollution. One of these indices is the “Accumulation Index of Environmental Earth,” calculated based on the Muller equation (1969). It is used to assess the pollution of samples with various elements.

$$I_{geo} = \log_2 (C_n / 1.5 B_n)$$

In this equation, C_n represents the concentration of measured elements, and B_n is the concentration of elements in reference samples (Muller, 1969).

Moreover, the “Enrichment Factor (EF)” utilizes the equation proposed by Yongming et al (2006) to determine the concentration of elements.

$$EF= (C_x /R)_{Sample} / (C_x /R)_{Reference}$$

In this equation, C_x represents the concentration of the specific element, and R denotes the concentration of the reference element (Yongming et al., 2006).

The Pollution Load Index (Cf) is also calculated using the equation proposed by Hakanson (1980) to assess the contamination of samples with toxic elements. This index reflects the ratio of the concentration of the target element in the study samples to the concentration of the element in the reference samples.

$$CF = [C]\ Sample / [C]\ Background$$

Additionally, the Nemerow Pollution Index (NIP) is employed as a standard index to assess the contamination risk of samples with heavy elements, and it is defined by the equation proposed by Yang et al (2015):

$$NIP = \surd\ Cf^2_{max} * Cf^2_{ave}\ /2$$

Cf_{max}: The maximum value of the pollution index for each element; Cf_{ave}: The average value of the pollution index for each element (Yang et al., 2015).

4. Discussion and Analysis

The conducted studies in this research present multiple results, each of which is individually examined in the following section.

4.1. Sediment Grain Size Studies

The analysis and examination of particle size measurements play a crucial role in understanding the sedimentary environment, enabling the analysis of sediment transport factors, and consequently, identifying the origins of various sediments (Morales et al., 2019; Hernandez-Corder, 2019). The results obtained from the investigation of 110 representative samples are presented in Table 1. Grain size studies indicate that the majority of these samples have a high percentage of silt and clay (Table 1). The presence of these fine particles can play a significant role in the transport of pollutants from upstream areas towards the plain. According to Table 1, the highest percentage of sedimentary particles consists of silt and clay, constituting over 60% in the selected samples. Therefore, the average percentage of silt and clay in the studied samples is 61.59%. Additionally, after silt and clay, sand comprises the highest percentage with an average of 25.7%, followed by gravel with an average percentage of 13.56% (Figure 2).

Table 1

Granulation analysis results for some studied sediments

NO	Mud %	Sand%	Gravel %
1	65.86	25.94	8.21
2	63.05	21.16	25.79
3	60.7	23.48	15.82
4	66.44	21.1	12.46
5	69.34	18.61	12.04
25	63.81	17.7	18.49
26	70.9	16.22	12.88
27	60.03	35.91	4.06
28	58.33	34.77	6.9
51	53.77	34.18	12.05
52	54.2	33.44	12.36
53	54.91	26.86	18.23
54	58.33	24.73	16.94
80	66.28	22.15	11.57
81	63.7	29.5	6.8
82	67.3	25.3	7.4
90	59.4	33.8	6.8
91	61.8	29	9.2
92	59.7	31.6	8.7
93	66.4	27.4	6.2
Average	**62.21**	**26.64**	**11.64**

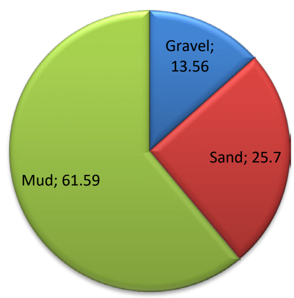

Figure 2
Average percentage composition of sedimentary components in the studied samples.

4.2. Mineralogical Studies

Mineralogical studies of sediments not only provide valuable information about the types of minerals constituting the sediments but also play a vital role in environmental analyses and the identification of pollution sources (Zhang et al. 2021). The conducted research for identifying minerals present in the studied samples (Table 2) indicates that epidote, quartz, orthoclase, and albite are the predominant minerals in these samples. Minerals such as orthoclase and albite are recognized as key minerals in the Earth's crust and can be considered

Table 2

The results of the study of the minerals present in the studied samples (%)

	Minimum	Maximum	Average	Standard Deviation	Range
Albite	3.9	50.1	13.61	10.18	46
Epidote	2.1	10.2	6.51	2.29	8
Orthosis	4.9	11.8	8.49	1.06	7
Quartz	29	72.9	44.93	8.47	46
Pyrite	4.8	22.8	9.57	4.36	19
Chlorite	2.8	28.8	10.72	5.79	25
Eleet	2.1	12.9	7.84	2.19	11
Montmorillonite	2.8	17.8	7.36	3.81	15
Kaolinite	3.9	12.9	7.39	1.81	12
Muscovite	5.2	25.9	11.91	2.96	22
Gypsum	3.1	10.9	7.51	1.71	7
Calcite	1.1	28.8	14.42	8.71	29
Alunite	2.8	6.8	3.91	2.41	4
Butlerite	1.2	13.8	7.18	2.06	14
Blodite	5.1	8.9	8.19	0.49	4
Jarosite	1.9	9.2	6.71	1.89	7
Carfosiderite	3.9	5.9	6.58	0.79	3

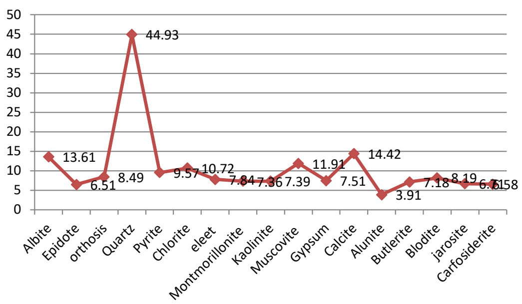

Figure 3
Comparative pie chart of the average percentages of different minerals in the studied samples.

essential resources in environmental buffering capacity, especially in mining areas. Therefore, the investigation of these minerals holds special importance in environmental studies (Patel et al., 2021). Furthermore, in addition to the primary minerals introduced in the studied samples, significant clay minerals such as illite, kaolinite, muscovite, montmorillonite, and chlorite are also notably present (Van der Meer, 2018). These minerals are capable of adsorbing toxic elements present in the soil through cation exchange processes and surface adsorption (MalAmiri et al., 2022). In the studied samples, gypsum minerals (hydrated calcium sulfate) are also observed. The presence of these minerals in the studied samples indicates the acidification of the environment due to the oxidation of various sulfide minerals. The only carbonate mineral identified in the studied samples is calcite, which plays a crucial role in pH variations of the environment and contributes significantly to neutralization capacity and buffering (Figures 3 and 4).

4.3. Elemental Studies

Diverse elements, including Ni, Th, La, V, Y, Co, Ta, Ce, Nb, Ti, Zr, Sc, Cs, preserve their inherent characteristics during various processes such as diagenesis, weathering, and metamorphism (Pourmorad et al., 2021; Wang et al., 2022). These elements possess the capability to retain their primary features, and this capacity can assist researchers in analyzing various geochemical data (Ahamad et al., 2021). For instance, the investigation and identification of environmental pollution are among the fundamental applications of these elements (Espejel-Garcia & Espejel-Garcia, 2022). Furthermore, the examination of diverse Earth characteristics, including tectonic and morphotectonic features, determination of the initial origin of sediments, and ancient climatic conditions, are essential features of these elements (Pourmorad & Mohanty, 2022). The results of elemental measurements (both major and trace) using the ICP Mass Spectrometer are presented in Table 3.

Table 3

The results of the statistical study of toxic elements in the studied samples in terms of PPM

Average in the earth's crust	Variation range	Coefficient of variation	Elongation	Bending	Standard Deviation	Average	Maximum	Minimum	Detection value	
102	136	0.79	2.36	1.5	27.96	35.92	136	3	1.9	Cr
14	1552.04	1.21	6.39	1.37	303.02	256.17	1571	10.39	1.8	Pb
1.2	311.96	0.94	1.07	1.23	68.96	75.05	318	1.6	2.1	Mo
0.15	21.92	1.71	17.59	3.89	3.61	2.18	22.1	0.07	0.04	Cd
950	6459	0.93	1.37	1.36	1419.39	1561.84	6498	59	0.1	Mn
25	139	0.48	3.71	1.29	20.98	46.02	151	8	0.18	Co
70	3598	0.97	0.87	1.29	856.12	898.16	3672	64	0.2	Zn
60	4782	0.57	4.19	1.53	818.06	1491.24	5102	327	0.2	Cu
84	152	0.67	5.16	1.96	26.14	40.08	159	11	2	Ni
1.8	197.11	0.89	1.38	1.56	47.46	52.01	203	4.5	0.49	As

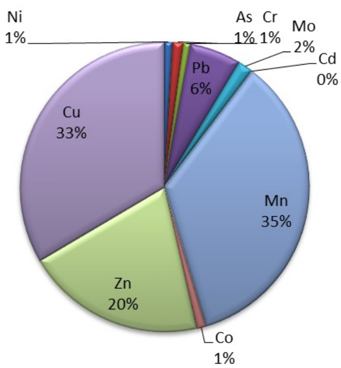

Figure 4
Comparative pie chart of the average percentages of toxic elements in the 110 samples (%).

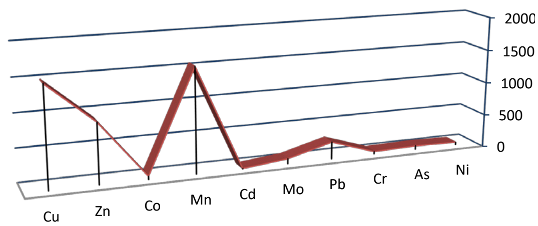

Figure 5
Linear comparison chart of the average concentrations of toxic elements in the studied samples (ppm).

Geochemical studies are conducted to achieve specific objectives such as determining the origin of sediments, assessing environmental pollution, and identifying long-term characteristics, among others (Pourmorad et al., 2022). The results of this research indicate a diverse range of concentrations for various toxic elements.

Examining the extent of variations between the minimum and maximum values of elements reveals a relatively wide range of fluctuations within these minimum and maximum values. Additionally, by examining Table 3, it is evident that the coefficient of variation for these elements (comprehensive statistical community index) is greater than one, indicating potential heterogeneity in the statistical community concerning various variables (toxic elements). Furthermore, through the circular diagram (Figure 4) and linear graph (Figure 5), it becomes apparent that the highest percentage belongs to copper (Cu), zinc (Zn), and manganese (Mn). Additionally, the concentration of some highly toxic elements, such as arsenic (As) and cadmium (Cd), is less than one percent, and the lead (Pb) concentration is 6 percent Due to the significant increase in soil pollution with elements such as copper, zinc, and manganese (similar to the studied samples), this issue may pose a potential hazard (Ahamad et al., 2021; Verma et al., 2021). Additionally, soil contamination with highly toxic elements such as arsenic, cadmium, and lead, even in low percentages, may have adverse effects on living organisms (Bastia et al., 2019; Yongming et al., 2006).

The most important adverse effects that these pollutions have on living organisms include problems such as gastrointestinal discomfort, diarrhea, vomiting, skin cancer, kidney cancer, lung cancer, and urinary tract and bladder problems (Armstrong-Altrin et al. 2020). Cadmium can also have detrimental effects on blood purification and kidney function, as well as consequences such as reproductive issues, infertility, serious neurological problems, and skeletal issues, all of which are negative outcomes of this element in the soil (Tapia-Fernandez et al., 2017). Even at low percentages, the presence of lead can lead to various problems, including anemia, joint problems, heart issues, mental retardation, and severe headaches (Sheikh et al., 2020).

4.4. Statistical Studies

Separately, statistical methods play a crucial role in determining the nature of pollution sources from a human or natural perspective (Espejel et al., 2022). In this article, correlation analysis was employed to investigate relationships between various elements, and the results of these analyses are presented in Table 4. Based on the conducted correlation analysis, three distinct clusters, indicating potential different sources, have been identified. These clusters include: 1. Lead, arsenic, molybdenum, 2. Nickel and cobalt, 3. Lead, zinc, and cadmium (Table 4). Statistical data are capable of delineating elemental relationships and the concentration of each element for various purposes, including pollution source identification (Gun & Park, 2020). In this study, correlation analysis was employed to determine the relationships between toxic elements in the collected samples. According to Table 4, three distinct groups with common origins are distinguishable, namely:

1. Lead, molybdenum, and arsenic
2. Lead, cadmium, and zinc
3. Nickel and cobalt

The results from Table 4 can play a significant role in identifying the origin or variability of these elements. It is worth mentioning that processes related to pollution and oxidation, including the absorption, mobility, and sedimentation of toxic elements, may impact the effectiveness of correlation analysis, leading to less conclusive results.

4.5. Environmental Index Studies

In this research, global standard environmental indicators were used to determine the concentration of different toxic elements in the study area. Environmental data analysis using the Accumulation Index of Soil Pollution indicates that the studied samples exhibit moderate to severe pollution for certain elements (Izah, 2017). In this article, Geoaccumulation index (Igeo), Contamination factor (Cf), Nemro integrated pollution (NIP) and Enrichment factor (EF) are used (Table 5).

According to this index, some samples show moderate to severe pollution levels for elements such as molybdenum (Mo), copper (Cu), lead (Pb), and cadmium (Cd). In contrast, these samples are free of pollution or have low pollution percentages for other elements based on this index. It is noteworthy that a small percentage of samples exhibit low to moderate pollution levels for magnesium (1.3%), nickel (2.9%), and praseodymium (5.3%) (Table 5). The results obtained from the Enrichment Factor (EF) for the studied samples show similar outcomes to the Accumulation Index of Soil. According to this index, the studied samples exhibit moderate to high enrichment for elements such as molybdenum (Mo),

Table 4

The results of the correlation study between the studied elements. Separated numbers indicate significant correlation between data

	As	Cd	Co	Cr	Cu	Mo	Ni	Pb	Zn	Fe	Clay
As	1										
Cd	0/48	1									
Co	0/19	-0/02	1								
Cr	0/25	-0/26	0/13	1							
Cu	0/15	0/23	0/17	-0/17	1						
Mo	**0/64**	0/22	-0/03	0/09	0/60	1					
Ni	-0/14	-0/17	**0/74**	**0/68**	0/42	-0/02	1				
Pb	**0/72**	**0/62**	0/12	-0/13	0/19	0/53	0/31	1			
Zn	0/38	**0/74**	0/19	-0/29	0/13	0/22	0/18	**0/79**	1		
Fe	**0/72**	0/28	0/25	0/62	0/32	0/09	0/16	0/43	0/50	1	
Clay	**0/57**	**0/30**	**0/34**	**0/67**	**0/59**	**-0/25**	**0/26**	**-0/55**	**- 0/6**	**0/58**	**1**

Table 5

The results of the evaluation of environmental indicators (Igeo, EF, Cf, NIPI)

<table>
<tr><th rowspan="2">Element</th><th colspan="2">Igeo</th><th colspan="2">EF</th><th colspan="2">Cf</th><th colspan="2">NIPI</th></tr>
<tr><th>Pollution class</th><th>Percent</th><th>class</th><th>Percent</th><th>Degree of pollution</th><th>Percent</th><th>Amount</th><th>Pollution level</th></tr>
<tr><td>Al</td><td>Completely uncontaminated</td><td>100</td><td>Very low enrichment</td><td>100</td><td>Low</td><td>100</td><td>0.45</td><td>Completely clean</td></tr>
<tr><td rowspan="2">Mg</td><td>Completely uncontaminated</td><td>98.7</td><td rowspan="2">Very low enrichment</td><td rowspan="2">100</td><td>Low</td><td>91.7</td><td rowspan="2">1.39</td><td rowspan="2">Little clean</td></tr>
<tr><td>Uncontaminated to moderate</td><td>1.3</td><td>Medium</td><td>8.3</td></tr>
<tr><td rowspan="2">Ti</td><td rowspan="2">Completely uncontaminated</td><td rowspan="2">100</td><td>Very low enrichment</td><td>98.4</td><td rowspan="2">Low</td><td rowspan="2">100</td><td rowspan="2">0.68</td><td rowspan="2">Completely clean</td></tr>
<tr><td>Medium Enrichment</td><td>1.6</td></tr>
<tr><td rowspan="2">P</td><td rowspan="2">Completely uncontaminated</td><td rowspan="2">100</td><td>Very low enrichment</td><td>98.3</td><td rowspan="2">Low</td><td rowspan="2">100</td><td rowspan="2">0.79</td><td rowspan="2">Clear</td></tr>
<tr><td>Medium Enrichment</td><td>1.7</td></tr>
<tr><td rowspan="2">Mn</td><td rowspan="2">Completely uncontaminated</td><td rowspan="2">100</td><td>Very low enrichment</td><td>97.4</td><td rowspan="2">Low</td><td rowspan="2">100</td><td rowspan="2">0.69</td><td rowspan="2">Completely clean</td></tr>
<tr><td>Medium Enrichment</td><td>2.6</td></tr>
<tr><td rowspan="3">Mo</td><td rowspan="2">Uncontaminated to moderate</td><td rowspan="2">78.4</td><td rowspan="2">Medium Enrichment</td><td rowspan="2">81.6</td><td>Low</td><td>36</td><td rowspan="3">3.07</td><td rowspan="3">Polluted</td></tr>
<tr><td>Medium</td><td>53</td></tr>
<tr><td>Moderate to severe</td><td>21.6</td><td>High Enrichment</td><td>18.4</td><td>High</td><td>11</td></tr>
<tr><td>Zr</td><td>Completely uncontaminated</td><td>100</td><td>Very low enrichment</td><td>100</td><td>Low</td><td>100</td><td>0.68</td><td>Completely clean</td></tr>
<tr><td rowspan="2">V</td><td rowspan="2">Completely uncontaminated</td><td rowspan="2">100</td><td>Very low enrichment</td><td>97.7</td><td rowspan="2">Low</td><td rowspan="2">100</td><td rowspan="2">0.73</td><td rowspan="2">Clear</td></tr>
<tr><td>Low to medium Enrichment</td><td>2.3</td></tr>
<tr><td>Cr</td><td>Completely uncontaminated</td><td>100</td><td>No Enrichment</td><td>100</td><td>Low</td><td>100</td><td>0.68</td><td>Clear</td></tr>
<tr><td rowspan="2">Ni</td><td>Completely uncontaminated</td><td>97.1</td><td>Very low enrichment</td><td>98.6</td><td rowspan="2">Low</td><td rowspan="2">100</td><td rowspan="2">0.69</td><td rowspan="2">Clear</td></tr>
<tr><td>Uncontaminated to moderate</td><td>2.9</td><td>Medium Enrichment</td><td>1.4</td></tr>
<tr><td>La</td><td>Completely uncontaminated</td><td>100</td><td>Very low enrichment</td><td>100</td><td>Low</td><td>100</td><td>0.53</td><td>Completely clean</td></tr>
<tr><td>Nd</td><td>Completely uncontaminated</td><td>100</td><td>Very low enrichment</td><td>100</td><td>Low</td><td>100</td><td>0.52</td><td>Completely clean</td></tr>
<tr><td rowspan="2">Cu</td><td>Uncontaminated to moderate</td><td>83.2</td><td>Very low enrichment</td><td>77.4</td><td>Low</td><td>82.4</td><td rowspan="2">2.77</td><td rowspan="2">Medium</td></tr>
<tr><td>Moderate to severe</td><td>16.8</td><td>High Enrichment</td><td>13.6</td><td>Medium</td><td>17.6</td></tr>
</table>

Table 5

The results of the evaluation of environmental indicators (Igeo, EF, Cf, NIPI)

Element	Igeo		EF		Cf		NIPI	
	Pollution class	Percent	class	Percent	Degree of pollution	Percent	Amount	Pollution level
Pb	Uncontaminated to moderate	79.9	Low to medium Enrichment	85.2	Low	76.2	3.1	Polluted
	Moderate to severe	20.1	High Enrichment	14.8	Medium	23.8		
Nb	Completely uncontaminated	100	Very low enrichment	98.2	Low	100	0.70	Clear
			Medium Enrichment	1.8				
Pr	Completely uncontaminated	94.7	Very low enrichment	98.3	Low	94.7	1.71	Little clean
	Uncontaminated to moderate	5.3	Medium Enrichment	1.7	Medium	5.3		
Sm	Completely uncontaminated	100	Very low enrichment	100	Low	100	0.67	Completely clean
Gd	Completely uncontaminated	100	Very low enrichment	98.4	Low	100 100	0.74	Clear
			Medium Enrichment	1.6				
Dy	Completely uncontaminated	100	Very low enrichment	100	Low	100	0.52	Completely clean
Er	Completely uncontaminated	100	Very low enrichment	96.8	Low	100	0.54	Completely clean
			Medium Enrichment	3.2				
Ta	Completely uncontaminated	100	Very low enrichment	100	Low	100	0.70	Clear
Tl	Completely uncontaminated	100	Very low enrichment	100	Low	100	0.31	Completely clean
Cd	Completely uncontaminated	18.6	Low to medium Enrichment	12.6	Medium	61.2	4.17	Polluted
	Uncontaminated to moderate	56.7	Medium Enrichment	61.7	High	38.8		
	Much	24.7	High Enrichment	25.7				
Zn	Completely uncontaminated	100	Very low enrichment	100	Low	100	0.46	Completely clean
Ba	Completely uncontaminated	100	Very low enrichment	100	Low	100	0.61	Completely clean
K	Completely uncontaminated	100	Very low enrichment	100	Low	100	0.31	Completely clean
Na	Completely uncontaminated	100	Very low enrichment	100	Low	100	0.19	Completely clean
Fe	Completely uncontaminated	100	Very low enrichment	100	Low	100	0.88	Clear

copper (Cu), lead (Pb), and cadmium (Cd). Additionally, a small percentage of the studied samples show low to moderate enrichment for manganese (2.6%), titanium (1.6%), nickel (2.9%), niobium (1.8%), praseodymium (1.7%), gadolinium (1.6%), and erbium (3.2%) based on this index (Table 5).

According to the Contamination Factor (Cf) index, the studied samples show significant contamination for molybdenum (Mo) and cadmium (Cd), low to moderate contamination for copper (Cu), lead (Pb), manganese (Mn), and praseodymium (Pr), and no contamination for other elements (Table 5). The data obtained from the study of contaminations in the studied samples based on the Nemerow Pollution Index (NIP) indicate similar results to other contamination determination indices. According to this index, the studied samples exhibit high contamination for molybdenum (Mo), lead (Pb), and cadmium (Cd), and moderate contamination for copper (Cu). Furthermore, the studied samples show very low to no contamination for other elements (Table 5). In general, the results of the environmental indices indicate that the studied samples have moderate to severe contamination for molybdenum (Mo), lead (Pb), cadmium (Cd), and copper (Cu). Further and more precise studies are required for source identification and prevention of the spread of soil contamination by these elements.

5. Conclusion

The results obtained from this study, aimed at determining the dispersion of various toxic elements using geochemical methods, have yielded multiple achievements, which will be discussed in the following section:

- Grain size studies indicate that the predominant composition of these samples consists of silt and clay. These results provide valuable information that can contribute to understanding the physical characteristics of Quaternary sediments and play a crucial role in the geochemical analysis of sediments.

- Mineralogical studies of the samples through X-ray diffraction analysis have led to the identification of various minerals in primary, secondary, and clay minerals sections. Primary minerals, including epidote, quartz, orthoclase, and albite, are noteworthy in the samples. Clay minerals encompass illite, kaolinite, muscovite, montmorillonite, and chlorite. Secondary minerals such as alunite, barite, and jarosite are also observed in the study samples. The presence of calcite as a carbonate mineral indicates environmental diversity and varied pollution sources. Additionally, some obtained minerals, including rare ones, exhibit characteristics associated with sulfide mineralization zones.

- The study area exhibits moderate to severe contamination in terms of the concentrations of toxic elements such as molybdenum (Mo), lead (Pb), cadmium (Cd), and copper (Cu). Environmental data analysis using the geoaccumulation index indicates that the studied samples are contaminated with molybdenum, copper, lead, and cadmium at moderate to severe levels. According to the Enrichment Factor (EF), the samples show moderate to high enrichment for molybdenum, copper, lead, and cadmium. The Contamination Factor (Cf) suggests that the samples have significant contamination levels for molybdenum and cadmium, while showing low to moderate contamination levels for copper, lead, manganese, and praseodymium. Additionally, the Nemerow Pollution Index (NIP) indicates high pollution for molybdenum, lead, and cadmium, with moderate pollution for copper.

A comprehensive analysis of the research results in the study area indicates a noticeable contamination with toxic elements such as molybdenum, lead, cadmium, and copper in the geochemical context, ranging from moderate to severe levels. These findings align with mineralogical investigations, as primary minerals like epidote, quartz, and orthoclase, as well as secondary minerals such as illite and kaolinite, have been identified as significant pollutants. The diversity in minerals may arise from various climatic conditions and the presence of diverse pollution sources. Overall, this integrated analysis of geochemistry, mineralogy, and environmental aspects highlights the extensive climatic and pollution influences on the geological composition and characteristics of the region. The information derived from this study can contribute to proper environmental management and conservation. The research results not only provide rich information about geochemical pollutants, but also, by linking these data to mineralogical analysis, position this study as a global model.

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