

Ecological Impact of Cement Dust Emissions on Vegetation Cover: A Case Study from Zliten-Libya

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الأثر البيئي لانبعاثات غبار الأسمنت على الغطاء النباتي: دراسة حالة من زليتن- ليبيا

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Abstract

Cement production, while vital to infrastructure, poses environmental risks—particularly through dust emissions. This study was conducted to assess the impact of cement dust from the Ahlia Cement Factory in Zliten, Libya, on vegetation cover. Vegetation samples were collected from five sites (500, 1000, 2000, 4000, and 8000 m) south of the factory, in areas most affected by dust deposition. Vegetation cover improved with distance: plant count and species diversity peaked at 4000 m (56 plants, 10 species; ANOVA $p = 0.0025, 0.0026$); biomass also peaked there (211 g fresh, 166.3 g dry), though not statistically significant ($p = 0.3395, 0.1270$). In *Hordeum murinum*, leaf area increased from 78 to 1007 cm² ($p = 1.84E-04$), and leaf length from 8 to 14 cm ($p = 0.0016$), while leaf number rose slightly (7 to 9; $p = 0.1333$). Strong positive correlations were observed between distance and leaf length ($r = 0.93$), leaf number ($r = 0.87$), and number of plants ($r = 0.79$), indicating improved vegetation condition with increasing distance from the dust source.

Keywords: vegetation cover, cement dust, plant diversity, dust deposition.

المخلص

يعد إنتاج الإسمنت عنصراً أساسياً في تطوير البنية التحتية، إلا أنه ينطوي على مخاطر بيئية ملحوظة، لا سيما من خلال انبعاثات الغبار. هدفت هذه الدراسة إلى تقييم تأثير غبار الإسمنت المنبعث من مصنع الأهلي للإسمنت بمدينة زليتن، ليبيا، على الغطاء النباتي في المناطق المحيطة. جمعت عينات نباتية من خمسة مواقع تقع جنوب المصنع وعلى مسافات 500 و1000 و2000 و4000 و8000 متر، وتمثل هذه المواقع مناطق تتعرض لمستويات مختلفة من ترسيب الغبار. ظهرت النتائج تحسناً واضحاً في خصائص الغطاء النباتي مع زيادة المسافة عن المصنع. فقد ارتفع كلٌّ من عدد النباتات وتنوع الأنواع بشكل معنوي، حيث سجلت أعلى القيم عند مسافة 4000 متر (56 نباتاً و10 أنواع)؛ تحليل التباين ANOVA بقيمة دلالة $p = 0.0025$ و $p = 0.0026$ على التوالي. كما بلغت الكتلة الحيوية للنباتات ذروتها عند هذه المسافة (211 غراماً وزناً طازجاً و166.3 غراماً وزناً جافاً)، إلا أن هذه الفروق لم تكن ذات دلالة إحصائية ($p = 0.3395, 0.1270$) بالنسبة لنبات *Hordeum murinum*، فقد ازدادت المساحة الورقية بشكل ملحوظ من 78 سم² عند مسافة 500 متر إلى 1007 سم² عند مسافة 8000 متر ($p = 1.84 \times 10^{-4}$)، كما ازداد طول الورقة من 8 إلى 14 سم ($p = 0.0016$)، في حين أظهر عدد الأوراق زيادة طفيفة غير معنوية من 7 إلى 9 أوراق ($p = 0.1333$). وأظهرت معاملات الارتباط وجود علاقة طردية قوية بين المسافة عن مصنع الإسمنت وكلٍّ من طول الورقة ($r = 0.93$)، وعدد الأوراق ($r = 0.87$)، وعدد النباتات ($r = 0.79$)، مما يدل على تحسّن الحالة النباتية مع الابتعاد عن مصدر الغبار. تؤكد هذه النتائج التأثيرات

السلبية لغبار الإسمنت على الغطاء النباتي في المناطق القريبة من مصدر الانبعاث، وتبرز أهمية المسافة كعامل رئيسي في الحد من آثاره البيئية.

الكلمات المفتاحية: الغطاء النباتي، غبار الأسمنت، تنوع النبات، ترسب الغبار.

1. Introduction

Cement, recognized as the most widely used construction material on a global scale, holds a pivotal position in the advancement and expansion of societies (Gagg, 2014). It serves as a crucial element in the production of concrete, a versatile substance that provides durability and strength to a wide range of structures, including buildings, bridges, roads, dams, and various other infrastructure projects. With the continuous surge in the global population and the ongoing process of urbanization, the demand for cement is projected to witness an annual growth rate of 2.4% between 2022 and 2026 (Statista Research Department, 2023). While cement is an essential component of modern construction, its production has significant environmental implications. One of the most notable environmental concerns associated with cement production is the dust emission of cement industry. Cement dust is generated at various stages of the production process, including raw material handling and grinding, clinker production, and cement handling and transportation.

The cement industry is a significant contributor to environmental pollution, ranking as the third largest industrial source according to the Environmental Protection Agency (U.S. Environmental Protection Agency, 2023). It emits over 500,000 tons annually of harmful pollutants, including sulfur dioxide, nitrogen oxide, and carbon monoxide. Siddique et al. (2021) note that the cement production process generates approximately 0.13 kg of cement dust for every ton of cement produced. This dust consists of fine particles, often ranging from a few micrometers to submicron sizes, which can be readily distributed throughout the atmosphere. Furthermore, Blois and Lay-Ekuakille (2021) emphasize that cement dust emissions may contain trace levels of heavy metals such as lead, cadmium, and chromium, along with other pollutants, which vary based on the specific raw materials and fuels used in the kiln.

Cement dust particles can travel over long distances and have the potential to cause various environmental and health impacts. Fine cement dust particles, typically in the range of a few micrometers or smaller, can be carried by wind currents for several kilometers or even hundreds of kilometers from the source of emission. They can lead to the deterioration of air quality and the formation of smog. The deposition of dust particles on the soil surface lead to changes in soil structure and texture. Excessive cement dust accumulation can result in soil compaction, reduced water infiltration, and impaired drainage (Bilen et al., 2025). These alterations can significantly impact the growth and development of vegetation, ultimately leading to a decline in vegetation cover.

Cement dust poses a significant threat to plant health by directly settling on leaves and stems, thereby disrupting photosynthetic processes. The accumulation of these dust particles can obstruct light penetration, impede gas exchange, and hinder the absorption of vital nutrients (Soheili et al., 20023). This interference not only affects the physiological functioning of plants but may also have broader ecological implications.

Libya is among the countries engaged in cement production, alongside oil, gas, and other industrial activities that contribute significantly to environmental pollution. This reality underscores the urgent need for regulatory frameworks and environmental legislation aimed at controlling emissions from various industrial sectors, particularly cement manufacturing, which is recognized as one of the most polluting industries. As such, studying the environmental impacts of cement factories—especially their effects on human health and surrounding ecosystems—has become increasingly important.

Environmental Impact Assessment represents a key modern tool for evaluating the consequences of human activities on natural systems. It plays a crucial role in guiding decisions about whether to proceed with, modify, or halt development projects (Joseph et al., 2018).

The Alahlia Cement Factory in Zliten is one of Libya's major production facilities, strategically located near densely populated areas and ecologically sensitive zones, including valleys and low-altitude plateaus that are rich in plant biodiversity. This geographic proximity heightens the potential for environmental harm, making it essential to assess the factory's impact on the local vegetation. This study aims to evaluate the influence of cement dust from the Ahlia Cement Factory in Zliten, Libya, on vegetation cover.

2. Material and methods

2.1. Study area and location

The study was carried out in Zliten, Libya, which is about 160 kilometers east of Tripoli, between February and April of 2024. Following the predominant north-northwest winds, sampling locations were situated 500, 1000, 2000, 4000, and 8000 meters downwind, south of a 37-ha cement factory (32°25'25 N, 14°28'59 E).

2.2. Vegetation sampling

The annual plants that emerge in the spring were the focus of the vegetation sampling, which served as a measure of how cement dust affected diversity and growth. To standardize sampling, a 1 × 1 m wooden frame was utilized and positioned randomly three times at each site, and the recorded data were averaged to reduce variability.

The following parameters were measured:

2.2.1. Number of plants

For each throw, the total count of individual plants within the quadrat was recorded.

2.2.2. Number of plant species

Diversity of plant species was documented to gauge ecological health.

2.2.3. Plant biomass

All the vegetation in the quadrat was gathered and placed in paper bags. Fresh weight was measured in the field, followed by oven drying at 65 °C for 48 hours to obtain dry weight.

2.3. Other leaf-based measurements

2.3.1. Leaf count

As an indicator plant, false barley (*Hordeum murinum*), a common annual grass species in the study area, was chosen. Three individuals were chosen at random from each site, and the number of leaves on each plant was counted. The following formula was used to determine the mean leaf count:

$$\text{Mean Leaf Count} = \frac{C1+C2+C3}{3} \dots\dots\dots(1)$$

where C1, C2, and C3 represent the number of leaves per sampled plant.

2.3.2. Leaf surface area

Every leaf from each of the three false barley plants sampled at each location was arranged on paper alongside a ruler and photographed. The images were analyzed using ImageJ software which allowed for scale calibration and measurement of total leaf surface area. The following formula was used to calculate the mean leaf surface area:

$$\text{Average Leaf Surface Area} = \frac{S1+S2+S3}{3} * N.(2)$$

where S1, S2 and S3 represent the total surface area of leaves from the three plants, and N is the total number of leaves.

2.3.3. Leaf length

Leaf lengths were also measured using ImageJ. The mean leaf length was determined as:

$$\text{Average Leaf length} = \frac{L1+L2+L3}{N} \dots\dots\dots(3)$$

where L1, L2 and L3 represent the total leaf lengths of the three sampled plants and N is the total number of leaves.

2.4. Data analysis

One-way analysis of variance (ANOVA) was used to compare vegetation parameters across sampling sites. Error bars in the figures indicate the standard deviation (± 1 SD), which was used to express the variability in the results.

3. Results and discussion

3.1. Number of plants

The assessment of plant populations using the quadrat method revealed significant insights into the impact of industrial activities on local vegetation. Mean plant counts showed an increase with distance from the factory, ranging from 21 plants at 500 meters to 56 plants at 4000 meters and 48 plants at 8000 meters. The trend, as shown in Figure (1) below, indicates that plant viability improves as proximity to the industrial site decreases.

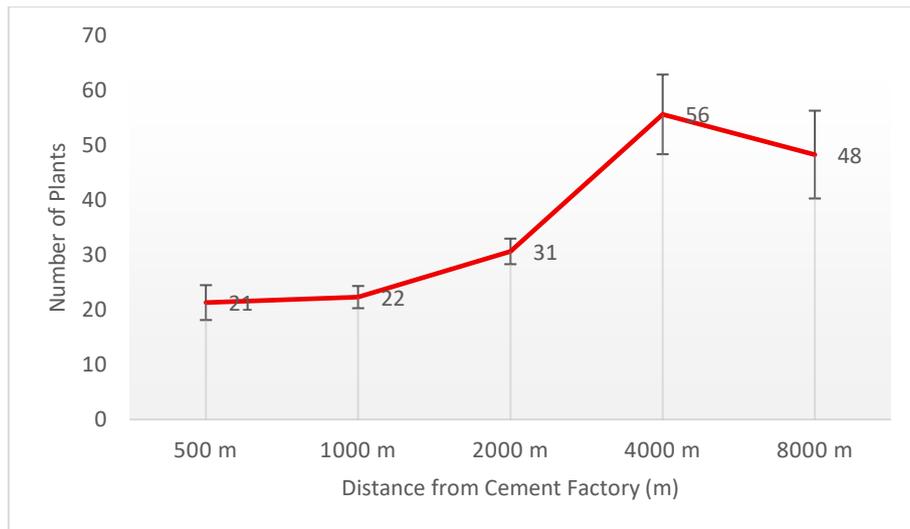


figure 1. Mean Number of Plants Across Study Sites. Error bars represent ± 1 standard deviation within each location.

The ANOVA analysis results indicate significant differences in plant numbers across the various sites. The analysis shows a p-value of 0.0025. This suggests that there are statistically significant differences in the mean number of plants among the groups.

The findings of Okasha (2008) are consistent with the present study, indicating a significant decline in the number of plants in areas close to the Elmergib Cement Factory. Notably, the area nearest to the factory—particularly the southern sampling site, which is more directly exposed to dust emissions—showed the lowest plant abundance. Plant numbers increased progressively with distance from the factory, especially in directions not exposed to prevailing winds.

3.2. Mean number of plant species

The assessment of plant species diversity showed that at 500 meters, the mean number of plant species was 5. At 1000 meters, this mean increased to 6, suggesting a slight recovery. By 2000 meters, the mean rose to 8, and at 4000 meters, it reached 10 species. At 8000 meters, the mean was 9 species, indicating minimal variation in plant diversity compared to 4000 meters. Figure (2) illustrates these results, highlighting the relationship between plant diversity and distance from the cement factory.

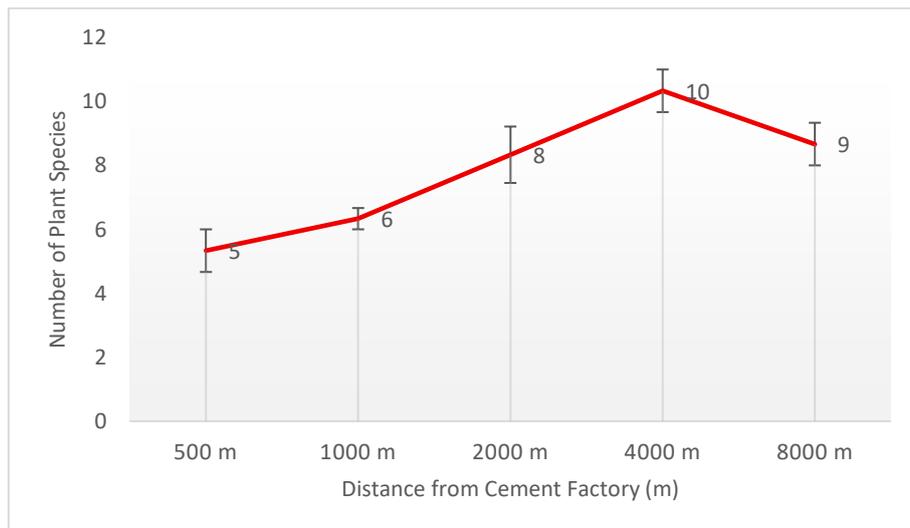


Figure 2. Mean Number of Plants Species Across Study Sites. Error bars represent ± 1 standard deviation within each location.

Similarly, the ANOVA analysis for the number of plant species yielded a p-value of 0.0026, indicating that there are statistically significant differences in the mean number of plant species among the groups. These findings are supported by Okasha's (2012) study which reported a notable reduction in plant species diversity in areas adjacent to the factory and a lower overall diversity compared to surrounding regions. This evidence further underscores the detrimental impact of industrial emissions on local flora.

3.2.1. Biomass accumulation

As shown in Figures (3) and (4), the lowest plant biomass was recorded at 500 meters with a fresh weight of 120 g and dry weight of 77.2 g, while the highest values occurred at 4000 meters, reaching 211 g (fresh) and 166.3 g (dry), indicating improved plant growth with increasing distance from the cement factory

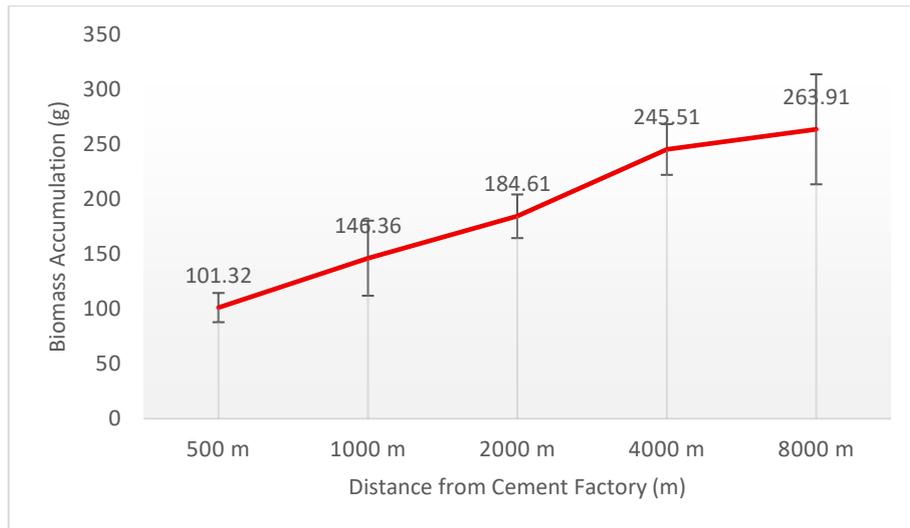


Figure 3. Plant Fresh Weight Across Study Sites. Error bars represent ± 1 standard deviation within each location.

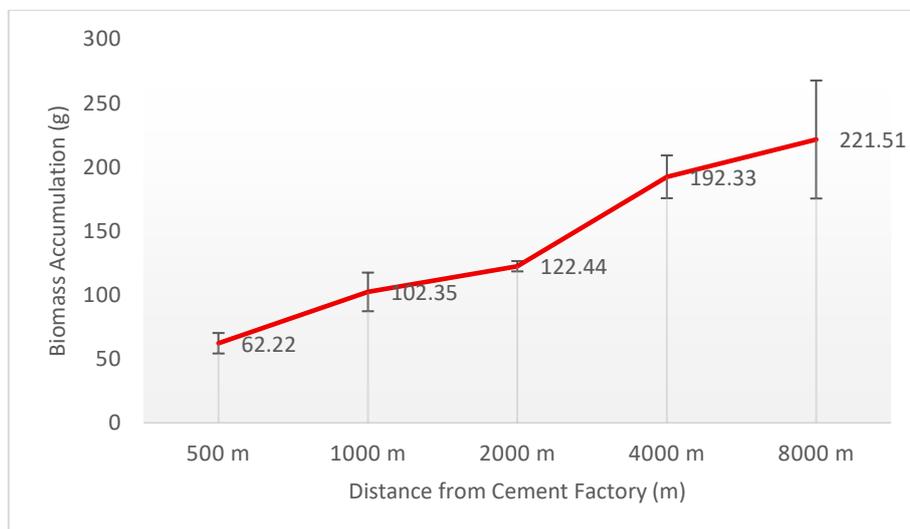


Figure 4. Plant Dry Weight Across Study Sites. Error bars represent ± 1 standard deviation within each location.

The ANOVA analysis for the fresh weight of plants indicates no statistically significant differences across the study sites, with a p-value of 0.3395. Similarly, although some variation in dry weight is observed, the ANOVA results also show no significant differences among the sites, yielding a p-value of 0.1270. These findings suggest that, despite visible trends in plant biomass, the differences are not statistically meaningful at the 0.05 significance level.

Although the ANOVA results in this study did not show statistically significant differences in plant biomass across the sites, the observed trend of increasing biomass with distance from the cement factory aligns with findings from Mao et al. (2023), who reported that cement pollution can negatively affect plant growth.

3.3. Leaf morphology of false barley

3.3.1. Mean number of leaves of false barley plant

The findings show that false barley had the lowest mean leaf count at 500 meters (7 leaves), while the highest count was observed at 8000 meters (9 leaves), suggesting improved plant health with increased distance from the cement factory, as shown in Figure (5).

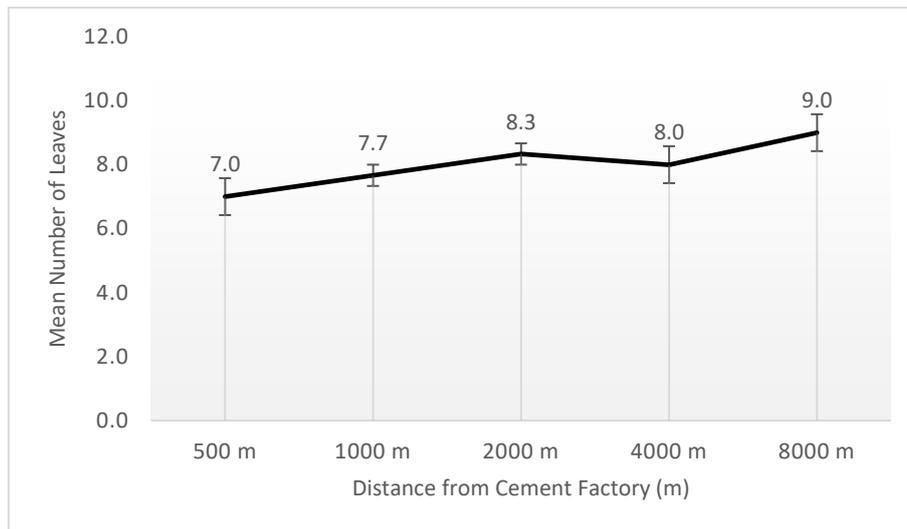


Figure 5. Mean Number of Leaves of False Barley Plant Across Study Sites. Error bars represent ± 1 standard deviation within each location.

While there is a trend indicating an increase in leaf count with greater distance from the Alahlia Cement facility, the ANOVA analysis showed no statistically significant differences among the groups, yielding a p-value of 0.1333. This suggests that the mean number of leaves does not vary significantly across the different distances from the factory.

These findings are consistent with a study by Iqbal et al. (2001), which demonstrated that cement dust pollution significantly affected the number of leaves in certain tree species. While one species exhibited a marked reduction in leaf count, another showed no significant difference compared to the control group.

Similarly, Ramanathan et al. (2023) investigated the effects of cement dust on *Azadirachta indica* (neem) and reported a substantial decrease in chlorophyll content in leaves collected near cement factories. Since chlorophyll content is closely linked to leaf health and function, this reduction suggests that neem leaves are adversely impacted by cement dust accumulation. The resulting physiological stress can lead to diminished plant vigor and potentially a lower number of leaves, underscoring the broader impact of cement pollution on plant health and growth.

3.3.2. Mean leaf surface area

The results of this study, as illustrated in Figure (6), show a clear trend of increasing leaf surface area with greater distance from the cement factory. At 500 meters, the mean leaf surface area is 78 cm², which increases significantly to 488 cm² at 1000 meters. This upward trend continues at 2000 meters with a mean of 727 cm², reaching 841 cm² at 4000 meters, and peaking at 1007 cm² at 8000 meters.

The ANOVA analysis yielded a p-value of 1.84E-04, indicating a strong and statistically significant effect of distance from the cement source on leaf surface area. These findings are consistent with the conclusions of Al-Awjali et al. (1999) and Al-Sal and Al-Qabi (2000), who also reported increased vegetation performance with greater distance from industrial pollution.

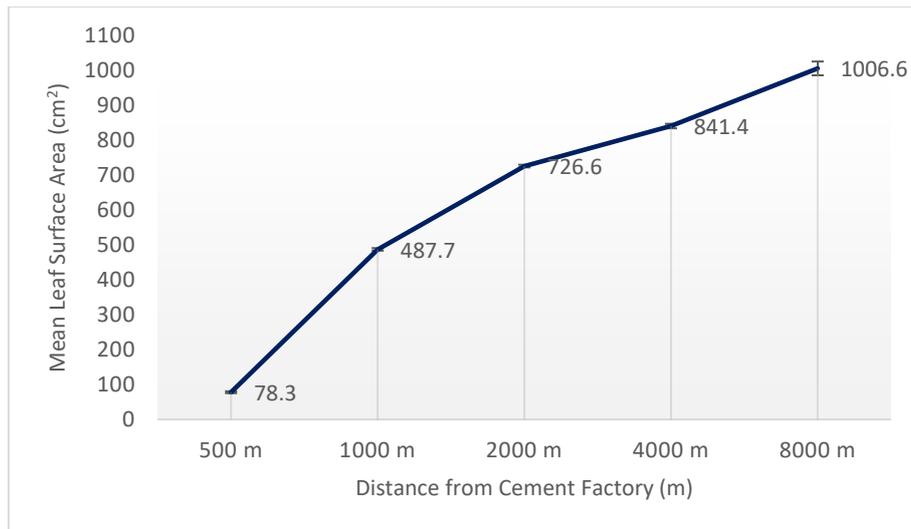


Figure 6. Mean Surface Area of False Barley Plant Across Study Sites. Error bars represent ± 1 standard deviation within each location

Furthermore, this study aligns with the findings of Salama et al. (1998), who observed that cement dust adversely affected olive trees, castor bushes, and squill grasses in the region between Misurata and Al-Khums, resulting in reduced leaf development and overall vegetation density.

Similarly, Premalatha et al. (2015) reported decreases in both the length and area of castor leaves in cement-impacted environments. In their review, Rawat and Katiyar (2015) highlighted the detrimental effects of cement dust on vegetation, noting its impact on leaf surface area, stomatal activity, and chlorophyll content. They observed that dust deposition impedes gas exchange, reduces photosynthesis, and leads to chlorosis and necrosis. These combined findings reinforce the harmful influence of cement emissions on local flora and provide strong support for the trends observed in this study.

3.3.3. Mean leaf length

Similarly, the mean leaf length of False Barley also increased with distance from the cement factory, as demonstrated in Figure (7). At 500 meters, the mean leaf length was 8 cm, which rose to 14 cm by the time sampling reached 8000 meters. This increase in leaf length may reflect an adaptive response to the less stressful conditions found further from the pollution source. Longer leaves could enhance photosynthetic efficiency and improve overall plant health, contributing to the increased biomass observed at greater distances

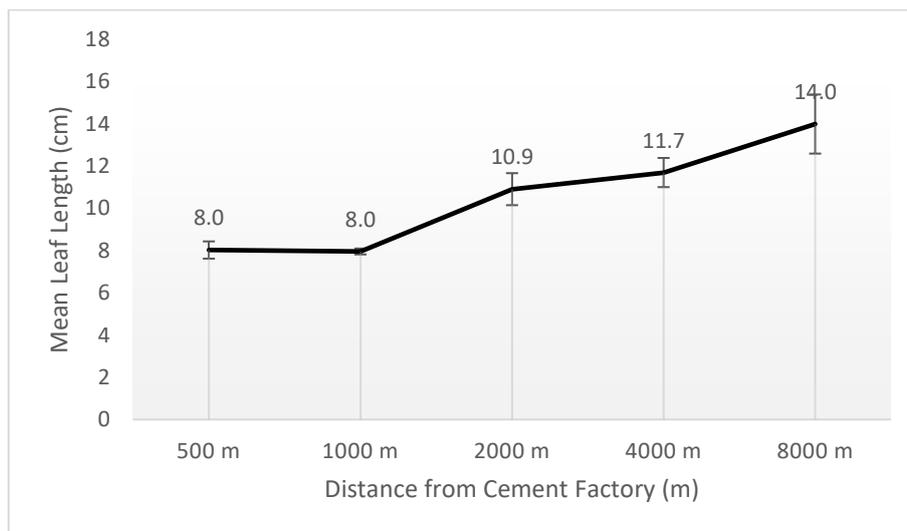


Figure 7. Mean Leaf Length of False Barley Plant Across Study Sites. Error bars represent ± 1 standard deviation within each location.

The results from the ANOVA analysis indicated that the leaf length of false barley plants exhibited a p-value of 0.0016, demonstrating a statistically significant difference. This finding aligns with the results reported by Premalatha et al. (2015), which indicate that cement dust pollution adversely impacts leaf development in castor plants. Their research revealed a significant reduction in leaf length among plants exposed to cement dust, with the shortest leaves observed at locations closest to the cement factory. This decline was attributed to the disruptive effects of cement dust on physiological processes such as photosynthesis and nutrient uptake. The study concluded that the accumulation of particulate matter on leaf surfaces hinders plant function and growth, reinforcing the present study's conclusion that cement emissions negatively affect leaf development.

3.4. Correlation analysis of vegetation parameters

The correlation analysis presented in Table (1) reveals significant relationships among vegetation parameters, highlighting how plant communities respond to environmental stress from cement dust. Notably, all parameters show positive correlations with distance, suggesting that these vegetation variables increase as distance from the pollution source increases. A moderately strong correlation ($r = 0.79$) exists between the number of plants and the number of species, indicating that higher plant abundance is associated with greater species richness, particularly in areas farther from the cement factory. Furthermore, the number of species correlates strongly with both fresh ($r = 0.928$) and dry biomass ($r = 0.986$), emphasizing the contribution of leaf production to overall plant health and growth.

Additionally, leaf surface area demonstrates strong correlations with leaf length ($r = 0.884$) and the number of leaves ($r = 0.808$), suggesting that larger leaves are associated with more favorable structural and functional traits. The high correlation between fresh and dry weight ($r = 0.966$) further supports the link between water content and biomass accumulation. Collectively, these findings underscore the interconnectedness of structural and physiological traits in influencing plant performance across gradients of pollution.

Table 1. Correlation Matrix of Vegetation Parameters in the Study Area

	Distance(m)	N_Plants	N_Species	N_Leaves	LSA	L_length	Fresh_Weight	Dry_Weight
Distance (m)	1.000							
N_Plants	0.786	1.000						
N_Species	0.739	0.952	1.000					
N_Leaves	0.870	0.607	0.682	1.000				
LSA	0.814	0.785	0.898	0.913	1.000			
L_length	0.933	0.844	0.866	0.808	0.884	1.000		
Fresh_Weight	0.438	0.826	0.928	0.452	0.769	0.649	1.000	
Dry_Weight	0.630	0.942	0.986	0.558	0.824	0.786	0.966	1.000

4. Conclusion

This study evaluates the influence of cement dust on vegetation cover. Vegetation health improved with distance from the Alahlia Cement Factory. Plant abundance peaked at 4000 m with a mean of 56 plants, showing significant variation among sites (ANOVA, $p = 0.0025$), while species diversity also reached its maximum at 4000 m with 10 species ($p = 0.0026$). Biomass accumulation increased with distance, reaching 211 g fresh and 166.3 g dry at 4000 m, though differences were not significant (fresh weight $p = 0.3395$; dry weight $p = 0.1270$). In false barley (*Hordeum murinum*), leaf surface area reached its maximum at 8000 m (1007 cm²; $p = 1.84E-04$), and leaf length also peaked at 8000 m (14 cm; $p = 0.0016$). Leaf number rose slightly from 7 to 9 but was not significant ($p = 0.1333$). Correlation analysis confirmed strong positive relationships between distance and vegetation parameters, particularly leaf length ($r = 0.93$), number of leaves ($r = 0.87$) and number of plants ($r = 0.786$).

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Compliance with ethical standards

Disclosure of conflict of interest

The author(s) declare that they have no conflict of interest.

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