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REVIEW ARTICLE

Pollution Effect and Effluent Discharge on Soil Physico-chemical Properties around Cement Factories in Tamil Nadu, India

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Abstract. Cement industry activities generate significant particulate matter, leading to heavy metal accumulation in soil, deterioration of soil health, and subsequent reductions in crop yield. This study investigates the pollution effects of two major cement factories in Tamil Nadu, India, by assessing soil contamination and effluent discharge at varying distances from the plants (0–750m, 750–2000m, and 2000–3000m). Soil and effluent samples were analyzed for heavy metals (Cu, Mn, Cr, Pb, Zn) and key physico-chemical properties, including total nitrogen (TN), organic carbon (OC), potassium (K), phosphorus (P), pH, moisture content, soil texture, bulk density, sulfate-sulfur (SO_4-S), and cation exchange capacity (CEC). Heavymetal concentrations were determined using Atomic Absorption Spectroscopy (AAS), and data were statistically evaluated using one-way ANOVA. Results indicate a marked increase in soil pH and bulk density near cement factories, accompanied by declining moisture content, organic carbon, and nitrogen levels, which may hinder soil fertility and agricultural productivity. Additionally, effluent analysis revealed excessive levels of Cu, Mn, and Cr, surpassing FAO safety limits, rendering it unsuitable for irrigation and posing potential risks to groundwater contamination. The study underscores the urgent need for stringent pollution control measures and sustainable waste management strategies in cement industries to mitigate their adverse environmental impacts and protect agricultural ecosystems.

Keywords: Particulate matter, effluent discharge, physico-chemical properties, cement pollution, heavy metals, soil contamination

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1. Introduction

Industrialization has led to significant environmental pollution, particularly from cement factories. While gaseous emissions receive much attention, the impact of particulate pollutants on soil quality and vegetation remains underexplored. Heavy metals from cement dust and effluent discharges accumulate in soil, leading to bioaccumulation, biomagnification, and adverse effects on agricultural productivity [1]. This study evaluates soil pollution levels around cement industries in Tamil Nadu, analyzing heavy metal content and changes in soil properties [2].

Cement dust emissions are known to affect nearby agricultural lands, altering soil physicochemical properties and reducing crop yields. The alkaline nature of cement dust can significantly change soil pH, leading to nutrient imbalance [3]. Studies indicate that heavy metal contamination from cement production can persist in the environment for long periods, impacting human and ecological health [4].

In addition to altering soil pH, cement dust deposition has been found to increase soil compaction, reducing water infiltration and root penetration, which negatively affects plant growth [5]. Research has shown that continuous exposure to cement dust can lead to the depletion of essential nutrients in the soil, such as potassium and nitrogen, thereby limiting the fertility of agricultural lands in affected areas [6]. These changes may have long-term implications for local farmers and biodiversity.

Furthermore, effluent discharge from cement industries often contains significant concentrations of heavy metals such as lead, cadmium, and chromium, which pose risks to human health and ecosystems [3]. Prolonged exposure to these toxic elements can lead to their accumulation in crops, which subsequently enter the food chain and pose a threat to consumers [4]. Effective regulatory measures and remediation techniques are necessary to mitigate these adverse effects and ensure sustainable land use near cement industries [6].

2. Literature review

Several studies have documented the environmental and agricultural impact of cement industry pollution. Cement dust, a major by-product of cement manufacturing, is known to deposit on soil surfaces, altering their physical and chemical properties. A study [7] reported that cement dust increases soil pH and bulk density while reducing organic matter and microbial activity, leading to reduced soil fertility.

A research [8] highlights that heavy metal contamination, primarily from cement industry emissions, affects plant growth and groundwater quality. Elevated levels of chromium, manganese, and lead were found in soils near cement factories, surpassing permissible limits set by the FAO.

The long-term accumulation of heavy metals in agricultural lands near cement factories has been extensively studied. According to [9], these metals not only persist in soil but also get absorbed by crops, entering the food chain and posing potential health risks to consumers. The bioaccumulation factor of cadmium and lead was found to be particularly high in crops cultivated within 1 km of cement production facilities.

Furthermore, effluent discharge from cement factories is another critical environmental concern. A study indicates that wastewater from cement plants often contains high concentrations of dissolved solids and heavy metals, rendering it unsuitable for irrigation and groundwater recharge [10]. Continuous exposure to such contaminated water can degrade soil structure and affect crop productivity.

Recent advancements in pollution mitigation techniques have been explored in several studies. Phytoremediation techniques using metal-tolerant plant species can help reduce soil contamination around cement factories [11]. Additionally, industrial filtration and dust control measures have shown promise in minimizing particulate emissions and their impact on surrounding ecosystems [12].

3. Study area and methods

Two cement factories in Tamil Nadu were selected:

1. Factory A - Located in Ariyalur District, known for limestone reserves.
2. Factory B - Located in Tirunelveli District, a major cement production hub.

Ariyalur District is home to multiple cement factories due to its rich limestone deposits, a key raw material for cement production. The region has a semi-arid climate, with an average annual rainfall of around 950 mm. The population in the vicinity of the cement factories largely depends on agriculture, with paddy, sugarcane, and groundnut being the major crops cultivated [13]. The district has witnessed rapid industrial growth, leading to environmental concerns related to air and water pollution.

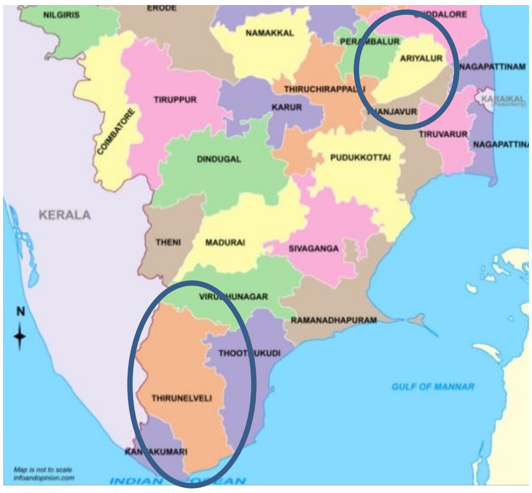

Fig. 1. Location of Ariyalur and Tirunelveli Districts.

Tirunelveli District, located in the southern part of Tamil Nadu, also hosts a significant number of cement industries. The area experiences a tropical climate with an annual average rainfall of approximately 850 mm. The demographic composition includes a mix of agricultural and industrial workers, with many engaged in limestone quarrying and cement manufacturing. The proximity of these industries to agricultural lands has raised concerns about potential contamination of soil and water resources [14]. Fig. 1 shows the location of Ariyalur and Tirunelveli Districts in Tamil Nadu map.

3.1. Geological and geomorphological features

The geological formations in Ariyalur District predominantly consist of sedimentary rocks, primarily limestone, sandstone, and shale. These formations play a crucial role in the availability of raw materials for cement production [13]. The geomorphology of the region includes undulating plains and low-lying floodplains, which influence surface water flow and groundwater recharge.

In contrast, Tirunelveli District features a mix of igneous and metamorphic rock formations, including granite and gneiss. The region is characterized by rugged terrain with hill ranges and river valleys, which impact sediment transport and soil composition. The presence of cement industries in these diverse geological settings highlights the need for localized pollution control strategies [14].

3.2. Groundwater conditions

Groundwater availability in both districts is influenced by the underlying geology and industrial activities. In Ariyalur, groundwater is extracted primarily from limestone aquifers, which are prone to contamination from industrial effluents and leachates. Studies have reported elevated levels of dissolved solids and heavy metals in groundwater near cement factories, raising concerns about its suitability for drinking and irrigation.

In Tirunelveli, groundwater occurs in fractured rock aquifers, where water movement is controlled by fault lines and rock permeability. The industrial discharge from cement factories has been observed to contribute to increased levels of fluoride, chloride, and sulfate in groundwater, affecting water quality in surrounding villages. Continuous monitoring and treatment measures are necessary to ensure safe water for local communities.

The study locations were chosen based on their proximity to cement factories and their impact on agricultural land. The selection also considered the prevailing wind direction and topographical features influencing dust dispersion [5]. Conducting research in these areas provides valuable insights into the long-term effects of cement pollution on soil properties and helps in formulating region-specific mitigation strategies.

3.3. Sampling and analysis

Soil samples (1kg each) were collected at depths of 0–20 cm at three distances from the factories (0–750m, 750–2000m, and 2000–3000m) to understand pollution gradients. Sampling followed a systematic grid method to ensure representativeness.

Effluent samples were collected from discharge points and analyzed for heavy metals (Cu, Cr, Mn, Fe, Pb, Zn) and other properties (pH, EC). Sampling was conducted in accordance with standard environmental monitoring guidelines [15].

3.3.1. Analysis methods

Standard soil analysis protocols were followed, including pH measurement using a pH meter, electrical conductivity (EC) using a conductivity meter, and bulk density using the core sampling method [16]. Atomic Absorption Spectroscopy (AAS) was employed for heavy metal quantification due to its high sensitivity and precision in detecting trace metal concentrations in environmental samples [17].

3.3.2. Quality Control Measures

All glassware used in the study was acid-washed to prevent contamination. Blanks and standard reference materials were included in all analyses to ensure accuracy and reliability. Each sample was analyzed in triplicate, and the mean values were reported [16].

3.3.3. Statistical Analysis

One-way ANOVA was conducted using SPSS software to determine the significance of variations in pollutant concentrations at different distances from the cement factories. A significance level of $p<0.05$ was used to assess statistical differences [14].

4. Results and Discussion

4.1. Physico-Chemical Properties

The soil pH varied significantly across distances, with higher alkalinity observed closer to cement factories (Table 1). This can be attributed to the deposition of alkaline cement dust, which influences soil chemistry [10]. Higher pH levels can reduce the bioavailability of essential nutrients like phosphorus and iron, affecting plant growth [11]. Increased pH also alters microbial activity in the soil, reducing the effectiveness of natural decomposition processes and soil fertility [18].

Table 1. pH, EC, Bulk Density, and Moisture Content.

Distance	pH	EC (µS/cm)	Bulk Density (g/cm^3)	Moist-ure (%)
0–750m	8.05	135.50	1.34	10.50
750–2000m	7.20	90.30	1.28	12.60
2000–3000m	6.55	75.40	1.25	13.30

Electrical conductivity (EC) was highest in soils closest to cement plants due to increased deposition of soluble salts and alkaline compounds from industrial emissions [12]. Higher EC levels indicate an increased concentration of dissolved ions, which can lead to salinity stress in crops, reducing water uptake and affecting growth rates [19].

Bulk density also increased near cement factories, indicating soil compaction, which can negatively impact root growth and water infiltration [20]. Compact soils have reduced aeration, leading to decreased microbial activity and slower organic matter decomposition [15].

Moisture content was significantly lower in soils within 750m of cement factories. This may be due to increased surface sealing from dust deposition, which reduces soil permeability and water retention [21]. Lower moisture content could exacerbate drought conditions in these areas, negatively impacting agriculture and causing yield losses [22].

4.2. Heavy Metal Contamination

Analysis of heavy metal concentrations revealed that Cu, Mn, and Cr levels were highest in soils closest to cement factories (Table 2). These metals are common by-products of cement manufacturing and can pose serious risks to plant and soil health if they accumulate beyond threshold limits [18].

Table 2. Heavy Metal Concentrations in Soil (mg/kg)

Distance	Cu	Mn	Cr	Pb	Zn
0–750m	56.2	234	48.5	5.2	98.1
750–2000m	34.1	167	32.8	3.1	78.4
2000–3000m	20.3	109	15.4	2.5	56.2

The elevated levels of Cu and Cr are concerning, as prolonged exposure can lead to reduced microbial activity and soil fertility [20]. Zinc levels, although high, were still within permissible limits according to FAO guidelines [21].
Statistical analysis (ANOVA) confirmed significant differences ($p<0.05$) in heavy metal concentrations at varying distances, reinforcing the localized impact of cement industry emissions [23].

5. Conclusions

The findings of this study highlight the significant impact of cement factory emissions on soil properties and environmental health. The key conclusions drawn from the study are:

1. Soil pH increase: Soil samples collected near cement factories exhibited increased pH levels, making the soil more alkaline. This change can lead to nutrient imbalance and reduced microbial activity, negatively impacting soil fertility.
2. High bulk density and reduced moisture content: The presence of cement dust caused soil compaction, leading to higher bulk density and lower moisture retention. This can restrict root growth, reduce water infiltration, and lower overall agricultural productivity.
3. Heavy metal accumulation: Concentrations of Cu, Mn, and Cr in soil samples exceeded FAO permissible limits, especially within a 750m radius of cement factories. These metals pose a risk to plant growth, soil microbial communities, and human health when they enter the food chain.
4. Effluent contamination: The discharge of industrial effluents contributed to increased levels of dissolved salts and toxic heavy metals in nearby soil and water sources. Long-term exposure to such contaminants can lead to bioaccumulation in crops and pose significant risks to human consumption.
5. Negative impact on agriculture: The findings indicate that prolonged exposure to cement dust and industrial effluents results in soil degradation, reducing crop productivity. Farmers in these areas may experience declining yields, particularly for sensitive crops requiring balanced soil conditions.
6. Statistical validation: The study's statistical analysis (ANOVA) confirmed significant variations in soil properties and heavy metal concentrations at different distances from the cement factories. This highlights the localized nature of pollution and the need for targeted mitigation measures.

The results strongly suggest that strict pollution control measures, including better dust suppression techniques, improved effluent treatment, and regulatory compliance, are necessary to mitigate environmental damage caused by cement factories.

Further studies should focus on long-term monitoring of soil health, remediation techniques, and alternative methods to reduce the environmental footprint of cement industries. Research into plant-based remediation (phytoremediation) and soil amendment strategies may provide sustainable solutions to pollution-related challenges.

Overall, the study emphasizes the need for stringent industrial regulations and proactive environmental management to minimize the adverse impacts of cement production on soil and agricultural ecosystems.

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