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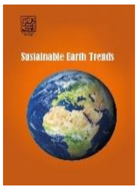

Evaluation of pollution indices in deposited dust (Case study; Qayen cement factory, Iran)

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ABSTRACT

The aim of the present research was to evaluate the ecological risk and assess the chemical accumulation indices and individual contaminant factors in the deposited dust at surrounding of Qayen Cement Factory. The necessity of the research lies in its role in protecting public health and the environment by identifying and mitigating heavy metal pollution, ensuring compliance with environmental regulations, and promoting sustainable practices in industrial operations. For this purpose, dust samples were collected along five axes, at distances ranging from 500 to 1500 meters, in the prevailing wind direction. Two dust samples were taken at each axis, resulting in a total of 10 samples, each collected in triplicate. The concentrations of chromium and cadmium were investigated. The geochemical accumulation index for chromium indicated that it fell into the highest pollution class, while cadmium was classified as non-polluting. The individual contaminant factor values for chromium and cadmium were highest at station 5. The geochemical accumulation index calculation in this study showed that the chromium index was at the highest pollution level in the study zone, while cadmium was positioned in non-polluted environmental conditions. The individual contaminant factor indicated that both chromium and cadmium had ICF values greater than 1, suggesting high bioavailability, which could be dangerous for the study area. This result indicates that the contaminants in the dust from Qayen Cement Factory were highest at station 4, likely due to higher chimney output in this direction compared to other stations. The geochemical accumulation index calculation in this study showed that the chromium index was in the highest pollution degree. The study reveals significant ecological risks due to high chromium pollution and bioavailability in dust around the Qayen Cement Factory, necessitating urgent monitoring and mitigation efforts.

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1. Introduction

Heavy metals are naturally occurring elements known for their high atomic weights and densities, which can pose toxic risks to human health and the environment, even in low concentrations. Common heavy metals include lead, mercury, cadmium, arsenic, chromium, and nickel. Their pollution is a significant environmental issue due to their persistence in ecosystems and potential for bioaccumulation. Sources of heavy metal pollution can be divided into natural origins, such as the weathering of rocks and volcanic activity, and anthropogenic sources, which encompass industrial processes, agricultural practices, waste disposal, and urban runoff (Mitra et al., 2022; Malekei et al., 2024). Industries are significant contributors to heavy metal pollution, releasing these harmful elements through various channels, including emissions, effluents, and solid waste. Key sectors such as mining, metallurgy, and manufacturing play a vital role in this pollution, contaminating air, water, and soil. The environmental impact of industrial activities can pose serious health risks to communities near polluted areas, highlighting the importance of effectively identifying and managing these sources (Mokarram et al., 2020).

Among the industries that significantly contribute to heavy metal pollution is the cement industry. The production of cement involves the extraction and processing of raw materials like limestone and clay, which may contain trace levels of heavy metals. Furthermore, the combustion of fossil fuels and alternative fuels in cement kilns emits metals such as mercury and lead into the atmosphere. The incorporation of waste materials, such as slag and fly ash, as raw materials can further introduce heavy metals into the production process. Tackling pollution from the cement industry is crucial for safeguarding public health and maintaining environmental quality (Moslempour and Shahdadi, 2013; Shahri et al., 2020).

The cement industry is among the largest industries in the country and, considering the application and key role of cement in various sectors, it possesses significant economic importance. The main issues of the cement-producing industry, like other industrial segments, are its environmental impacts and its stable role in the advancement trend (Lee at al., 2008). Although these factories are generally established far from urban centers, the regional zones are still affected by their negative impacts. The most important side effect of cement factories on their surrounding environment is the dissemination of dust containing toxic metals (Shahri et al., 2020). Heavy metals are a major source of toxicity in the environment, as most living entities cannot tolerate concentrations above natural limits (Malekei et al., 2024).

Heavy metals play a dual role in biological processes: as micronutrients (iron, zinc, copper, manganese, cobalt, and molybdenum) and as toxic factors (mercury, silver, chromium, Cd, lead, and nickel). Various activities lead to the distribution of heavy metals in the atmosphere, resulting in their accumulation as contaminated dust on soils. Contaminated soils can, in turn, produce dust under windy conditions, affecting air quality (Kalteh et al., 2020). The progression of heavy metals in soil is an extended process. Insoluble metals accumulate in the environment, and their dangers increase over time. To protect the environment and health from heavy metal pollution, it is crucial to have a thorough understanding of the nature and extent of heavy metal contamination (Sayadi and Torabi, 2009).

Regarding heavy metals present in dust, several studies have been conducted in Iran and worldwide. Yang and Wei investigated heavy metals in urban soils, road dust, and agricultural soils in different cities across China. Their measurements indicated that the concentration of heavy metals in these areas was higher than the local soil values of China (Yang and Wei, 2010). Akbari and collages in their study on the spatial changes of heavy metals, specifically Cr, in the soil surrounding the Behbahan Cement Factory, concluded that the average concentration of Cr in the soil samples was lower than the standard level (Akbari and Azimzadeh, 2013). The necessity of this research is crucial for safeguarding public health and preserving environmental integrity. By identifying and mitigating heavy metal pollution, the role contributes to reducing health risks associated with contaminated air and dust, which can lead to serious health issues in nearby communities (Isinkaralar et al., 2024). Furthermore, ensuring compliance with environmental regulations helps prevent legal repercussions for industries while promoting accountability and responsible practices. This position also plays a vital role in advancing sustainable industrial operations, encouraging the adoption of cleaner technologies and practices that minimize environmental impact. Ultimately, the work fosters a healthier ecosystem and enhances the quality of life for local populations, making it an essential function in today's industrial landscape. Therefore, the aim of the present research was to evaluate the ecological risk, chemical accumulation indices, and individual contaminant factors in the deposited dust at Qayen Cement Factory located nearby Qayen city, South Khorasan Province, Iran.

2. Material and methods

2.1. Study area

Qayen City is located at 33˚43’ latitude and 59˚11’ longitude. The Qayen Cement Factory is situated 12 km along the Qayen-Birjand road, nestled in proximity to limestone and alluvium deposits (Fig. 1). Fig. 2 shows the wind direction in the study area. The Qayen Cement

Factory was registered in 1981 in the Companies Registration Office for grey cement production with a daily capacity of 2000 tons. After economic and technical assessments, the site for Qayen Cement Factory was selected 12 kilometers along the Qayen-Birjand road, near limestone and alluvium mines. Production at Qayen Cement Factory began in December 1994. In 2006, following the successful execution of the capacity increase plan, the factory's daily production increased to 2600 tons. In 2008, the highest production of clinker and cement reached 834,739 tons and 815,624 tons, respectively. The products of this company include Portland cement type 1-325, type 1-425, type 2, type 5, and Pozzolana Portland cement (The factory’s environment and mine management report–EMS, 2013, Extensive Sustainable Improvement).

2.2. Sampling

In this research, dust samples were collected and analyzed for heavy metals (Cr and Cd) concentration around the Qayen Cement Factory. Sampling was conducted in summer season along five axes within a distance range of 500 to 1500 meters in the prevailing wind direction. Four dust samples were taken from each axis, resulting in a total of 20 samples. After collection and transport to the laboratory, the samples were air-dried, passed through sieves of different sizes, and classified as aerosols smaller than 63 µm. 1g of each dust sample was mixed with 60% nitric acid and digested. After 24 hours, the samples were heated at 80˚C for 30 minutes, then filtered through Whatman paper 42, and finally diluted to a volume of 25 ml with 1% nitric acid (Adekola et al., 2012; Ogunkunle and Fatoba, 2014; Sayadi et al., 2015).

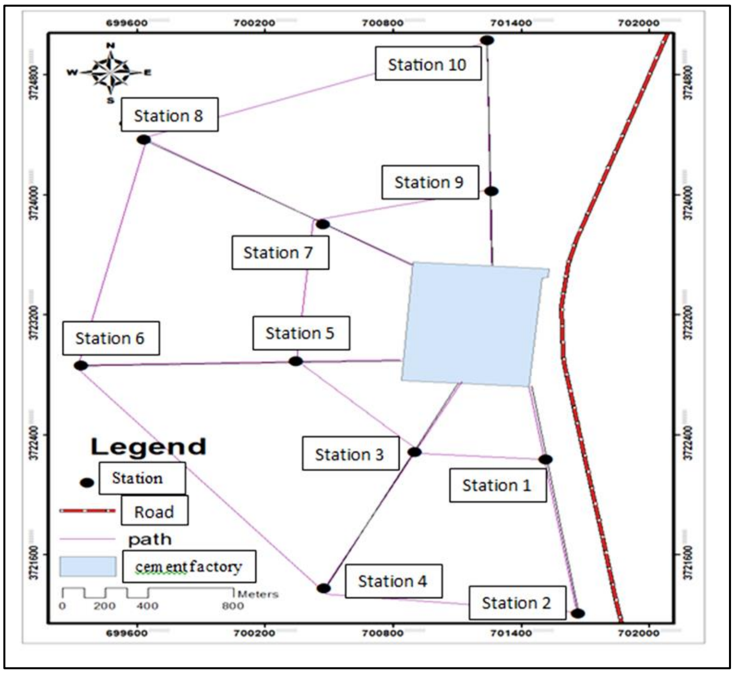

Fig. 1. Sampling points surrounding Qayen Cement Factory.

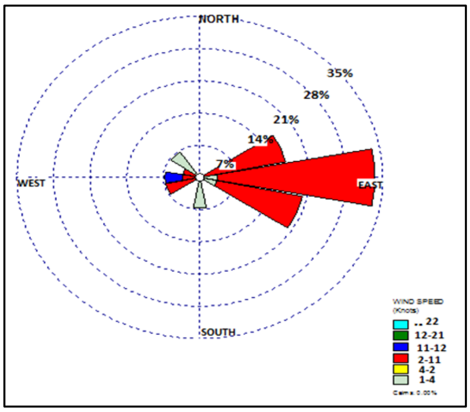

Fig. 2. The wind rose of Qayen meteorology in autumn season.

The total concentration of the heavy metal Cr and Cd was measured using Atomic Absorption Spectrophotometer (Shimadzu; AA-7000 series) by flame mode, with detection limits for Cd (0.5) and Cr (0.1) mg/L.

2.3. Data analysis

After the laboratory analysis of the samples, the data was processed and analyzed using Excel 2010 software. Excel 2010 was used for data organization, visualization, and initial calculations. This combination of software facilitated comprehensive data analysis, enabling the researchers to draw meaningful conclusions about the concentration and distribution of heavy metals in the dust samples collected around the Qayen Cement Factory.

2.4. Calculation of pollutant indices

In this study, the Geochemical Accumulation Index (Igeo), Individual Contaminant Factor (ICF), and Ecological Risk Index (RI) were utilized to assess heavy metal pollution in the dust around the cement factory.

2.4.1. Geochemical Accumulation Index

The Geochemical Accumulation Index (Geoaccumulation Index) was introduced by Muller (1986). It is calculated according to Eq. 1:

$$\text{Igeo} = \text{Log}_2\left(\frac{C_n}{1.5\,B_n}\right) \quad \text{(Eq. 1)}$$

In this equation, (C_n) represents the concentration of the case study toxic metal in the dust sample, and (B_n) is the geochemical concentration rate of the toxic metal in the field. The constant 1.5 is introduced to minimize the potential effects of variations in field values that could be related to petrology variations of the deposits (Sayadi and Sayyed 2010). The Igeo index is comprised of seven degrees (0-6) ranging from non-polluted to severely polluted, as depicted below (Table 1).

Table 1. Classification of geoaccumulation index

Pollution class	Index domain
Non polluted environment	Igeo≤0
Non polluted to medium pollution	0<Igeo<1
Medium pollution	1<Igeo<2
Medium pollution to severe pollution	2<Igeo<3
Severe pollution	3<Igeo<4
Severe pollution to maximum pollution	4<Igeo<5
Maximum pollution	Igeo>5

2.4.2. Ecological risk potential index

The Ecological Risk Index (RI) was introduced for the first time to assess the pollution of heavy metals in soil, based on metal toxicity, environmental reactions, and ecological risk assessment of aquatic deposits by Hakanson (1980). The calculation methodology of RI according to Eqs 2-4 is as follows:

$$\text{PI} = \text{Cs}/\text{Bn} \quad \text{(Eq. 2)}$$

$$\text{ER} = \text{Tr} \times \text{PI} \quad \text{(Eq. 3)}$$

$$\text{RI} = \sum_{i=1}^{m} \text{Er} \quad \text{(Eq. 4)}$$

In these equations, (Cs) is the concentration of the case study metals, (Bn) is the field concentration, (PI) is the pollution index, (ER) is the ecological risk index for each of the elements, (RI) is the ecological risk of all elements combined, and (Tr) is the toxic response coefficient of each metal. The defined toxicity coefficients for metals are as follows: Zn=1 < Cr=2 < Cu=Ni=Pb=5 < As=10 < Cd=30 (Sayadi et al., 2020). For the analysis of the obtained values, four different classes are defined as shown in Table 2.

Table 2. Classification of RI and ecological risk values.

Ecological risk rate	RI value
Low ecological risk	RI<150
Medium ecological risk	150<RI<300
Significant ecological risk	300<RI<600
Very high ecological risk	RI>600

3. Results and discussion

3.1. Geochemical Accumulation Index (Igeo)

The variation trend of the geochemical accumulation index for Cr in the study zone indicated that it is in the highest pollution class. In contrast, for Cd, the results from the Table 3, with values below zero, indicate that it falls into the non-polluted environment class. The highest Igeo value for Cr was 9.2 at station 5, located near the green belt landscape of the factory, while the lowest value was 8.09 at station 1. For Cd, the highest level was -4.74 at station 4, and the lowest level was -6.38 at station 1 (Table 3). Mousavi and Pournia studied the soils around the Karoon Cement Factory, compared the results with standards, and assessed indices such as the geochemical accumulation index. They reported that, to date, the Karoon Cement Factory had no significant pollution impact on the surrounding soils concerning these metals (Moosavi and Pournia, 2013). Table 3 shows that the variation trend of the geochemical accumulation index for Cr was at a high level, whereas the Cd levels were much lower, exhibiting negative values and falling below the first degree of this index (Liu et al., 2024).

Table 3. Concentration of metals and geochemical accumulation index in the dust of case study zone.

Station	Metal concentration Cr mg/kg	Igeo-Cr	Metal concentration Cd mg/kg	Igeo-Cd
1	8.09	6.551	0.09	-6.381
2	8.32	6.592	0.205	-5.193
3	8.33	6.594	0.208	-5.172
4	8.72	6.66	0.28	-4.743
5	**9.2**	**6.737**	**0.31**	**-4.597**
Average		6.6268		-5.2172

3.2. Individual Contaminant Factor (ICF)

The Individual Contaminant Factor (ICF) exhibits the bioavailability value of metals; the higher this value, the greater the metal access. If the ICF value is lower than 1, the metal concentration is not dangerous for the environment. Table 4 tabulates the ICF values. The obtained factors for the case study metals in this study indicated that both Cr and Cd have high bioavailability (ICF>1) and can be dangerous to the environment. For Cr, the highest ICF value was 3.597 at station 5, and the lowest value was 3.50 at station 2. For Cd, the highest ICF value was 4.27 at station 5, and the lowest value was 1.881 at station 2. The results indicate that the Individual Contaminant Factor (ICF) for both metals were highest at station 5, near the green belt landscape of the factory, which could pose the greatest danger to the environment (Chen et al., 2023). As shown in Table 5, the ecological risk level at station 5 is medium (155.2), while the other stations are low. Dust from various industries, especially cement factories, has been extensively studied due to the significance of heavy metals in the dust. The entry of heavy metals into the human body can lead to their accumulation in tissues, affecting the bloodstream and nervous system. Additionally, these metals can disrupt the normal functioning of internal organs or contribute to the development of other diseases (Sayadi et al., 2020; Das et al., 2023). Akbari and collogue in their research in Behbahan, stated that the effect of a factory on the Cr concentration in the surrounding environment is significant up to a distance of 660 meters, beyond which the differences become less pronounced (Akbari and Azimzadeh, 2013).

Table 4. Individual contaminant factor index values of Cr and Cd in the case study zone.

Station	ICF Cr	ICF Cd
1	3.543	3.909
2	3.504	1.881
3	3.569	3.492
4	3.542	2.989
5	3.579	4.27
Average	3.5474	3.3082

Table 5. Metals concentration and ecological risk of heavy metals in the dust of case study zone.

Station	Cr		Cd		RI	Ecological risk
	Concentration mg/kg	Er	Concentration mg/kg	Er		
1	58.74	6.76	0.28	42	48.76	low
2	29.87	3.44	0.35	52.5	55.94	low
3	29.59	3.40	0.66	99	102.4	low
4	31.46	3.62	1.01	151.5	155.12	medium
5	32.44	3.73	0.49	73.5	77.23	low

Gupta and Sharma during their research in Bikaner, reported that the prevailing wind direction influences the distribution of heavy metals present in cement dust (Gupta and Sharma, 2013). Isikli and collogues in a study conducted in Turkey, concluded that the average Cr concentration in soil samples around a cement factory was lower than the determined standard level for Cr (Isikli et al., 2006). Mousavi and Pournia investigated the distribution of heavy metals in the agricultural soils around Karoon Cement Factory and reported that the accumulation trend of heavy metals in the surface soils around the zone was as follows: Cr>Zn>Ni>Pb >Cu>Co>Cd. The results indicated that the origin of heavy metal accumulation is primarily due to dust enriched with heavy metals from cement production (Moosavi and Pournia, 2013). Al Khashman and Shawabe conducted a study on the distribution of heavy metals in the soils surrounding a cement factory in southern Jordan. Their results showed that the heavy metal concentrations in the soils around the cement factory were lower than the standard levels (Al Khashman and Shawabe, 2006). Moslampour et al. studied the distribution of heavy metals (nickel, copper, lead, Cd, and Cr) in the soils around Khash Cement Factory. The results showed high levels of these elements, with the average concentrations in the soils around the factory being higher than the global averages (Moslampour et al. 2013).

Moosavi and Pournia studied the distribution of heavy metals surrounding Karoon Cement Factory and concluded that there exists a significant correlation between the heavy metals at all sampling points. Additionally, the distribution trend of heavy metals in the soils around Karoon Cement Factory showed an equilibrium and relatively uniform state, decreasing in value as one moves away from the pollution source (Moosavi and Pournia, 2013).

Ogunkunle and Fatoba studied the soil around the Mega Cement Factory and, through the correlation coefficient between different metals, concluded that Cd and Cr have a negative correlation coefficient (r=-0.383) at the 0.05% level (Ogunkunle and Fatoba, 2014), in their studies on cement dust in the United States and Nigeria, reported average nickel and Cr levels of 597.5 µg/g and 75.45 µg/g in the United States, and 17.34 µg/g and 91.67 µg/g in Nigeria, respectively. The calculation of correlation coefficients in different gradings and chemical separation stages showed a high correlation between Cr levels at a distance of 1500 meters and 500 meters, as well as between Cd levels at the same distances. The ecological risk calculation demonstrated that all sampling stations had low ecological risk, except for station 4, which showed medium ecological risk (Adekola et al., 2012; Kolo et al., 2018; Jafari et al., 2023).

4. Conclusions

The findings reveal that the highest levels of contaminants in the dust from the Qayen Cement Factory were observed at station 4, likely due to increased chimney emissions in that direction compared to other locations. The geochemical accumulation index indicated that chromium (Cr) was classified within the highest pollution category in the study area, while cadmium (Cd) was deemed non-polluting. Additionally, the individual contaminant factor showed that both Cr and Cd had ICF values exceeding 1, suggesting high bioavailability that could pose risks to the region. Referring to Table 3 and the wind rose, the prevailing eastern winds in autumn led to elevated levels of Cr and Cd at stations 7, 8, 9, and 10, which are situated near the factory's green belt and adjacent to the area's agricultural lands. Managers and authorities should implement regular monitoring of heavy metal concentrations around the Qayen Cement Factory and enhance emission controls to reduce pollution. Community awareness programs should be initiated to educate residents about health risks. Strengthening regulatory compliance and promoting sustainable practices within the industry are essential. Collaboration with environmental agencies will further support efforts to mitigate ecological risks and protect public health.

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