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THE EFFECTS OF CEMENT PARTICULATE DISCHARGE ON TWO TREES AND A COMMON SHRUB IN ASHAKA, GOMBE STATE

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ABSTRACT

Air pollution causes morphological alterations in plants which may affect the plant either through direct toxic effects or indirectly by altering the physiology of the plant. The trees (*Azadirachta indica, Balanites aegyptiaca*) and shrub (*Calotropis procera*) were sampled from a distance gradient of (0km, 2km, 4km and 6km) using systematic random selection. Leaf samples from both polluted and control sites were collected and treated using leaf maceration method. Results revealed variations in stomatal size and frequencies of samples from polluted and the control sites. Soil samples were chemically analyzed. Stomata size and frequency decreased with increasing distance from source of pollution. Areas closer to the factory were more affected than those further away (0 km > 2 km >4 km >6 km) from the factory site. Chlorophyll content, leaf abundance, species density and basal area increased significantly with distance from the factory site. Similarly, Co and CaO content in dust around the factory site were very high 75 – 90 % and 41.7 % respectively. The results provide evidence that cement particulate discharge is hazardous to leaf health. This study highlights the need to periodically conduct EIAs so that informed actions can be taken to safeguard the health and safety of humans and biodiversity. We recommend further research and EIA beyond 0 - 6 km radius to inform intervention actions. Our findings suggest environmental threats with dire consequences for Agriculture and human health, as the pollutants could bio-magnify and infiltrate the food chain over time.

Keywords: Particulate Discharge, Pollutants, Ashaka Cement, Stomata, Trees

INTRODUCTION

Cement manufacturing processes produce a great amount of dust particles both fine and coarse thereby, decreasing the quality of atmospheric air, this leads to the release of toxic gases and particulate matters into the atmosphere causing significant air pollution. Cement contains oxides of sulphur and nitrogen, which damage vegetation by affecting their gaseous exchange processes (Russel, 2007). Cement dust deposits on plants interferes with the biosynthesis of chlorophyll and damage leaf cells making photosynthesis slower than it should be. Cement dust incorporated in phytotoxic gas pollutants in fruit plants weaken respiratory and transpiration processes, the impact of the atmospheric pollution on the ecosystem was demonstrated at several times (Bliefert and Perraud, 2001). Zerrouqui *et al.* (2008) reported that the main impacts of the cement activity on the environment are the broadcasts of dusts and gasses. These particulate discharges are very numerous and varied. Cement industries are considered major sources of GHG (greenhouse gases) emission and contributors of extremely large amount of dust (Magiera *et al*., 2013; Ghada and Ahmed, 2016) and fly ash with alkaline nature of pH >7.2 and significant amount of trace elements (Magiera *et al.,* 2013). Of the total global GHG emission, fossil fuel and industrial process accounts for nearly 65% carbon emission. In most of the countries in the world, the environment has reached its carrying capacity in terms of air pollutants like sulfur dioxide (SO_2), nitrous oxide (N_2O), carbon monoxide (CO), carbon dioxide (CO_2), suspended particles and toxic heavy metals (Radhapriya *et al.,* 2012). Moreover, the cement production requires massive amount of energy and during storage, milling, packing and transportation huge amount of fly ash and particulate discharge is generated.

In general, the cement industry from extraction of raw materials, processing, packaging and distribution, has developed as a potential threat to the environment and living organisms (Gbadebo and bankole, 2007; El-Abbay *et al*., 2011; Dubey, 2013; Magiera *et al.,* 2013). Apart from its direct impact on the physiology of the plants it also forms a blanket of particulate matter that reduces the amount of light available to the plants for photosynthesis limiting the productive capacity and overall well-being of the plant (Sayara *et al*., 2021). The indirect effects of cement dust particles are alkalinization of the ecosystem and changing of the chemical composition of the soil. Hence, contaminated soil can adversely affect plant survival and growth (Yalgado *et al*., 2023). Despite the detrimental effects of cement dust on plants, some still remain tolerant to cement dust pollution, probably because of genetic make-up or due to some biochemical/anatomical modifications during the stress periods (Erdal and Demirtas, 2010). The aim of the study was to assess the effects of Ashaka cement particulate discharge on two tree species (*Azadirachta indica, Balanites aegyptiaca*) and shrub (*Calotropis procera*) in Ashaka Funakaye L.G.A Gombe state, Nigeria. The findings of this study contribute valuable data to ongoing and future Environmental Impact Assessments (EIAs), aimed at evaluating the ecological and public health consequences of industrial activities associated with cement production. By aligning with the One Health framework—which integrates environmental, animal, and human health—this research supports a holistic understanding of pollution-related stressors on biodiversity and ecosystem integrity.

Objectives

i. To identify the level of tolerance in micro-morphology of the studied species, by assessing their stomatal size and frequency.
ii. To determine the amount of dissolved pollutants/physio-chemical properties of soil across a distance gradient.
iii. Evaluate the level of toxicity and safe distance thresholds for sustainable agriculture and environmental safety.

MATERIALS AND METHODS

The Study Area

Ashaka town is located in Funakaye Local Government Area of Gombe state, 77 km to Gombe municipal, the state capital. The town lies within latitude $10^0$50'N to $10^0$60'N and longitude $10^0$35'E to $11^0$25'E; within the Northern part of Gombe state. The distance between polluted site (0-6 km) and control site (Gombe state university) is around 82 km. The climate of the area is seasonally wet and dry type, classified as tropical wet-dry climate (Abaje *et al.,* 2013). The study area is of the Sudano-Sahel vegetation dominated by grasses interspersed with trees and shrubs like the "Desert date" commonly called thorn tree (*Balanites aegyptiaca*), African fan palm (*Borassus aethiopum*), Neem (*Azadirachta indica*), Baobab tree (*Adansonia digitata*), Tamarind tree (*Tamarindus indica*), Sodom apple, and rubber bush (*Calotropis procera*). Tree density decreases as one moves further north of Ashaka town (Abaje, *et al.,* 2012). At Ashaka, rainfall peaks in the month of July and annual rainfall is within the range of 387 mm (15.24") while temperature can exceed 32.0^0 C. Ashaka is an industrial settlement with a population of over 236, 0879 (2006 Funakaye population census) and surrounded by Juggol Barkono, Gongila villages to the North and Lariski, Malari, Darumpa to the South.

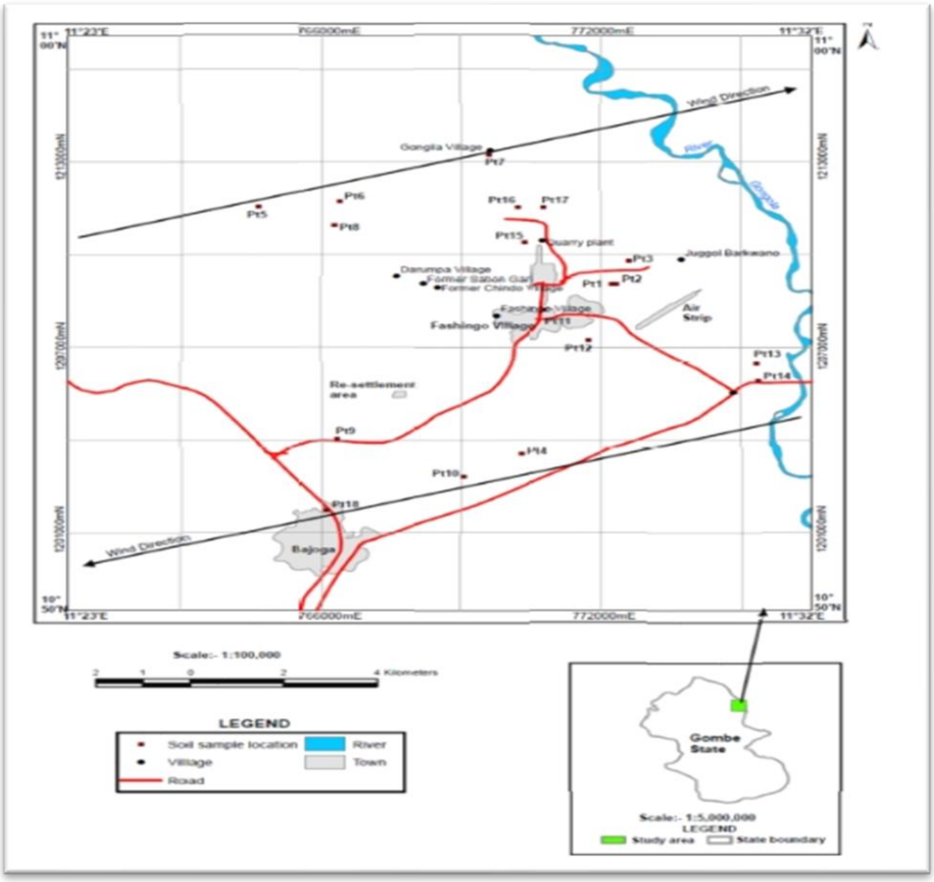

Figure 1: Map of Study Area Showing Wind Direction

Sampling Protocol

Morphological measurements, including leaf diameter and length, were obtained using a measuring tape and digital scale. Leaf samples from three plant species—*Azadirachta indica*, *Balanites aegyptiaca*, and the shrub *Calotropis procera*—were collected systematically along a defined distance gradient (0–6 km) from the pollution source. Each sample was appropriately labeled and preserved for subsequent laboratory analysis. In situ observations included leaf diameter, length, and color.

Microscopic examination of leaf micro-morphology was conducted post-collection, following standard maceration procedures. Soil samples were similarly collected across the same distance gradient and analyzed using X-ray fluorescence (XRF) spectroscopy to determine the presence and concentration of selected chemical elements.

Leaves Sample Collection

Fresh leaves of *Calotropis procera*, *Azadirachta indica* and *Balanites aegyptiaca* from 0 km - 6 km around the cement factory were collected around 8 am (using the North, West, South and East position), control samples were collected from Gombe State University (GSU) at 8 am the next day using systematic random selection for both polluted site and control site (using the four coordinates). A total of 80 samples were collected. These plants were chosen because they were readily available around the factory and also in all study locations/gradients. The labeled leaf samples, with an area of approximately 1cm^2 were immersed in (HNO_3) Nitrite acid for 20 minutes (in a petri dish) to prevent the leaves from denaturing as a result of exposure and desiccation. The upper (adaxial) and lower (abaxial) epidermis of leaves were then separated using dissecting needle and forceps and rinsed in water. The epidermal layers were stained with 1% aqueous Safranin for 5 minutes (staining helps reveal the cells clearly under the microscope) and excess stain specimens was rinsed off with water (Olofinobinu and Oladele, 1997). The stained specimens were then mounted in immersion oil on a slide for microscopic observations using a microscope and digital camera. Stomata and trichome counts were taken from 20 samples for each (10 abaxial and 10 adaxial surfaces) of the studied plant species at varying objective magnifications.

Slide Preparation (Soil Sample)

Soil samples from the different locations (0, 2, 4, 6) km from a depth of (0-30 cm and 30-50 cm) also using systematic random selection, were collected and taken to the laboratory for chemical analysis. Each soil sample was divided and weighed to 200 g in the laboratory using a digital scale for each sample, then mixed with steric acid and then ground to powder for 60 seconds to ensure consistency. The powdered mixture was made into a pellet and then analyzed using an XRF machine, to estimate the level of Ca, Mg, K, Na, and soil pH.

Stomatal frequency (%) was calculated using the formula:

SF (%) = (NS/ TSC x 100) (1)

Where SF = Stomatal Frequency

NS = Number of Stomata

TSC = Total Number of stomata counted

To analyze stomatal frequency data we employed descriptive statistics (mean) and the result was presented in tables.

Pollutant Concentration Analysis

Elemental concentrations in soil samples were quantified using chromatographic techniques. The analysis targeted key constituents, including SiO_2, NaO, Al_2O_3, Fe_2O_3, SO_3, MgO, CaO, and CO. The resulting data were subjected to statistical evaluation to determine mean concentrations across defined distance gradients from the pollution source.

Correlation Between Stomatal Frequency and Pollutant Concentration Across a Distance Gradient

The relationship between stomatal frequency and pollutant concentration along a spatial gradient was assessed using Pearson's correlation coefficient. This statistical approach was employed to evaluate the adaptive responses of plants to chemically induced stress, specifically through alterations in stomatal morphology and frequency. The underlying hypothesis posits that increasing distance from the pollution source corresponds with reduced physiological stress, thereby diminishing the need for morphological adjustments in stomatal traits.

RESULTS AND DISCUSSION

Micro Morphological/ Leaf Epidermal Analysis and Stomatal Response to Pollution Gradient

The findings of this study indicate a general reduction in stomatal number and a loss of stomatal openings in areas affected by pollution. Mean stomatal frequency exhibited a progressive increase with distance from the cement plant, the identified source of pollutants. However, no statistically significant difference was observed between the 4 km and 6 km sampling points, suggesting a plateau in stomatal recovery beyond a certain threshold (Table

Table 1 Stomatal Frequency Across Distance Gradient

Parameters	Stomatal Frequency across distance gradient				
	0 km	**2 km**	**4 km**	**6 km**	**Control site**
Mean	18.25	11.7	21.25	21.25	67.87
Standard Error	4.883	3.465	5.204	5.204	15.13
Minimum	0	0	0	0	15
Maximum	90	70	75	75	9

Note: Values represent stomatal frequency (number of stomata per unit area) measured across a spatial gradient from the cement plant (pollution source). The control site is located outside the influence zone of the emission source

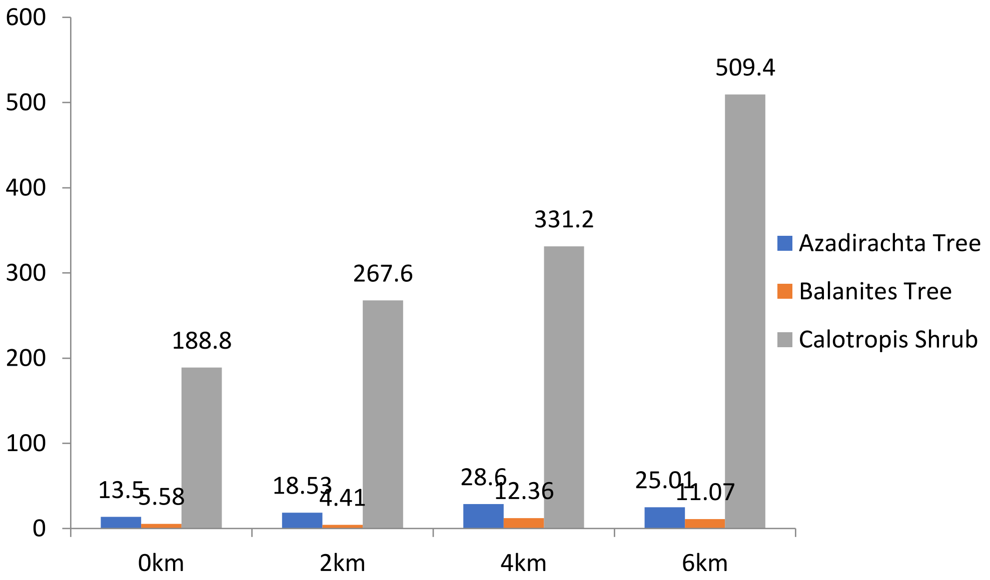

Figure 2: Mean Leaf Length Across Distance Gradient from Source of Pollutants

Variation in Leaf Length Relative to Pollution Gradient

Leaf length exhibited a decreasing trend in proximity to the pollution source, potentially attributable to growth inhibition and morphological adaptation in response to elevated pollutant concentrations across the three plant species studied. The shortest leaf lengths were recorded at the source point (0 km), while the longest were observed at a distance of 6 km from the emission site. This pattern was most pronounced in the shrub *Calotropis procera*, which showed the greatest sensitivity to pollutant exposure (Figure 4.1).Mineral Composition across distance gradient

There was a marked decline in mineral composition observed with increasing distance from the pollution or emission source. This reduction was most pronounced within the 0–4 km range, indicating a strong spatial influence of the pollutant on mineral distribution. Beyond 6 km, the variation in mineral composition became negligible, with some measurements showing no discernible difference from baseline levels (Table 3)

Table 3: Composition of Mineral Elements across Distance Gradient and Control Site. Values are in Kg

Mineral Component	Distance Gradient from source Pollutant				
	0km	**2km**	**4km**	**6km**	**Control site**
SiO_2 (Silicon Oxide) Silica	14.24	14.24	9.11	9.01	106.5
NaO (Sodium Oxide)	0.06	0.06	0.13	0.17	-0.26
Al_2O_3 (Aluminum Oxide) Alumina	4.11	3.97	3.17	1.93	2.01
Fe_2O_3 (Iron Oxide)	1.89	1.87	0.66	0.51	0.31
SO_3(Sulfate)	0.54	0.54	0.31	0.21	-0.06
MgO (Magnesium Oxide)	0.54	0.54	0.54	0.61	-0.56
CaO (Calcium Oxide)	41.71	41.60	40.35	37.49	-1.78
CO (Carbon Oxide)	75-90	75-87	68-50	50.38	0.008 – (-0.028)

Chemical Composition of Soil Samples Across Distance Gradient

Quantitative analysis of soil samples revealed a marked reduction in mineral pollutant concentrations at the control site, located beyond the influence zone of the Ashaka cement manufacturing plant. In contrast, elevated levels of these pollutants were consistently observed at experimental sites within the 0–6 km radius of the facility. These findings strongly suggest that the increased concentrations are attributable to particulate emissions from the cement production process (Tables 3 and 4). The results revealed that sites within the 0–2 km radius exhibited the highest concentrations of chemical constituents, indicating substantial impact from industrial emissions. Moderate levels were recorded at 4 km, while the 6 km site showed minimal to negligible contamination. The control site, located outside the influence zone, displayed the lowest concentrations across all measured parameters (Table 4).

Table 4: Analysis of Mineral Composition and Concentration at Control Site

Mineral components	M Weight (kg)
SiO_2 (Silicon oxide) Silica	106.5
NaO (Sodium oxide)	-0.26
Al_2O_3 (Aluminum oxide) Alumina	2.01
Fe_2O_3 (Iron oxide)	0.31
SO_3 (Sulfate)	-0.06
MgO (Magnesium oxide)	-0.56
CaO (Calcium oxide)	-1.78
CO (Carbon oxide)	0.008-0.028

The Pearson correlation analysis reveals a strong positive relationship between stomatal frequency at 0 km and 2 km ($r = 0.755$) (Table 5), suggesting similar physiological responses to pollutant exposure within this proximity to the cement plant. However, the correlation between stomatal frequency at 0 km and those at 4 km and 6 km drops markedly ($r = 0.369$), indicating a divergence in stomatal behavior as distance from the pollution source increases.

Interestingly, stomatal frequencies at 4 km and 6 km are perfectly correlated ($r = 1.000$), implying that plant responses at these locations are nearly identical and may reflect a threshold beyond which pollutant impact becomes negligible. The moderate correlations between 2 km and both 4 km and 6 km ($r = 0.340$) further support a transitional zone of impact between 2 km and 4 km. (Table5).

These patterns suggest a spatial gradient in pollutant-induced stress, with the most pronounced effects occurring within the 0–2 km range, tapering off beyond 4 km (Table 5).

Table 5: Correlation Analysis of Dissolved Pollutants Across Distance Gradient

	Stomatal Freq	**Stomatal Freq**	**Stomatal Freq.**	**Stomatal Freq.**
	0km	**2km**	**4km**	**6km**
Stomatal Frequency	0 km			1
Stomatal Frequency	2 km	0.755		1
Stomatal Frequency	4 km	0.369	0.340	1
Stomatal Frequency	6 km	0.369	0.340	1

The chemical analysis of soil samples collected at varying distances from the cement production site reveals a clear spatial gradient in pollutant concentrations:

The highest concentrations of key pollutants—including SiO_2 (14.24%), Al_2O_3 (4.11–3.97%), Fe_2O_3 (1.89–1.87%), SO_3 (0.54%), and CaO (41.71%)—were recorded at 0 km and 2 km. These values suggest intense deposition of particulate matter near the emission source. The carbon monoxide (CO) range was also elevated (75–90 at 0 km and 75–87 at 2 km), indicating significant gaseous contamination. (Table 6)

A notable decline in pollutant concentrations was observed at 4 km. SiO_2 dropped to 9.11%, Al_2O_3 to 1.93%, and Fe_2O_3 to 0.51%. SO_3 decreased to 0.31%, and CaO slightly reduced to 40.35%. CO levels also declined (68–50), reflecting reduced atmospheric deposition.

At 6 km, pollutant concentrations were lowest across most parameters. SiO_2 (9.01%), SO_3 (0.21%), and CaO (37.49%) showed further reductions, while CO levels fell to 50–38. Interestingly, NaO and MgO showed slight increases (NaO: 0.17%, MgO: 0.61%), possibly due to natural soil variation or background geo-chemical composition. (Table 6).

Table 6: Percentage Concentration of Dissolved Particles

Location	**Pollutants**							
	SiO_2	**NaO**	**Al_2O_3**	**Fe_2O_3**	**SO_3**	**MgO**	**CaO**	**CO**
0 km	14.24	0.06	4.11	1.89	0.54	0.54	41.71	75-90
2 km	14.24	0.06	3.97	1.87	0.54	0.54	41.71	75-87
4 km	9.11	0.13	1.93	0.51	0.31	0.54	40.35	68-50
6 km	9.01	0.17	1.93	0.51	0.21	0.61	37.49	50-38

Discussion

This study provides compelling evidence of the adverse effects of cement particulate emissions on environmental health, with particular emphasis on plant physiology and morphological function. The findings underscore the fact that foliar structures especially leaves, are the primary sites of pollutant deposition. In addition it demonstrates that; dust accumulation on leaf surfaces impairs light interception, thereby disrupting photosynthetic efficiency and overall plant vitality (Ogunkunle *et al*., 2013).

The study emphasizes the long-held notion that among airborne particles, cement dust exhibits strong adherence to leaf surfaces, particularly those with trichomes or rough textures. Studies have shown that; over time, particulate discharge accumulation forms a persistent, impermeable layer that obstructs light penetration and interferes with essential physiological processes such as water absorption and evapo-transpiration (Bankole , 2003; Ogunkunle *et al*., 2012; Ogunkunle *et al*., 2013). In another related study, foliar uptake via stomatal pores or the leaf cuticle was touted as the principal pathway for pollutant entry into plant tissues in contaminated environments (Ajon and Chagbe, 2018).

The findings of this study also resonates with the notion that pollution-induced stress can lead to structural alterations in leaf anatomy, as has been clearly demonstrated by the study species (*Azadiracta indica, Balanites aegyptiaca* and *Calatropis procera*). However the adaptive responses and coping strategies vary from species to species. While some show minimal alterations in stomatal frequency, others exhibit values near the upper limit of the observed range, reflecting species-specific differences in adaptive capacity to environmental stress. However, a reduction in stomatal index appears to be a common strategy adopted by most species generally since it potentially limits the uptake of gaseous pollutants thereby mitigating physiological damage (Gostin, 2009).

Analysis of stomatal frequency across the distance gradient reveals a clear relationship between plant response and proximity to the pollution source. The results indicate that the further away from pollutant source the more the number of stomatal openings. This aligns with expectations, as pollutant intensity is typically greatest near the emission point (Igomu *et al*., 2023).

The fluctuations in the stomatal frequency with increasing distance away from pollution source as indicated by the results of this study (Table 1) is indicative of a complex interplay of factors, potentially involving pollutant dispersion, wind patterns, and the adaptive capacity of plant species. Apart from the variations in stomatal frequency as an adaptive response, plants also display other morphological alterations and adjustments as a coping strategy. For instance Owoleke *et al.* (2020) demonstrated that cement dust pollution at the Obajana cement factory, Kogi State, Nigeria altered leaf anatomical features in multiple plant species. Notably, *Sida acuta* exhibited increased trichome density as an adaptive response to dust exposure. In *Azadirachta indica*, trichomes were absent in unpolluted areas but developed as unicellular structures on the abaxial surface near stomata in polluted sites . The findings of these two studies indicate that trichomes may serve as protective barriers, restricting particulate pollutants from entering through stomatal openings (Igomu *et al*., 2023).

Increased trichome density on leaves is known to protect plants from direct sunlight, lowering leaf temperatures and reducing metabolic rates that can harm plant tissues. The changes in trichome frequency, stomatal frequency, and stomatal size observed in leaves from polluted sites in this study, indicate that atmospheric pollutants have reached hazardous levels for these particular species. Melo et al. (2007) noted that higher stomatal density combined with smaller stomatal sizes can help provide sufficient CO2 for photosynthesis while minimizing excessive transpiration. Therefore, the observed stomatal frequency and size in this study may be responses to cement dust pollution in the area. In some cases, plants in polluted sites used leaf curling as a strategy to reduce overall leaf area available for transpiration (Ogunkunle *et al*., 2013). Interestingly, the studied plants (*Azadiracta indica, Balanites aegyptiaca* and *Calatropis procera*) responded to air pollution in the area by reducing their stomatal frequency, most likely as a strategy to limit the amount of pollutants entering the stomata during gas exchange. This adaptation involving stomatal frequency has been noted as characteristic of plants growing in polluted environments in similar studies (Amit, 2000; Ogunkunle *et al*., 2013).

Generally, plants differ in their strategies and adaptive mechanisms to overcome and survive in polluted areas. For instance; a study by Sayara et al. (2021) found that the number of branches on plants growing in polluted areas decreased significantly, while reduced leaf emergence perhaps due to malformation of developing leaves was reported by El-Shintinawy (1999); and Hajiboland et al. (2010). Similarly, Yalgado *et al*., 2023) reported a reduction in stomatal density on the leaf epidermis of plants located in polluted areas as an adaptive response that allows for regulated transpiration and controlled entry of harmful pollutants into plant tissues found in polluted soils (Kapitonova, 2002; Gostin, 2009). The variation in stomatal frequency as seen in this study underscore the significant variability in responses among the plant populations and species studied. This diversity may result from the varying physiological traits of the three different species and their unique adaptive mechanisms to pollution stress. (Igomu *et al*., 2023).

The decrease in the stomatal frequency may also be an evasive mechanism against the inhibiting effect of pollutants on physiological activities such as photosynthesis and also portends quicker response to external stimuli (Hetherington *et al.,* 2003; Verma *et al.,* 2006). According to Melo *et al.* (2007) increased stomatal density coupled with decreased stomatal size can serve as a strategy to ensure sufficient supply of CO_2 for photosynthesis; this assertion by Melo et al. (2007), is in agreement with the findings of this study. Similarly, Gostin, (2009) opined that modifications in frequency and sizes of stomata are direct responses to environmental stress and seem to be an important strategy of controlling the leaf absorption of pollutants by plants. Ayanbamji (1996) suggests that these structural changes may represent adaptive strategies to optimize gaseous exchange and transpiration when leaf surfaces are coated with cement dust. The observed reduction in stomatal frequency in this study could be a protective mechanism by the plants, to limit pollutant entry during gaseous exchange. (see Sharma *et al*., 2020).

Elemental concentrations of pollutants followed a noticeable trend and pattern. For instance, SiO_2, NaO, Al_2O3, Fe2O3, SO3, and MgO exhibit relatively consistent concentrations at 0 km and 2 km, followed by a marked decrease at 4 km and 6 km. This trend may be indicative of the immediate influence of the pollution source on these elements, with dispersion or reduction occurring with increasing distance from source of pollutants (Oko *et al*., 2024). CaO, on the other hand, displayed a progressive decrease from 0 km to 6 km. This progressive decrease in concentration of CaO, could be attributed to the natural processes influencing the dispersion of this particular pollutant. The consistent decrease suggests a dilution effect or a decline in the emissions of CaO as the distance from the pollution source increases. The concentrations of CO exhibit a range of (75 - 90, 75 - 87, 68 - 50, 50 - 38) for 0, 2, 4 and 6 km respectively, implying variability in CO levels at different distances away from source. This variability could be influenced by factors such as seasonal variations, atmospheric conditions, fluctuations in emission sources, or cement production process (Swapana *et al.,* 2024).

Overall Implications for Dissolved Pollutants

The findings of this study suggest that the concentration of pollutants in the soil is not randomly distributed but follows discernible patterns across the distance gradient from the pollutant source. In addition, the identification of strong correlations between certain components provides insights into potential pollution sources. This knowledge can be crucial for environmental monitoring and remediation efforts. The negative correlations, such as the one between NaO and SiO2, hint at a dilution effect as the distance from the pollutant source increases. This could be indicative of natural attenuation processes occurring with distance. The presence of stomata on the adaxial and abaxial surfaces of the leaves of the studied plant species is also an important feature that could be responsible for the survival of the plants in the presence of cement dust pollution (Igomu *et al*., 2023).

The observed structural differences in leaf lengths of the study species (figure 4) is in alignment with the notion that under strong alkaline conditions, the availability of certain plant nutrients such as phosphorus and boron can be reduced to deficiency level, it can result in low levels of micro-nutrients such as Fe, Mn, Zn, Cu and Co; this can affect plant growth and overall performance at high pH (Bilen 2010; Barrow and Hartemink, 2023). This assertion is buttressed by the outcome of a similar study in Sokoto state, North West Nigeria (Warrah *et al.,* 2013); the authors reported a nexus between soil pH changes and cement dust composition. Warrah et al (2013), attributed the high level of heavy metal concentration observed in the study to the deposition of calcium oxide from the cement company located within the vicinity of the study area. According to the authors the situation was compounded by the low rainfall experienced in the region, particularly in Sokoto, preventing calcium compounds from being leached away to reduce the alkalinity level of the soil. (Warrah *et al.,* 2013). The findings of the authors are consistent with our results and emphasizes the need for a remediation protocol and intervention plan to ameliorate the devastating effect of particulate discharge from cement plants and other allied pollutants. . Field observations revealed that the trees (*Azadiracta indica, Balanites aegyptiaca* and shrub, *Calatropis procera*) at locations (0-4km) were densely covered with cement dust during harmattan. However, the situation was more profound and severe in the absence of rain, with dire consequences for plant growth and productivity in the area (Gruptal 2022; Oko *et al.*, 2023), thus the abundance and distribution of most sensitive and less tolerant species might be reduced. This may lead to collapse in networks of inter-dependent species and ecological community persistence (Oko *et al*., 2023). In addition, physical examination of the studied species revealed that the leaves of the shrub, *Calatropis procera* exhibited chlorosis due to negative impact of cement discharge on its chloroplast. On the other hand, the focal trees *Balanites aegyptiaca*, and *Azadirachta indica*, suffered a general reduction in the activities of apical merristems resulting in reduced growth and stunting of individuals. The observed adverse effects on each focal species tend to increase in severity as one approaches the source point (0 km), this outcome is consistent with similar studies across cement dust polluted landscapes (Kumar and Sharma 2001; Gruptal 2022; Oko *et al.*, 2023)

The observed difference in heavy metal concentration is consistent with other similar or related studies within the region and elsewhere (Narimi *et al*., 2025). As a survival strategy plants tend to increase stomatal frequency in other to adapt to polluted environments (Kapitonova, 2002; Gostin, 2009). According to Sharma et al. (2001), high stomatal density of leaves in plants around polluted environments may be a response of the plants to the loss of matured and healthy stomata through the process of degradation caused by air pollution, a reduction in the stomatal size of leaves has been reported to be responses to environmental stress (Aloysius *et al*., 2013). This seems to be an important strategy for controlling the absorption of pollutants by plant leaves (Gostin, 2009; Aloysius *et al*., 2013). The relatively higher heavy metal concentrations such as Ca, Co, Zn, Al and Pb, observed in this study may be attributed to the deposition of calcium oxide from cement factory. , However, these metals were in very low or negligible concentrations at the control site, further strengthening the notion that these heavy metals are a consequence of the cement particulate discharge from the cement factory over the years. .

The three plant species, in addition to adopting a general strategy of reducing stomatal frequency, exhibited unique morphological adaptations. For example, *Calotropis procera* developed a strategy to minimize the surface area available for dust penetration and accumulation. As a result, there was a noticeable decrease in both the total number and size of its leaves. Additionally, this perennial succulent shrub undergoes a process of leaf waxing, which helps to further reduce dust penetration through the leaf surfaces.

On the other hand, *Balanites aegyptiaca* exhibits remarkable adaptive responses to environmental pollutants, characterized by the thickening and toughening of its leaves, which are further enhanced by a glossy coating that provides protection against arid conditions. Additionally, the plant utilizes its elongated spines and spiked branches as photosynthetic appendages, maintaining its ability to photosynthesize even after leaf abscission. This robust coping mechanism is believed to contribute significantly to the plant's success in thriving under extreme conditions, including high temperatures, low moisture availability, and elevated levels of pollution. These adaptations underscore the resilience of *Balanites aegyptiaca*, positioning it as a vital species in challenging habitats.

CONCLUSION

In conclusion, our study demonstrates that cement particulate discharge poses significant threats to the growth, diversity, and overall health of tree and shrub populations, notably affecting species such as *Calotropis procera* and *Azadirachta indica*, which exhibit adaptive structural changes in response to dust exposure. The soil analysis indicates a direct impact of cement dust on soil pH and an indirect reduction in acid phosphatase enzyme activity, further compounding the ecological concerns associated with cement production. Given *Azadirachta indica*'s resilience in poor, acidic, and polluted soils, its potential to mitigate soil acidity through leaf litter presents a valuable opportunity for phytoremediation. However, our findings also raise serious concerns about food safety and health risks linked to cement residues in agricultural produce and soil, highlighting the urgent need for comprehensive investigations into these hazards.

The resultant physical and chemical changes in soil composition have led to diminished crop yields, disproportionately affecting farming communities and raising alarms about food security and public health. Therefore, we advocate for immediate collaborative efforts among environmental agencies, local authorities, and the cement industry aimed at lessening long-term ecological and health risks. Specifically, we recommend the implementation of phytoremediation strategies, the construction of earth barriers to mitigate particulate discharge, and enhanced community engagement to monitor the well-being of populations impacted by cement factory operations. Such initiatives are critical to safeguarding both human health and environmental integrity.

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