Balkh International Journal of Natural Science

ISSN – P 0000 -0000 E: 0000- 0000
Vol. 1 NO.1 2025
URL: https://bjns.ba.edu.af/index.php/bjns

Assessment of the Spatial Distribution of Heavy Metal Contamination of Soils Surrounding the Ghori Cement Factory Using the Contamination Factor (CF) Index

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Received: 04/7/2025 Accepted: 31/10/2025 Published: 20/12/2025

Abstract

Soil contamination with heavy metals, particularly around cement factories, is among the most pressing environmental and public health concerns. This study aimed to assess the contamination of surface soils surrounding the Ghori Cement Factory, which has operated for years without due consideration of its environmental impacts. The concentrations and contamination levels of heavy metals, including mercury (Hg), arsenic (As), cadmium (Cd), lead (Pb), chromium (Cr), nickel (Ni), cobalt (Co), and aluminum (Al), were examined. Seventeen soil samples were collected from inside and around the factory based on prevailing wind directions. The samples were chemically digested following the international standard method (ISO 11466), and metal concentrations were measured using atomic absorption spectrophotometry.The degree of soil contamination was assessed using the Contamination Factor (CF) index. The results showed that aluminum, nickel, chromium, and cobalt levels indicated low

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contamination, while lead and cadmium reflected moderate contamination. Arsenic and mercury exhibited high to very high contamination levels. The highest CF value was observed for mercury, with an average exceeding 14, indicating very severe contamination. The increasing CF values toward the southeast direction of the factory and proximity to the pollution source highlight the direct impact of industrial activities on soil contamination. This severe contamination poses potential environmental and health risks, emphasizing the need for effective monitoring and control measures.

Keywords: Soil contamination, Mercury, Contamination Factor (CF) index, Heavy metals, Cement factory.

1. Introduction:

Irreversible changes, often resulting in extensive and complex consequences, stem from human activities impacting the Earth. Over time, alterations in water, soil, and air disrupt the balance and stability of ecosystems, lead to environmental degradation, and contribute to pollution. Such pollution currently represents one of the most significant environmental, health, and economic challenges (Stafilov et al, 2010).

Soil is a natural resource whose renewal is difficult. Research indicates that the average global soil formation rate ranges from approximately 10.93 to 114.27 millimeters per century. In arid environments, numerous interactions and reactions occur among the solid, liquid, gas phases, and living organisms within the soil, which serve as a vital ecological crossroads. Due to human activities or natural processes, soil degradation happens gradually and continuously over long periods. These consequences are long-lasting and typically irreversible within a human lifetime (Stockman et al., 2014).

One of the most critical issues facing humanity in contemporary societies is environmental pollution. Currently, the primary soil pollutants include heavy metals, acid rain, and organic substances. Although heavy elements naturally exist in soil, due to the high sensitivity of this ecosystem, soil is easily exposed to metal contaminants. Because of the toxic characteristics of metals in soil, this issue has received significant attention in recent years (Baidourela et al., 2021; Zhang et al., 2018).

The occurrence of negative environmental impacts and destructive effects on the health of living organisms can result from increased levels of heavy elements such as lead, chromium, and cadmium in water, soil, and air (Sadegh et al., 2018). In most regions, heavy metal infiltration into the soil due to human activities exceeds natural rates (Liu et al., 2005). Most heavy metals cause toxicity in living organisms, and even excessive amounts of essential elements can lead to poisoning. Heavy metals are involved in biochemical processes that pose risks to human health, plant growth, and animal life (Akbar et al., 2006).

Certain heavy elements such as lead, nickel, chromium, zinc, and iron are of significant environmental concern due to their persistence, accumulation in soil, and eventual entry into the food chain. Among these, elements that are highly toxic and pose serious risks to human health include lead, nickel, and chromium (Gevorgyan et al., 2017).

In recent years, the rapid growth of industry and urbanization has led to a significant increase in the production of dust and airborne particulate matter, reaching millions of tons annually. These pollutants pose a substantial threat to the environment and human health (Rai. 2011). Among various industries, the cement industry is one of the major contributors to dust emissions due to the nature of its production processes (Zeleke et al., 2010).

Dust particles released from cement factory chimneys combine with other airborne pollutants, not only contaminating the surrounding soil but also having detrimental effects on plants and agricultural crops. In addition, they contribute to the deterioration of textiles and the corrosion of metal equipment (Mosavi et al., 2015).

Cement factories are considered among the most polluting industries in the world and are major sources of heavy metals such as cadmium (Cd), chromium (Cr), lead (Pb), nickel (Ni), manganese (Mn), copper (Cu), and zinc (Zn), which are released into the environment during various stages of the cement production process (Yahya et al., 2013). Heavy metals are of particular concern even at low concentrations due to their impact on microorganisms and their physiological effects on humans and other living organisms (Saeb et al., 2015).

Given the environmental problems caused by dust emissions from the Ghori Cement Factory, along with their adverse effects on human health and surrounding ecosystems, it is essential to conduct research on the pollutants deposited into the soils around this facility.

2. Materials and Methods:

2.1. Study Area Description:

As shown in Figure 1, the Ghori Cement Factory is located north of Pul-e-Khumri city, adjacent to the Baghlan River, in a region with a moderate climate characterized by hot summers and very cold winters. The site lies at an elevation of 634 meters above sea level, between the longitudes 68°40′41.04″ to 68°41′38.05″ E and latitudes 35°57′33.08″ to 35°58′31.44″ N (Google Earth, 2025). The study area encompasses a one-kilometer radius around the factory. To the west of the factory lies a mountain that serves as the source of raw cement materials (limestone), while residential areas and agricultural lands occupy the other three directions. The factory is situated near the city of Pul-e-Khumri, where the majority of the population resides within a one to four-kilometer radius.

The Baghlan River flows alongside the factory from south to north, and its water is utilized for various purposes, including industrial processes within the factory, agriculture, and horticulture. The factory employs 812 individuals in various departments, including production, technical operations, mining, services, security, and gardening. The land use around the factory includes industrial, residential, agricultural, green areas, recreational spaces, horticulture, and a fish hatchery.

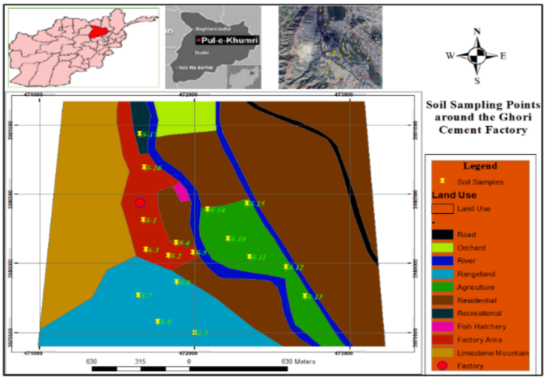


Figure 1: Geographical Location of Ghori Cement Factory (Nazari. 2025)

2.2. Sampling and Sample Preparation

In order to conduct this study, a total of 17 surface soil samples were randomly collected from the vicinity of the Ghori Cement Factory during the autumn of 2023, from a depth of 0 to 15 cm, taking into account the prevailing wind direction in the area. The locations of the sampling points are shown in Figure 1. Subsequently, 16 of these samples were composited together for analysis, as illustrated in Table 1. In the end, chemical digestion was performed on 7 composite samples and 2 individual samples, which were considered as control and reference samples. The chemical digestion process was carried out in accordance with the international standard method ISO 11466-1996. Based on this method, soil samples were air-dried for 24 hours, then sieved using a 2 mm mesh (mesh 60).

Exactly 3 grams of soil were weighed using a scale with 0.001 g precision and placed into a sterilized beaker. Then, 1 mL of distilled water was added for moistening. After mixing, 21 mL of concentrated hydrochloric acid (37%) was added to the soil. Once the reaction was completed, 7 mL of concentrated nitric acid (65%) was added. After the fumes dissipated, 15 mL of 0.5 M nitric acid was added to the contents of the beaker. The beaker was then covered with a sterilized watch glass and left at room temperature for 16 hours. Afterward, the beaker was placed on a hot plate for 2 hours to evaporate part of the solution until one-third of the original volume remained. Once cooled, 10 mL of diluted nitric acid (0.5 M) was added to each beaker. The resulting solution was filtered using filter paper and a volumetric flask, and the volume was adjusted to 100 mL with distilled water. Finally, the extract was transferred into plastic bottles for further analysis.

In this study, the concentrations of heavy metals (Cadmium, Cobalt, Nickel, Mercury, Arsenic, Lead, Chromium, and Aluminum) were measured using the Atomic Absorption Spectrophotometer (AAS). To assess the level of soil contamination by heavy metals, the Contamination Factor (CF) index was used.

2.3. Contamination Factor (CF)

To evaluate the degree of soil contamination, the Contamination Factor (CF) is used. This index is calculated by dividing the concentration of a given element in the collected sample by the concentration of the same element in the background (reference) sample. It reflects the level of contamination of the soil by trace elements and is determined using Equation 1:

$$C_i^i = \frac{C_i}{C_{ri}} \quad (1)$$

Where:

C_f^i Is the contamination factor of element *i*, C_i is the concentration of element *i* in the soil sample from the study area, C_{ri} is the concentration of the reference element (Cabrera et al., 1999).

In this study, the background concentration of each element was determined from the control (reference) sample.

Table 2. Classification of Contamination Factor (Hakanson., 1980 ;Kowalska et al., 2018)

Class	Contamination Factor (CF)	Soil Quality
1	CF < 1	Low contamination
2	1 ≤ CF < 3	Moderate contamination
3	3 ≤ CF < 6	Considerable contamination
4	CF ≥ 6	Very high contamination

3. Research Findings

In this study, the concentrations of heavy metals (lead, nickel, chromium, cadmium, cobalt, mercury, arsenic and aluminum) in the soil samples were evaluated using the Contamination Factor (CF) index. The calculated CF values for each heavy metal are presented in Table 3**.**

Table 3: Contamination Factor (CF) of Heavy Metals in Soil around the Ghori Cement Factory

No	Sample	Station Location	Pb	Ni	Cr	Cd	Co	Hg	As	Al
1	F/115	Inside Factory	0.952	0.288	0.04	1.818	0.717	16	3	0.573
2	F/116	Inside Factory	0.262	0.125	0.036	3.939	0.507	14.333	2.8	0.367
3	F/117	Inside Factory	1.429	0.183	0.03	4.848	0.433	15.333	3.067	0.583
4	F/118	South of Factory	1.19	0.3	0.037	2.121	0.767	15.556	3.156	0.607
5	F/119	South of Factory	0.952	0.314	0.04	1.212	0.757	15.111	3.378	0.67
6	F/120	SE of Factory	0.976	0.263	0.036	0.909	0.687	14.333	3.289	0.653
7	F/121	SE of Factory	1.31	0.3	0.03	1.818	0.807	16.556	3.578	1.033
8	F/122	East of Factory	1.048	0.277	0.027	1.515	0.763	15.333	3.444	0.773
9	F/123	North of Factory	1.429	0.3	0.026	3.333	0.727	15	3.422	0.753
Average			1.061	0.261	0.033	2.391	0.685	15.284	3.237	0.668

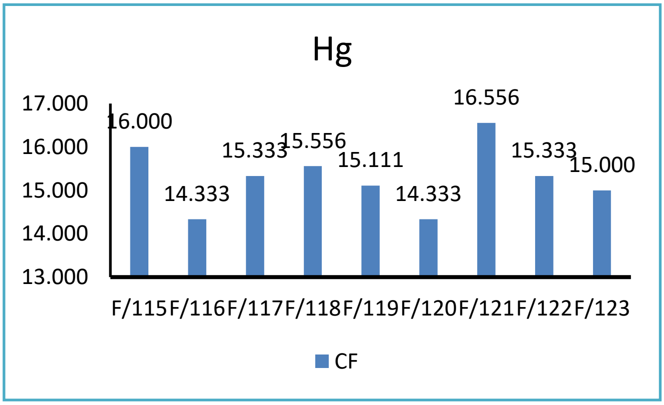
Based on the comparison between the average Contamination Factor (Cf) values of heavy metals presented in Table 3 and the classification of contamination levels shown in Table 2, the studied soil shows the following characteristics:

According to the average Cf values, the elements aluminum, nickel, chromium, and cobalt (indicated in light yellow) fall under the *low contamination* class. The elements lead and cadmium (indicated in orange) fall under the *moderate contamination* class. However, **arsenic** (indicated in light red) falls under the *considerable contamination* class, while mercury (indicated in dark red) falls under the *very high contamination* class.

Thus, the studied soil is not significantly contaminated in terms of aluminum, nickel, chromium, and cobalt. However, moderate contamination is observed for cadmium and lead, and severe to very high contamination is detected for arsenic and mercury, respectively, indicating serious environmental pollution risks.

Mercury (Hg):

According to the results presented in Table 3, mercury is identified as the most contaminating heavy metal in the studied soil based on the calculated Contamination Factor (Cf). The concentrations of this element in all samples exceed the standard threshold. As shown in Figure 2, the highest mercury contamination was observed in sample F/121 (located southeast of the factory), while the lowest was found in sample F/116 (representing dust settled on the administrative building of the factory). Additionally, based on Figure2, the contamination factor for mercury increases with proximity in the southeastern direction from the factory, while it decreases in the southern direction.



2: Figure Contamination Factor (Cf) of Mercury (Hg) in Soil Samples

Arsenic (As):

According to the Contamination Factor (Cf) of arsenic, as presented in Figure 3 and Table 3, all soil samples fall within the moderate to considerable contamination classes. On average, however, the contamination level is categorized as considerable, indicated by light red color. The highest contamination factor for arsenic was observed in the sample collected southeast of the factory, while the lowest was found in the samples collected within the factory premises and from limestone. Moreover, as shown in Figure 3, the contamination factor of arsenic increases in the southern and southeastern directions as the distance from the factory increases.

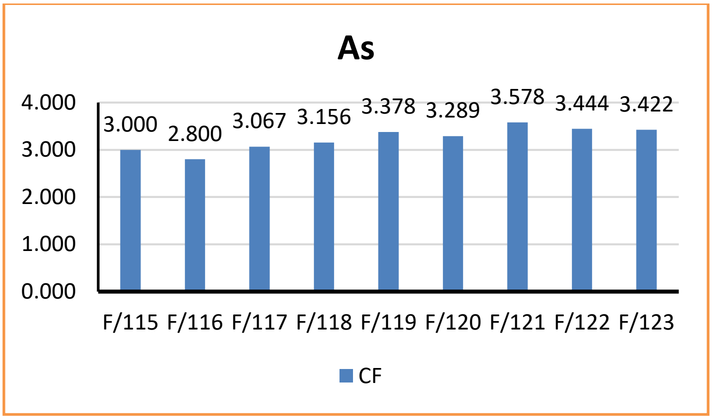


Figure 3: Arsenic Pollution Index in Soil Samples

Cadmium (Cd):

Based on the quality of the studied soil according to Table (2) and Figure (4), and according to the Pollution Factor Index, all soil samples examined fall within the moderate to severe pollution class for cadmium. However, their average classification indicates a moderate pollution level. The maximum pollution index for cadmium corresponds to the soil sample inside the factory (Sample 3), while the minimum is related to the soil sample in the southeastern part of the factory (Sample 6). As clearly shown in Figure (4), the cadmium pollution index decreases as the distance from the factory increases toward the south, and conversely, it increases toward the southeastern direction.

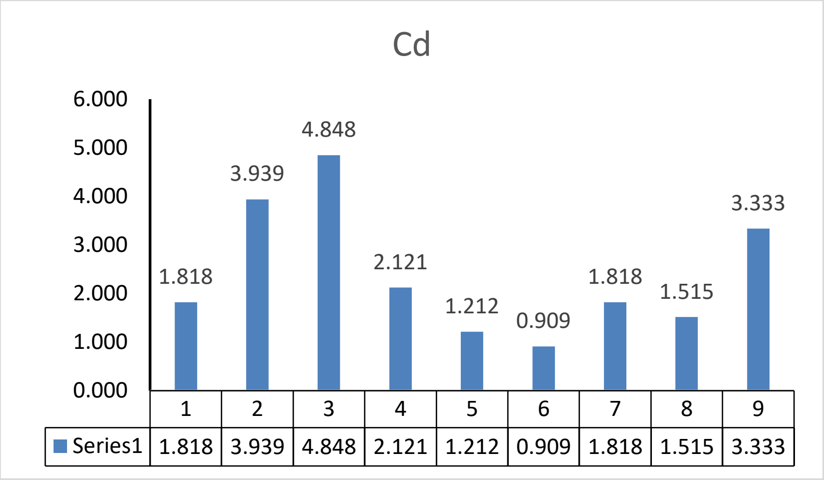


Figure 4: Cadmium Pollution Factor Index in Soil Samples

4.Discussion

In this study, the Pollution Factor Index (CF) for the element's arsenic mercury and cadmium in soils surrounding the factory was examined. The results indicate that the average CF values are greater than 3 for arsenic, more than 14 for mercury, and less than 3 for cadmium. In a study conducted by Gomes et al, (2025), the CF for antimony was reported to be less than 1 in over 95% of the samples, with only one sample reaching a value of 1.11. These findings suggest that the soil in that area was free from contamination or had very minimal contamination by antimony. In contrast, the present study shows an average CF for antimony exceeding 14,indicating very severe contamination. Therefore, there is a clear contradiction between the results of these two studies regarding the element antimony.

Additionally, in a study by Erazo et al. (2025), the arsenic CF in some samples reached approximately 12. This element was identified as the most significant environmental risk factor. The high CF values for arsenic in that research are consistent with the current findings, where the CF for arsenic exceeds 3. Both studies emphasize severe arsenic contamination in the soil.

5.Conclusions and Recommendations

This study aimed to assess the level of heavy metal pollution in soils surrounding the Ghori Cement Factory, utilizing the Pollution Factor (CF) index for heavy elements including lead, cadmium, nickel, chromium, cobalt, arsenic, antimony, and aluminum. The data analysis revealed that the soils in the studied area exhibit low pollution levels for aluminum, nickel, chromium, and cobalt. In contrast, lead and cadmium showed moderate pollution, while arsenic and antimony indicated severe to very severe contamination. Among the measured elements, the antimony pollution index had the highest average value, exceeding 14, reflecting a critical situation concerning this element's contamination.

The spatial pollution pattern indicated that the southeastern direction from the factory, identified as the predominant wind dispersion pathway, experienced the highest pollution levels. This finding confirms that the industrial activities of the cement factory directly influence pollutant distribution and that proximity to the emission source significantly contributes to increased heavy metal concentrations in the soil.

Comparing the results of this study with global investigations revealed that the CF for antimony in the study area is considerably higher than the global average reported. Conversely, the arsenic results align with similar studies in other countries. This discrepancy in antimony pollution may stem from differences in fuel types, raw materials used, or a lack of control systems within the factory.

Given the environmental and health risks associated with the accumulation of heavy metals particularly arsenic and antimony in soils, it is essential to implement comprehensive measures for monitoring, controlling, and reducing pollution in the area. Practical recommendations include employing soil remediation technologies, enhancing filtration systems in the factory, and conducting regular environmental assessments to promote sustainable pollution management in the region.

Based on the findings, the following strategies are proposed for soil pollution management, control, and reduction:

Regular Monitoring: Implement periodic soil surveillance programs to identify changes in pollution levels over time and evaluate the effectiveness of remedial actions.

Use of Advanced Filtration Technologies: Install sophisticated filtration systems in the factory’s smokestacks and production units to reduce dust and heavy metal emissions.

Soil Remediation: Apply decontamination methods such as chemical stabilization, phytoremediation, and physical soil treatment to decrease the mobility of heavy metals.

Development of Green Belts: Establish resilient vegetation cover around the factory as a natural barrier to prevent pollutant dispersion and transfer.

Public Awareness: Educate and inform local residents about the hazards of heavy metal contamination and preventive measures.

Environmental Impact Assessments: Require the factory to conduct regular environmental evaluations and comply with national and international standards related to industrial production and waste management.

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