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Seasonal Variations in Particulate Matter Concentrations and Risk Factors for Respiratory Symptoms Among Residents Near Dumpsites in Benin City, Nigeria

Aimuanmwosa Frank Eghomwanre[1], Faith Osayekemwen Edokpolo[1]
[1]Department of Environmental Management and Toxicology, University of Benin, Nigeria
Corresponding Author: Aimuanmwosa F. Eghomwanre; Email: frank.eghomwanre@uniben.edu

A R T I C L E I N F O

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A B S T R A C T

Rapid urbanization in Nigeria has increased the number of open dumpsites and waste burning, which are significant sources of particulate matter (PM). This study investigated seasonal PM variations and respiratory risk factors near the Otofure dumpsite in Benin City. PM2.5 and PM10 levels were measured at the dumpsite and residential areas during the wet and dry seasons. A cross-sectional survey was also conducted with 204 residents to assess self-reported health symptoms and potential risk factors. The data were analysed using nonparametric tests and logistic regression. The PM concentrations at the dumpsite (62.5–121.4 μg/m3) consistently exceeded residential levels and WHO 24-hour guidelines. The dry season peaks reached 8 times (PM2.5) and 2 times (PM10) the recommended limits, with significantly higher median concentrations than those in the wet season ($p<0.05$). Prevalent symptoms included cough (44.1%), eye irritation (27.0%), and shortness of breath (25.5%). Waste collection was significantly associated with shortness of breath (aOR: 4.52) and skin rashes (aOR: 2.85). Residents living in the area for 5–9 years were 3.71 times more likely to report eye irritation than shorter-term residents were. The Otofure dumpsite is a major source of PM pollution, creating a disproportionate health burden and environmental injustice. Urgent interventions are needed, including the cessation of open burning, improved waste management, and community health education to protect vulnerable residents.

INTRODUCTION

Rapid urbanization and population growth in developing countries such as Nigeria have significantly increased the volume of solid waste, straining already limited waste management resources and infrastructure. This has led to the widespread use of open dumpsites, particularly in densely populated urban centres, as a common, although problematic, method of municipal solid waste (MSW) disposal (Daffi et al., 2020). These sites, often located on the fringes of cities, have become repositories for diverse waste streams, ranging from household waste to industrial byproducts and even hazardous materials (Osim et al., 2020). While currently a necessary part of waste management practices, these dumpsites pose considerable risks to both the environment and public health (Ibrahim et al., 2020).

The accumulation of waste at open dumpsites leads to the generation of toxic emissions, presenting a significant risk to the respiratory health of surrounding communities through the release of pollutants like particulate matter (PM) (Oyedele et al., 2022). PM, a complex mixture of microscopic particles suspended in air, originates from various sources, including the open burning of waste, vehicular emissions, industrial activities, and natural processes. Dumpsites, particularly those where waste is routinely burned, become substantial point sources of PM, releasing a spectrum of particle sizes, including the more pernicious fine particulate matter ($PM_{2.5}$) (WHO, 2021). Nigeria's national air pollution index is 76 (Beijing Real-time Air Quality Index, 2021); however, it is masked by significant regional and seasonal variations. Benin City, Edo State, experiences considerably worse air quality, with unhealthy average AQI values of 117 and 42.3 μg/m^3, which are 8.4 times higher than the WHO (2021) air quality guidelines. Importantly, the composition of pollutants, particularly near dumpsites, can vary widely depending on location and waste management practices (WHO, 2015). Exposure to high PM2.5 concentrations is particularly alarming, given its ability to penetrate deep into the lungs.

The WHO's latest air quality guidelines set the maximum acceptable 24-hour mean for $PM_{2.5}$ at 15 μg/m^{3}and for PM_{10} at 45 μg/m^3 (WHO, 2021). The health implications of PM pollution are far-reaching and include a variety of negative health effects, ranging from respiratory illnesses such as asthma and chronic obstructive pulmonary disease (COPD) to cardiovascular problems, neurological disorders, and even increased cancer risk (Opara et al., 2021; Krismanuel et al., 2025). The severity of health effects from particulate matter (PM) exposure is determined by several factors, notably the length of exposure and the concentration of the particles (Wyer et al., 2022). Larger PM_{10} particles, which can become trapped in the nose and upper respiratory tract, can contribute to conditions such as allergic rhinitis, sinusitis, and upper respiratory infections (Manisalidis et al., 2020). Fine particulate matter poses a severe health risk because of its ability to penetrate deep into the lungs and enter the bloodstream (Xing et al., 2016).

Furthermore, these particles can exacerbate existing respiratory conditions, potentially leading to increased hospitalizations, reduced lung function, and diminished quality of life (de Vries, 2021). Residents living near dumpsites are particularly susceptible due to their consistent exposure to elevated particulate matter levels. Individuals with preexisting health conditions, elderly individuals, and children are especially vulnerable (Issa et al., 2021). Inadequate waste management practices, often due to limited infrastructure, funding constraints, and low public awareness, plague many regions of Nigeria, including Benin City (Ikpe et al., 2020). Consequently, open dumpsites such as Ikhueniro and Otofure have become the primary disposal methods. These Nigerian dumpsites typically receive a wide variety of waste, encompassing everything from electronic waste and textiles to plastics, metals, and organic materials (Ezemonye et al., 2020).

Communities residing in proximity to dumpsites are disproportionately exposed to elevated PM concentrations emanating from these sites. The distribution of particulate matter (PM) from dumpsites to nearby residents is a complex process involving several interconnected factors. Dumpsites contain a heterogeneous mix of waste, including organic matter, plastics, metals, and other materials. The decomposition of organic waste, particularly under anaerobic conditions, can generate PM and gaseous pollutants (Nordahl et al., 2023). The open burning of waste, a common practice at many dumpsites, is a major source of PM, including black carbon, organic aerosols, and heavy metals (Krecl et al., 2021). The combustion process releases fine particles that can be easily inhaled (Krecl et al., 2021). Activities at dumpsites, such as waste collection, transportation, and scavenging, can generate dust and resuspend existing PM (Akpeimeh et al., 2019). Microclimatic conditions such as temperature, relative humidity, wind speed, and direction are crucial factors in PM dispersion. Stronger winds can carry PM further distances, while the wind direction determines the areas most affected (Galindo et al., 2011).

Under stable atmospheric conditions, pollutants can become trapped near ground level, leading to higher concentrations (Yavuz, 2023). Inhalation is the primary route of exposure to PM. People living or working near dumpsites can inhale PM directly from the air, and PM can also be deposited on surfaces, such as food and water, leading to ingestion (Huang et al., 2014; Wu et al., 2018). This heightened exposure creates a significant environmental justice issue, as these communities often bear a disproportionate burden of environmental risk (Gochfeld, 2011). Furthermore, these populations may face a compounded burden due to coexisting environmental challenges associated with living near dumpsites, including exposure to leachates, noxious odours, and disease vectors (Agbeni et al., 2025).

Previous studies in sub-Saharan countries, including Nigeria, have focused on investigating particulate matter concentrations around the vicinity of dumpsites and the associated health risks (Kihampa, 2013; Rim-Rukeh, 2014; Ogbemudia et al., 2020; Opara et al., 2021; Amoabeng et al., 2020; Kipter, 2023; Daramola & Makinde, 2024). These studies generally reported higher concentrations of $PM_{2.5}$ and/or PM_{10} near the landfill site than at the control site, and significantly deteriorated the local air quality in the study area. While studies often quantify concentration levels near dumpsites, there remains a critical knowledge gap regarding the complex interplay of meteorological, socioeconomic, and behavioural factors that contribute to residents' exposure and subsequent health risks. Furthermore, there is a lack of localized data that links these environmental exposures directly to public health outcomes in Nigerian settings. These factors can span socioeconomic status, housing conditions, proximity to the dumpsite, occupational exposures, and individual behaviours (Jonidi et al., 2021). Socioeconomic disparities may influence access to adequate housing and sanitation, thereby increasing vulnerability to PM exposure.

Hence, this study seeks to close this gap by critically examining the multifaceted socioeconomic, environmental, and behavioural factors that may influence PM exposure among the local population. By elucidating these factors, this study seeks to contribute valuable evidence-based insights for policymakers, environmental agencies, and public health officials. These insights can inform the development and implementation of effective and context-specific strategies to mitigate the impacts of PM pollution from dumpsites, ultimately protecting the health and well-being of vulnerable communities in Benin City and similar settings across Nigeria. Therefore, this study aims to comprehensively quantify the seasonal variation in pollution near the Otofure dumpsite and identify the critical socioeconomic and behavioural risk factors associated with self-reported health symptoms, thus providing evidence for targeted public health policy.

MATERIALS AND METHODS

Description of the Study Area

This study was conducted at the Otofure Dumpsite, which is situated on the outskirts of Benin City and serves as the capital of Edo State in Nigeria. Like many urban centers across Nigeria, Benin City faces the challenge of managing its municipal solid waste, and the Otofure Dumpsite represents one of several designated final disposal locations within the city. Specifically, this site receives a diverse array of household refuse generated by the residents of the greater Benin City metropolis. The operational oversight of the Otofure Dumpsite falls under the purview of the Waste Management Board, a division of the Ministry of Environment within the Edo State Government. Interestingly, the land on which the dumpsite now exists was not originally intended for waste disposal. Instead, it was previously a burrow pit excavated to extract lateritic sand, a common material used in construction. This former excavation was subsequently repurposed to accommodate the growing volume of municipal solid waste.

Geographically, the Otofure Dumpsite is located within the following coordinates: longitude 005°35ʼ52.56ʺ E to 005°36ʼ02.29ʺ E and latitude 06°27ʼ40.48ʺ N to 06°27ʼ48.99ʺ N, with elevations ranging from 97 to 106m above sea level. The Otofure Dumpsite spans an estimated area of 300 - 500 square km² and has served as the primary waste disposal site for Benin City for approximately two decades, leading to significant environmental accumulation. The refuse accumulated within this space is a heterogeneous mixture comprising various types of metallic items, organic matter (such as food scraps and plant debris), and nonbiodegradable materials (such as plastics, glass, and textiles). The mixed nature of the waste at the Otofure Dumpsite, which contains both biodegradable and recyclable materials, serves as a clear indication of ineffective source segregation practices within the city. The dumpsite is 221 m from residential zones and is surrounded by road networks.

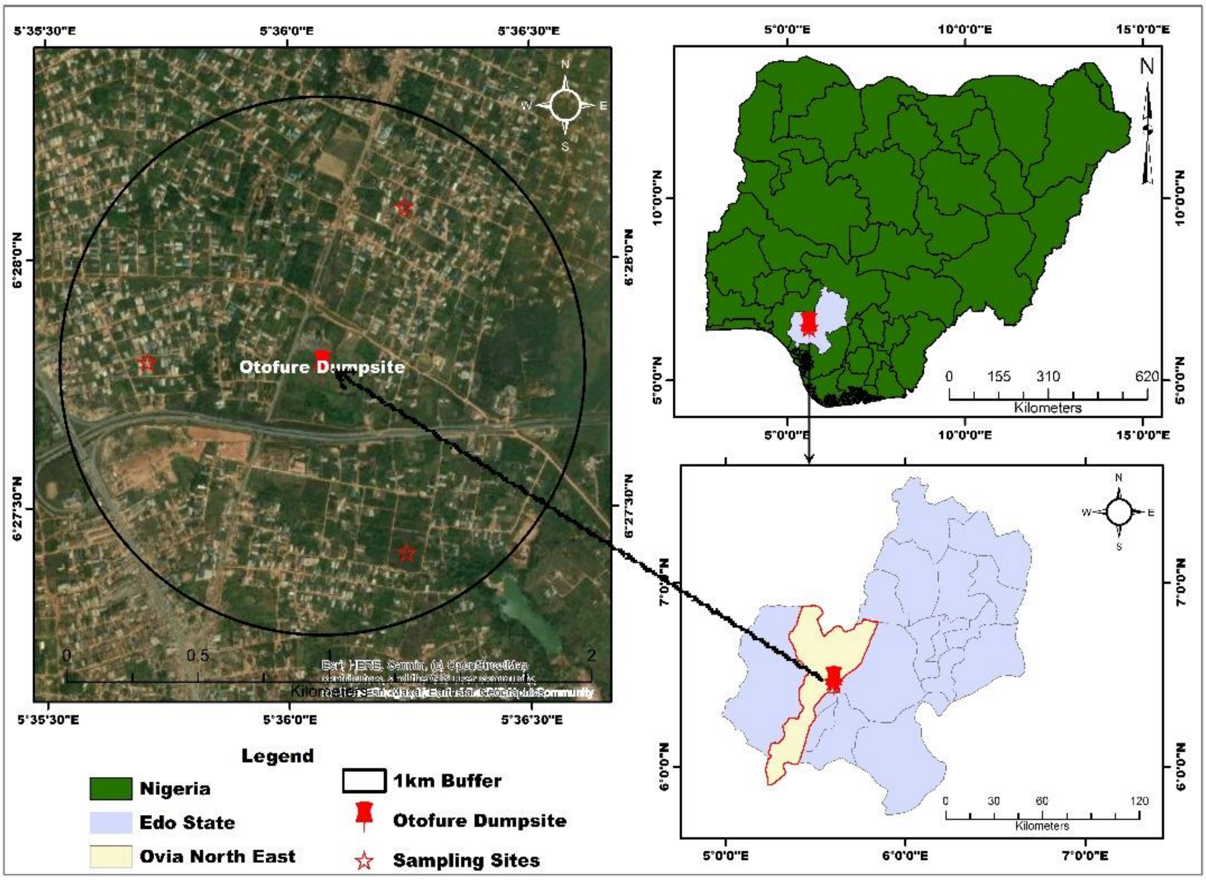

Figure 1. Map of Benin City showing the dumpsite and the sampling points

Study Design and Selection of Sampling

This study employed quantitative methods by directly measuring the levels of particulate matter (PM) in the sampling area. These measurements were taken across two distinct periods in 2024: the Wet Season (June and July) and the Dry Season (October and November). This approach provides a more comprehensive understanding of typical PM exposure across the year and allows for a direct comparison of pollutant levels between dumpsites and residential areas under different climatic conditions. In addition to the air quality measurements, the study utilized a cross-sectional design involving a questionnaire to determine the prevalence of reported health effects and examine the risk factors associated with these health effects. The survey also gathered information about potential risk factors, such as the duration of residency near the dumpsite, lifestyle factors, and demographics, to explore whether certain characteristics or exposures were associated with a higher likelihood of reporting specific health problems. The survey was conducted in households located within a 1-kilometer radius of the dumpsite (WHO, 2015). This proximity suggests that these residents were likely to be most exposed to air pollution from the dumpsite.

Questionnaire Data Collection

We developed a well-structured questionnaire that underwent a pretest to ensure its validity. The questionnaire was divided into two main sections. Section A presents sociodemographic information and details on reported risk factors for residents. This included data on age, sex, education level, smoking status, and how long they had lived in the area. Section B focused on health symptoms experienced by residents in the month leading up to the survey. We specifically asked about respiratory symptoms that residents had experienced since living in the area for at least a year, particularly those that began after the dumpsite opened two decades prior. We recruited residents through door–to-door interviews. Each survey typically took between 20 and 30 minutes to complete. To maximize efficiency, we also scheduled appointments with households within the defined study area and made two attempts to contact each household.

Sample Size Determination

The sample size (216) was estimated using a formula based on the prevalence of respiratory symptoms among residents near dumpsites in previous studies (Poole & Basu, 2017). The target sample size was participants, selected systematically from residents living within the defined exposure area. A total of 204 residents successfully completed the cross-sectional survey, yielding a response rate of (204/216). This achieved sample size was used for all subsequent statistical analyses.

Reliability of the Questionnaires

Internal consistency did not apply to this study, but its reliability was ensured by the use of standardized protocols throughout the data collection process. Cronbach's alpha test was performed to assess the reliability of the structured questionnaire (Bonnet & Wright, 2015). The resulting alpha value of >0.85 indicated strong internal consistency for the survey instrument.

Inclusion and Exclusion Criteria for Participants

The residents had to have lived in the area for more than one year and had to be the head of the household or family to be included in the study. Residents who were not at home at the time of the visit were excluded, as they could not participate in the survey. Individuals with a preexisting history of asthma, tuberculosis, or chest disease, or those previously diagnosed with such conditions by a physician, were excluded. The rationale for this exclusion was to minimize the possibility of these preexisting conditions skewing the results related to health effects potentially caused by dumpsite pollution.

Ethical Considerations

Informed consent was obtained from all survey respondents. Participation in the study was entirely voluntary and anonymous, with respondents being fully briefed on the study's purpose and their right to withdraw at any time. The confidentiality of all the data was strictly maintained in accordance with the ethical principles. For the air quality measurements, formal permission was secured from the heads of the Edo state Ministry of Environment and the heads of the households. This step ensured full compliance with institutional and community regulations, granting appropriate access to all the sampling locations.

Measurement of Particulate Matter Concentrations

A BR-Smart-126S hand-held meter was utilized to quantify the concentration of particulate matter during this study. This instrument is specifically designed for real-time monitoring of air quality. A key feature of this meter is its integrated, high-precision sensor chip, which enables accurate detection of airborne pollutants. The principle behind the operation of a meter is a light scattering mechanism. Essentially, the device shines a light beam into the air sample drawn into it. When particulate matter passes through this light beam, it causes the light to scatter. The amount and pattern of this scattered light are then measured by the sensor. On the basis of these measurements, the instrument internally calculates the concentration of atmospheric particulate matter. This calculated concentration is subsequently presented as visual data on the meter's display. The BR-Smart-126S meter used in this study has a defined precision range for its measurements, ranging from 0 to 999 micrograms per cubic meter ($\mu g/m^3$).

Furthermore, it offers a resolution of 1.0 $\mu g/m^{3,}$ i.e., it can detect and display changes in particulate matter concentrations as small as one microgram per cubic meter. This level of precision and resolution is important for discerning even subtle variations in air quality. At each designated sampling site (dumpsite or residential), several measurements were taken before the final readings were recorded. This helps to minimize the impact of any instantaneous or transient fluctuations in particulate matter levels, leading to more representative and stable data points for each sampling time and location. To specifically measure the particulate matter levels within the breathing zone and avoid interference from fugitive dust, the meter was consistently positioned at a height of 1.5 m above ground level. This standardized height was maintained across the sampling sites, ensuring a degree of consistency in the sampling process. Ambient PM concentrations ($PM_{2.5}$ and PM_{10}) were measured continuously over 24-hour periods at each monitoring site. To ensure seasonal representation and statistical robustness, a total of 48 independent 24-hour measurements were collected over the four-month study period: 12 measurement days at the dumpsite and 12 days at the residential area were sampled during both the wet and dry seasons (2 sites × 2 seasons × 12 measurement days). These 24-hour mean values were used for comparison against the WHO 24-hour air quality guideline.

Determination of Meteorological Parameters

Meteorological data (temperature, relative humidity, and wind speed) were recorded at each sampling location simultaneously with particulate matter measurements. These paired measurements were taken weekly in duplicate across all the sites. Humidity was measured using a Smart Sensor AS8700A, whereas wind speed and temperature were measured with a BTMETER BT-100 anemometer.

Quality Control for Air Quality Measurements

To ensure the accuracy and reliability of the collected data, the researchers adhered to a strict protocol for calibration. The meter was calibrated both before and after each sampling session according to the manufacturer's guidelines. Calibration is a crucial step that verifies the instrument's accuracy against a known standard, thereby minimizing potential measurement errors and ensuring that the data obtained are valid and suitable for addressing the study's objectives. After the raw data were collected, they underwent a cleaning process to identify and remove any outliers—data points that were significantly different from the rest and could skew the overall results owing to errors or unusual events. The average particulate matter concentrations were calculated for each sampling location and time period. These average concentrations were then compared against the World Health Organization (WHO) 24-hour air quality standard to assess the measured particulate matter levels in the context of established health guidelines.

Data Analysis

The data were statistically and graphically analysed using SPSS version 21.0. The normality of the particulate matter (PM) and meteorological measurements was first assessed via the Kolmogorov–Smirnov and Shapiro–Wilk tests. Since the data were found to be nonparametric, box-and-whisker plots were used to present the median values of the PM and meteorological parameters. To determine the variations in PM and meteorological parameters across different seasons and locations, the Mann–Whitney U test was employed. Descriptive statistics were used to present the questionnaire data as frequencies and percentages. The relationships between self-reported respiratory symptoms and risk factors were identified using a chi-square test. Factors exhibiting a significant association in the bivariate analysis (χ^2 test) were subsequently entered into a multivariate binary logistic regression model to calculate the adjusted odds ratios (aOR). This was necessary to control for confounding variables and determine the independent predictors of self-reported health symptoms among the residents. All the statistical analyses were performed via SPSS version 21.0, with statistical significance set at a p-value of less than 0.05.

RESULTS AND DISCUSSION

The normality of the data for particulate matter (PM) and meteorological parameters was assessed via the Kolmogorov–Smirnov and Shapiro–Wilk tests. The results of these tests are presented in Table 1. The p-values for nearly all the parameters are less than 0.05, indicating that the data are not normally distributed. This non-normal distribution pattern is consistent across all PM levels and most meteorological variables, including temperature and wind speed. The only exceptions were relative humidity in the dry season and wind speed in the dry season, which had p-values slightly greater than 0.05 according to the Kolmogorov–Smirnov test (0.062) and Shapiro–Wilk test (0.067), respectively. However, owing to the overall non-normal distribution of the majority of the data, a non-parametric approach was deemed appropriate for further statistical analysis.

Table 1. Tests of normality for particulate matter and meteorological parameters

Parameter	Kolmogorov-Smirnov test	p-value	Shapiro-Wilk test	p-value
$PM_{2.5}^{W}$	0.166	0.001	0.835	0.001
$PM10^{W}$	0.242	0.001	0.836	0.001
$PM2.5^{D}$	0.242	0.001	0.836	0.001
$PM10^{D}$	0.176	0.001	0.766	0.001
$TEMP^{W}$	0.135	0.001	0.931	0.001
$TEMP^{D}$	0.208	0.001	0.870	0.001
RH^{W}	0.119	0.001	0.953	0.001
RH^{D}	0.086	0.062	0.963	0.005
WS^{W}	0.15	0.001	0.887	0.001
WS^{D}	0.116	0.002	0.977	0.067

P value significant at $p<0.05$, W=wet season, D=dry season

Seasonal Variations in Meteorological Parameters

Table 2 presents a statistical summary of temperature, relative humidity, and wind speed across two distinct seasons: the wet season and the dry season. The dry season temperatures are significantly higher than the wet season temperatures. The median temperature in the dry season is 33.33°C, whereas it is 29.40°C in the wet season. The variance (10.54) and standard deviation (3.25) for temperature are greater in the wet season than in the dry season (5.27 and 2.30), indicating a wider range of temperature fluctuations during the wet season. The interquartile range also shows a greater spread in the wet season (5.60) than in the dry season (1.90), further supporting this observation. The wet season relative humidity is notably higher, with a median of 78.40%, than the 64.25% in the dry season. This aligns with the expected seasonal weather patterns, where more precipitation leads to higher atmospheric moisture. The standard deviation and variance for relative humidity are similar between the two seasons, suggesting that while the median humidity is different, the spread of values is consistent in both seasons. The wind speed is higher in the dry season, with a median of 1.70 m/s, than it is 0.60 m/s in the wet season. The variance and standard deviation for wind speed are also higher in the dry season (0.59 and 0.77, respectively) than in the wet season (0.28 and 0.53), indicating greater variability and stronger gusts during the dry season. The interquartile range also confirms this, with a greater spread in the dry season (1.00) than in the wet season (0.60).

Table 2. Statistical summary of meteorological parameters

	Wet season			Dry season		
	Temp	Rh	Ws	Temp	Rh	Ws
Median	29.40	78.40	0.60	33.33	64.25	1.70
Variance	10.54	68.63	0.28	5.27	63.16	0.59
Std. Deviation	3.25	8.28	0.53	2.30	7.95	0.77
Interquartile Range	5.60	12.60	0.60	1.90	9.20	1.00

PM Concentration by Season and Location

Figure 2 illustrates the seasonal variation in the PM2.5 and PM10 concentrations at a dump site and a residential site. The box and whisker plots clearly show that pollutant concentrations are significantly higher during the dry season than during the wet season. The median $PM_{2.5}$ concentration at the dump site more than doubled during the dry season (121.4 μg/m^3) compared with the wet season (66.5 μg/m^3). A similar seasonal increase was observed for PM_{10} at both locations: median concentrations at the dumpsite rose from

73.5 μg/m^3 (wet season) to 87.5 μg/m^3 (dry season), while the residential site concentrations increased from 52.5 μg/m^3 to 62.5 μg/m^3 This distinct seasonal pattern is visually represented by clear peaks in PM levels during the dry months. The dump site consistently presented higher PM concentrations than did the residential site, confirming its role as a significant source of particulate matter in both the dry and wet seasons. The interquartile range (IQR) provides insight into the spread and variability of the data. The dry season is characterized by significantly higher variability, particularly for $PM_{2.5}$, with an IQR of 77.7 μg/m^3. This suggests that while the median is high, there are frequent events, such as open burning or periods of high activity, that cause extreme fluctuations in $PM_{2,5}$ concentrations. In contrast, the IQRs for the wet season are much lower (14.0 and 15.0 μg/m^3 for $PM_{2.5}$ and PM_{10}, respectively), indicating that pollutant concentrations during this period are more consistent and stable, likely due to the cleansing effect of rainfall.

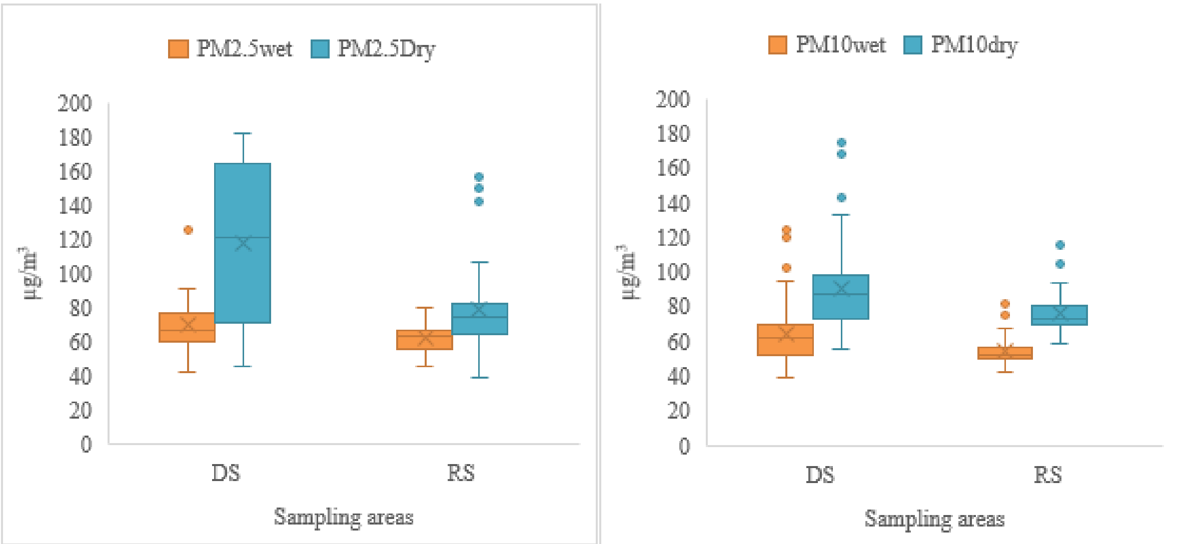

Figure 2. Seasonal Variations in PM2.5 and PM10 at Dump and Residential Sites

Table 3 presents the results of the Wilcoxon signed-rank test to compare the PM levels between the dry and wet seasons. The results revealed that out of the 102 total paired observations, 86 presented relatively high $PM_{2.5}$ values in the dry season. The average rank of these 86 differences was 56.97. In contrast, only 16 observations presented higher values in the wet season, and their average rank was much lower at 22.09. These findings indicate that $PM_{2.5}$ levels are substantially higher in the dry season. The large absolute values of the Z scores across all the parameters indicate a very strong statistical effect. PM10 shows a similar pattern, with a much larger number of observations and a higher mean rank, confirming their higher values in the dry season. All p-values are less than 0.001, which is extremely significant and provides strong evidence that the differences observed are not due to random chance.

Table 3. Seasonal comparison of the PM levels across the sampling areas

Parameter	N (Dry > Wet)	Mean Rank	N (Dry < Wet)	Mean Rank	Z score	p value
$PM_{2.5}$	86	56.97	16	22.09	-7.588	< 0.001
PM_{10}	72	52.06	30	50.17	-3.744	< 0.001

P value significant at p<0.05, wet=wet season, dry=dry season

Sociodemographic Characteristics of the Study Population

Table 4 presents the sociodemographic characteristics of the 204 participants from the residential sampling site. Out of the 216 participants required for the survey, 204 responded, resulting in a 97.2% response rate. The results revealed that the study population had an average age of 33.59 years, with a standard deviation (SD) of 13.3. This indicates a relatively young population with a moderate spread in age. The sample is predominantly male, comprising 120 (58.8%), whereas females make up 84 (41.2%). The majority of the residents had a primary education level, accounting for 59.8% of the population. A smaller percentage have no formal education (11.3%), whereas a significant portion have secondary (19.6%) or tertiary (9.3%) education. The population is quite mobile, with 45.6% of residents having lived in the area for less than four years. However, a significant number have been long-term residents, with 20.1% having lived there for 10 years or more (13.2% for 10 -14 years and 6.9% for over 15 years). The results also provide insights into behaviours that may be relevant to the study's focus on air quality. The vast majority of the residents (80.9%) were nonsmokers, whereas 19.1% were smokers. This information is important, as smoking is a direct source of $PM_{2.5}$. The data show that a small but notable percentage of the population engages in activities directly at the dumpsite. Specifically, 21.1% of residents collect waste there, and 44.1% grow vegetables. These activities may expose them to higher PM levels and can be considered additional variables contributing to their health outcomes.

Table 4. Sociodemographic attributes of residences at the sampling site (n=204)

Sociodemographic Characteristics	Mean (SD)	Frequency (n)	Percentage (%)
Age	33.59 (13.3)		
Gender			
Male		120	58.8
Female		84	41.2
Educational level			
No formal Education		23	11.3
Primary		122	59.8
Secondary		40	19.6
Tertiary	`	19	9.3
Stay duration in the area			
<4yrs		93	45.6
5-9yrs		70	34.3
10-14yrs		27	13.2
>15yrs		14	6.9
Smoking status			
No		165	80.9
Yes		39	19.1
Collection of waste at dumpsite			
No		161	78.9
Yes		43	21.1
Grow vegetables at dumpsite			
No		114	55.9
Yes		90	44.1

Reported Health Symptoms Among Residents

Figure 3 shows the frequency and percentage of various health symptoms reported by the residents. A significant number of residents reported symptoms such as cough (44.1%) and wheezing (17.2%), which are commonly linked to exposure to airborne irritants such as particulate matter. A high proportion of residents reported eye irritation (27.0%) and skin rashes (32.4%), which are typical reactions to pollutants and dust in the air. More severe symptoms, such as shortness of breath (25.5%) and chest tightness (15.2%), were reported by a notable percentage of the population. Although less frequent than other symptoms, these symptoms are significant, as they are associated with the more dangerous health effects of $PM_{2.5}$, which can penetrate deep into the lungs.

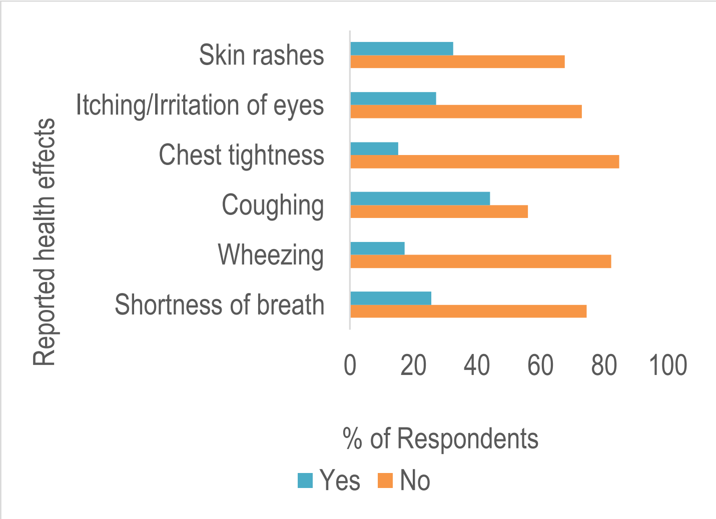

Figure 3. Reported health symptoms among residences

Predictors of Reported Health Effects

Table 5 presents the results of a logistic regression analysis to identify the risk factors associated with specific health symptoms among residents near the dumpsite. The results revealed a strong and significant association between collecting waste at the dumpsite and reporting shortness of breath. Individuals who collect waste are 4.52 times more likely to report shortness of breath after adjusting for other factors. Similarly, waste collection at dumpsites is significantly associated with a higher risk of skin rashes. People who collect waste are 2.85 times more likely to report this symptom. The association with eye irritation was not statistically significant. The adjusted odds ratio of 0.88, with a confidence interval that includes 1, indicates that there is no reliable evidence that waste collection at the dumpsite affects the risk of eye irritation. The duration of stay was significantly associated with eye irritation. The adjusted odds ratio of 3.71 indicates that residents who have lived in the area for 5-9 years are 3.71 times more likely to report eye irritation than those who have lived there for less than 4 years. There was no statistically significant association between the duration of stay and the risk of shortness of breath or skin rashes.

Table 5. Predictors of reported health effects among residents near the dumpsites

	Shortness of breath		Skin Rashes		Itching/Irritation of the eyes	
Risk Factors	cOR (95%Cl) [a]	aOR (95%Cl) [b]	cOR (95% Cl) [a]	aOR (95%Cl) [b]	cOR (95% Cl) [a]	aOR (95%Cl) [b]
Dumpsite waste collection						
No	1(ref.)	1(ref.)	1(ref.)	1(ref.)	1(ref.)	1(ref.)
Yes	4.00 (1.96-8.18)*	4.52 (1.78-11.50)*	2.46 (1.23-4.91)*	2.85 (1.19-6.85)*	0.91 (0.42-1.97)	0.88 (0.34-2.29)
Duration of stay						
<4yrs	1(ref.)	1(ref.)	1(ref.)	1(ref.)	1(ref.)	1(ref.)
5-9yrs	1.00 (0.25-4.05)	1.51 (0.34-6.62)	1.15 (0.32-4.06)	0.85 (0.23-3.19)	1.07 (0.21-3.92)	3.71 (1.04-13.17)*

Ref=Reference group, cOR= Crude odds ratio, aOR= adjusted odd ratio, a=simple binary logistic regression, b=Multinomial logistic regression, *statistically significant at $p<0.05$

The observed seasonal variations in temperature, relative humidity, and wind speed in the study area are driven primarily by Nigeria's tropical climate, which is influenced by two major air masses: the moist maritime tropical air mass from the Atlantic Ocean and the dry continental tropical air mass from the Sahara Desert (SoneyeArogundade & Rappenglück, 2024). High temperatures and low humidity in the dry season can exacerbate respiratory conditions, such as asthma, due to the presence of airborne dust and pollutants (D'Amato et al., 2014). The strong winds of Harmattan can also increase the dispersion of pollutants over a wider area (Anuforom, 2007). In contrast, the high humidity and heavy rainfall during the wet season can lead to an increase in the incidence of vector-borne diseases such as malaria, as stagnant water bodies serve as breeding grounds for mosquitoes. The observed relationships between high solar radiation and temperature, as well as the inverse relationship with humidity, are consistent with climate patterns worldwide (Nooni et al., 2025). Numerous studies in Nigeria and West Africa corroborate these findings (Salami & Fenta, 2022; Awode et al., 2025). Nigeria's southwestern region reported similar seasonal variations.

The significantly higher concentrations of $PM_{2.5}$ and PM_{10} during the dry season, as confirmed by the Wilcoxon signed-rank test, could be due to a combination of meteorological factors and human activities. The dry season is characterized by reduced precipitation, which is a major factor. Rainfall acts as a natural "washout" mechanism, removing particulate matter from the atmosphere. Without this cleansing effect, pollutants can accumulate (Guo et al., 2016). Additionally, dry conditions lead to increased resuspension of dust and other particles from unpaved roads and open ground because of higher wind speeds. This effect is particularly pronounced near dumpsites, where there is constant movement of vehicles and machinery on unpaved surfaces. The absence of moisture in the soil and waste makes it easier for these particles to become airborne. Another crucial factor is increased thermal activity, such as open burning, which is a common practice at dumpsites for waste volume reduction.

This activity directly releases large quantities of $PM_{2.5}$ and PM_{10}, along with other harmful gases, into the atmosphere (Jandacka et al., 2024; Souza et al., 2025). The combination of these factors creates a perfect storm for elevated PM concentrations. The significantly higher median concentrations of $PM_{2.5}$ and PM_{10} pose serious risks to public health (Wyzga & Rohr, 2015; Karmakar et al., 2025). These tiny particles can penetrate deep into the respiratory and cardiovascular systems, leading to a higher incidence of respiratory illnesses such as asthma, bronchitis, and chronic obstructive pulmonary disease (COPD) (Deepak et al., 2025; Sangkham et al., 2024). Long-term exposure can also lead to increased rates of heart attack, stroke, and lung cancer (Pun et al., 2017). The pronounced variability and extreme spikes in $PM_{2.5}$ during the dry season predispose residents to sudden, intense episodes of pollution, likely due to activities such as open burning, which is a common practice at dumpsites.

This indicates that a seemingly "moderate" air quality day could quickly turn hazardous without warning. The consistently higher concentrations at the dumpsite site than at the residential site confirm that the dumpsite is a primary source of this pollution, making those living closest to the dumpsite the most vulnerable. The observed findings are consistent with both global and local studies on air quality. Numerous studies from around the world, particularly in developing countries, confirm that dumpsites are major point sources of particulate matter and that PM concentrations are significantly higher in the dry season (Ferronato & Torretta, 2019; Jakhar et al., 2023; Gumede & Gumede, 2025). This finding calls for community-level interventions such as public health education to inform residents about the risks of PM exposure and advise them to limit outdoor activities during high-pollution periods, especially for children and elderly individuals. The community could also be provided with dust masks and encouraged to keep windows and doors closed, particularly during windy, dry days.

Several sociodemographic factors of the study population could contribute to their vulnerability to the health effects of air pollution. The most critical factor is the direct engagement of a significant portion of the population (21.1%) in waste collection at the dumpsite and a large percentage (44.1%) in growing vegetables, which is higher than the prevalence of vegetable farming reported in other studies at dumpsite communities (Norsa'adah et al., 2020). This places them in direct, prolonged contact with high concentrations of PM and other pollutants, increasing their risk of both respiratory and chronic illnesses (Mahler et al., 2016). The majority of residents have only a primary education, and a notable portion have no formal education. This is a crucial factor, as lower education levels are often associated with a lack of awareness about environmental health risks and limited access to healthcare (Hajat et al., 2015). This can prevent residents from recognizing symptoms or taking effective protective measures. While a large percentage of the population has lived in the area for a relatively short time (< 4 years), a significant number are long-term residents. This suggests that while there is turnover, there is also a stable population segment that has been exposed to dumpsite pollution for a prolonged period, increasing the likelihood of developing chronic health issues.

This finding is similar to that of Norsa'adah et al. (2020), who reported that the duration of exposure to dumpsites is a risk factor for adverse health effects among residents. The high prevalence of self-reported symptoms directly reflects the public health implications of living near dumpsites. The reported symptoms—particularly eye irritation (27.0%), cough (41.1%), and wheezing (17.1%)—are consistent with the effects of exposure to airborne irritants such as PM. The presence of more severe, albeit less frequent, symptoms such as shortness of breath and chest tightness is especially concerning, as they indicate that the pollutants are penetrating deep into the respiratory and cardiovascular systems. Research from a South African study revealed that people living near a landfill often reported influenza-like illnesses, eye irritation, and body weakness. These symptoms are directly linked to poor air quality at the site and are reported less frequently by residents who live farther away (Njoku et al., 2019).

A cross-sectional study conducted in Kota Bharu on waste collectors further supports these findings, revealing a high prevalence of various health problems. A previous study revealed that 75.0% of workers suffer from chronic respiratory issues such as cough and wheezing. Additionally, 70.3% had dermatological symptoms such as itchy skin and rashes, and 65.5% experienced gastrointestinal problems, including nausea and diarrhoea (Aminuddin & Rahman, 2015). The strong and significant association between collecting waste and both shortness of breath and skin rashes is likely due to the nature of the work. Waste collectors are in direct and prolonged contact with complex mixtures of pollutants, including fine particulate matter (PM), bioaerosols (airborne microorganisms such as bacteria and fungi), and toxic chemicals (Oloruntoba et al., 2021).

The direct inhalation of $PM_{2.5}$ and PM_{10}, as well as bioaerosols, can cause inflammation and damage to the respiratory system, leading to symptoms such as shortness of breath (World Health Organization, 2016). Waste collectors are at greater risk because they are constantly exposed to these irritants during their work. Contact with unsanitary waste can lead to skin rashes. Waste may contain irritating chemicals, infectious agents, and allergenic substances. This is a common issue for waste workers globally (Oloruntoba et al., 2021). Conversely, the lack of a significant association between waste collection and eye irritation suggests that this symptom may be related to general, widespread pollutants in the atmosphere, such as dust and PM, rather than the specific, direct contact experienced by waste collectors. The significant association between duration of stay and eye irritation suggests that this symptom is a result of long-term, cumulative exposure to general environmental pollutants in the area, which affects the entire residential population, not just those who work at the dumpsite. The fact that the risk increases for those living in the area for 5-9 years indicates that this is a chronic exposure issue rather than an acute one.

CONCLUSION

This study revealed that residents living near the Otofure dumpsite in Benin City, Nigeria, are exposed to significant seasonal variations in particulate matter (PM) concentrations, which are linked to a high prevalence of self-reported respiratory symptoms. The findings highlight a clear public health risk directly attributable to the dumpsite. Our research also confirms that PM concentrations, especially those of PM2.5 and PM10, are significantly higher during the dry season because of a lack of rainfall and increased human activities, such as waste burning. The consistently elevated PM levels at the dumpsite, compared with those in the residential areas, confirm its status as a major point source of pollution. The weak correlation between meteorological factors and PM concentrations at the residential site further suggests that local, human-driven activities, specifically open burning, are the primary drivers of air pollution.

Furthermore, a questionnaire-based survey revealed that a large portion of the population is directly involved in waste collection or vegetable farming, placing them at increased risk. The reported high prevalence of symptoms such as eye irritation, cough, and sneezing is consistent with exposure to airborne irritants. Critically, our study established a strong and significant association between engagement in waste collection and serious health issues such as shortness of breath and skin rashes. This underscores the disproportionate health burden on those who are most directly exposed. The positive association between the duration of residency and eye irritation also points to the cumulative and chronic health effects of living in the area. These findings call for action by public health officials to implement targeted interventions, such as improved waste management practices and community education on air pollution risks, to protect the health and well-being of this vulnerable population.

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