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Original article

Impact of Cement Dust on Soil Composition Near ElFataih Cement Factory: An X-Ray Fluorescence–Based Study

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Abstract
The X-Ray Fluorescence (XRF) technique was utilized to examine how the cement dust from Elfataih influences soil pH and to assess the concentrations of metal oxides in both the surface and subsurface soil samples collected from the areas surrounding the El-Alfataih region. The findings from this research revealed a direct impact of the cement dust on the distribution of metal oxides in the analyzed soil samples, highlighting a variation between the oxides present in the surface and subsurface layers. Different types of metal oxides were detected in the studied samples, including CaO, SiO_2, Al_2O_3, Fe_2O_3, Na_2O, $MgCO_3$, K_2O, MgO, SO_3, TiO_2, P_2O_5, and MnO, besides the presence of different amounts of calcium carbonate, $CaCO_3$, and Magnesium carbonate, $MgCO_3$. The results of PH values showed high variations, their values ranged between (7.8± 0.05 and 8.8±0.01) for the subsurface samples, compared with the values of surface samples of (7.28 ± 0.01 and 9.48 ±0.1). In general, elevated levels of metal oxides were observed in the surface samples in comparison to the subsurface ones. Moreover, the results indicated that certain areas exhibited higher concentrations than others, with the most significant values noted in the southern and eastern parts near the factory locations.
Keywords. Metal Oxides, X-ray Fluorescence, PH, Cement Dust.

Introduction

Cement is one of the most used construction materials, whose production is increasing all over the world. It is impossible to imagine the current life limit cement. Cement is a very important development material that is used for housing and infrastructure, and is the key to economic growth. Demand for cement is directly related to economic growth. Cement is a crucial binding agent for the building industry and is produced in enormous quantities throughout the world [1].

Although the cement industry contributes to the construction of the structures in today's modernized and advanced world, dust is produced during manufacture. Pneumoconiosis, chronic obstructive pulmonary disease, restrictive lung disease, chronic obstructive pulmonary disease, and colon, stomach, and liver cancer are all brought on by cement dust. Other studies have demonstrated that exposure to cement dust has the potential to affect virtually all of the body's organs, including the heart, liver, spleen, bone, muscles, and hair tissues, as well as their microstructure and physiological function [2].

Environmental concerns were brought on by the cement industry's pollution, which had a negative effect on the land, water, and air. The Central Pollution Control Board has named the cement sector as one of the top 17 most polluting industries. The emission of dust from cement manufacturers has increased during the past few decades. Significantly, as a result of the establishment of additional cement plants to supply the demand for cement supplies for building construction [3].

One of the main sources of environmental contamination is emissions from industrial facilities. There are both overt and covert effects on soil, plants, and human health when large amounts of dust from cement manufacturing facilities are released into the atmosphere [4]. Industrial establishments are a significant cause of environmental pollution. Cement factories are responsible for releasing a large amount of dust into the air, which has visible and hidden effects on human health, soil quality, and vegetation. People living near cement factories in Nigeria have frequently reported crop damage and an increased prevalence of lung-related illnesses among cement workers compared to control groups. This study is part of a comprehensive project that aims to examine the actual impact of cement operations on human health, soil quality, and vegetation in the vicinity of two major cement factories in Nigeria. This paper presents the findings of our analysis of surface soil samples collected from within and around these factories, including major, minor, and some heavy trace [4].

Cement production methods generate a huge amount of dust particles (coarse and fine), which deteriorate the quality of the surrounding air. The emission of significant amounts of toxic gases and particles into the ecosystem causes serious air pollution. Cement contains sulfur and nitrogen oxides, which harm vegetation by reducing its gas exchange processes. Cement dust Deposits on the surface of plants are penetrated by cement dust oxides, which can react with water droplets to form acid rain, which damages soil, plants, and other organisms [5]. Dust from cement can spread over large areas via wind and rainfall, accumulating in and on soils. The particles can penetrate the soil as both dry and wet deposits, ultimately compromising its physicochemical properties. Many studies indicated that atmospheric particles can contribute to a reduction in soil biodiversity [6]. Moreover, cement raw materials consist mainly of 75% limestone ($CaCO_3$), 20-25% clay (Al_2O_3 + Fe_2O_3), 5% sand (SiO_2), and 2% Ferric oxide (Fe_2O_3). Cements are mineral materials, primarily composed of hydrated silicate and portlandite [$Ca(OH)_2$] for ordinary Portland cement [6].

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Numerous investigations have established a correlation between alterations in soil characteristics and environmental changes caused by human actions. When cement comes into contact with the soil surface, it usually modifies both the physical and chemical constituents of the soil. Owing to the fact that cement contains a significant amount of carbonate, the dust emanated from it is typically strongly alkaline. Therefore, it is highly probable that the soil that has been contaminated by cement will exhibit a high pH. Various studies have documented that the biological, physical, and chemical features of soil, including electrical conductivity, pH, and moisture content, are all impacted by the application of cement dust [6]. The impact of human activities on ecosystem components (air, soil, water, and vegetation) can increase the rate of nature's slow geochemical cycle of metals. As a result, most soils in rural and urban environments may accumulate one or more heavy metals, posing risks to human health and ecosystems [6].
As an illustration, the interaction between $CaCO_3$, $Al_3(SiO_3)_2$, and Fe_2O_3 results in the formation of alite, (Ca_3SiO_5); belite, (Ca_2SiO_4); tricalcium aluminate, a complex mixture of ($Ca_3Al_2O_6$); and tetracalcium aluminoferrite, ($4CaO.Al_2O_3.Fe_2O_3$), which is abbreviated as C_4AF, accompanied by the release of CO_2 gas in the Portland cement clinker [7]. The cement sector plays a significant role in the discharge of anthropogenic carbon dioxide into the atmosphere, accounting for approximately 5-7% of the total anthropogenic carbon dioxide emissions. Although the production of one ton of clinkers involves the use of an average of 1.52 tons of raw materials and 0.1 tons of fuel, the remaining 0.52 tons of raw materials are transformed mainly into carbon dioxide through processes such as :

$$CaCO_3 \longrightarrow CaO + CO_2$$

This poses a grave environmental challenge on a global scale, as the increase in atmospheric carbon dioxide directly contributes to global warming. In addition to CO_2, the cement industry emits other harmful pollutants into the air [7]. In recent times, the industrial sector in Uzbekistan has been witnessing rapid growth. Even though this progress is encouraging, as it generates new employment opportunities and proves to be economically feasible, the unwise usage of these industries has resulted in environmental degradation [8]. As evidence, industrial activities contribute to 5-7% of the carbon dioxide gas mixture released into the atmosphere due to anthropogenic factors, while the primary environmental pollutants are the cement industry's generated dust. During cement production, 87-91% of the substances are released into the atmosphere, with 913% in the form of gas and the rest in the form of dust [8].
The cement sector has achieved noteworthy advancements in minimizing CO_2 discharges by enhancing its procedures and effectiveness. Nevertheless, there are constraints to further enhancements since the production of CO_2 is an inherent aspect of the fundamental process of heating limestone. The cement industry contributes significantly to the imbalances of the environment in particularly air quality. The key environmental emissions are nitrogen oxides (NO_x), sulphur dioxide (SO_2), and grey dust [9].
Previous studies have emphasized the impact of cement particles discharged from the surroundings of the Zliten cement factory on the soil. The study examined the types of fungi that exist in the soil's microflora in the region polluted by cement, along with the pH level, moisture, and concentration of heavy metals in the contaminated soil [10]. This study evaluates the environmental impact of emissions from the Elfataih cement factory, focusing on how cement dust affects the surrounding soils. Building on previous research, which linked cement pollution to changes in soil microflora pH, moisture, and heavy metal concentration [10], this investigation specifically analyzes the pH, moisture, and concentration of metal oxide levels in soil near the factory. These results are compared against samples from an unpolluted control site to determine the extent of contamination.

Methods

Fourteen soil samples were collected from five different locations at the Elfataih cement factory. Surface (1cm) and subsurface (10cm) samples were collected from the three different sectors during winter 2023. The samples were collected from the East, South, and North sections around the factory. At each section, surface and subsurface soil samples were collected from about one kilometer and 2 kilometers from the cement factory. The fourth location, 50 kilometers away from the factory as the control, to examine metal oxides and pH of unpolluted soil (control) and soil that had been continually exposed to cement dust. The fifth location was the area near the factory that contains waste from the factory. The collected samples were kept in polyethylene bags and transferred to the central unit of chemical analysis, Elfataih Cement Factory. The samples and their locations are shown in (Table 1). The map of the Elfataih cement factory location was shown in the (Figure).

Table 1. The sample locations

Samples	Locations
A1, A2, A3	1km, East, South, North, respectively, from the cement factory.
B1, B2, B3	2km, East, South, North, respectively, from the cement factory.
Waste sample D	A waste dump next to the factory.
Control sample C	50km away from the factory.

Figure 1. The location of the cement factory & the studied areas

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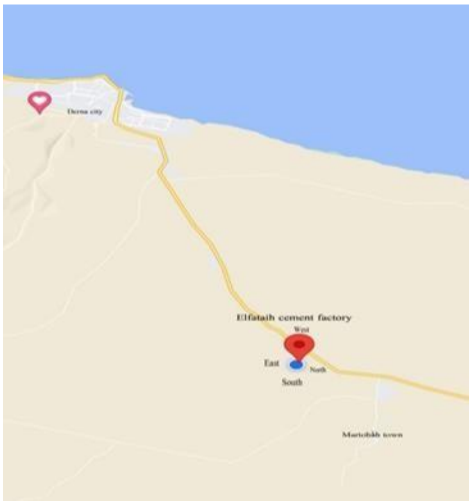

The samples were washed with distilled water and dried at 180 C°, then sent to the central lab of Elfataih Cement Factory. Moreover, the samples were analyzed using X-Ray Fluorescence scanning (XRF). The X-ray micro scanning of the samples was carried out by using X-ray scanning at the central lab of Elfataih Cement Factory. The Standard deviation and average values were calculated by Excel software.

Results

The results of pH were obtained by examining some physicochemical properties of soils from and around the Elfataih cement pH of soil results are shown in (Table 2. The pH values for three locations around the factory (A1, A2, A3, B1, B2, and B3) for both surface and subsurface samples ranged between 7.5 and 9, which means there is an increase in the pH values of the soil samples which is exposed to factory dust, especially in the north (A3), in the direction of the dust emitted from the factory. These values are similar to the values of the waste sample, while the control sample was less than 7.5. The standard division of PH showed small variations in the same direction as East, South, and North with values of (7.98 ± 0.05, 7.58 ± 0.02, and 9.48 ±0.1) compared with their values of subsurface samples of (8 ±0.01, 7.8±0.05, and 8.8±0.01) for the above directions, respectively.

Table 2. Illustrate the pH value of different locations from the cement factory. Sites A (1 km from the factory), B (2 km from the factory), (50 km from the factory for the control), and waste sample

Locations	**pH values at surface (mean± SD)**	**pH values at subsurface (mean± SD)**
A1 East	7.98 ± 0.05	8 ±0.01
A2 South	7.58 ± 0.02	7.8±0.05
A3 North	9 ± 0.1	8.8±0.01
B1 East	7.98 ± 0.05	8±0.01
B2 South	7.58 ± 0.02	7.8± 0.05
B3 North	9.48 ±0.1	8.8±0.01
Control sample C	7.28 ±0.01	-
Waste D	8.88 ± 0.01	-

The results from X-ray fluorescence (XRF) analysis of metal oxides within the samples taken from the examined area are displayed in (Tables 3 and 4). The findings from location A, which is situated 1km away from the cement factory, indicated that for both surface and subsurface soil samples, the identified metal oxides included ($CaCO_3$, CaO, SiO_2, Al_2O_3, Fe_2O_3, Na_2O, $MgCO_3$, K_2O, MgO, SO_3, TiO_2, P_2O_5, and MnO), with their respective concentrations presented in table 3. A notable increase in the levels of CaO and $CaCO_3$ was observed in the surface samples compared to their concentrations in the subsurface samples.

Conversely, the metal oxides measured in the subsurface samples from the same site, such as (SiO_2, Al_2O_3, and Fe_2O_3), were found to be more abundant in the subsurface samples as opposed to those from the surface samples. The findings indicated that the levels of CaO and $CaCO_3$ in the surface and subsurface samples at location A1 (to the east of the cement factory) surpassed those measured in the other sites A2 and A3, located to the south and north, respectively. This increase is primarily linked to the influence of cement dust, as this is the path that dust emissions from the factory take. Meanwhile, the amounts of the remaining metal oxides (K_2O, MgO, SO_3, TiO_2, P_2O_5, and MnO) were relatively uniform across all three locations, showing no significant differences in their concentrations within both surface and subsurface samples.

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The trend of metal oxide contents at this location (1km) is as follows: $CaCO_3$> CaO> SiO_2> Al_2O_3> Fe_2O_3> Na_2O> $MgCO_3$> K_2O > MgO> SO_3> TiO_2> P_2O_5 > MnO. In addition, the (XRF) examination of samples taken from site (B) (located 2km from the cement factory) revealed the existence of various metal oxides (SiO2, Al2O3, Fe2O3, CaO, MgO, Cl, SO3, K2O, TiO2, MnO, P2O5, CaCO3, MgCO3 and Na2O).
The respective values can be found in (Table 4), which details the surface and subsurface soil samples. Similar to the findings at location A, certain metal oxides in the surface samples displayed elevated values compared to those in the subsurface samples, specifically ($CaCO_3$ and CaO), while the metal oxides (SiO_2, Al_2O_3, Fe_2O_3) were found to have higher concentrations in the subsurface soil samples. At this site (2km), the level of Cl was detected to be between 0.26 and 0.15%.
The trend of metal oxide contents at this location is as follows:
SiO_2> $CaCO_3$> Al_2O_3> Fe_2O_3> K_2O > other oxides.

Table 3. The metal oxide values in locations A (1km) from the cement factory for both surface and subsurface samples

Metals oxides	East		South		North	
	A1 surface (mean± SD)	A1 subsurface (mean± SD)	A2 Surface (mean± SD)	A2 subsurface (mean± SD)	A3 surface (mean± SD)	A3 subsurface (mean± SD)
$CaCO_3$	63.43±0.02	45.03±0.001	30.42±0.05	21.52±0.01	33.12±0.01	13.3±0.01
CaO	35.54±0.012	25.23±0.002	17.05±0.01	12.1±0.0.1	18.56±0.00	7.44±0.02
SiO_2	21.6±0.02	34.07±0.01	47.3±0.02	58.03±0.05	47±0.01	68.45±0.01
Al_2O_3	4.83±0.021	7.46±0.03	8.97±0.01	10.8±0.1	8.45±0.1	12.8±0.05
Fe_2O_3	2.86±0.02	3.67±0.012	4.55±0.01	5.13±0.02	4.43±0.012	5.72±0.01
Na_2O	1.45±0.00	1.19±0.01	0.7±0.012	0.5±0.01	0.7±0.04	0.56±0.012
$MgCO_3$	1.7±0.01	1.9±0.021	2.46±0.01	2.15±0.012	1.6±0.02	2.55±0.01
K_2O	1±0.01	1.34±0.01	1.55±0.03	1.74±0.12	1.4±0.01	1.74±0.1
MgO	0.81±0.03	0.9±0.01	1.18±0.01	1.03±0.01	0.76±0.012	1.22±0.012
SO_3	0.22±0.1	0.1±0.01	0.031±0.012	0.01±0.05	0.1±0.01	0.05±0.00
TiO_2	0.31±0.02	0.53±0.1	0.71±0.01	0.8±0.02	0.7±0.02	0.87±0.05
P_2O_5	0.15±0.01	0.12±0.02	0.1±0.01	0.08±0.001	0.1±0.1	0.07±0.01
MnO	0.03±0.00	0.05±0.01	0.05±0.02	0.07±0.02	0.05±0.2	0.08±0.01

Table 4. The values of metal oxides in three locations, B (2km) from the cement factory, for both surface and subsurface samples

Metals oxides	East		South		North	
	B1 surface (mean± SD)	B1 subsurface (mean± SD)	B2 Surface (mean± SD)	B2 subsurface (mean± SD)	B3 surface (mean± SD)	B3 subsurface (mean± SD)
SiO_2	40.77±0.01	64.4±0.01	58.18±0.1	62.23±0.01	54±0.01	67.2±0.01
$CaCO_3$	39.4±0.03	19.65±0.01	22.3±0.01	19.75±0.01	25±0.01	10.94±0.01
CaO	22.1±0.01	11±0.01	12.5±0.01	11.1±0.1	14.01±0.1	6.13±0.5
Al_2O_3	7.0±0.05	10.18±0.2	9.90±0.04	9.70±0.5	10.02±0.05	13.33±0.01
Fe_2O_3	3.74±0.5	5.05±0.01	4.85±0.01	4.90±0.05	4.94±0.01	5.89±0.1
$MgCO_3$	0.77±0.02	1.01±0.01	2.15±0.01	1.4±0.01	2.15±0.02	2±0.01
K_2O	2.11±0.01	1.51±0.1	1.54±0.5	1.6±0.1	1.55±0.01	1.7±0.02
Na_2O	0.5±0.1	0.5±0.02	0.5±0.01	0.5±0.1	0.5±0.1	0.5±0.01
MgO	0.37±0.01	0.52±0.1	1.03±0.01	0.66±0.01	0.99±0.01	0.95±0.01
TiO_2	0.6±0.02	0.8±0.01	0.78±0,1	0.8±0.02	0.76±0.5	0.9±0.5
Cl	0.26±0.1	0.15±0.1	0.25±0.02	0.20±0.01	0.15±0.2	0.15±0.01
SO_3	0.27±0.2	0.05±0.02	0.13±0.04	0.08±0.05	0.06±0.02	0.15±0.01
P_2O_5	0.11±0.01	0.08±0.01	0.08±0.01	0.08±0.1	0.08±0.01	0.061±0.00
MnO	0.04±0.05	0.06±0.5	0.06±0.1	0.06±0.01	0.06±0.01	0.1±0.001

Table 5 outlines the metal oxide composition of soils collected from two distinct sites. The first site (C) serves as the control sample, situated 50 kilometers north of the factory, while the second site (D) is located in the waste area adjacent to the factory to the west. The metal oxides identified at these sites include (SiO_2, Al_2O_3, Fe_2O3, CaO, MgO, Cl, SO_3, K_2O, TiO_2, MnO, Na_2O, $CaCO_3$, $MgCO_3$, and P_2O_5), with their quantities detailed in table 5. It is evident that the concentrations of certain metal oxides (CaO, $CaCO_3$, SO_3, Na_2O, K_2O, and Cl) are generally greater in the waste soil samples (D) when compared to the control sample (C). On the contrary, the control sample shows results for metal oxides (SiO_2, Al_2O_3, Fe_2O_3, $MgCO_3$, and Cl) that align with the levels of the same metal oxides found in the examined areas (A and B).

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Table 5. The contents of metal oxides in location C (control sample) & D (waste sample)

Metal oxide	C Control sample (mean± SD)	D Waste sample (mean± SD)
SiO2	47.8±0.01	17.98±0.01
Al2O3	13.6±0.002	3.8±0.1
Fe2O3	5.76±0.01	2.5±0.01
CaO	12.9±0.01	33.88±0.5
MgO	0.7±0.5	0.85±0.1
SO3	0.04±0.01	0.4±0.01
Na2O	0.5±0.01	1.6±0.1
K2O	1.46±0.01	4.22±0.01
TiO2	0.82±0.5	0.23±0.02
MnO	0.08±0.02	0.03±0.5
P2O5	0.09±0.01	0.15±0.01
$CaCO_3$	23.1±0.01	60.46±0.1
$MgCO_3$	1.45±0.01	0.42±0.2
Cl	0.15±0.1	0.42±0.1

Discussion

The analytical results indicate a significant impact from the factory, with the eastern (A1) and southern (A2) areas showing the highest accumulation of cement dust. This is evidenced by the metal oxide concentration at 1 km distance (Location A), which are substantially elevated compared to those at 2 km (Location B) and the more distant region (C & D). Notably, the oxide levels in the eastern sector (A1) closely resemble those found in the cement manufacturing waste area (D). This correlation confirms that proximity to the factory is a key factor, with contaminant levels increasing significantly nearer the source.

Numerous studies have investigated the impact of industrial dust on soil properties, with consistent findings indicating the absorption of such dust into the soil matrix. For instance, research on soils near two cement factories in Nigeria identified calcium and silicon as major elemental components of cement, establishing them as markers for environmental contamination from cement production [3,4]. A study conducted near the Elfataih cement factory further corroborates this, showing that calcium concentrations peak at 1 km distance, specifically to the east (upwind) and south (downwind) of the facility. A similar trend was observed for $CaCO_3$ content (Table 6) [2], which aligns with the findings of the present research. While silica (SiO_2) is the most abundant component in the study's soils, its concentration does not follow a predictable spatial pattern relative to the factory, a result that is also consistent with our own findings (Section 2). Furthermore, the reported pH values of soil samples in this study ranged from 7.5 to 9.4. These elevated pH levels agree with experimental results from other cement factory sites, such as the Ziliten factory (pH 8.46-8.68) [10,12] and the Almarqub factory (pH 8.2-8.8) [5,6], confirming the alkalizing effect of cement dust on surrounding soils.

Conclusion

This study demonstrates a clear link between elevated soil calcium levels and cement factory emissions, with mineralogical analysis pointing to calcite or dolomite as the primary compounds. The spatial distribution of contamination, concentrated on the easterly and southerly windward directions, provides compelling evidence that fugitive dust is the main dispersal mechanism [6]. Addressing these emissions is essential for effective pollution control and environmental protection. To build upon these findings, future work should include a more extensive geographical survey at distances of 5, 10, 15, and 20 km. Furthermore, a holistic assessment requires sampling across multiple seasons and incorporation of analyses of plant tissues and ambient air quality to fully delineate the factory's impact on the surrounding ecosystem.

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Conflicts of Interest

No conflict of the results recorded in this study with ones of any other studies.

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