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Effects of Solid Waste Storage Facilities on Ambient Air Quality in Ado-Ekiti, Southwestern Nigeria

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ABSTRACT

Rapid urbanization coupled with inadequate municipal solid waste management has become a significant environmental challenge in many developing countries, including Nigeria. Waste storage facilities located within residential neighbourhoods are important sources of atmospheric pollutants generated during the decomposition of organic wastes. This study assessed the effects of solid waste storage facilities on ambient air quality in selected neighbourhoods of Ado-Ekiti, Ekiti State, Nigeria. Ten municipal waste storage facilities and one control location were investigated. The geographical coordinates and storage capacities of the facilities were determined using a handheld Global Positioning System (GPS) receiver and field measurements. Ambient concentrations of carbon dioxide (CO_2), methane (CH_4), ammonia (NH_3), volatile organic compounds (VOCs), and particulate matter (PM) were measured in situ using calibrated portable air quality monitoring instruments at distances of 0 m, 50 m, and 100 m from each storage facility over the sampling period. Data were analysed using descriptive statistics and one-way Analysis of Variance (ANOVA) at a 5% level of significance.

The results revealed considerable spatial and temporal variations in pollutant concentrations across the sampled neighbourhoods. Carbon dioxide and methane constituted the dominant gaseous emissions from the storage facilities, while ammonia concentrations exceeded recommended ambient air quality standards in several locations. Particulate matter concentrations also surpassed the Federal Environmental Protection Agency (FEPA) permissible limits, indicating potential risks to public health. Although VOC concentrations remained below regulatory limits, their continuous emission may contribute to long-term environmental and health impacts. Generally, pollutant concentrations declined with increasing distance from the waste storage facilities, suggesting that proximity significantly influences human exposure.

The study concludes that municipal solid waste storage facilities contribute significantly to localized air pollution in Ado-Ekiti and may pose respiratory and environmental health risks to nearby residents. Improved waste evacuation schedules, strategic siting of storage facilities, continuous air quality monitoring, and stricter enforcement of environmental regulations are recommended to reduce pollutant emissions and protect public health.

Keywords: Municipal solid waste, Air pollution, Waste storage facilities, Ambient air quality, Greenhouse gases, Ado-Ekiti, Nigeria

INTRODUCTION

Municipal solid waste (MSW) management has become one of the most pressing environmental challenges associated with rapid urbanization, industrialization, and population growth across the world (Abubakar *et al.,* 2022; Rashed, 2026). The continuous increase in the quantity and complexity of solid waste generated in urban centres has outpaced the capacity of many municipalities to provide effective collection, transportation, storage, treatment, and disposal services (Ukala *et al.,* 2020; Kitole *et al.,* 2024; Robert, 2024; Kasem *et al.,* 2025). While developed countries have made significant progress through integrated waste management systems that emphasize waste minimization, recycling, resource recovery, and sanitary landfilling, many developing countries continue to rely on inefficient waste collection systems and temporary storage facilities that often become sources of environmental pollution and public health hazards (Ukala *et al.,* 2020; Robert, 2024; Kasem *et al.,* 2025).

The storage stage is a critical component of municipal solid waste management because it directly influences the efficiency of waste collection and the environmental quality of surrounding communities (Rossit & Nesmachnow, 2022). Waste storage facilities, including communal bins, collection centres, transfer stations, and temporary holding sites, are designed to temporarily contain waste before evacuation to final disposal or treatment facilities (Manteaw & Boachie, 2019; Rahmawati, 2024). However, when waste evacuation is delayed or storage facilities are overloaded, the accumulated refuse undergoes physical, chemical, and biological decomposition, resulting in the emission of numerous gaseous pollutants and particulate matter into the surrounding atmosphere (Manteaw & Boachie, 2019; Usman *et al.,* 2025; Sandy *et al.,* 2026). These emissions have attracted increasing attention because of their potential impacts on ambient air quality, ecosystem integrity, and human health.

The decomposition of organic waste is a complex microbial process that generates several gaseous by-products, including carbon dioxide (CO_2), methane (CH_4), ammonia (NH_3), hydrogen sulphide (H_2S), volatile organic compounds (VOCs), and bioaerosols (Kodiya *et al.,* 2023; Khaleel *et al.,* 2024; Damayanty et al., 2025). Carbon dioxide and methane are the principal greenhouse gases produced during aerobic and anaerobic decomposition of waste respectively. Methane is particularly important because of its high global warming potential, estimated to be approximately 28 times greater than that of carbon dioxide over a 100-year period (Djoukouo, 2021; Magazzino, *et al.,* 2024). Besides their contribution to climate change, elevated concentrations of these gases within poorly ventilated environments may reduce oxygen availability and adversely affect human health (Taha *et al.,* 2025). Ammonia is produced mainly from the degradation of nitrogen-containing organic materials and is well known for causing irritation of the eyes, skin, and respiratory tract (Yarandi *et al.,* 2021; Bist *et al.,* 2023). Similarly, volatile organic compounds emitted from decomposing waste may contribute to unpleasant odours, atmospheric photochemical reactions, and long-term carcinogenic and non-carcinogenic health risks (David & Niculescu, 2021; Srinivasan & Divahar, 2025). In addition, particulate matter generated through waste handling activities, wind resuspension, and decomposition processes can penetrate deep into the respiratory system, increasing the incidence of respiratory and cardiovascular diseases (Ghosh *et al.,* 2025).

Air pollution associated with municipal waste facilities has become a significant environmental health concern worldwide. Numerous studies have demonstrated that residents living close to landfills, dumpsites, and waste storage facilities are more likely to experience respiratory illnesses, eye irritation, headaches, allergies, cardiovascular complications, and reduced quality of life due to prolonged exposure to air pollutants. These adverse health outcomes are particularly pronounced among vulnerable populations such as children, older adults, pregnant women, and individuals with pre-existing respiratory conditions. Beyond direct health effects, gaseous emissions from waste management facilities contribute to atmospheric pollution, climate change, ecosystem degradation, and economic losses through increased healthcare costs and reduced environmental quality.

The challenge of municipal solid waste management is particularly severe in many low- and middle-income countries where rapid urban expansion has not been matched by corresponding investments in waste management infrastructure. In Nigeria, increasing population growth, changing consumption patterns, inadequate funding, weak institutional capacity, limited public awareness, and ineffective enforcement of environmental regulations have collectively contributed to inefficient municipal waste management systems. Consequently, communal waste storage facilities frequently become overloaded, while delays in waste collection allow refuse to accumulate for extended periods. Such conditions create favourable environments for microbial decomposition, odour generation, insect breeding, and the continuous release of atmospheric pollutants into nearby residential and commercial areas.

Several investigations conducted across Nigeria have reported elevated concentrations of gaseous pollutants around open dumpsites and waste disposal facilities. Previous studies have documented increased levels of methane, carbon dioxide, ammonia, particulate matter, hydrogen sulphide, and other pollutants in the vicinity of waste disposal sites, often exceeding recommended national and international air quality standards. These findings highlight the significant environmental burden associated with poor waste management practices in the country. However, most available studies have focused on major dumpsites and final disposal facilities, with relatively limited attention given to neighbourhood waste storage facilities that serve as intermediate collection points within residential communities. Despite their widespread distribution and close proximity to human settlements, these facilities remain poorly investigated regarding their contributions to localized air pollution.

Ado-Ekiti, the capital city of Ekiti State in southwestern Nigeria, has experienced considerable urban growth during the past two decades. Population increase, commercial expansion, and changing lifestyles have resulted in increased municipal solid waste generation and greater dependence on communal waste storage facilities managed by environmental sanitation authorities. Although these storage facilities play an important role in facilitating waste collection, delays in evacuation and inadequate maintenance frequently lead to waste accumulation, offensive odours, and concerns among residents regarding deteriorating air quality. Despite these concerns, there is a paucity of scientific data quantifying gaseous emissions from municipal waste storage facilities within the metropolis and evaluating their compliance with national and international ambient air quality standards.

The absence of localized air quality data presents significant challenges for environmental planning, public health protection, and evidence-based waste management policy formulation. Environmental managers require reliable information on the types, concentrations, spatial distribution, and temporal variation of pollutants emitted from municipal waste storage facilities to design effective mitigation strategies. Likewise, regulatory agencies need baseline data to support environmental monitoring programmes and ensure compliance with air quality guidelines established by agencies such as the Federal Environmental Protection Agency (FEPA), the National Ambient Air Quality Standards (NAAQS), the United States Environmental Protection Agency (USEPA), and the World Health Organization (WHO).

Against this background, this study evaluated the effects of solid waste storage facilities on ambient air quality in selected neighbourhoods of Ado-Ekiti, Nigeria. Specifically, the study assessed the concentrations of selected gaseous pollutants and particulate matter around municipal waste storage facilities, examined their spatial and temporal variations, and compared observed concentrations with established national and international air quality standards. The findings provide important baseline information for environmental regulators, urban planners, public health practitioners, and waste management authorities seeking to improve municipal solid waste management practices, reduce human exposure to harmful air pollutants, and promote healthier urban environments in Nigeria.

MATERIALS AND METHODS

2.1 Study Area

The study was conducted in Ado-Ekiti, the capital city of Ekiti State, Southwestern Nigeria. Ado-Ekiti lies between latitudes 7°10′N and 7°45′N and longitudes 5°10′E and 5°28′E. The city is situated within the tropical savanna climatic zone and experiences two distinct seasons: the rainy season, which typically extends from April to October, and the dry season, which lasts from November to March. Mean annual temperatures range between 24 and 32°C, while annual rainfall averages between 1,200 and 1,500 mm. Relative humidity is generally high during the wet season but decreases considerably during the dry season. Ado-Ekiti has experienced rapid urban expansion over the past two decades due to increasing population growth, commercial activities, institutional development, and rural-to-urban migration. According to available demographic estimates, the metropolis has a population of approximately 424,340 inhabitants. This rapid urbanization has significantly increased municipal solid waste generation, thereby placing considerable pressure on existing waste collection and storage infrastructure. Municipal solid waste generated within the metropolis consists primarily of household refuse, food waste, plastics, paper, metals, glass, textiles, market wastes, and commercial wastes. These wastes are temporarily deposited in communal storage facilities located across residential and commercial neighbourhoods before evacuation to designated disposal sites by the state waste management authority. Delays in waste evacuation often result in prolonged waste accumulation, encouraging microbial decomposition and the emission of gaseous pollutants into the surrounding atmosphere. The strategic importance of Ado-Ekiti as the administrative headquarters of Ekiti State, combined with its increasing waste generation and dependence on communal storage facilities, makes it an appropriate location for investigating the effects of municipal waste storage facilities on ambient air quality.

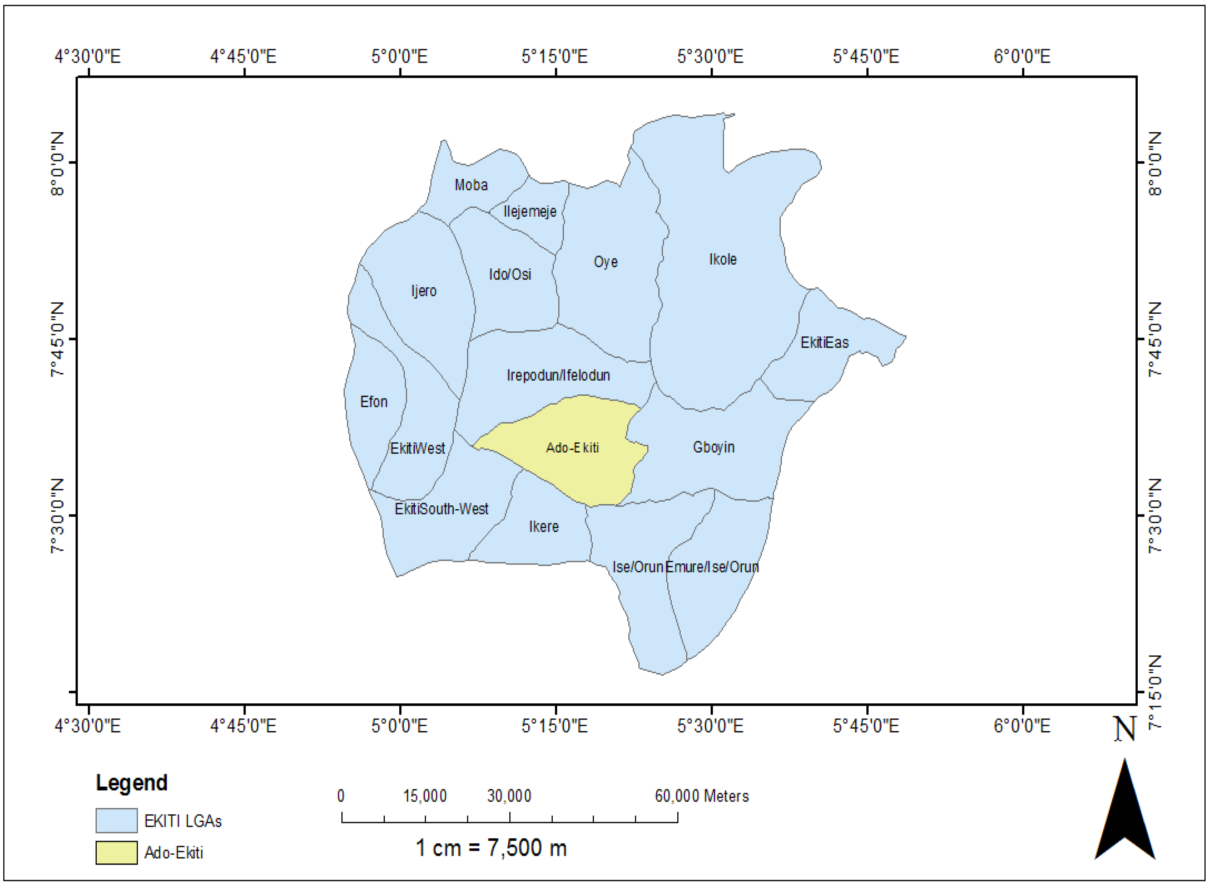

Figure 1: Map of Ekiti State Showing Ado-Ekiti
Source: National Space Research and Development Agency (NASRDA)

2.2 Research Design

This study employed a field-based cross-sectional environmental monitoring design to evaluate ambient air quality around municipal solid waste storage facilities in Ado-Ekiti. Direct field measurements were conducted to determine the concentrations of selected gaseous pollutants and particulate matter around waste storage facilities under natural environmental conditions. The study involved repeated measurements of selected air quality parameters at different sampling locations and distances from each waste storage facility to determine spatial variations in pollutant concentrations. Monthly monitoring was also conducted to assess temporal variations during the study period.

2.3 Selection of Sampling Locations

Ten municipal solid waste storage facilities distributed across different neighbourhoods within Ado-Ekiti were purposively selected for the study. Selection was based on the following criteria:

- Size (storage capacity) of the waste facility.
- Accessibility for routine monitoring.
- Proximity to residential and commercial activities.
- Frequency of waste accumulation.
- Spatial distribution across the metropolis.

In addition to the ten storage facilities, one control location situated away from major waste storage activities was selected to provide background ambient air quality measurements for comparison. The geographical coordinates of all sampling locations were recorded using a handheld Global Positioning System (GPS) receiver, while the spatial distribution of the storage facilities was mapped using ArcGIS version 10.1.

2.4 Determination of Storage Facility Volume

The dimensions of each waste storage facility were measured using a calibrated measuring tape. The length, width, and height of each facility were recorded in metres, and the storage volume was calculated using:

V= L*W*H where: **V** = Volume (m^3); **L** = Length (m); **W** = Width (m); **H** = Height (m)

The calculated storage volumes ranged from approximately **4.86 m^3 to 18.67 m^3**, indicating considerable variation in storage capacities among the selected facilities.

2.5 Air Quality Sampling

Ambient air quality measurements were conducted in situ using calibrated portable monitoring instruments. Air samples were collected at three predetermined distances from each storage facility: 0 m (immediately adjacent to the storage facility), 50 m and 100 m. These distances were selected to assess the spatial dispersion of gaseous pollutants away from the waste source. To minimize measurement errors, all instruments were held approximately 1.5 m above ground level within the breathing zone of an average adult. During sampling, the equipment was positioned facing the prevailing wind direction to ensure representative measurements of pollutant concentrations transported from the waste storage facilities. At each sampling point, pollutant concentrations were measured three consecutive times after instrument readings stabilized. The average of the three readings was used for statistical analysis. Sampling was conducted during daylight hours under relatively stable meteorological conditions to minimize the influence of extreme weather on pollutant dispersion.

2.6 Air Quality Parameters Measured

Five major ambient air quality parameters were investigated because of their importance in waste decomposition processes and potential impacts on environmental and human health. This include: Carbon dioxide (CO_2), Methane (CH_4), Ammonia (NH_3), Volatile Organic Compounds (VOCs) and Particulate Matter (PM).

2.7 Air Quality Monitoring Instruments

The following calibrated portable instruments were used during field measurements:

Parameter	Instrument Used
Carbon dioxide (CO_2)	Land Duo Multi Air Sampler
Methane (CH_4)	iTX Multi Gas Monitor
Ammonia (NH_3)	QRAE Multi-Gas Meter
Volatile Organic Compounds (VOCs)	QRAE Multi-Gas Meter
Particulate Matter (PM)	pDR-1200 Aerosol Monitor

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All instruments were calibrated according to the manufacturers' specifications before commencement of field measurements to ensure accuracy and reliability.

Figure 2: Air Samplers used for Measuring Different Air Samples

2.8 Quality Assurance and Quality Control

Several quality assurance measures were implemented throughout the study. All monitoring equipment was calibrated before field deployment following manufacturers' operational guidelines. Instrument functionality was verified daily before sampling commenced. Multiple readings were obtained at each sampling point, and the arithmetic mean was used for analysis to reduce random measurement errors. Sampling procedures were standardized across all locations with respect to instrument height, sampling duration, and orientation relative to prevailing wind direction. Measurements were conducted under similar environmental conditions to reduce the influence of meteorological variability on pollutant concentrations. Data recording sheets were checked immediately after each field exercise to minimize transcription errors and ensure completeness of observations.

2.9 Data Analysis

Field data were entered into Microsoft Excel and subsequently analysed using the Statistical Package for the Social Sciences (SPSS) (version 26). Descriptive statistics, including means and standard deviations, were computed to summarize pollutant concentrations across sampling locations, distances, and sampling periods. One-way Analysis of Variance (ANOVA) was employed to determine whether significant differences existed among the mean concentrations measured across neighbourhoods, sampling distances, and monitoring periods. Measured pollutant concentrations were further compared with relevant national and international air quality standards, including those established by the Federal Environmental Protection Agency (FEPA), the National Ambient Air Quality Standards (NAAQS), the United States Environmental Protection Agency (USEPA), and the World Health Organization (WHO), to evaluate potential environmental and public health implications.

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RESULTS

3.1 Characteristics of the Selected Solid Waste Storage Facilities

Ten municipal solid waste storage facilities distributed across different neighbourhoods within Ado-Ekiti were investigated. The geographical location of the solid waste storage receptacles in the neighbourhood of Ado-Ekiti determined using a Global Positioning System was determined in decimal unit (Table 1). The map of the selected neighbourhoods with waste storage facilities are also presented in Figure 3. Their geographical coordinates were recorded using a handheld GPS receiver and subsequently mapped using ArcGIS 10.1 to illustrate their spatial distribution across the study area. The storage facilities varied considerably in size, with calculated storage volumes ranging from 4.86 m³ [(Ekiti State University Teaching Hospital (7.641988 N, 5.22021 E), Adehun-Oluwa (7.660196 N, 5.234395 E), Olaoluwa school (7.618519 N, 5.205605 E) and Basiri market (7.635853 N, 5.210972 E)] to 18.67 m³ [Adebayo Junction (7.653421 N, 5.228624 E), Nigerian Television Authority (NTA) (7.626304 N, 5.191315 E), Ejigbo Roundabout (7.617905 N, 5.224644 E), Matthew Street (7.615350 N, 5.226594 E), Saidat Hotel (7.617108 N, 5.211527 E) and Post-office (7.621549 N, 5.221635 E)].

Table 1: The Geographical Location and Volume of Selected Waste Storage Facility in Ado-Ekiti

S/N	Physical Location	N	E	Volume(m^3)
1	Ekiti State University Teaching Hospital	7.641988	5.22021	4.86
2	Adebayo Junction	7.653421	5.228624	18.67
3	Adehun-Oluwa	7.660196	5.234395	4.86
4	Nigerian Television Authority(NTA)	7.626304	5.191315	18.67
5	Ejigbo Roundabout	7.617905	5.224644	18.67
6	Matthew Street	7.615350	5.226594	18.67
7	Saidat Hotel	7.617108	5.211527	18.67
8	Olaoluwa school	7.618519	5.205605	4.86
9	Basiri market	7.635853	5.210972	4.86
10	Post-office	7.621549	5.221635	18.67
	Control	7.633704	5.200432	

*the unit of measurement is in Decimal

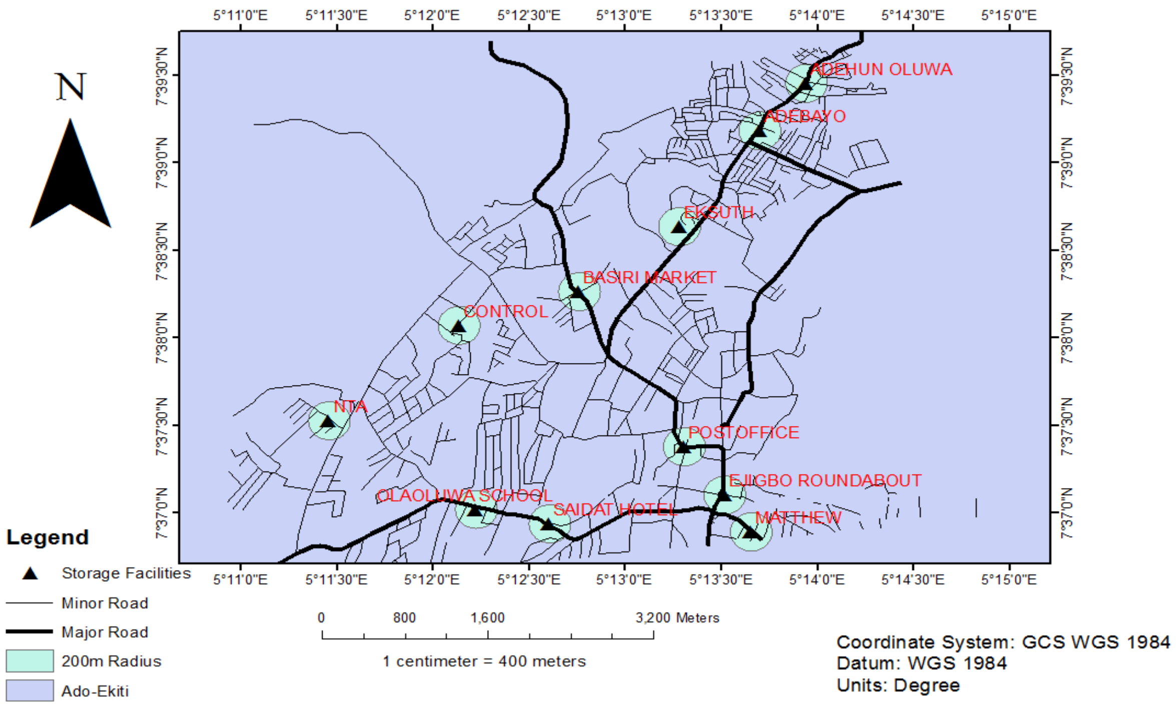

Figure 3: Map of Selected Neighbourhoods with Waste Storage Facilities in Ado-Ekiti

3.2 Air Quality across the Selected Neighbourhoods

The mean concentrations of carbon dioxide (CO_2), methane (CH_4), ammonia (NH_3), volatile organic compounds (VOCs), and particulate matter (PM) measured across the selected neighbourhoods are presented in Table 2 . Carbon dioxide (CO_2) concentration among the neighbourhood of the solid waste storage facilities ranged from 5.54±3.64 mg/m^3 at Basiri Market to 16.07±9.76 mg/m^3 at EKSUTH. Ammonia concentration varied between 3.56±2.97 mg/m^3 at Adehun-Oluwa and 6.33±3.13 mg/m^3 in Ejigbo Roundabout. For methane, the concentration was lowest at EKSUTH (3.33±0.93 mg/m^3) and highest at Ejigbo Roundabout (6.11±5.31 mg/m^3). The VOC concentration ranged between 4.33±3.76 mg/m^3 at Basiri Market and 8.26±2.73 mg/m^3 at Matthew Street, while PM concentration was lowest at Saidat Hotel (1.06±0.65 µg/m^3) and highest at Ola-Oluwa School (2.67±1.82 µg/m^3). It is worthy of note that the control site has no concentration recorded for all the pollutants. The result of statistical analysis showed that only CO_2 and PM concentrations were significantly different among the neighbourhood of the facilities at $p<0.05$. The Post Hoc test further showed that CO_2 concentration was significantly lower in Basiri Market and Saidat Hotel but significantly higher in EKSUTH, Adebayo and Ejigbo Roundabout; while PM emission was significantly higher in Ola-Oluwa School than others except in Matthew Street. Particulate matter (PM) concentration were generally lower than the United States Environmental Protection Agency (EPA) standard of 20 µg/m^3 for 1 hour, World Health Organization (WHO) (2005) standard of 25 µg/m^3 for 24 hours, National Ambient Air Quality Standards (NAAQS) of 200 µg/m^3 for 24 hours but higher than Federal Environmental Protection Agency (FEPA) (1999) standard of 0.0005 µg/m^3 for 30 minutes. On the other hand, VOC concentrations were all lower than the FEPA (1999) standard of 40 mg/m^3 for 30 minutes while Ammonia concentrations were generally higher than the NAAQ standard of 0.4 mg/m^3 for 30 minutes (Table 4.3.1) in the sampling areas.

Table 2: Mean Gaseous Concentrations across the Neighbourhood with Storage Facilities

Neighbourhood	CO_2 (mg/m^3)	NH_3(mg/m^3)	CH_4(mg/m^3)	VOC (mg/m^3)	PM (µg/m^3)
	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD
EKSUTH	16.07±9.76^b	4.28±2.30^a	3.33±0.93^a	5.26±1.13^{abc}	1.07±0.71^a
Adebayo	14.22±7.34^b	3.72±3.44^a	3.82±1.24^a	6.08±1.78^{abc}	1.2±0.76^a
Adehun-Oluwa	12.15±6.66^{ab}	3.56±2.97^a	4.78±1.77^a	6.41±1.66^{abc}	1.39±0.54^a
NTA	11.78±5.36^{ab}	5.96±4.42^a	4.42±1.10^a	6.56±2.47^{abc}	1.52±0.52^a
Ejigbo Roundabout	14.56±8.07^b	6.33±3.13^a	6.11±5.31^a	6.95±1.69^{abc}	1.32±0.88^a
Matthew Street	12.37±4.83^{ab}	4.44±4.40^a	4.78±1.32^a	8.26±2.73^c	1.98±1.0^{ab}
Saidat Hotel	6.22±4.05^a	4.61±3.57^a	3.39±1.39^a	6.25±3.89^{abc}	1.06±0.65^a
Ola-Oluwa School	12.04±5.94^{ab}	5.45±1.80^a	3.5±0.89^a	4.45±1.99^{ab}	2.67±1.82^b
Basiri Market	5.54±3.64^a	4.78±0.51^a	3.78±1.65^a	4.33±3.76^a	1.42±0.85^a
Post Office	11±4.17^{ab}	6.11±2.9^a	4±1.73^a	7.44±1.83^{bc}	1.15±0.07^a
EPA Standard	-	-	-	-	20 for 1 h
WHO(2005)	-	-	-	-	25 for 24 h
NAAQS	-	0.4 for 24 h	-	-	200 for 24 h
FEPA (1999) (for 30 min)				40	0.0005
F-value	2.239	0.571	1.214	1.942	2.482
p-value	0.029*	0.815	0.304	0.061	0.016*

Superscripts with the same letters down the column are not significantly different at ($p<0.05$)
* Shows significant difference at $p<0.05$

3.3 Spatial Variation of Air Pollutants around the Storage Facilities

The spatial distribution of gaseous pollutants measured at distances of 0 m, 50 m, and 100 m from the storage facilities is presented in Table 3. Carbon dioxide (CO_2) concentration ranged from 9.76±6.49 mg/m^3 at 100m from the facilities to 14.02±7.59 mg/m^3 at the waste storage facilities (0m). Ammonia concentration varied between 2.89±1.43 mg/m^3 at 100m from the facilities and 6.97±4.01 mg/m^3 at the waste storage facilities (0m).

For methane, the concentration was lowest at 100m from the facilities (3.27±1.42 mg/m^3) and highest at the waste storage facilities (0m) (5.17±2.69 mg/m^3). The VOC concentration ranged between 5±1.85 mg/m^3 at 100m from the facilities and 7.32±2.68 mg/m^3 at the waste storage facilities (0m), while PM emission was lowest with 1.35±0.9 µg/m^3 at 50m from the source of the facilities and highest with 1.78±1.29 µg/m^3 at the waste storage facilities (0m). Statistically, all the gases concentrations was significantly different for the points of sampling at $p<0.05$, except for carbon dioxide (CO_2) and PM. The Post Hoc test showed that methane and VOC emission were significantly lower at 100m from the facilities and significantly higher at the source than that of 50 m from the facilities and for Ammonia; the emission at the source was significantly higher than the other points. The concentration of PM were generally lower than the EPA standard of 20 µg/m^3 for 1 hour, WHO (2005) standard of 25 µg/m^3 for 24 hours, NAAQ standard of 200 µg/m^3 for 24 hours but higher than FEPA (1999) standard of 0.0005 µg/m^3 for 30 minutes. The concentration of VOC were all lower than the FEPA (1999) standard of 40 mg/m^3 for 30 minutes; while that of Ammonia were generally higher than the NAAQ standard of 0.4 mg/m^3 for 30 minutes for all the sampling points.

Table 3: Mean Spatial Gaseous Concentrations around the Storage Facilities

	Source	**50m**	**100m**	**EPA**	**WHO (2005)**	**NAAQS**	**FEPA (1999)**		
Gases	**Mean±SD**	**Mean±SD**	**Mean±SD**	**1 hr**	**24 hr**	**24 hr**	**30 min**	**F-value**	**p-value**
CO_2 (mg/m^3)	14.02±7.59^b	11.18±5.78^{ab}	9.76±6.49^a	-	-	-	-	2.806	0.067
NH_3 (mg/m^3)	6.97±4.01^b	4.54±2.71^a	2.89±1.43^a	-	-	0.4	-	10.753	0.0001*
CH_4 (mg/m^3)	5.17±2.69^b	4.17±1.25^{ab}	3.27±1.42^a	-	-	-	-	5.617	0.006*
VOC (mg/m^3)	7.32±2.68^b	6.18±2.53^{ab}	5±1.85^a	-	-	-	40	5.924	0.004*
PM (µg/m^3)	1.78±1.29^a	1.35±0.9^a	1.40±0.67^a	20	25	200	0.0005	1.438	0.244

Superscripts with the same letters across the row are not significantly different at ($p<0.05$)
* Shows significant difference at $p<0.05$

3.4 Temporal Variation in Air Quality

Monthly variations in pollutant concentrations recorded during the study period are presented in Table 4**.** The mean monthly concentration of carbon dioxide (CO_2) ranged from 6.15±3.48 mg/m^3 in December to 16.50±8.08 mg/m^3 in October. Ammonia concentration varied between 2.89±1.43 mg/m^3 in December and 6.42±2.49 mg/m^3 in November. For methane, the concentration was lowest in October (3.80±2.67 mg/m^3) and highest in December (5.27±0.83 mg/m^3). The VOC concentration ranged between 4.55±2.18 mg/m^3 in December and 6.96±2.10 mg/m^3 in November, while PM concentration was lowest in November with 1.22±0.67 µg/m3 and highest in December 1.89±1.42 µg/m^3. The statistical analysis showed that all the gases' concentration was significantly different for the three months of sampling at $p<0.05$ except for methane (CH4). The Post Hoc for the three sampling months showed Ammonia and VOC, the concentration in December were significantly lower than the other months; the concentration of Methane in December was significantly higher than the other months while that of PM is significantly lower and higher in November and December respectively. The mean monthly concentration for PM were generally lower than the EPA standard of 20 µg/m3 for 1 h, WHO (2005) standard of 25 µg/m^3 for 24 h, NAAQ standard of 200 µg/m^3 for 24 h but higher than FEPA (1999) standard of 0.0005 µg/m^3 for 30 minutes. The mean monthly VOC concentration in the sampling points were all lower than the FEPA (1999) standard of 40 mg/m^3 for 30 minutes while the mean monthly Ammonia concentration for all the sampling points were generally higher than the NAAQ standard of 0.4 mg/m^3 for 30 minutes.

Table 4: Mean Spatial Gaseous Concentrations around the Storage Facilities

Gases	October Mean±SD	November Mean±SD	December Mean±SD	EPA 1 hr	WHO (2005) 24 hr	NAAQS 24 hr	FEPA (1999) 30 min	F-value	p-value
CO_2 (mg/m3)	16.50±8.08^{c}	12.09±4.05^{b}	6.15±3.48^{a}	-	-	-	-	21.596	0.0001*
NH_3 (mg/m3)	4.77±3.59^{b}	6.42±2.49^{b}	1.21±0.56^{a}	-	-	0.4	-	18.202	0.0001*
CH_4 (mg/m3)	3.80±2.67^{a}	4.02±1.75^{a}	5.27±0.83^{b}	-	-	-	-	2.772	0.07
VOC (mg/m3)	6.67±2.73^{b}	6.96±2.10^{b}	4.55±2.18^{a}	-	-	-	40	7.537	0.001*
PM (µg/m3)	1.50±0.74^{ab}	1.22±0.67^{a}	1.89±1.42^{b}	20	25	200	0.0005	3.072	0.052*

Superscripts with the same letters across the row are not significantly different at ($p<0.05$)
* Shows significant difference at $p<0.05$

3.5 Temperature of Sampling Points

The mean monthly temperature of the various neighbourhoods of the solid waste storage facilities is presented in Table 5. The result showed that the temperature ranged from 21±18.19 °C in Saidat Hotel and Ola-Oluwa School to 36.67±2.08 °C in EKSUTH and Adebayo in October. In November, Basiri Market and Saidat Hotel had the lowest temperature of 17.67±15.31 °C, while the highest temperature of 22±19.7°C was recorded in Adebayo. In December, the temperature varied between 10±17.32 °C (Saidat Hotel and Post Office) and 31.33±1.53 °C in Adebayo. The temperature for the three sampling months were not significantly different at $p<0.05$.

Table 5: Measured Temperature (Mean±S.D) (^{O}C) of Sampling Points

	October Mean±SD (^{O}C)	November Mean±SD (^{O}C)	December Mean±SD (^{O}C)
EKSUTH	34.33±4.51	19.00±16.46	17±14.8
Adebayo	34.33±2.08	22.00±19.70	31.33±1.53
Adehun-Oluwa	34.00±1.00	20.67±18.34	22.33±19.35
NTA	32.67±1.53	18.00±15.59	22.33±19.40
Ejigbo RA	21.33±18.48	19.00±16.46	11.00±19.05
Matthew Street	21.33±18.48	19.33±16.86	11.00±19.05
Saidat Hotel	21.00±18.19	17.67±15.31	10.00±17.32
Ola-Oluwa School	21.00±18.19	17.33±15.01	11.33±19.63
Basiri Market	22.33±19.5	17.67±15.31	11.33±19.63
Post Office	22.00±19.29	18.33±15.95	10.00±17.32
F-value	0.578	0.024	0.523
p-value	0.800	1.000	0.841

DISCUSSION

In this study, nine of the storage facilities are located along the major road networks of Ado-Ekiti while only one is located along the minor road network. This agrees with previous studies on urban waste management. Yusuf (2010), the geographical setting of a place plays a key role in determining the scale and nature of human activities and structures as well as influence the types of waste produced. Ferronato and Torretta (2019) reported that developing cities frequently prioritize operational accessibility over environmental and public health considerations, resulting in storage facilities being situated close to densely populated residential and commercial areas. The capacity of the storage facilities in Ado-Ekiti are either 4.86 m^3 or 18.67 m^3 for the ten neighbourhoods, this differences in capacity may be associated with the population density of these locations which determines the quantity of waste that are generated. Other factors such as environmental and legal impact, centrality, adequacy of space, other neighbouring land-uses, etc. may also have been considered in siting these storage facilities in these neighbourhoods (Ogwuche, 2013). Similarly, Kaza et al. (2018) observed that increasing urbanization and population density directly influence both the capacity and distribution of municipal waste collection infrastructure. Therefore, the larger storage capacities (18.67 m^3) observed in densely populated neighbourhoods of Ado-Ekiti are consistent with global municipal waste planning practices.

This study demonstrated that municipal solid waste storage facilities in Ado-Ekiti are important localized sources of atmospheric pollutants. Significant spatial and temporal variations were observed in the concentrations of carbon dioxide (CO_2), methane (CH_4), ammonia (NH_3), volatile organic compounds (VOCs), and particulate matter (PM), indicating that the magnitude of gaseous emissions differs among waste storage facilities and over time. These variations are expected because waste decomposition is influenced by several interacting factors, including waste composition, storage duration, moisture content, microbial activity, ambient temperature, waste compaction, storage capacity, and evacuation frequency (Tian *et al.,* 2025). The observed differences among neighbourhoods suggest that waste management practices and operational conditions vary across the metropolis. Storage facilities receiving larger quantities of biodegradable organic waste are expected to produce greater gaseous emissions than facilities dominated by inert materials such as plastics, glass, and metals. Similarly, prolonged storage resulting from delayed waste evacuation provides sufficient time for microbial degradation, thereby increasing the release of decomposition gases into the surrounding atmosphere. These findings agree with previous studies that reported considerable variability in gaseous emissions from municipal waste facilities depending on waste characteristics, climatic conditions, and operational management practices (Gavrila *et al.,* 2025; Zari, 2025; Lakhouit, 2026).

Carbon dioxide constituted one of the dominant gaseous emissions detected around the storage facilities. The concentrations obtained in this study are consistent with the natural biological decomposition of organic matter within municipal solid waste. Carbon dioxide is primarily generated during aerobic microbial decomposition of biodegradable materials such as food waste, vegetables, paper, leaves, and other organic refuse. Since household wastes in many Nigerian cities contain high proportions of biodegradable materials, continuous carbon dioxide production is expected within communal storage facilities. Although ambient carbon dioxide is generally not regulated as a conventional air pollutant, elevated concentrations indicate active microbial decomposition and poor waste management efficiency. Furthermore, carbon dioxide remains one of the principal greenhouse gases responsible for global climate change. Consequently, municipal waste storage facilities represent small but continuous sources of greenhouse gas emissions, particularly when waste remains uncollected for extended periods. While the concentrations measured are unlikely to produce acute toxic effects under outdoor conditions, persistent emissions contribute cumulatively to atmospheric greenhouse gas accumulation. Continuous monitoring therefore remains important within rapidly urbanizing cities such as Ado-Ekiti.

Methane was the second dominant gaseous pollutant measured during this study. Its occurrence confirms that anaerobic decomposition was actively taking place within portions of the stored waste. Methane production occurs when oxygen becomes depleted inside accumulated waste masses, allowing methanogenic microorganisms to decompose organic matter under anaerobic conditions. The production rate depends largely on waste age, moisture content, temperature, organic composition, and storage duration. The relatively high methane concentrations observed in some neighbourhoods may indicate prolonged waste retention before evacuation. Larger storage facilities are likely to contain deeper waste layers where oxygen penetration becomes limited, creating favourable conditions for methane generation. Methane deserves particular environmental attention because it possesses a global warming potential approximately 28–34 times greater than carbon dioxide over a 100-year period. Consequently, even relatively small emissions contribute disproportionately to climate change. Beyond its climatic significance, methane also presents occupational hazards. Under confined conditions it can displace oxygen and, at sufficiently high concentrations, create explosion risks. Although ambient concentrations measured around outdoor storage facilities rarely approach explosive limits, continuous emissions nevertheless indicate inefficient waste management practices.

Ammonia concentrations varied considerably among the sampled neighbourhoods, with several locations exceeding recommended National Ambient Air Quality Standards. This finding is of considerable public health importance because ammonia is among the first gases perceived by residents living close to waste storage facilities due to its characteristic pungent odour. Ammonia originates from microbial degradation of proteins, amino acids, and other nitrogen-containing organic materials commonly present in domestic refuse. Food waste, vegetable residues, animal products, market wastes, and slaughterhouse wastes are particularly important sources. The elevated ammonia concentrations observed suggest substantial quantities of biodegradable organic wastes were present within the storage facilities during sampling. Delays in waste evacuation likely intensified microbial degradation and subsequent ammonia release. Exposure to ammonia may produce irritation of the eyes, nose, throat, and respiratory tract even at relatively low concentrations. Individuals suffering from asthma, chronic obstructive pulmonary disease, allergic conditions, and other respiratory disorders are particularly susceptible. From an environmental perspective, atmospheric ammonia contributes to the formation of secondary particulate matter through reactions with acidic gases, thereby worsening regional air pollution. The findings therefore emphasize the importance of minimizing prolonged storage of organic wastes within residential neighbourhoods.

Volatile organic compounds were detected at all sampling locations, although measured concentrations remained below applicable FEPA guideline values. VOCs emitted from municipal waste originate from microbial metabolism, solvent-containing household wastes, paints, petroleum products, plastics, pharmaceuticals, and other volatile chemical constituents disposed within municipal refuse. Although concentrations remained below regulatory limits, their presence should not be disregarded. Many VOCs participate in atmospheric photochemical reactions leading to the formation of ground-level ozone and photochemical smog. Certain VOC species, including benzene, formaldehyde, and vinyl chloride, are also recognized carcinogens. Long-term exposure to mixtures of VOCs has been associated with neurological disorders, headaches, irritation of mucous membranes, liver dysfunction, kidney damage, and increased cancer risk depending on exposure duration and chemical composition. The relatively low VOC concentrations observed may reflect adequate atmospheric dilution under outdoor conditions and the predominance of biodegradable rather than industrial wastes within the storage facilities.

Particulate matter represented one of the most important pollutants measured during the investigation because its concentrations exceeded the permissible FEPA limits. Unlike gaseous pollutants, particulate matter originates from multiple environmental processes. Around waste storage facilities, particles may be generated through waste handling operations, wind erosion of exposed waste, vehicular movement, nearby road traffic, combustion activities, and resuspension of dust deposited on surrounding surfaces. Interestingly, particulate matter did not exhibit the same spatial trend as the gaseous pollutants. While gaseous concentrations generally decreased with increasing distance from the storage facilities, particulate matter concentrations at 100 m were occasionally higher than those recorded at 50 m. This pattern suggests that atmospheric transport processes, wind direction, road traffic, and human activities substantially influenced particulate dispersion. Elevated particulate matter concentrations are particularly concerning because inhalable particles penetrate deeply into the respiratory tract. Fine particles may reach the alveolar region of the lungs, initiating inflammatory responses and increasing the risk of asthma, chronic bronchitis, cardiovascular disease, reduced lung function, and premature mortality. The observed exceedance of FEPA limits therefore indicates that communities located near waste storage facilities may face increased respiratory health risks, particularly vulnerable populations including children, elderly individuals, and persons with pre-existing respiratory diseases.

One of the major findings of this study is the progressive reduction in gaseous pollutant concentrations with increasing distance from the waste storage facilities. This pattern demonstrates that the storage facilities function as localized point sources of atmospheric pollution. Atmospheric dispersion, dilution, turbulent mixing, and chemical transformation reduce pollutant concentrations as emissions move away from their source. From a public health perspective, this finding implies that individuals residing or working immediately adjacent to waste storage facilities experience the highest exposure levels. Consequently, the siting of communal waste storage facilities within densely populated residential areas should receive careful consideration during urban planning. The results also support the establishment of appropriate buffer distances between waste storage infrastructure and sensitive land uses such as schools, hospitals, markets, and residential buildings.

The monthly fluctuations observed throughout the monitoring period demonstrate that gaseous emissions from municipal waste storage facilities are dynamic rather than constant. Seasonal changes in rainfall, temperature, humidity, microbial activity, waste composition, and waste evacuation frequency likely contributed to the temporal variability observed. Higher temperatures generally accelerate microbial metabolism, increasing gaseous emissions, whereas increased rainfall enhances moisture availability and stimulates decomposition while also influencing pollutant dispersion. Operational factors such as irregular waste collection schedules may further increase temporal variability by allowing waste to accumulate for longer periods before evacuation. These observations emphasize that air quality monitoring around municipal waste storage facilities should be conducted continuously rather than relying on single measurements.

Among the three months, there was no significant difference in the temperature of the storage facilities neighbourhood. In places with high temperatures, it is most likely that the waste in these storage facilities have not stayed longer as it has been observed that the longer the waste, the lower the temperature and this corroborate the observation that the short-term temperature increase in waste due to aerobic decomposition was directly correlated with the placement temperature of waste (Ibrahim, 2012).

4.9 Implications for Environmental Management

The findings of this study have important implications for municipal solid waste management in rapidly urbanizing Nigerian cities.

Although communal storage facilities remain essential components of urban waste management systems, poor operational practices, including prolonged waste retention, inadequate storage capacity, and irregular waste evacuation can transform these facilities into persistent sources of atmospheric pollution.

Environmental regulators should therefore prioritize routine air quality monitoring around municipal waste storage facilities, particularly those located within residential neighbourhoods. Waste evacuation schedules should be optimized to minimize decomposition time, while engineered storage systems incorporating odour control, covers, and improved ventilation should be considered.

Furthermore, strengthening waste segregation at source and increasing composting of biodegradable organic waste could substantially reduce microbial decomposition within communal storage facilities and consequently lower greenhouse gas emissions.

CONCLUSION

This study evaluated the effects of municipal solid waste storage facilities on ambient air quality in selected neighbourhoods of Ado-Ekiti, Ekiti State, Nigeria. The findings demonstrate that waste storage facilities constitute important localized sources of atmospheric pollutants, with measurable concentrations of carbon dioxide (CO_2), methane (CH_4), ammonia (NH_3), volatile organic compounds (VOCs), and particulate matter (PM) detected around all sampled locations. The observed spatial and temporal variations indicate that pollutant emissions are influenced by waste composition, storage capacity, waste evacuation frequency, environmental conditions, and proximity to the storage facilities.

Carbon dioxide and methane were the predominant gaseous emissions, reflecting active aerobic and anaerobic decomposition of biodegradable municipal solid waste. Although these gases are not commonly regulated as conventional ambient air pollutants, they are significant greenhouse gases that contribute to climate change. Ammonia concentrations exceeded recommended ambient air quality standards at several locations, suggesting potential respiratory and environmental health risks to nearby residents. Likewise, particulate matter concentrations surpassed the permissible limits established by the Federal Environmental Protection Agency (FEPA), indicating an increased likelihood of adverse respiratory outcomes, particularly among vulnerable population groups.

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The study further established that pollutant concentrations generally decreased with increasing distance from the waste storage facilities, confirming that the facilities act as localized point sources of atmospheric pollution. This finding emphasizes the importance of appropriate siting of communal waste storage facilities and the need to maintain adequate separation distances between waste storage infrastructure and residential buildings, schools, healthcare facilities, and other sensitive land uses.

Overall, the study provides important baseline information on ambient air quality around municipal waste storage facilities in Ado-Ekiti. The findings contribute to the growing body of evidence demonstrating that inefficient municipal solid waste management can significantly degrade urban air quality and pose risks to public health and environmental sustainability. The study therefore highlights the need for improved waste management practices, regular environmental monitoring, and evidence-based policy interventions aimed at minimizing emissions from communal waste storage facilities.

RECOMMENDATIONS

Based on the findings of this study, the following recommendations are proposed:

- Municipal authorities should increase the frequency of waste collection from communal storage facilities to minimize prolonged waste accumulation and reduce microbial decomposition responsible for gaseous emissions.
- Future waste storage facilities should be located at safe distances from residential areas, schools, hospitals, markets, and other sensitive public locations. Existing facilities situated within densely populated neighbourhoods should be reviewed and relocated where feasible.
- The Ekiti State environmental authorities should establish continuous air quality monitoring programmes around municipal waste storage facilities to provide early detection of pollutant build-up and facilitate timely intervention.
- Residents should be encouraged to separate biodegradable wastes from recyclable and non-biodegradable materials before disposal. This practice would reduce organic decomposition within communal storage facilities and consequently lower greenhouse gas emissions.
- Open communal waste bins should gradually be replaced with enclosed or covered storage systems designed to reduce odour generation, gaseous emissions, insect infestation, and wind dispersion of particulate matter.
- Government agencies and community organizations should intensify environmental awareness campaigns to educate residents on proper waste handling practices and the public health implications of indiscriminate waste disposal.
- Environmental protection agencies should strengthen enforcement of existing waste management regulations and ensure compliance with national ambient air quality standards through routine inspection and monitoring of municipal waste management operations.
- Considering the contribution of municipal waste to greenhouse gas emissions, municipal authorities should promote composting, anaerobic digestion, recycling, and other resource recovery approaches capable of reducing methane generation while supporting circular economy initiatives.

STUDY LIMITATIONS

The study assessed only selected gaseous pollutants and particulate matter, excluding other potentially important pollutants such as hydrogen sulphide (H_2S), sulphur dioxide (SO_2), nitrogen oxides (NO_x), ozone (O_3), and bioaerosols. Meteorological parameters including wind speed, wind direction, atmospheric pressure, and relative humidity were not incorporated into the statistical analysis despite their influence on pollutant dispersion. Furthermore, the investigation was limited to ten municipal waste storage facilities within Ado-Ekiti, which may restrict the generalizability of the findings to other urban centres in Nigeria.

SUGGESTIONS FOR FUTURE RESEARCH

Future investigations should:

- Conduct year-round monitoring to evaluate seasonal variations in pollutant emissions.
- Include additional pollutants such as hydrogen sulphide, sulphur dioxide, nitrogen oxides, ozone, and bioaerosols.
- Incorporate meteorological modelling to better explain pollutant dispersion patterns.
- Undertake quantitative human health risk assessments for communities living near waste storage facilities.
- Apply Geographic Information Systems (GIS) and atmospheric dispersion models to identify pollution hotspots.
- Compare emissions from waste storage facilities with those from open dumpsites, transfer stations, engineered landfills, and waste treatment facilities.
- Evaluate the effectiveness of alternative waste storage technologies and waste management interventions in reducing emissions.

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