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Assessment of Particulate Matter (Pm_{10}) Emissions and Air Quality Impacts around Ewekoro Cement Factory, Ogun State, using Aermod Modelling

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Abstract

This research assessed particulate matter (PM_{10}) emissions and air quality impacts around the Ewekoro Cement Factory, Ogun State, using the AERMOD Air Dispersion Modelling. It analysed the relationship between socio-economic characteristics of residents and industrial pollution, identified the significant sources of pollution, analysed the spatial-temporal pollutants dispersion in the study area, and established the correlation between living close to the factory and satisfaction with operations. A multi-stage sampling method was employed to sample the four selected communities in Ewekoro. 240 questionnaires were administered, while 233 were retrieved. The AERMOD model with meteorological and terrain information exhibited seasonal fluctuation in PM_{10} dispersion, whereby the values were more than 0.34 µg/m³ around the factory during the dry season and dispersed to remote locations such as Papalanto (>0.065 µg/m³) during the wet season. The Chi-Square test correlation analysis indicated a significant negative correlation between distance from the Lafarge Cement Factory and respondents' satisfaction with the factory's overall operations ($r = -0.187$, $p = 0.004$). Therefore, the study recommends dynamic air quality control, monitoring, and spatial planning interventions for safeguarding public health and catalysing environmentally friendly industrial growth in Ogun State.

Keywords: Particulate Matter (PM_{10}), Cement, Air Quality, Air Dispersion, AERMOD Modelling.

1.0 Introduction

Air quality is a significant concern due to its impact on the health and well-being of the population, especially in urban areas (Dong et al., 2019). Organisations and researchers have acknowledged air pollution as a severe environmental health hazard that significantly impacts residents' daily lives, particularly in urban areas (WHO, 2021; Pantusheva et al., 2022). Globally, the combined effects of ambient (outdoor) air pollution and indoor (household, in particular) air pollution cause approximately 7 million premature deaths every year, according to the World Health Organisation (2020). This problem, as Adeyanju and Okeke (2019) pointed out, is primarily exacerbated by industrialisation, urbanisation, and increasing road

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traffic. This phenomenon ranks among the most pressing environmental challenges of the 21st century. Long-distance atmospheric transport of distant sources of pollutants is one of the leading causes of urban air pollution (WHO, 2021). In 2018, the World Health Organisation reported that 90% of the world's population inhales air with pollutant concentrations higher than safety levels, particularly in developing nations, including Nigeria (Khaniabadi et al., 2017; Goudarzi et al., 2017). Similarly, the World Health Organisation (WHO) fact sheet dedicated to ambient pollution revealed that in 2019, 99% of the world's population was living in places where the levels of the WHO air quality guidelines were not met (WHO, 2021). However, it is worth noting that the effect is most severe in Asia and Africa, where 90% of air pollution-related mortality has been reported. Statistics from the pollution index offered by Numbeo, as cited in Adeyanju & Okeke (2019), show clearly that Asia's pollution index is high. In contrast, few African countries have sufficient data for sophisticated analysis. Hence, air pollution indices vary from average to maximum levels in regions where data are available, with Africa, South America, and Asia all reporting indices above the average threshold (Adeyanju & Okeke, 2019).

Air pollution directly impacts climate change, which is a result of anthropogenic factors. However, climate change increases the production of allergenic air pollutants such as pollen and mould, which can be hazardous to health (D'Amato et al., 2020). This scenario has, over time, cascaded to the alteration of energy balance between the atmosphere and the surface of the earth. These complex atmospheric interactions cause thermal and chemical composition changes (European Commission, 2010). The elevated levels of atmospheric particles prevalent in urban environments, including nitrogen oxides (NO), carbon dioxide (CO_2), ozone (O_3), and various harmful gases, serve as principal factors contributing to the health afflictions observed during pollution episodes (Ridzuan et al., 2020). Therefore, the following scholars like Mehraj et al. (2013), Oyinloye (2015), Chukwu & Ubosi (2016) and Pantusheva et al. (2022), the emission of air pollutants results in cardiovascular, pulmonary, and respiratory diseases, cancer of the lung, bronchus, and trachea, and asthma. Likewise, according to Zhang et al. (2018) and the Alzheimer Association (2022), air pollution is thought to impair children's

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and adults' cognitive functioning. It suggests consequences for dementia, Alzheimer's disease, and Parkinson's disease.

Nigeria is sadly the 4th most polluted country globally, with a relatively disturbing number of deaths attributed to bad air (Nyakuma et al., 2022). Part of the main perpetrators in this process is particulate matter (PM), which tends to be commonly discussed as among the most significant polluters in our air. It consists of small particles that are a solid and liquid matter mixture and present in the smallest sizes (Samek et al., 2018). Particulate matter is generally classified into different categories: coarse particles with a diameter of 10 micrometres or less (PM_{10}), fine particles that are 2.5 micrometres or smaller, and ultrafine particles that measure less than 0.1 micrometres (Samek et al., 2018). Therefore, breathing in these particles can cause severe health issues, such as illnesses and, in other instances, death, as noted above. Likewise, Ezeh et al. (2012) and Moses and Orok (2015) have also established that breathing in $PM_{2.5}$ and PM_{10} can result in chronic health issues, such as respiratory organ damage. However, the study of Ware et al. (1986) established a clear link between PM levels in the air and the rates of bronchitis and coughing, a conclusion that was further validated by Pope et al. (1991). Numerous studies have also pointed out that fine particles are mostly harmful to health compared to their coarse counterparts, significantly contributing to climate change (Janssen et al., 2011; Chen, 2018). The World Bank (2015) reports that Nigeria's particulate matter ($PM_{2.5}$) levels exceed 94% of the WHO guideline threshold, well above the Sub-Saharan African average of 72%. The primary drivers of worsening urban air pollution include the burning of fossil fuels (Oguntoke & Adeyemi, 2017), rapid industrialisation and urbanisation, and economic expansion (Laumbach & Kipen, 2012; Dons et al., 2013; Adeyanju & Okeke, 2019). The rise in industrial emissions, urban sprawl, and traffic congestion in Nigeria has amplified environmental and health risks, echoing trends found in other developing nations (Khaniabadi et al., 2017; Goudarzi et al., 2017; Chukwu et al., 2023). Urban residents are exposed to more than 200 air pollutants, with particulate matter being the most pressing issue in Nigeria (Khaniabadi et al., 2017; Geravandi et al., 2017; Daryanoosh et al., 2017).

Cement production contributes significantly to particulate matter emissions, particularly from kilns, quarrying activities, and material processing

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(Farhadi et al., 2017; Goudarzi et al., 2016; Akinrogunde, 2024). The global cement industry has seen record expansion over the last three decades, from 1.2 billion tonnes in 1990 to 4.1 billion tonnes in 2019, driven by industrialisation and urbanisation. Cement manufacturing is a significant source of calcium particulates (Lee & Pacyna, 1999). People near cement factories mostly communicate their dissatisfaction with the probable adverse effects they are likely exposed to (Schuhmacher, Nadal & Domingo, 2009). Although cement has become a dominating construction material, its production involves nearly 25% of worldwide industrial CO_2 emissions, hence air pollution and land deterioration (Tong et al., 2019; Chen et al., 2022). It is worth noting that Nigeria's cement industry thrived due to supportive government policies and abundant limestone deposits, making the country one of Africa's leading producers (Alayande, 2019; Etim et al., 2021; Ahmed et al., 2022). However, this growth, especially in places like Ewekoro, brings serious environmental and public health challenges, including increased energy demands, greenhouse gas emissions, community conflicts, and health hazards from pollution (Adekoya, 2020; Ojo & Ogunnusi, 2019; Salami et al., 2004; Oladimeji, 2019; Akinrogunde, 2024). Even though some of these cement companies have focused on attaining sustainability (Fernando, 2023; Reckmann, 2023), problems still arise. Resident displacement, air, noise and water pollution are still prevalent challenges (Idowu, 2023; Akinrogunde, 2024). This requires the imperative necessity of coordinated measures to reconcile industrial development with protecting the environment and the health of the public (World Health Organisation, 2023; Pollution Prevention & Abatement, 1998; Ojo & Ogunnusi, 2019; Dubey & Narayanan, 2010; Zhang et al., 2015; Ganguli et al., 2016; Akinrogunde, 2024).

More importantly, air dispersion models such as the American Meteorological Society/Environmental Protection Agency Regulatory Model (AERMOD), California Puff Model (CALPUFF), and Computational Fluid Dynamics (CFD), alongside GIS tools, are increasingly being utilised to simulate and predict pollution concentration, assess health risks, and support data-driven environmental planning and policy making. However, previous studies on industrial emissions in Nigeria have mostly employed ground-based measurements, with only a few utilising high-level air dispersion modelling

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techniques (Nyakuma et al., 2022). As complexity increases for scientific and engineering problems, calculation models such as AERMOD, CALPUFF, and CFD are becoming more popular to mimic emissions and predict their far-reaching spatial impact (Di Sabatino et al., 2013; El-Harbawi, 2013; Leelossy et al., 2014; Lateb et al., 2016). These models are valuable for urban planners, as they help improve air quality, protect public health, reduce environmental degradation, and prevent economic losses. A well-chosen, effective modelling system is essential in resolving the above issues and preparing accurate predictions for air pollution dispersion (Leelossy et al., 2014). This study, therefore, addresses that gap by applying science-based models to generate more accurate, predictive insights into air quality dynamics. In the same vein, this study aligned with Sustainable Development Goals (SDGs) 11 and 13, "promoting sustainable urban environments" and "climate action", respectively. Hence, this study assesses the spatial-temporal variations in air quality around the Ewekoro Cement Factory using air dispersion modelling (AERMOD), with the overarching aim of providing insight into effective air quality management and spatial planning policies that protect public health, improve environmental conditions, and support sustainable development in industrial areas.

This research is necessitated to critically examine the extent to which industrial emissions, particularly from cement manufacturing, influence local air quality, given that such operations are well-documented contributors to the release of particulate matter (PM). The study investigates the dispersion of emissions under varying weather and operational conditions to identify regions with elevated exposure levels. Thus, the outcomes of this research are helpful to guide the formulation of effective regulations and pollution control policies. In effect, the research is guided by several critical issues of concern that must be empirically ascertained: What is the relationship between residents' socio-economic characteristics and the impacts of industrial pollution in Ewekoro? What are the significant sources of air pollution in the study area? How do concentrations of pollutants disperse over time and across different geographical locations? Is there a relationship between the distance from emission sources and the distance of buildings to the Lafarge Cement Factory and respondents' satisfaction with the factory's overall operations in the study area? By investigating these questions, the study seeks to

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identify the main contributors to air pollution, analyse the dispersion of pollutants across various locations and timeframes in Ewekoro, and evaluate the relationship between the proximity of residential buildings to the Lafarge Cement Factory and the level of respondents' satisfaction with the factory's overall operations. Ultimately, this research is set to enhance understanding of air quality issues in Ewekoro and encourage informed discussions regarding public health and environmental policy.

2.0 Materials and Method

Brief description of the study area

Ogun, known as "the Gateway State," is one of Nigeria's 36 states, established on February 3, 1976, from the former Western Region and named after the Ogun River. It spans a land area of 16,981.26 square kilometres and shares borders with Ondo State to the east, Oyo and Osun States to the north, Lagos and the Atlantic Ocean to the south, and the Republic of Benin to the west. The state is divided into twenty Local Government Areas (LGAs) for effective planning and land administration. According to the 2006 Census, Ogun's population was recorded at 3.95 million, ranking it 16th in Nigeria, and with a growth rate of 3%, the estimated population in 2011 was 5.86 million (Omole & Isiorho, 2011, as cited in Adewunmi et al., 2023) and 6.275 million in 2016 (National Bureau of Statistics, 2016). Ogun State, ranked as the 24th largest in Nigeria by land area, is socio-economic activities with growth in its population and industries, especially in lively towns like Akute, Alagbole, and Mowe. This flourishing development is largely due to Ogun's close ties with Lagos, Nigeria's economic powerhouse (Adewunmi et al., 2023). Amid this ever-changing landscape, the Ewekoro Local Government Area stands out. Founded in 1981, Ewekoro is renowned for its rich limestone deposits and houses the West African Portland Cement Company. The area covered approximately 594 square kilometres; Ewekoro had a population of 55,093 according to the 2006 census. Its location offers a rich tapestry of natural resources and community life, making it a vital contributor to the region's development. Its strategic location along key roads, particularly the Sango-Ifo-Abeokuta expressway, alongside a well-developed transportation network that includes private vehicles, commercial taxis, trucks, and motorcycles, makes it well-connected both locally and regionally (Badejo, Olasunkanmi, & Ogunseye, 2020). Thus, Ewekoro serves as a prime

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example of how abundant natural resources and urban development can come together, playing a vital role in Ogun State's economic and infrastructural advancement.

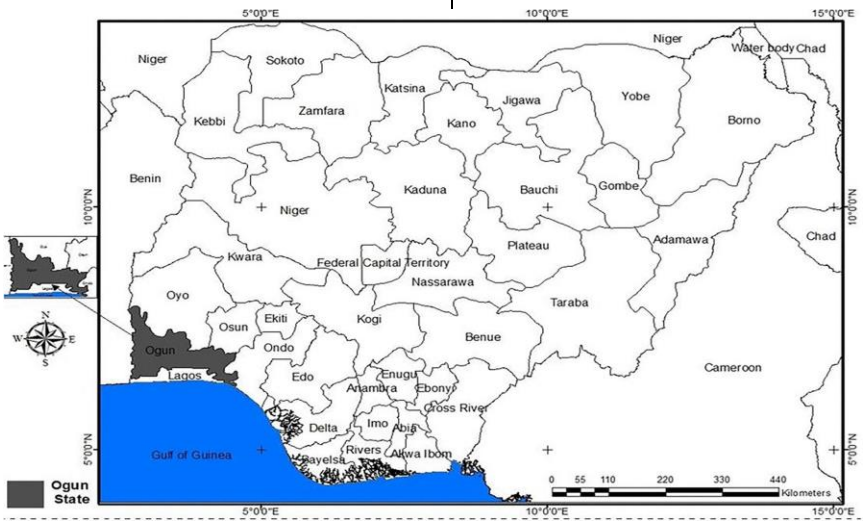


Figure 1: Map of Nigeria showing Ogun State in its Regional setting
Source: Ogun State, Ministry of Land and Housing (2017)

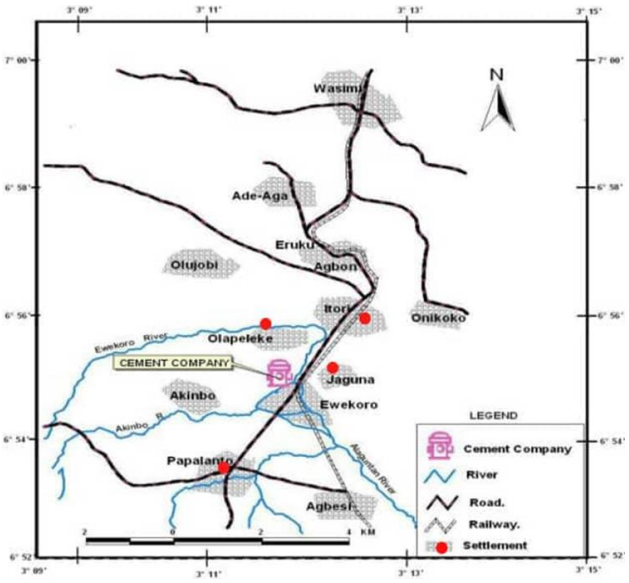


Figure 2: Map of Ogun State showing Ewekoro LGA in its local setting
Source: Ogun State Ministry of Physical Planning and Urban Development (2023)

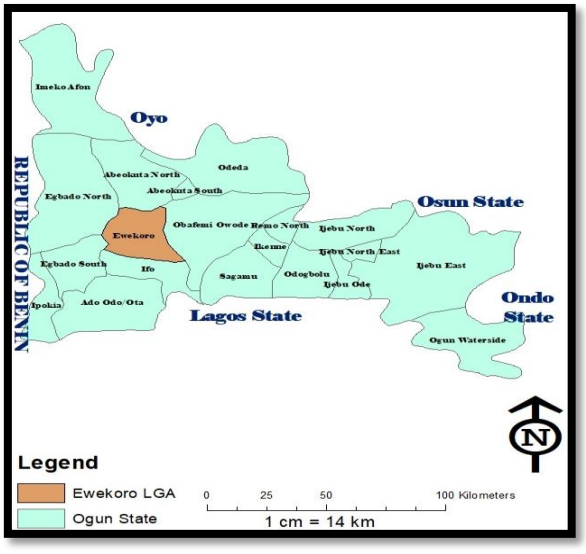


Figure 3: Location of the selected settlement in Ewekoro
Source: Adapted from Bada et al. (2013)

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Research design and data collection

This study employed the mixed method of household survey investigation and the AERMOD modelling to examine the spatial-temporal impact of factory emissions on air quality in the Ewekoro area of Ogun State. Primary data were collected through a questionnaire survey of the residents in the spatially demarcated zones: Papalanto, Jagunna, Lapeleke, and Itori. The questionnaire was adopted to elicit details on perceived air quality, perceived impact of the cement factory, self-reported health, and socio-economic implementation. The questionnaire was surveyed through the multi-stage technique among homes in every zone. Two hundred forty (240) questionnaires were administered, and 233 were retrieved, forming the basis for this study's analysis. Ethical measures such as informed consent were upheld at all costs while responding to the survey. The Chi-Square test of independence was employed to examine whether there was any correlation between the distance of the building from the cement factory and general satisfaction. The self-reported answers in the questionnaire for perceived levels of air quality were coded as nominal variables (e.g., "Good," "Fair," "Poor") and cross-tabulated against the bounded spatial zones. The Chi-Square test still sought to identify whether there was a statistically significant relationship between whether or not the resident was located in a bounded zone and their perception of ambient air quality in the vicinity around them. The level of significance for this test was $\alpha = 0.05$.

Dispersion of air pollutants was modelled with AERMOD using factory emission inventories, hourly meteorology, and the Nigerian Meteorological Agency (2024) terrain data. An AERMOD receptor grid covering the study area and the available sensitive points were established. Model output, ground-level concentrations of major pollutants (PM_{10}), were processed and mapped within Surfer software to produce spatial distribution maps, which described the patterns of dispersion within the given study area and unique spatial regions classified according to proximity to the factory. The temporal aspects of air quality were also investigated using AERMOD modelling by simulating concentrations of pollutants for different averaging times suitable to define air quality standards (24-hour). Surfer software visualisation outputs were created for these various time intervals to determine possible temporal changes in the spatial dispersion patterns. Where the Chi-Square test of association between space

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and response to questionnaires existed, descriptive probing for possible temporal patterns in air quality self-rating by zone, where responses from filled questionnaires existed, was made. Using combined AERMOD simulation, Surfer visual presentation, and statistical comparison of questionnaire response analyses, an integrated description of the spatial-temporal effect of the emissions on air quality and perception by the populace of the case among the people of the Ewekoro community was achieved.

Air dispersion modelling for the Ewekoro Cement plant focused mainly on particulate matter ≤10 μm (PM_{10}) distribution, which is hazardous to human health and the environment. Three (3) cement plants (Plants 1, 2, and 3) were considered, and the emission rates were calculated using the USEPA (1989) emission factor method. AERMOD (23132) and ISCST-3 Gaussian plume dispersion models were run with parameters including discharge temperature, stack diameter, exit velocity, release height, and effluent rate in conjunction with surface and upper-air meteorological conditions. Dry and wet seasons were run hourly (1, 3, 8, and 24 hours). The results were then analysed using Surfer software to generate geospatial visualisations, including detailed maps and 2D plots, revealing pollution patterns, hotspots, and the influence of topography and weather on dispersion. These findings provide critical insights for the region's environmental management and public health planning. Table 1 below shows the existing cement plant stack parameters.

Table 1: The Existing Cement Plant Stack Parameters

Stack	Discharge Temperature (^{o}k)	Stack Diameter (m)	Exit Velocity (m/s)	Release Height (m)	Rate of Effluent (kg/s)	Location	
						X(m)	Y(m)
Cement plant 1	383	1.0	10	25	31.2	101718.98	86851.22
Cement plant 2	383	1.0	10	25	31.2	102474.16	85718.38
Cement plant 3	383	1.0	10	25	31.2	99453.24	87228.84

Source: *Adapted from Fakinle, Oki & Sonibare (2018)*

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The quantitative data were analysed statistically using IBM SPSS (Version 23) to generate descriptive and inferential statistics to match the study objectives. Complete air quality modelling was also conducted using the AERMOD dispersion model, supplemented by spatial interpolation and visualisation procedures utilising Surfer software. This double-analytical method allowed the examination of spatial-temporal differences in pollutant dispersion under various seasonal conditions, i.e., wet and dry seasons, thus furnishing empirical evidence of the environmental impact of cement production. This integrated approach collectively supports the research aims to assist in developing data-informed air quality management policy and spatial planning interventions that support public health, environmental integrity, and the values of sustainable development in industrialised peri-urban areas.

3.0: Results

240 questionnaires were administered for the purpose of this study and 233 of them were successfully retrieved, giving a 97.1% response rate. This rate of retrieval formed the foundation of data analysis. The questionnaire was administered in four communities named Papalanto, Jagunna, Lapeleke, and Itori, which are near the Lafarge Cement Factory in Ewekoro, Nigeria.

3.1 The socio-demographic characteristics of respondents

Table 2 shows socio-demographic attributes of the respondents in Ewekoro. Most respondents were male (68.7%), and most were aged 36-45 (42.1%). Most of the residents were married (57.9%), and the occupations most common included factory work (27.0%) and trade (23.6%). A large segment of the population had an average monthly income between 30,000 and 60,000 Naira (70.4% combined) and attained secondary education (42.1%). A considerable number of residents had lived in the community for more than 10 years (48.5% combined), with a notable portion being renters (41.2%) and living within 1-4 kilometres of the cement factory (64.4% combined). The highest household size was 4-6 members (48.5%). By implication, this analysis reveals an essentially male, middle-aged group with good industrial and commercial sector representation, moderate income levels, and a good long-term residence, with most of them residing in rented dwellings approximately near the cement factory.

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Table 2: The Socio-Demographic Characteristics of Residents in Ewekoro

Socio-demographic variables	Categories	Frequency	Percent (%)
Gender	Male	160	68.7
	Female	73	31.3
	Total	233	100
Age group	18-25 years	13	5.6
	26-35 years	46	19.7
	36-45 years	98	42.1
	46-55 years	55	23.6
	56-65 years	18	7.7
	Above 65 years	3	1.3
	Total	233	100
Marital status	Single	27	11.6
	Married	135	57.9
	Divorced	25	10.7
	Widowed	32	13.7
	Separated	14	6.0
	Total	233	100
Occupation	Unemployed	19	8.2
	Farming	23	9.9
	Trading	55	23.6
	Artisan	48	20.6
	Factory Worker	63	27.0

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	Civil Servant	25	10.7
	Total	233	100
Average monthly income (₦)	Below 30,000	16	6.9
	30,000 - 50,000	86	36.9
	51,000 - 60,000	78	33.5
	61,000 - 80,000	29	12.4
	81,000 - 100,000	13	5.6
	Above 100,000	11	4.7
	Total	233	100
Highest educational qualification	No formal education	21	9.0
	Primary education	32	13.7
	Secondary education	98	42.1
	Tertiary education	73	31.3
	Others	9	3.9
	Total	233	100
Period of residing in this community (Years)	Indigene	11	4.7
	Less than 5	52	22.3
	5-10	57	24.5
	11-20	85	36.5
	More than 20	28	12.0
	Total	233	100
Building occupancy status	Owner / Occupier	91	39.1
	Rented	96	41.2
	Inherited	34	14.6

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	Others	12	5.2
	Total	233	100
Distance of building to the Cement Factory (Kilometers)	Less than 1	43	18.5
	1 - 2	81	34.8
	3 - 4	69	29.6
	4 - 5	18	7.7
	Above 5	22	9.4
	Total	233	100
Household size	1-3	32	13.7
	4-6	113	48.5
	7-10	62	26.6
	More than 10	26	11.2
	Total	233	100

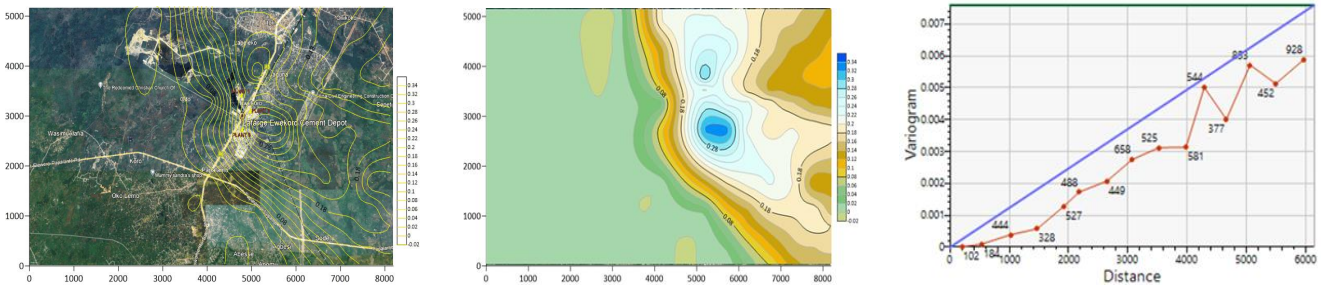
Source: Author's fieldwork, 2024

3.2 Air dispersion for dry season in Ewekoro

3.2.1 Dispersion of 1-Hr Average PM_{10} During the Dry Season

The analysis in Figures 4 (a, b, and c) provides a detailed examination of the dispersion tendencies and concentrations of particulate matter (PM) with a diameter of ≤ 10 µm, based on a 1-hour average during the dry season in the study area. The contour configuration map easily identifies the areas with PM_{10} levels above 0.34 µg/m³, especially around Lafarge Cement plants 1, 2, and 3, where emissions contribute significantly. There are also areas with comparatively moderate PM levels ranging from 0.02 to 0.08 µg/m³. Moreover, this analysis shows that the Jagunna and Lapeleke communities faced higher PM_{10} levels on average over an hour. The time series graph also depicts the ups and downs in PM_{10} concentrations, which can fluctuate above or below the set standards, mainly due to industrial activities and weather changes.

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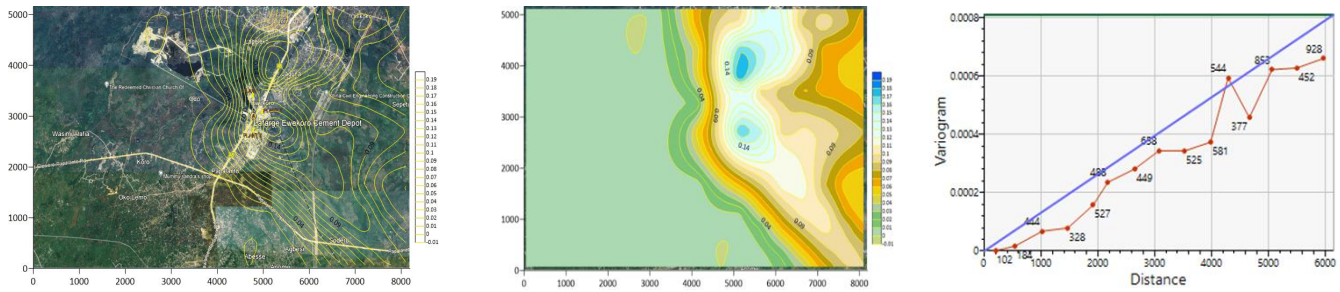
(a) **(b)** **(c)**

Figure 4: (a) Contour configuration map of Lafarge Cement, Ewekoro, showing particulate matter concentration for 1-hour average during the dry season
(b) Pattern of particulate matter concentration for 1-hour during the dry season in Ewekoro
(c) Time Series Graph of particulate matter concentration for 1-hour during the dry season in Ewekoro
Source: Author's Fieldwork (2024)

3.2.2 Dispersion of 3-hr Average PM_{10} during the Dry Season

The analysis shown in Figure 5 (a, b, and c) looks at how particulate matter (PM) with a diameter of ≤ 10 µm is spread out and its concentrations, based on a three-hour average during the dry season in the study area. The contour map identifies hotspots with PM_{10} levels above 0.19 µg/m³, primarily residential buildings near the Lafarge Cement factory. Unlike residential areas close to the cement factory, areas located away from it show lower concentrations of PM_{10}, between 0.01 and 0.04 µg/m³. The terrain map shows PM_{10} concentrations getting lower as the distance from emitters of air pollutants increases, as seen on the concentration map. Those areas such as Jagunna and Lapeleke also have more concentration of particulate matter in that three-hour mean. Additionally, variogram analysis also indicates a trend in the concentration of particulate matter, so PM_{10} will be even more similar when you are closer together and increases as you move away from the source. This supports the appeal to consider distance to emission sources while assessing air quality, indicating a demand for extra efforts in zones with high PM_{10} levels.

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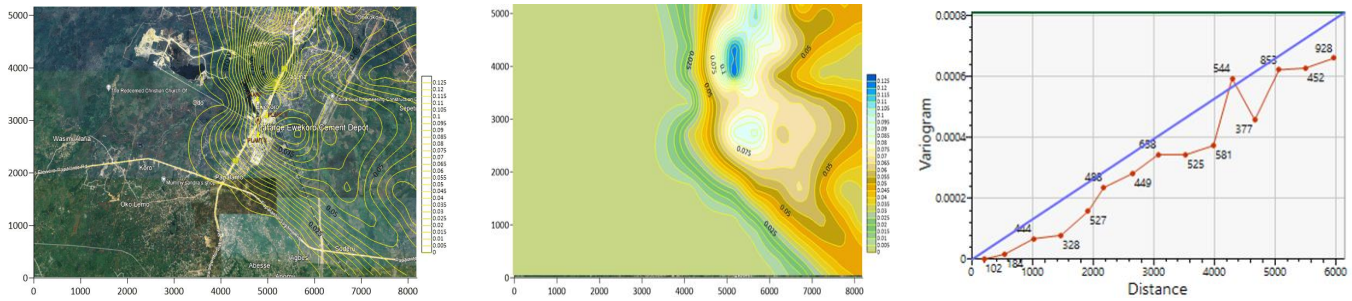
(a) **(b)** **(c)**

Figure 5: (a) Contour configuration map of Lafarge Cement, Ewekoro, showing particulate matter concentration for 3-hour average during the dry season
(b) Pattern of particulate matter concentration for 3-hour during the dry season in Ewekoro
(c) Time Series Graph of particulate matter concentration for 3-hour during the dry season in Ewekoro
Source: Author's Fieldwork (2024)

3.2.3 Dispersion of 8-hr Average PM_{10} During the Dry Season

The air dispersion pattern study exhibited in Figure 6 (a, b, and c) gives an overview of particulate matter (PM) with a diameter of ≤ 10 µm dispersion patterns and concentration, derived from an 8-hour average concentration during the dry season in the study area. The areas of hotspots with PM concentrations of >0.125 µg/m³ are observed around the Lafarge Cement factories, which are marked as high-emission sources. Conversely, locations farther from these plants have lower PM concentrations, ranging from 0.05 to 0.025 µg/m³. The terrain map shows a distinct gradient of decreasing particulate matter levels with increasing distance from the emission sources, as expected from the spatial distribution patterns in the contour map. Of particular interest is that some parts of Lapeleke and Itori have been discovered to have higher levels of particulate matter on the 8-hour average. The pattern of the variogram also represents a spatial connection between particulate matter concentrations and higher PM levels at nearer distances from the point sources. This variation increases as the distance grows larger. The implication is that being close to the Lafarge Cement factories will be an overarching factor affecting the air quality and, therefore, special monitoring and possible interventions in areas with significant concentrations of particulate matter. More generally, this conversation highlights the need to understand the spatial distribution of air pollution to inform public health policy and environmental regulation.

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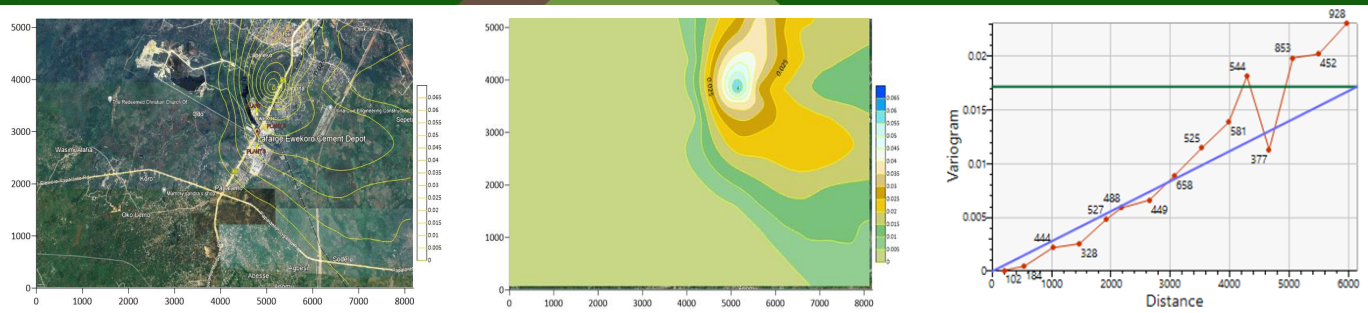
(a) **(b)** **(c)**

Figure 6: (a) Contour configuration map of Lafarge Cement, Ewekoro, showing particulate matter concentration for 8-hour average during the dry season
(b) Pattern of particulate matter concentration for 8-hour during the dry season in Ewekoro
(c) Time Series Graph of particulate matter concentration for 8-hour during the dry season in Ewekoro
Source: Author's Fieldwork (2024)

3.2.4 Dispersion of 24-hr Average PM_{10} during the Dry Season

Figure 7 (a, b, and c) shows the distribution and concentration of particulate matter (PM) using the 24-hour average during the dry season at the study site. The contour map shows that the hotspots indicate concentrations greater than 0.065 µg/m³ around Lafarge Cement, which is noted to be an emission source location. Instead, concentrations are higher near the factory, 0.05 to 0.025 µg/m³. The terrain map supports these results with a spatial pattern of particulate matter concentrations. Also, examining the variogram indicates that PM_{10} concentrations are closer in more proximate distances, which implies a local effect of the emission sources. Specifically, Jagunna has hotspots of elevated levels of particulate matter within 24 hours, and it is an area of air quality concern. Therefore, the overall picture reaffirms that there should be monitoring of levels of particulate matter, especially around and near factories, to detect their influence on surrounding communities and arrange intervention in public health.

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(a) **(b)** **(c)**

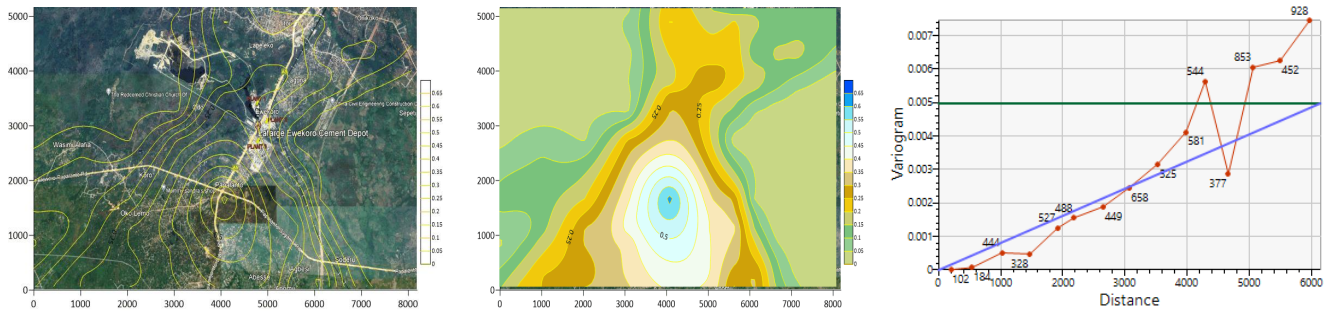
Figure 7: (a) Contour configuration map of Lafarge Cement, Ewekoro, showing particulate matter concentration for 24-hour average during the dry season
(b) Pattern of particulate matter concentration for 24-hour during the dry season in Ewekoro
(c) Time Series Graph of particulate matter concentration for 24-hour during the dry season in Ewekoro
Source: Author's Fieldwork (2024)

3.3 Air dispersion for wet season in Ewekoro

3.3.1 Dispersion of 1-hr Average PM_{10} during the wet Season

The analysis presented in Figure 8 (a, b, and c) illustrates the dispersion of particulate matter (PM_{10}) based on a 1-hour average during the rainy season in the study area. The contour map indicates hotspots where PM_{10} concentrations exceed 0.065 µg/m³, notably far from the Lafarge Cement factory. In contrast, areas near the factory exhibit lower concentrations, ranging from 0.05 to 0.25 µg/m³. The terrain map further supports these findings, showing that the highest particulate matter concentrations are near the Papalanto area of Ewekoro. Locates farther away from the Lafarge Cement plants may have elevated particulate matter levels during rainy seasons. However, the variogram analysis indicates that concentrations of particulate matter are closer to each other when measured at short distances, which indicates a localized impact of emissions. This indicates the distribution of particulate matter, which is rain and wind-dependent during rainy seasons and results in shocked concentrations at some points. Hence, there is a need to study how seasonal patterns impact air quality, particularly industrial emissions and their impact on neighbouring communities.

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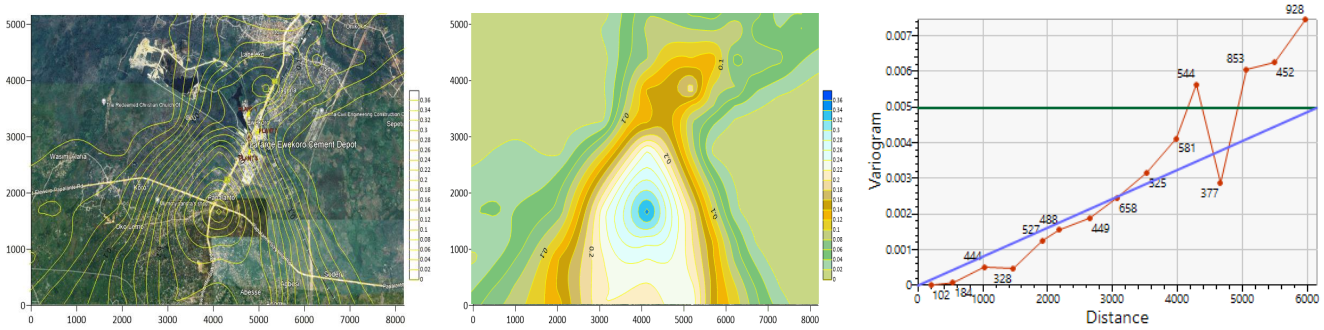
(a) **(b)** **(c)**

Figure 8: (a) Contour configuration map of Lafarge Cement, Ewekoro, showing particulate matter concentration for 1-hour average during the wet season
(b) Pattern of particulate matter concentration for 1-hour during the wet season in Ewekoro
(c) Time Series Graph of particulate matter concentration for 1-hour during the wet season in Ewekoro
Source: Author's Fieldwork (2024)

3.3.2 Dispersion of 3-hr average PM_{10} during the wet season

This is a dispersion analysis of particulate matter (PM_{10}) in the air over a 3-hour average in the wet season within the study area. The hotspots where the concentration of PM is above 0.36 µg/m³ according to the contour map are quite far from the Lafarge Cement plants. Conversely, areas near the plants show much lower concentrations, hovering between 0.02 and 0.1 µg/m³. This shift in particulate matter levels during the wet season is quite telling, with the highest concentrations around the Papalanto area of Ewekoro. Notably, particulate matter dispersion patterns differ between the damp and dry seasons. Dry season hotspots were primarily observed in the areas of Lafarge Cement plants with values over 0.065 µg/m³. Rain and wind seasonal conditions were observed to impact particulate matter dispersion, making it disperse further away from the source under rainy conditions. This is a reflection that seasonality must be considered while estimating air quality since it has potential impacts on the distribution and concentration of pollutants within the environment.

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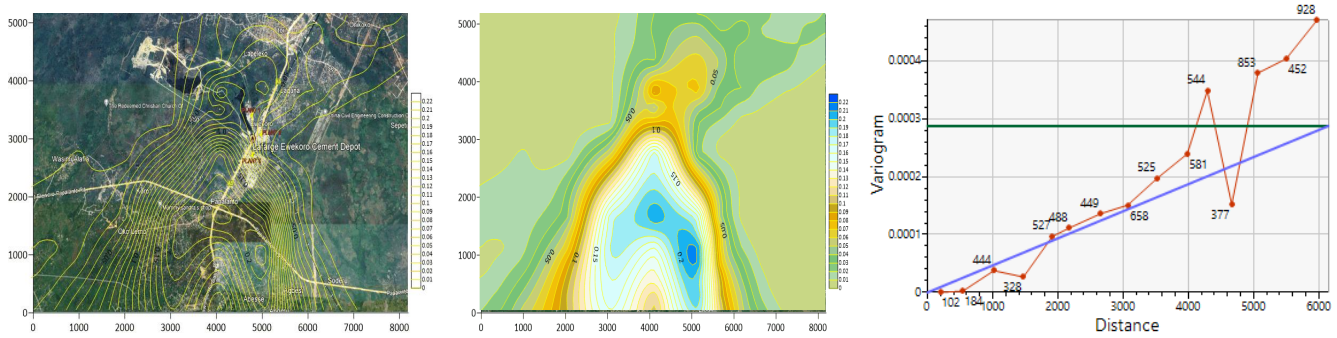
(a) **(b)** **(c)**

Figure 9: (a) Contour configuration map of Lafarge Cement, Ewekoro, showing particulate matter concentration for 3-hour average during the wet season
(b) Pattern of particulate matter concentration for 3-hour during the wet season in Ewekoro
(c) Time Series Graph of particulate matter concentration for 3-hour during the wet season in Ewekoro
Source: Author's Fieldwork (2024)

3.3.3 Dispersion of 8-hr Average PM_{10} during the Wet Season

The analysis of particulate matter dispersion in Figure 10 (a, b, and c) focuses on the 8-hour average concentrations during the wet season in the study area. The contour map highlights hotspots where PM_{10} levels exceed 0.22 µg/m³, indicating significant pollution hotspots located far from the Lafarge Cement factories. Conversely, regions farther away from the factories have relatively lower PM_{10} concentrations, 0.01 to 0.04 µg/m³, which imply that regional factors beyond distance influence particulate matter concentration. This observation is supported by the terrain map, as observed in the case of Ewekoro region, with higher concentrations reported in the vicinity of Papalanto, which indicates that topography at a regional scale could influence dispersal. Results indicate the highest concentration rates of PM_{10} during rainfall seasons are significantly remote from Lafarge Cement facilities, the south east of Papalanto, in comparison with a concentration distant from pollution source centres. Deviation in 3-hour average indicates that long periods of exposure can result in increased levels of particles even for those areas, which are remotely situated from emission point. This is a call to the need for constant monitoring and flexible control over emissions. It is more specifically a call for the delicate balance of how particulate matter gets in during rainy season and the need for ongoing study on public health and environmental issues.

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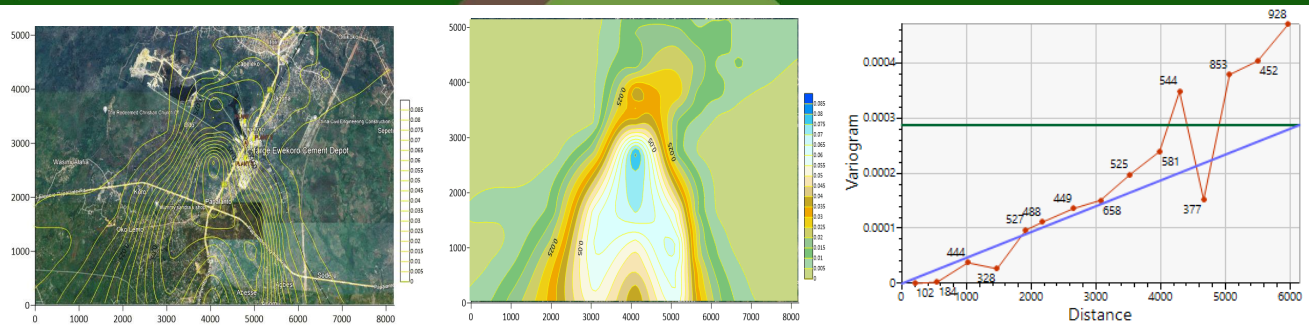
(a) **(b)** **(c)**

Figure 10: (a) Contour configuration map of Lafarge Cement, Ewekoro, showing particulate matter concentration for 8-hour average during the wet season
(b) Pattern of particulate matter concentration for 8-hour during the wet season in Ewekoro
(c) Time Series Graph of particulate matter concentration for 8-hour during the wet season in Ewekoro
Source: Author's Fieldwork (2024)

3.3.4 Dispersion of 24-hr Average PM_{10} during the Wet Season

The analysis presented in Figures 11 (a, b, and c) examines the air dispersion of particulate matter (PM) over a 24-hour average during the wet season in the study area. The contour map highlights hotspots where PM_{10} levels exceed 0.085 µg/m³, which are located far from the Lafarge Cement plants. In contrast, nearby areas show lower concentrations, ranging from 0.05 to 0.025 µg/m³. The terrain map further indicates a significant concentration of particulate matter in the Papalanto region during the wet season. This analysis reveals that the 24-hour mean PM_{10} rates are highest in locations away from the Lafarge Cement plant, particularly in Papalanto, while areas closer to the factory exhibit lower rates. It should be noted that concerning the 8-hour mean, in which the highest PM_{10} value was 0.22 µg/m³, values at 24 hours would show a dispersal and dilution effect with time passing. This is just an indication that when particulate matter is subjected to environmental conditions for so long, the concentration gets reduced, which is why distance and time should be considered in quantifying air quality.

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(a) **(b)** **(c)**

Figure 11: (a) Contour configuration map of Lafarge Cement, Ewekoro, showing particulate matter concentration for 24-hour average during the wet season
(b) Pattern of particulate matter concentration for 24-hour during the wet season in Ewekoro
(c) Time Series Graph of particulate matter concentration for 24-hour during the wet season in Ewekoro
Source: Author's Fieldwork (2024)

3.4 The variations in air quality around the Ewekoro Cement plants

The PM_{10} dispersion patterns exhibit strong seasonality in particulate matter concentrations around Jagunna, Lapeleke, Papalanto, and Itori compared to industry and weather (see Table 2). There are high concentrations around the Lafarge Cement factory during the dry season, with local maxima well above 0.34 µg/m³ of 1-hour mean, especially around Jagunna and Lapeleke. Conversely, the dispersion patterns in the wet season reverse so that the concentrations are higher in areas that are more distant from the plants, particularly in Papalanto, with concentrations of 1-hour mean particulate matter above 0.065 µg/m³. This calls for dynamic air quality management where the time and space of particulate matter dispersion are considered. During the dry season, emissions need to be restricted in the industrial areas. On the contrary, intervention and surveillance should be strengthened during the rainy season in remote areas. Effective control is achieved through the proclamation of buffer zones and green infrastructure, public sensitisation, and continued adaptive monitoring to avert pollution and safeguard the community's health at any time. This affirmation is consistent with Adanma and Ogunbiyi (2024), who affirm that including environmental policy, especially air and water quality improvement policies, is the tipping point of the public health revolution. However, success in driving ecologic problems and stakeholder concerns lies in an interdisciplinary standpoint and

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effective governance towards realising a sustainable policy.

Table 2. The spatial and temporal variations in air quality around the Lafarge Cement plants, Ewekoro

Season	Location	1-hour Average (µg/m³)	3-hour Average (µg/m³)	8-hour Average (µg/m³)	24-hour Average (µg/m³)	Implication
Dry	Near Lafarge Plants (Jagunna, Lapeleke)	0.02 - 0.34+	0.01 - 0.04	0.005 - 0.025	0.005 - 0.025	Highest concentrations near plants
Dry	Farther Areas (Papalanto, Itori)	< 0.02	< 0.01	< 0.005	< 0.005	Lower concentrations
Wet	Near Lafarge Plants (Jagunna, Lapeleke)	0.05 - 0.25	< 0.36	< 0.22	< 0.085	Lower than dry season
Wet	Farther Areas (Papalanto)	> 0.065	> 0.36	> 0.22	> 0.085	Higher concentrations than near plants

Source: Author's Fieldwork, 2024

3.5 Data analysis and presentation on the test of hypothesis

3.5.1 Hypothesis statement

H_0: There is no significant relationship between the distance of buildings to the Lafarge Cement Factory and respondents' satisfaction with the factory's overall operations.

H_1: There is a significant relationship between the distance of buildings to the Lafarge Cement Factory and respondents' satisfaction with the factory's overall operations.

Based on the Pearson Correlation statistical analysis result in Table 3, At a 5% significance level ($\alpha = 0.05$), the hypothesis test yielded a p-value of 0.004. Since the p-value is less than the chosen significance level ($p = 0.004 < \alpha = 0.05$), the null hypothesis ($H_0$) is rejected. The correlation analysis also indicates a highly negative correlation ($r = -.187$, $p = .004$) between the distance of

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buildings from the Cement Factory and respondents' satisfaction with the overall operations of the factory. This weak to moderate correlation indicates that satisfaction also improves with increased distance from the factory. Therefore, the p-value of 0.004 is lower than the significance level of 0.05, supporting the null hypothesis (H_0) rejection. It suggests that living near the factory can be connected to lesser satisfaction due to noise, pollution, or nuisance. These people living near the factory may be affected more; thus, there might be lesser satisfaction. While a statistically significant correlation exists, the comparatively low correlation coefficient reveals that other variables also affect satisfaction in factory operations.

Table 3: Correlation Test of Distance of Building to the Cement Factory and Satisfaction with the overall operations of the Lafarge Cement Factory

		Distance of Building to the Cement Factory	Satisfaction with the overall operations of the Lafarge Cement Factory
Distance of Building to the Cement Factory	Pearson Correlation	1	-.187**
	Sig. (2-tailed)		.004
	N	233	233
Satisfaction with the overall operations of the Lafarge Cement Factory	Pearson Correlation	-.187**	1
	Sig. (2-tailed)	.004	
	N	233	233

**. Correlation is significant at the 0.05 level (2-tailed).
Source: Author's Fieldwork, 2024

4.0 Discussion

4.1 Socio-economic characteristics and industrial pollution exposure in Ewekoro

The demographic profile of the study area reveals a predominance of male and middle-aged residents, suggesting an active labour force primarily engaged in industrial factory work and trading, which serve as major economic drivers. The majority of residents earn between ₦30,000 and ₦60,000 monthly, reflecting moderate income levels that correspond with a high prevalence of rented housing. A considerable proportion of the population stays in Ewekoro for over a decade, with residential stability. But the majority of the population reside within the 1 – 4 kilometre zone of

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Lafarge Cement Factory, and question arises regarding potential impacts on the environment and health caused by exposure to continuous industrial discharges, predominantly particulate emissions. This physical proximity necessitates further studies on the public health risk of the activities of the factory. The findings confirm the study by Oyinloye (2015) and Akinrogunde (2024), which concluded that residential buildings within less than 1 kilometre and 5 kilometres from the cement factory are greatly vulnerable to health effects, thereby proposing total relocation of the affected population as a way of reducing adverse health effects.

4.2 PM_{10} dispersion patterns during dry and wet seasons in Ewekoro

The spatial and temporal distribution of PM_{10} in Ewekoro shows significant seasonal variation, with particulate matter concentrations varying notably with distance from the cement plants and changes in meteorological conditions during the wet and dry seasons. Throughout the dry season, concentrations of PM_{10} are consistently highest at or around Lafarge Cement factories, with Jagunna, Lapeleke, and Itori being main hotspots at 1-hour to 24-hour averaging periods, highlighting the cement factories' contribution as a major source of emissions. Conversely, in wet seasons, radical variation is witnessed in which higher values of PM_{10} are seen outside the region of the cement industry, more dominantly higher within the region of Papalanto due to precipitation, dilution in air and wind spreading processes, wherein particle particles spread over longer distances.

This spatial variation highlights the significant role of wet-season processes in transporting contaminants beyond the immediate industrial zone. Variograms across all scales reveal consistent patterns of spatial autocorrelation, with contaminant concentrations tending to be more alike over short distances and increasingly varied over greater distances. These results present an adaptive management of air quality that considers seasonality and vicinity to source locations, such as the use of buffer zones, increasing ongoing monitoring of air quality, encouraging green infrastructure, and triggering public health advisories for reducing the adverse health impacts of PM_{10} exposure throughout the year. It offers space-time evidence-based data on how industrial discharge and weather seasons affect air quality. Similarly, it favours the development of zoning regulations, especially creating buffer zones around cement plants with buffer zones. It advises urban

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planners on distancing sensitive land use, e.g., residential areas, from the polluting source. It also guides infrastructure planning, like green belts and monitoring points, and public health preparedness efforts specific to seasonal pollution patterns.

4.3 PM_{10} dispersion and implications for air quality management in Ewekoro

The spatial-temporal patterns of PM_{10} levels in the areas around Lafarge Cement factories, Ewekoro indicate pronounced seasonality, with much higher particulate matter levels around Jagunna and Lapeleke during the dry season of over 0.34 μg/m³ (mean 1-hour mean). During the wet season, the levels fluctuate and become even higher in remote areas such as Papalanto, over 0.065 μg/m³. These trends require dynamic spatial and temporal air quality management, i.e., curtailing emissions within industrial zones during the dry season and increased monitoring and interventions on the peripheries during the rainy season. Control measures involve the imposition of buffer zones, green infrastructure, public awareness, and dynamic round-the-clock continuous monitoring to mitigate pollution and ensure strong public health round the clock. This study supports the findings of Adanma & Ogunbiyi (2024) and Akinrogunde (2024), who argue that "environmental policy has improved air and water quality as well as public health. Achieving sustainable outcomes, however, demands collaborative efforts across various disciplines and strong governance to tackle ecological challenges and the interests of different stakeholders. This assessment takes into account urban planning traditions and geographically responsive zoning laws, such as buffer zones for factories and seasonal pollution program operation. Knowledge of population variation in susceptibility is also useful information for urban planners to come up with healthier and more sustainable environments. It helps identify where to place green infrastructure, i.e., parks and green space, and public health facilities, i.e., hospitals and community centres. Hence, by considering the spatial pattern of environmental conditions and health outcomes, planners can use this information to inform land use decisions that are environmentally light-footed and build healthy, resilient communities.

4.4 Relationship between proximity to the Cement Factory and residents' satisfaction

Findings from the Pearson Correlation analysis indicated a statistically significant correlation between the distance of residential houses from the

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Lafarge Cement Factory and the respondents' satisfaction level with the factory's general operations. With a 5% significance level ($\alpha = 0.05$), the analysis produced a correlation coefficient of $r = -0.187$ and a p-value of 0.004, resulting in the rejection of the null hypothesis. This negative, low correlation indicates that satisfaction levels are incrementally greater the farther the distance from the factory. That is, individuals in closer proximity to the cement factory have lower satisfaction levels. Perhaps this is explained by environmental disruptions generally associated with industrial activity, such as air pollution, noise pollution, and visual intrusions. However, because the correlation is low, other factors such as; socio-economic status, housing quality, or community involvement can also cause residents' satisfaction. These findings necessitate further studies on the mixed impacts of industrial facilities on the resident communities.

5.0 Conclusion And Recommendation

From the foregoing, this study assessed particulate matter emissions and air quality from the Ewekoro Cement Factory, using Air Dispersion Modelling (AERMOD). The study examined the relationship between residents' socio-economic characteristics and the impacts of industrial pollution in Ewekoro, identified and the major sources of air pollution in Ewekoro, investigated the spatial-temporal dispersion of pollutant concentrations across different geographical locations within the study area, and assessed the relationship between the proximity of buildings to the Lafarge Cement Factory and residents' level of satisfaction with the factory's operations. Importantly, the results indicate that the air quality in Ewekoro is poor, mainly due to Cement Factory emissions. It is worth mentioning that a seasonal fluctuation was observed; pollution is mostly greater during the dry season than the wet season. This is primarily due to the dry weather conditions, which make it easier for particulate matter to spread, as well as increased industrial activity during that time. Further, the air quality was poor near the cement factory, particularly around the host communities like Lapeleke, Itori, Jagunna, and Papalanto. The levels of pollutants were high there. Lastly, poor air quality is a danger to human health (e.g., respiratory diseases) and the environment, and it risks the sustainable development of the host communities. Nevertheless, future research may investigate the long-term impact on the health of inhabitants exposed to varying amounts of pollution and the success of possible prevention

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techniques like green buffer zones or enhanced emission suppression technology.

Based on the findings, the following recommendations were proposed for the study to enhance environmental management practices, enhance air quality, promote sustainable development, and safeguard public health in the host communities around the Cement Factory:

i. Cement factories like Lafarge Cement must strictly follow pollution control regulations to ensure environmental integrity.
ii. Real-time monitoring stations for air quality should be installed within and around industrial estates to monitor air quality in real-time and effectively respond to air pollution in the area.
iii. Factories, particularly those whose production processes cause emissions, would have to fund cleaner production processes and switch to greener ones so that emissions are reduced at source.
iv. Public campaigns should be done regularly to educate citizens on the health risks of air pollution and how citizens can protect their health, especially vulnerable populations and those with pre-existing conditions.
v. Introduce buffer zones and green belts between residential neighbourhoods and factories. Green belts would help shield the area from pollutants, leaving nature clean and the direct effect minimal on the population.
vi. Detailed Environmental Impact Assessments (EIAs) should be mandatory before new industrial activities or expansions of existing ones are approved. Thus, potential environmental and health risks are adequately taken into account beforehand.

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