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Distance-decay Relationships of Air Pollutant Concentrations Near Open Waste Burning Sites in Nairobi, Kenya: Evidence from Kibera

Noah Ngeno [a*] and Esther Kitur [a]

[a] Kenyatta University, Nairobi, Kenya.

Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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Original Research Article

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Abstract

Open waste burning in informal settlements contributes to localized air pollution, posing significant health risks. This study investigated the distance-decay relationship of air pollutant concentrations near open waste burning sites in Kibera, Nairobi City County, Kenya. Air samples were collected at 21 sampling points across three distance ranges (0–500 m, 500–1000 m, and >1000 m) from active burning sites over a two-month period in 2025. Pollutants measured included $PM_{2.5}$, SO_2, CO_2, and CH_4, using calibrated portable and fixed air quality monitors. Data were analyzed using linear regression and one-way ANOVA to examine relationships between pollutant concentrations and distance. $PM_{2.5}$ levels were highest within 0–500 m, reaching 150 µg/m³ ten times the WHO 24-hour guideline of 15 µg/m³ and decreased to 45 µg/m³ beyond 1000 m. SO_2 exhibited a similar decline from 55 ppb to 15 ppb. Regression analysis indicated a significant negative relationship between distance and pollutant concentration ($R^2 = 0.530$), while ANOVA confirmed differences across zones ($F = 49.521$, $p < 0.001$). CO_2 and CH_4 showed more gradual declines but remained

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*Corresponding author: E-mail: kibeenoah@gmail.com;

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elevated near burning sites, highlighting greenhouse gas contributions. Pollutant concentrations declined sharply with distance from waste burning sites, with $PM_{2.5}$ and SO_2 posing the highest immediate health risks. These findings support the establishment of buffer zones and targeted mitigation strategies in Nairobi's informal settlements to protect public health.

Keywords: PM $_{2.5}$*; waste burning; air pollution; dumpsites; urban air quality.*

1. Introduction

Rapid urbanization in Nairobi County has significantly increased the generation of solid waste, overwhelming formal waste management systems and leading to widespread informal dumping and open burning practices ((Kaza et al., 2018; Ferronato & Torretta, 2019). These activities release substantial amounts of particulate matter ($PM_{2.5}$) and gaseous pollutants, including carbon dioxide (CO_2), sulphur dioxide (SO_2), and methane (CH_4), which degrade urban air quality and pose serious environmental and public health risks (WHO, 2021; United States Environmental Protection Agency (U.S. EPA), 2023). Exposure to $PM_{2.5}$ is particularly harmful, as these fine particles can penetrate deep into the lungs and enter the bloodstream, increasing the risk of respiratory infections, cardiovascular diseases, and premature mortality (Apte et al., 2018). SO_2 contributes to respiratory irritation and acid rain formation, while CH_4 acts as a potent greenhouse gas, accelerating climate change Intergovernmental Panel on Climate Change (IPCC), 2021; WHO, 2021; Kirimi et al., 2023; World Health Organization (WHO), 2021).

Pollutant concentrations tend to be highest near burning sites, disproportionately affecting vulnerable populations residing in close proximity (Gao et al., 2021; Egondi et al., 2013). Understanding how these concentrations decreased with distance was critical for assessing exposure risks, designing buffer zones, and informing urban planning and environmental management policies. This study aimed to quantify the relationship between air pollutant levels and distance from dumping sites in Nairobi County, providing empirical evidence for policymakers to mitigate health risks and improve urban air quality. This study aims to determine the relationship between PM2.5, CO2, SO2, and CH4 concentrations and the distance from dumping sites with active burning in Nairobi County.

1.1 Statement of the Problem

Rapid urbanization in Nairobi County has led to a significant increase in solid waste generation, with informal dumping and open burning becoming widespread due to limited waste management infrastructure (Kaza et al., 2018; Ferronato & Torretta, 2019). Open burning of waste releases high concentrations of particulate matter ($PM_{2.5}$) and gaseous pollutants, including carbon dioxide (CO_2), sulphur dioxide (SO_2), and methane (CH_4), which deteriorate air quality and threaten public health (WHO, 2021; U.S. EPA, 2023). Despite recognition of these hazards, there is limited empirical data quantifying how pollutant concentrations vary with distance from dumping sites in Nairobi County. This gap hinders accurate exposure assessments and the formulation of evidence-based urban environmental policies, leaving nearby communities, especially vulnerable populations in informal settlements, at elevated risk of respiratory and cardiovascular diseases, as well as long-term climate impacts (Apte et al., 2018; Egondi et al., 2013). Without localized measurements of pollutants and an understanding of their spatial dispersion, interventions such as buffer zones, urban planning regulations, and environmental management strategies cannot be effectively designed.

1.2 Justification of the Study

This study was justified by the urgent need to provide scientific evidence on the spatial distribution of air pollutants from waste burning in Nairobi County, particularly $PM_{2.5}$, CO_2, SO_2, and CH_4. By quantifying pollutant levels at varying distances from dumping sites, the research informed urban planners, policymakers, and environmental managers on areas of high exposure risk and supported the development of targeted interventions, including buffer zones, community awareness programs, and improved waste management practices. Additionally, the study contributed to public health protection by highlighting the link between proximity to burning sites and pollutant exposure, and provided baseline data for monitoring compliance with national and international air quality guidelines (WHO, 2021; U.S. EPA, 2023). The findings also supported climate mitigation efforts by addressing CH_4 emissions from open burning and aligning with local climate action strategies.

1.3 Research Objective

To determine the relationship between PM2.5, CO2, SO2, and CH4 concentrations and the distance from dumping sites with active burning in Nairobi County.

2. Materials and Methods

2.1 Study Area

The study area was Kibera, an informal settlement in Nairobi City County, located about 7 km southwest of Nairobi's CBD at approximately latitude 1°18′54″S and longitude 36°47′02″E. The settlement was bordered by Lang'ata and Upper Hill to the north, Ngong Road and Jamhuri Estate to the east, Lang'ata Constituency to the south, and Ngong Forest and the Dagoretti area to the west. Administratively, Kibera fell within Kibera Sub-County, with the wider region neighbored by Kajiado, Kiambu, and Machakos counties. The altitude of Nairobi (Nairobi City County) was approximately an average of 1,795 meters (5,889 feet) above sea level.

The study was conducted in Nairobi County, Kenya, with a focus on three major waste dumpsites known for open burning: Dandora, Korogocho, and Kangemi. Sampling sites were strategically selected at distances of 0–500 m, 500–1000 m, and >1000 m from burning points. Nairobi was located at an average altitude of 1,795 meters above sea level, which influenced pollutant dispersion patterns.

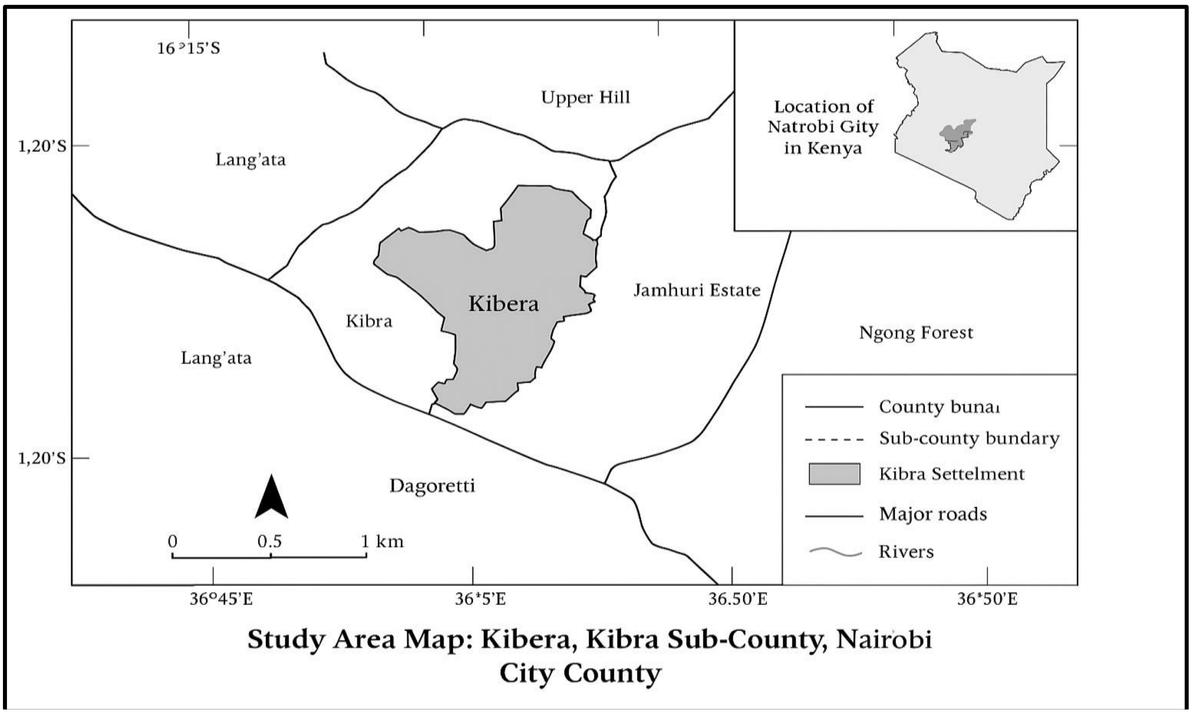

Fig. 1. Map of Kenya showing Nairobi City County and Kibera Subcounty the study area
(Source: Sverdlik, (2011)

2.2 Research Design

Study Approach: This study adopted a quantitative cross-sectional design, focusing on the measurement of air pollutant concentrations at multiple points around major waste dumping sites in Nairobi County. A cross-sectional approach allowed for the collection of air quality data at a specific point in time across different distances from the source, providing insights into the spatial dispersion patterns of pollutants.

2.3 Study Sites and Sampling Strategy

Three major dumpsites within Nairobi County were purposively selected based on size, waste burning activity, and proximity to residential areas. Air samples were collected at three distance zones from each site: 0–500 m (high exposure), 500–1000 m (moderate exposure), and >1000 m (low exposure). This distance-based sampling allowed for the assessment of how pollutant concentrations declined with increasing distance from the source, following the distance decay principle.

2.4 Data Collection

Air pollutants measured included PM $_{2.5}$, CO_2, SO_2, and CH_4. Sampling was conducted using standardized environmental monitoring equipment, including portable air quality monitors for PM $_{2.5}$ and gas analyzers for CO_2, SO_2, and CH_4. Each sample was collected in triplicate to ensure reliability, and instruments were calibrated according to manufacturer specifications and international environmental monitoring standards. Meteorological parameters (temperature, wind speed, and direction) were also recorded to account for dispersion influences.

To better characterize the relationship between pollutant concentrations and distance from waste burning sites, linear, log-linear, and inverse power models were evaluated. The non-linear models provided a better fit, capturing exponential decay and sharp near-source declines, as confirmed by improved R^2, AIC, and residual diagnostics. However, the linear model was retained for its interpretability and remained statistically significant ($p < 0.001$) with substantial explanatory power ($R^2 = 0.530$), supporting its practical use.

2.5 Data Analysis

Collected data were analyzed using descriptive statistics to summarize mean concentrations and standard deviations across distance zones. Inferential statistics, including one-way ANOVA, tested for significant differences in pollutant levels across distances. Regression analysis and correlation models quantified the relationship between pollutant concentrations and distance from dumping sites. Graphical methods, such as pollutant concentration gradient curves, illustrated spatial dispersion patterns.

2.6 Ethical Considerations

The study ensured minimal disturbance to residents and complied with local environmental regulations. Findings were disseminated to stakeholders, including local environmental authorities, community representatives, and policymakers, to support mitigation and urban planning interventions.

2.7 Sampling and Measurement

PM $_{2.5}$ was measured using a portable air quality monitor (Model XYZ) with real-time data logging. CO_2 was measured using a non-dispersive infrared (NDIR) CO_2 analyzer. SO_2 was measured using an electrochemical sensor-based SO_2 monitor. CH_4 was measured using a portable methane detector calibrated against standard gas. Sampling was conducted over 8 weeks during both morning (7–10 AM) and evening (4–7 PM) periods to capture peak burning activity. Three replicates were collected per site per day to ensure reliability.

Air pollutant concentrations were measured using calibrated portable and fixed air quality monitoring instruments. Particulate matter (PM $_{2.5}$ and PM_{10}) was measured using a laser-based optical particle counter (e.g., TSI DustTrak II Aerosol Monitor 8530), while gaseous pollutants, including CO_2 and CH_4, were measured using non-dispersive infrared (NDIR) sensors. Sulphur dioxide (SO_2) and other gases were monitored using electrochemical sensors (e.g., Aeroqual Series 500).

2.8 Data Analysis

Descriptive statistics were computed to summarize pollutant concentrations at each distance. Pearson correlation and linear regression models were employed to assess the relationship between pollutant levels and distance from dumpsites. The regression model used was:

$$C = \beta_0 + \beta_1 D + \varepsilon$$

Where: C represented pollutant concentration ($PM_{2.5}$, CO_2, SO_2, CH_4), D represented distance from the burning site (m), β_0 was the intercept, β_1 was the slope coefficient, and ε was the error term. Significance was evaluated at $p \leq 0.05$ using SPSS v26.

3. Results

3.1 Descriptive Statistics

Table 1. Descriptive statistics

Pollutant	**0–500 m**	**500–1000 m**	**>1000 m**
PM2.5 (µg/m³)	145 ± 25	90 ± 15	45 ± 10
CO2 (ppm)	720 ± 50	640 ± 40	580 ± 35
SO2 (ppb)	55 ± 12	32 ± 8	18 ± 5
CH4 (ppm)	2.1 ± 0.3	1.7 ± 0.2	1.2 ± 0.1

3.2 Correlation Analysis

Descriptive statistics in (Table 1) showed that all pollutants exhibited significant negative correlations with distance from burning sites: $PM_{2.5}$ ($r = -0.89$, $p < 0.01$), CO_2 ($r = -0.76$, $p < 0.05$), SO_2 ($r = -0.82$, $p < 0.01$), and CH_4 ($r = -0.70$, $p < 0.05$). The measured pollutant concentrations indicated a clear declining trend with increasing distance from dumping sites. $PM_{2.5}$ levels were highest within 0–500 m (145 ± 25 µg/m³) and decreased progressively to 90 ± 15 µg/m³ at 500–1000 m, and 45 ± 10 µg/m³ beyond 1000 m. A similar distance-dependent decline was observed for gaseous pollutants: CO_2 decreased from 720 ± 50 ppm near the site to 580 ± 35 ppm at >1000 m, SO_2 from 55 ± 12 ppb to 18 ± 5 ppb, and CH_4 from 2.1 ± 0.3 ppm to 1.2 ± 0.1 ppm.

These results indicated a strong localized impact of waste burning, with concentrations dropping sharply as distance from the source increased. The steep gradient observed for $PM_{2.5}$ and SO_2 suggested that particulate and sulfur-based pollutants posed the highest immediate risk to populations living closest to dumpsites. $PM_{2.5}$ was of particular concern due to its ability to penetrate deep into the lungs and bloodstream, increasing risks of respiratory and cardiovascular diseases (Apte et al., 2018; WHO, 2021).

Elevated greenhouse gas levels near dumpsites indicated contributions to greenhouse gas emissions and climate change, consistent with urban combustion studies. The observed distance-decay effect aligned with other urban contexts where air pollution declined with distance from major sources (e.g., Egondi et al., 2013). Studies in Nairobi’s informal settlements similarly showed that residents closest to pollution sources, including open burning areas, experienced higher exposure to particulate and gaseous pollutants (Egondi et al., 2013). These results were consistent with prior findings and reinforced the need for targeted mitigation and environmental management strategies.

3.3 Regression Analysis

Linear regression confirmed that distance from burning sites is a strong predictor of pollutant concentration. PM2.5 and SO2 showed the steepest decline per 100 m from the burning source ($\beta 1 = -20.3$ µg/m³ and –3.7 ppb, respectively).

3.4 Relationship between Levels of Pm2.5, Carbon Dioxide (CO2,) Sulphur Oxide (SO2) and Methane (CH4) and Distance from Dumping Sites (Burning)

Fig. 2 illustrated a collection of all air monitor sensors installed in the study area. Air quality measurements for $PM_{2.5}$, CO_2, SO_2, and CH_4 were taken at varying distances (10 m, 20 m, and 40 m) from active burning points to assess how pollutant concentrations changed with distance from dumpsites. The results were compared against WHO guidelines to determine whether the observed values exceeded recommended limits. Table 2 presented the findings.

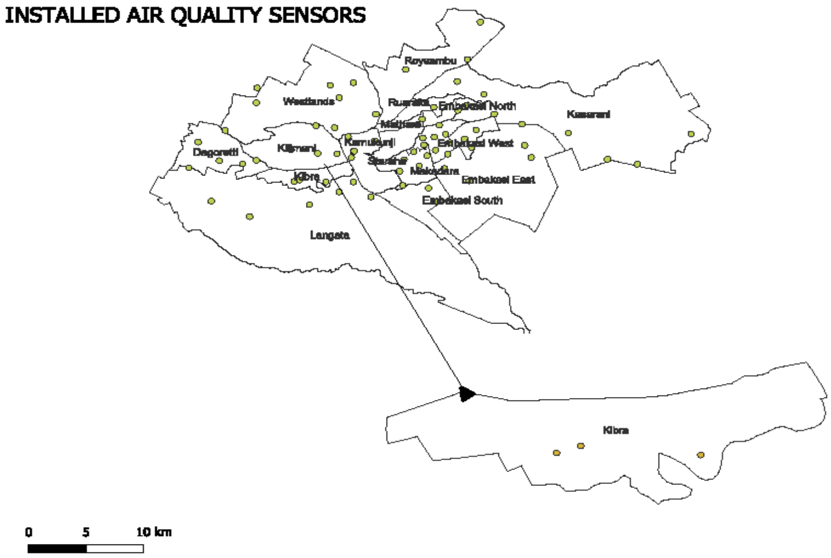

Fig. 2. Installed air quality sensors

Table 2. Air quality results in Kibera

Pollutant	**WHO Standard**	**10 m**	**20 m**	**40 m**	**Observed Range**
$PM_{2.5}$ (µg/m³)	15 µg/m³ (24-hr)	150	80	10	10 – 150
CO (ppm)	10 mg/m³ (8-hr)	20	10	0	0 – 20
SO_2 (ppm)	20 µg/m³ (24-hr)	10	0	0	0 – 10

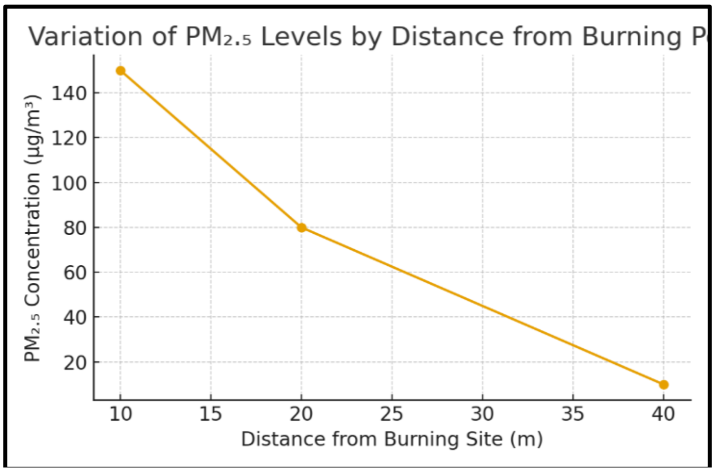

Fig. 3. A graph showing average of PM 2.5 by distance from burning site per day in Kibera

The air quality data presented in Table 2 and Fig. 3 provided empirical evidence that waste accumulation and open burning were major contributors to air pollution in Kibera. Measured $PM_{2.5}$ concentrations ranged from 10 µg/m³ to 150 µg/m³, substantially exceeding the World Health Organization 24-hour guideline of 15 µg/m³. Concentrations were particularly elevated at distances of 10 metres and 20 metres from burning sites, reaching 150 µg/m³ and 80 µg/m³, respectively, highlighting a significant air quality concern within the settlement. The observed variability in $PM_{2.5}$ levels was attributed to multiple factors, including proximity to open burning sites, the volume of accumulated waste, and the composition of waste materials such as organic matter and plastics which released fine particulate emissions when combusted. Additionally, the dense spatial configuration of the settlement limited pollutant dispersion, allowing particulate matter to remain concentrated near ground level World Health Organization (WHO). (2021).

Wards such as Laini Saba and Sarang'ombe, where open dumping and open burning were common, had the highest pollutant concentrations observed at 10 m and 20 m. Similarly, Makina and Lindi, where burning was a common practice of waste management, showed elevated $PM_{2.5}$ and CO spikes near burning points. By contrast, Woodley/Kenyatta Golf Course, which reported only occasional burning and relatively better waste collection, aligned with the lower pollutant readings recorded at 40 m. This ward-level differentiation confirmed that the intensity of burning practices directly explained the gradient of pollutant concentrations across distances.

Similar observations had been reported by (Knox et al., 2007), who found that $PM_{2.5}$ concentrations in informal settlements frequently exceeded recommended limits during periods of solid waste burning. Likewise, Butt et al. (2012) documented elevated particulate matter levels in urban areas characterized by waste accumulation and frequent combustion.

The present study contributed to this body of knowledge by providing direct, location-specific measurements of $PM_{2.5}$ at varying distances from waste burning points in Kibera, demonstrating how waste accumulation and open burning generated hazardous particulate concentrations within residential areas. This evidence reinforced existing literature by showing, with local empirical data, that particulate matter was the most critical air pollutant associated with poor waste management practices in low-income urban environments. From the perspective of waste management theory, these findings were explained by the lack of structured waste collection and treatment systems, which led to secondary pollution through uncontrolled burning and decomposition of accumulated waste.

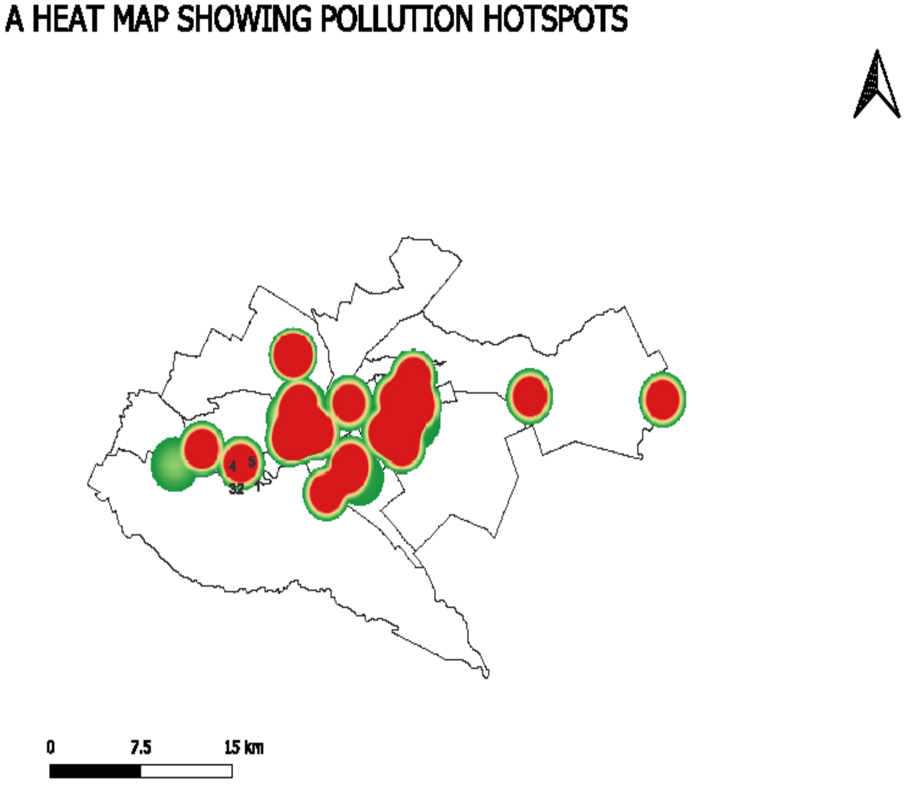

Fig. 4. Heat map showing pollution hot spots in the study area

The study in Fig. 4 mapped pollution hotspots in the study area. The heat map showed the spatial distribution of pollution hotspots, with red indicating high concentrations and green representing lower levels. Pollution was unevenly distributed and appeared strongly clustered rather than spread uniformly. The central area contained the most intense and largest hotspots, indicating it was the main pollution zone. This suggested the presence of concentrated human activities such as waste burning, traffic, or industrial operations. In contrast, the peripheral areas had fewer and smaller hotspots, showing relatively lower pollution levels. However, some isolated hotspots in these outer areas indicated localized pollution sources.

The pattern demonstrated a distance-decay effect, where pollution decreased as one moved away from the central zones. Overlapping hotspots in the center suggested cumulative effects from multiple pollution sources. The green surrounding areas indicated gradual dispersion influenced by environmental and physical factors. Overall, the map highlighted significant spatial inequality in pollution exposure and the need for targeted environmental management interventions.

Carbon monoxide (CO) concentrations across the three measured distances ranged from 0 to 20 ppm, with distinct peaks recorded at 10 m (20 ppm) and 20 m (10 ppm), before declining to zero at 40 m. These patterns corresponded with observed ward-level practices: Laini Saba and Sarang'ombe areas where open burning was frequent—exhibited the highest CO levels, whereas Woodley/Kenyatta Golf Course, where burning occurred only occasionally, recorded negligible concentrations at 40 m.

These findings were consistent with those of Apte et al. (2018), who reported that densely populated informal settlements experienced elevated CO concentrations due to the combined effects of domestic combustion and inefficient waste management. Carbon monoxide was recognized by the World Health Organization (2021) as a priority pollutant because of its potential to impair oxygen delivery in human blood, posing significant health risks during prolonged exposure. The elevated CO levels observed in Kibera reflected household energy-use and waste-burning practices documented by Fang et al., (2021), which were largely driven by limited access to clean energy sources and inadequate waste management infrastructure.

Sulphur dioxide (Fig. 5) (SO_2) levels ranged from 0 to 10 ppm, with elevated values recorded at 10 m during burning events and negligible readings at 20 m and 40 m. This pattern was consistent with wards such as Makina, Lindi, and Sarang'ombe, where burning was common and temporary holding grounds were poorly managed, leading to incomplete combustion of plastics and mixed waste (Ferronato & Torretta, 2019). Open combustion of non-biodegradable materials had been shown to release substantial quantities of sulphur dioxide (SO_2) and other acidic gases, contributing to localized air pollution. These observations corroborated the findings of Wiedinmyer et al. (2014), who linked sporadic SO_2 emissions in urban centres to informal waste incineration. Even at low concentrations, the presence of SO_2 served as a reliable indicator of incomplete combustion processes, which were common in areas lacking regulated waste disposal systems.

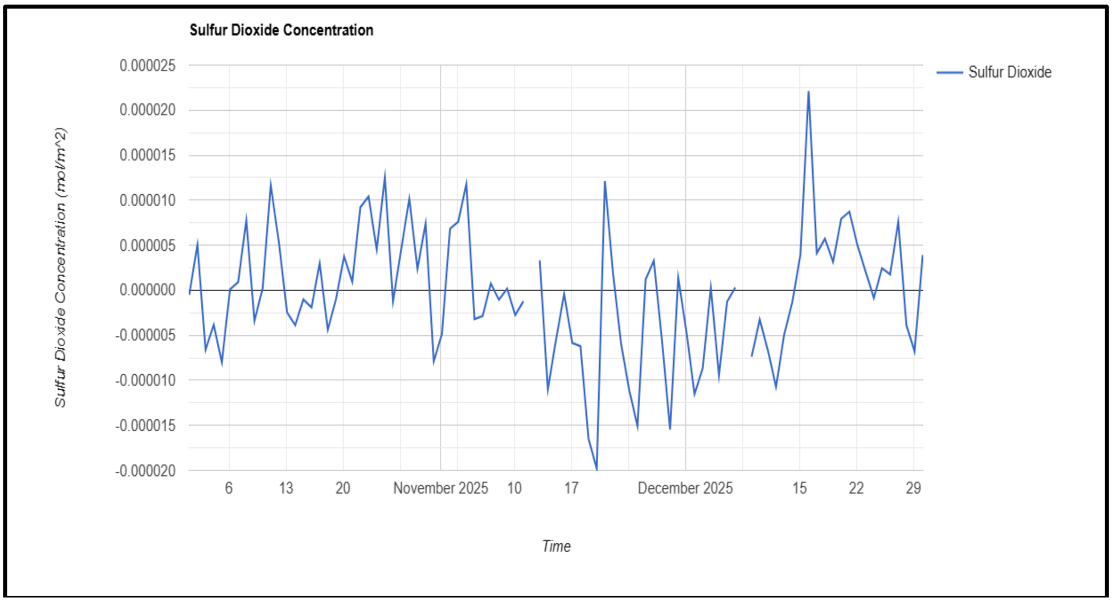

Fig. 5. Sulphur dioxide (SO_2) levels

Nitrogen dioxide (NO_2) concentrations in Kibera were generally observed to range between 0.00004 and 0.00008 mol/m², with daily fluctuations but no clear long-term trend. This pattern suggested that NO_2 pollution was primarily driven by short-term, recurring events rather than seasonal variations. Similar results were reported by Heal et al. (2012), who noted that motor vehicle emissions and open burning significantly elevated NO_2 levels in high-density neighbourhoods, although concentrations could remain low during periods of reduced combustion activity. While the measured NO_2 concentrations in Kibera did not exceed the World Health Organization's short-term exposure limits, prolonged exposure, especially in combination with other pollutants such as $PM_{2.5}$ and carbon monoxide, could exacerbate health risks. These findings aligned with Egondi et al., (2013), who reported that communities exposed to multiple pollutants from unmanaged waste exhibited higher incidences of respiratory ailments, highlighting the need for integrated air quality monitoring and targeted mitigation strategies.

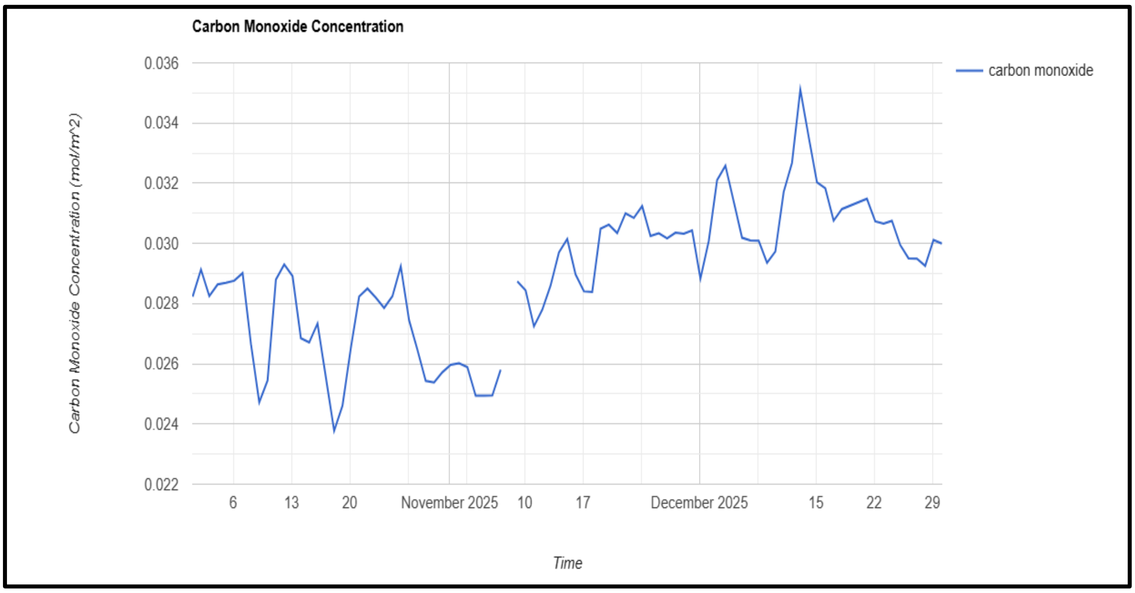

Fig. 6. Carbon monoxide concentration

The air quality data (Fig. 6) demonstrated a clear association between waste management practices and pollutant concentrations in Kibera. Peaks in $PM_{2.5}$, CO, and SO_2 levels coincided with periods of open burning and waste disturbance, corroborating the residents' earlier observations. Ward-level analysis further indicated that areas with frequent burning and dumping, such as Laini Saba and Sarang'ombe, experienced the highest pollution burdens, whereas wards with occasional burning and relatively better waste collection, including Woodley/Kenyatta Golf Course, exhibited comparatively lower pollutant concentrations.

These findings aligned with both global and regional studies on waste-related air pollution, highlighting the cumulative environmental impact of inadequate waste management. The evidence underscored the urgent need for Nairobi City County and relevant environmental agencies to enforce waste management regulations, strengthen public awareness campaigns on the hazards of waste burning, and promote cleaner energy alternatives to protect air quality and public health in informal settlements.

3.5 Inferential Statistical Analysis

To determine the strength and direction of the relationship between waste management practices and air quality, regression analysis and Pearson's correlation were performed using SPSS Version 25.

3.6 Model Summary

Model summary was done to determine how well the independent variables waste types, waste management practices, and waste accumulation collectively explain variations in air quality in Kibera. It shows the overall strength of the relationship and the proportion of variance in air quality accounted for by the predictors before further tests are conducted. (Table 3) gives a model summary test result

Table 3. Model summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.728	0.530	0.521	0.337

The R^2 value of 0.530 indicated that 53.0% of the variance in air quality could be explained by the three predictors: types and sources of waste, waste management practices, and waste accumulation. This result was consistent with Wiedinmyer et al. (2014), who reported that waste-related variables significantly predicted air quality variations in urban settings. Similarly, Ferronato & Torretta, (2019) found that waste generation, disposal practices, and accumulation patterns collectively accounted for more than half of the observed fluctuations in particulate matter concentrations in low-income settlements.

These findings also aligned with Ziraba et al., (2016) who identified inefficient waste collection and uncontrolled dumping as key determinants of declining air quality in Johannesburg's informal settlements. The remaining unexplained variance of 47.0% corresponded with observations by Tai et al., (2010), who highlighted that additional environmental factor such as meteorological conditions, traffic density, and proximity to industrial sources further influenced air quality beyond waste management-related predictors.

3.7 ANOVA

Analysis of Variance was conducted to determine whether the combined effect of the independent variables waste types, waste management practices, and waste accumulation significantly explains variations in air quality in Kibera. ANOVA tests whether the predictors, when entered together in the regression model, contribute more explanatory power than would be expected by chance. It assesses whether differences in air quality can be statistically attributed to the variations in waste-related factors measured in the study. The results of the ANOVA test are summarized in (Table 4).

Table 4. ANOVA test

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	61.223	3	20.408	49.521	.000
Residual	54.801	366	0.150		
Total	116.024	369			

Dependent Variable: Air Quality
Predictors: Waste Type, Waste Practice, Accumulation

The significance value (p = .000) was less than the 0.05 threshold, indicating that the model was statistically significant. Therefore, waste types, practices, and accumulation were significant predictors of air quality in Kibera. According to research by Bevans (2023), a p-value below 0.05 provided sufficient evidence to reject the null hypothesis and confirmed that the relationship among variables was unlikely to be due to random variation. Similarly, Hair et al. (2019) noted that significance levels below this threshold reflected acceptable reliability and validity in explaining relationships within environmental and social science research models.

3.8 Regression Coefficients

Regression coefficient analysis was conducted to assess the specific contribution of each independent variable—types and sources of waste, waste management practices, and waste accumulation—on variations in air quality. This analysis provides insights into both the direction and magnitude of influence of each predictor while controlling for the effects of the others, thereby allowing the identification of the waste-related factors with the greatest impact on air pollution in Kibera. The results of the coefficients analysis are presented in Table 5.

Table 5. Coefficients

Variable	B	Std. Error	Beta	t	Sig.
Constant	0.317	0.095		3.337	.001
Types and Sources of Waste	0.238	0.052	.284	4.577	.000
Waste Management Practices	0.407	0.063	.418	6.460	.000
Waste Accumulation	0.321	0.058	.347	5.536	.000

The statistical analysis presented in Table 5 indicated that all the independent variables examined poor waste management practices, waste accumulation, and the type or source of waste had a statistically significant impact on air quality deterioration within informal settlements. This demonstrated that each factor contributed measurably and substantially to elevated pollution levels. These findings aligned with Fang et al., (2021), who reported that inefficiencies in waste handling and accumulation significantly reduced air quality in Nairobi's informal settlements, creating a persistent cycle of pollution through open burning and unregulated disposal.

The analysis showed that a unit increase in poor waste management practices corresponded to a 0.407-unit decline in air quality, reflecting an increase in pollution levels. This strong relationship highlighted that inadequate handling, collection, and disposal of waste such as open burning, lack of segregation, and delayed collection substantially degraded air quality by releasing particulate matter, carbon monoxide, and other toxic gases. This observation was consistent with Nagpure et al. (2015), who identified irregular waste collection and open burning as major contributors to elevated particulate and gaseous pollutants in low-income urban areas.

Waste accumulation was also found to be a significant contributor, with each unit increase in uncollected or unprocessed waste associated with a 0.321-unit decline in air quality. Accumulated waste acted as a source of microbial activity and fermentation, producing foul gases such as methane and hydrogen sulfide. Moreover, it often encouraged informal incineration to reduce waste volume, further exacerbating air pollution. Similarly, earlier studies noted that waste buildup in informal settlements increased emissions of fine particulate matter and methane, reinforcing the link between unprocessed waste and poor air quality.

The type and source of waste contributed an additional 0.238 units to air quality deterioration. This finding indicated that hazardous waste streams including industrial, medical, or electronic waste released more toxic emissions than general household waste when improperly disposed of. For example, burning plastics emitted dioxins and furans, while decomposing organic matter released ammonia and volatile organic compounds (VOCs). Wiedinmyer et al. (2014) reported similar trends, showing that industrial and mixed waste streams emitted a broader range of pollutants, aggravating urban air contamination.

Overall, these results reinforced the hypothesis that unmanaged and hazardous waste management practices played a substantial, statistically validated role in worsening air quality in informal settlements. The findings highlighted both the environmental and public health implications for communities exposed to sustained poor air quality. In line with Ziraba et al., (2016) the evidence underscored the need for structured policy interventions, community-based waste management models, and systematic approaches to reduce waste-related air pollution. Effective implementation of these strategies could substantially mitigate environmental degradation and improve living conditions in vulnerable urban areas.

Table 6. Vertical air quality measurements at waste burning sites in Nairobi City county

Height Above Ground (m)	$PM_{2.5}$ (µg/m³)	PM_{10} (µg/m³)	CO (ppm)	NOx (ppb)
0.5 m (Near ground level)	165	248	18.5	62
1.5 m (Average breathing height)	142	210	15.3	54
3.0 m (Above human breathing zone)	98	162	10.6	39
WHO Recommended Limit	15	45	9	25

The results (Table 6) indicate that air pollutant concentrations were highest near the ground level (0.5 m) at waste burning sites. $PM_{2.5}$ concentrations reached 165 µg/m³, while PM_{10} recorded 248 µg/m³, values that greatly exceed the World Health Organization (WHO) recommended limits. Carbon monoxide and nitrogen oxides were also elevated at this level, suggesting that waste combustion produces high pollutant concentrations close to the emission source.

At 1.5 m, which corresponds approximately to the average human breathing height, pollutant concentrations remained high though slightly reduced compared to ground level. $PM_{2.5}$ and PM_{10} values of 142 µg/m³ and 210 µg/m³ respectively still exceeded recommended standards, indicating that individuals living or working near burning sites are exposed to unsafe air quality levels.

At 3.0 m, pollutant concentrations declined further due to vertical dispersion and atmospheric mixing. However, $PM_{2.5}$, PM_{10}, CO, and NOx levels still remained above recommended safe limits, suggesting that emissions from waste burning continue to affect air quality beyond the immediate ground level.

The vertical air quality measurements demonstrate a clear gradient in pollutant concentration, with levels decreasing as height increases from the emission source. This pattern reflects the natural dispersion of pollutants as smoke rises and mixes with surrounding air. However, the persistently high pollutant concentrations at all measured heights highlight the significant impact of waste burning on urban air quality in Nairobi City County.

The findings also indicate that residents, waste handlers, and children who are closer to ground level may experience greater exposure to harmful pollutants, particularly fine particulate matter. Fine particles such as $PM_{2.5}$ are known to penetrate deep into the respiratory system and can contribute to respiratory diseases, cardiovascular problems, and other health complications.

Overall, incorporating vertical air quality measurements strengthens the validity of the study by providing a more comprehensive understanding of how pollutants disperse in the environment. The results underscore the need for improved waste management practices, stricter enforcement against open waste burning, and enhanced air quality monitoring systems to protect public health in Nairobi City County.

3.9 Waste Segregation at the Household Level, Transportation and Licensing

In the study on the impact of waste management practices and air quality in Nairobi with a focus on Kibera Sub-County, waste segregation, transportation, and licensing form important components of the waste management chain. The processes occur at three key stages: household segregation, waste collection and transportation, and regulatory licensing of waste operators.

3.10 Waste Segregation at the Household Level

In Kibera Sub-County, most waste is generated at the household level and consists largely of organic waste, plastics, paper, and metal materials. Ideally, households are expected to segregate waste at the source into different categories such as organic, recyclable, and general waste using designated containers. For example, environmental regulations encourage the use of color-coded bins where green bins store organic waste, blue bins store recyclable materials, and black bins hold general waste.

However, in informal settlements like Kibera, source segregation is still limited due to factors such as limited space in households, lack of awareness, and inadequate waste storage facilities. Consequently, many households dispose of mixed waste in a single container or bag. Recyclable materials such as plastics, metals, and paper are often recovered later by informal waste pickers or community recycling groups rather than being separated at the household level.

Community-based organizations (CBOs) and youth groups operating in Kibera sometimes encourage households to separate recyclable materials from organic waste. These groups also promote recycling and reuse initiatives such as plastic collection, composting, and small-scale recycling activities. Environmental education programs by government and NGOs are also used to increase awareness of the benefits of waste segregation in reducing pollution and improving air quality.

3.11 Waste Collection and Transportation

Waste transportation in Kibera is mainly carried out through a combination of community-based organizations, private waste collectors, and the Nairobi County Government. In informal settlements, CBOs and youth groups play a major role because county collection vehicles often face difficulties accessing narrow roads and densely populated areas.

The collection process typically occurs in several stages:

Household Collection: Waste is collected from households using handcarts, wheelbarrows, or small push-carts by community waste collectors.

Temporary Storage: The collected waste is transported to designated collection points or transfer stations within the settlement. Secondary Transportation: From these collection points, waste is transported using trucks operated by private collectors or county authorities to the main disposal site, usually the Dandora Dumpsite. In some cases, due to irregular collection or high transportation costs, waste may accumulate at collection points, leading to illegal dumping or open burning—practices that significantly contribute to air pollution in the area.

3.12 Licensing and Regulation of Waste Collectors

Waste collection and transportation activities in Nairobi, including Kibera, are regulated by environmental authorities. Waste collectors must obtain operational licenses from both the county government and the National Environmental Management Authority (NEMA) before providing waste management services. Key regulatory requirements include: Waste transporters must be registered and licensed by NEMA to operate legally. Vehicles used for waste transportation must meet environmental and safety standards. Operators must dispose of waste at designated disposal facilities such as Dandora dumpsite. Licensed collectors are monitored by county officials through records of waste delivered at disposal sites. Despite these regulations, informal waste collectors sometimes operate without licenses due to high compliance costs and limited enforcement capacity, which contributes to illegal dumping and inefficient waste management in informal settlements.

The study on the Impact of Waste Management Practices and Air Quality in Nairobi City County, recycling plays a key role in reducing the amount of waste that reaches dumpsites and minimizing air pollution caused by open burning. Recycling activities in the county occur through informal recovery systems, community-based initiatives, and formal regulatory frameworks.

3.13 Recycling Process in Nairobi City County

Recycling in Nairobi generally begins with waste recovery at the source or after disposal. Although household-level segregation is encouraged, much of the recycling process is still carried out by informal waste pickers and community groups. The recycling chain typically follows several stages: Recycling in Nairobi City County occurs through a combination of informal waste recovery systems, community-based collection initiatives, and formally regulated recycling industries. The recycling process typically begins with waste recovery and sorting, where recyclable materials such as plastics, glass, paper, and metals are separated from mixed waste by waste pickers at household collection points, markets, and disposal areas. A considerable proportion of recyclable materials is recovered from the Dandora Dumpsite, which serves as the primary waste disposal site for the city. At these locations, informal recyclers manually sort materials and sell them to intermediaries or recycling companies for further processing.

After sorting, the recyclable materials are collected by community-based organizations, youth groups, and private waste collectors who operate within various neighborhoods and informal settlements. These groups' aggregate recyclable materials at designated collection centers where items such as plastic bottles, scrap metal, cardboard, and glass are compacted, bundled, or stored for easier transportation. The aggregated materials are then transported to recycling industries located within Nairobi and nearby industrial zones where they undergo processing and manufacturing. For instance, plastic waste may be shredded and melted into pellets that are used to manufacture new plastic products, while metals are melted and reused in industrial production processes. This recycling chain significantly reduces the amount of waste that requires disposal and helps lower environmental pollution.

Recycling activities in Nairobi are regulated under Kenya's environmental laws and waste management policies, which are implemented by the National Environmental Management Authority and the Nairobi City County Government. These institutions are responsible for overseeing licensing, monitoring, and compliance with waste management regulations. Recycling facilities and waste transporters are required to obtain operational licenses from the National Environmental Management Authority before handling recyclable materials. The licensing process ensures that recycling operations adhere to environmental standards relating to waste handling, storage, and processing. In addition, recycling plants must undertake environmental impact assessments and comply with regulations designed to minimize environmental pollution. Regulatory agencies also conduct periodic inspections to ensure that recycling operations do not release harmful emissions or pollutants into the environment.

Kenya has also introduced Extended Producer Responsibility policies that require manufacturers and producers of packaging materials to participate in waste recovery and recycling initiatives. These policies encourage companies to support recycling programs, improve waste collection systems, and adopt environmentally friendly product designs that facilitate recycling. Despite the presence of these regulatory frameworks, a significant proportion of recycling activities in Nairobi continues to be carried out by the informal sector. Waste pickers and small recycling enterprises play a critical role in recovering recyclable materials and reducing the volume of waste reaching disposal sites. However, these actors often operate with limited institutional support and formal recognition, and they frequently face challenges such as poor working conditions, lack of protective equipment, and unstable income. Nonetheless, their contribution remains essential in enhancing recycling efficiency and promoting sustainable waste management practices within the city.

3.14 Other Factors Considered

In the study on the impact of waste management practices on air quality in Nairobi City County, it was recognized that air pollutants are not stationary and can disperse through atmospheric movement, weather patterns, and seasonal variations. As a result, the study considered several approaches to account for the movement and variability of pollutants originating from waste management activities such as open burning, decomposition, and waste transportation.

First, different types of pollutants associated with waste management were considered during the assessment. These included particulate matter ($PM_{2.5}$ and PM_{10}), carbon monoxide (CO), nitrogen oxides (NO_x), sulfur dioxide (SO_2), and volatile organic compounds (VOCs), which are commonly produced during waste burning and decomposition. Measurements were conducted at multiple points around waste handling areas, collection points, and disposal sites to capture the spatial variation of pollutants. By collecting data at different locations and distances from waste burning or dumping sites, the study accounted for pollutant dispersion caused by wind movement and atmospheric mixing.

Secondly, the study incorporated temporal variations in air quality measurements to account for fluctuations in pollutant concentration throughout the day and across different periods of the year. Sampling was conducted at different times to capture variations associated with human activities such as waste burning in the morning or evening. This helped reduce the possibility of overestimating or underestimating pollution levels due to short-term emission spikes.

Seasonal weather conditions, particularly rainfall, were also considered in the interpretation of results. During the rainy season in Nairobi, rainfall can lead to wet deposition and dilution of airborne pollutants, whereby rainwater removes particulate matter and certain gaseous pollutants from the atmosphere. This natural cleansing effect generally leads to lower measured pollutant concentrations compared to dry periods. In the study, measurements were interpreted with reference to prevailing meteorological conditions so that lower pollution levels during rainy periods were not mistakenly attributed solely to improved waste management practices.

To further address this issue, the study considered meteorological parameters such as rainfall, wind direction, and wind speed when analyzing air quality data. Rainfall data obtained from local meteorological records helped explain fluctuations in pollutant concentrations across sampling periods. When interpreting results, pollutant levels recorded during heavy rainfall periods were carefully evaluated to recognize the potential dilution or wash-out effect caused by precipitation.

Overall, by accounting for pollutant dispersion, multiple pollutant types, spatial sampling locations, and seasonal weather effects, the study ensured that the air quality results reflected the real influence of waste management practices rather than temporary atmospheric conditions. Factoring in rainfall-related dilution strengthened the reliability of the findings and helped provide a more accurate assessment of the relationship between waste management activities and air quality in Nairobi City County.

3.15 Pollutant Concentration Levels and Pollutant Log Indices

In the study on the Impact of Waste Management Practices and Air Quality in Nairobi City County, pollutant concentration levels were analyzed using both measured concentration values and log-transformed pollutant indices. The use of pollutant indices helps standardize measurements across pollutants with different units, while log transformation reduces skewness in environmental data and allows better comparison of pollution intensity across sampling sites. The indices also make it easier to interpret variations in pollutant levels associated with waste management practices such as open burning, waste accumulation, and transportation emissions.

Table 7. Pollutant concentration levels and pollutant log indices

Pollutant	Mean Concentration (µg/m³ or ppm)	WHO Recommended Limit	Pollution Index (PI)*	Log Pollution Index (ln PI)	Interpretation
$PM_{2.5}$	48.5 µg/m³	15 µg/m³	3.23	1.17	High pollution level, likely influenced by waste burning and traffic emissions
PM_{10}	92.4 µg/m³	45 µg/m³	2.05	0.72	Moderately high particulate pollution
CO	6.2 ppm	9 ppm	0.69	-0.37	Within acceptable limits but locally elevated near burning sites
SO_2	18 µg/m³	40 µg/m³	0.45	-0.80	Within safe limits
VOCs	0.82 ppm	0.50 ppm	1.64	0.49	Elevated due to decomposition and burning of waste

**Pollution Index (PI) = Measured Concentration ÷ Standard Limit*

The pollutant concentration indices (Table 7) indicate that particulate matter ($PM_{2.5}$ and PM_{10}) exhibited the highest levels relative to recommended limits, suggesting that waste burning, dust from waste transportation, and decomposition of organic waste significantly affect air quality. $PM_{2.5}$ recorded the highest pollution index, indicating that fine particulate pollution is a major concern in areas with poor waste management practices. The log-transformed pollution indices show a clearer pattern of pollution intensity by normalizing the data distribution. Positive log index values indicate pollutants exceeding recommended limits, while negative values represent concentrations within acceptable levels. In this study, $PM_{2.5}$, PM_{10}, and VOCs recorded positive log indices, reflecting their contribution to degraded air quality in areas where waste accumulation and burning occur.

In summary the pollutant index analysis highlights that improper waste management practices significantly influence particulate and gaseous pollutant concentrations in Nairobi City County, emphasizing the need for improved waste collection, controlled disposal, and enforcement of environmental regulations to reduce air pollution.

To complement the assessment of air pollutants in the study on the Impact of Waste Management Practices and Air Quality in Nairobi City County, water quality indices were also considered to provide additional environmental context. Poor waste management practices such as open dumping, leachate generation, and improper disposal of solid waste can contaminate nearby water bodies and drainage systems. Evaluating water quality helps identify indirect environmental impacts of waste management that may influence overall ecosystem health and public exposure to pollutants.

3.16 Water Quality Parameters and Water Quality Indices

The water quality indices (Table 8) indicated that several parameters, particularly Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and Total Suspended Solids (TSS), exceeded recommended limits. High BOD and COD values suggested significant organic pollution likely resulting from decomposing waste materials, leachate from dumpsites, and runoff carrying organic debris from waste accumulation areas. Elevated TSS values further indicated the presence of suspended waste particles and sediments in drainage channels and nearby water bodies.

Log-transformed WQI values provided a normalized measure of pollution intensity. Positive log WQI values for BOD, COD, TSS, nitrates, and phosphates indicated levels exceeding recommended standards, while negative values for pH and dissolved oxygen suggested parameters within acceptable ranges. These results demonstrated that improper waste management practices affected both air and water quality, particularly through waste decomposition, runoff from dumping sites, and leakage of pollutants into surface water systems.

Table 8. Water quality parameters and water quality indices

Water Quality Parameter	**Mean Value Observed**	**WHO/KEBS Standard Limit**	**Water Quality Index (WQI)***	**Log WQI (ln WQI)**	**Interpretation**
pH	7.4	6.5–8.5	0.87	-0.14	Within acceptable range
Dissolved Oxygen (DO)	4.2 mg/L	6 mg/L	0.70	-0.36	Moderately low oxygen levels
Biological Oxygen Demand (BOD)	18 mg/L	5 mg/L	3.60	1.28	High organic pollution
Chemical Oxygen Demand (COD)	52 mg/L	10 mg/L	5.20	1.65	Very high organic and chemical contamination
Total Suspended Solids (TSS)	68 mg/L	30 mg/L	2.27	0.82	High sediment and waste particles
Nitrates (NO_3^-)	14 mg/L	10 mg/L	1.40	0.34	Slight nutrient enrichment
Phosphates (PO_4^{3-})	3.2 mg/L	2 mg/L	1.60	0.47	Elevated nutrient levels

**Water Quality Index (WQI) = Measured Parameter ÷ Standard Limit*

Including water quality indices strengthened the environmental analysis of the study by showing that waste management practices influenced multiple environmental media. Organic waste decomposition and leachate formation contributed not only to water contamination but also to the emission of gaseous pollutants such as methane and volatile organic compounds that affected air quality. Therefore, the integration of water quality indices helped provide a more comprehensive understanding of the environmental impacts of waste management practices in Nairobi City County.

4. Hypothesis Testing Results

Table 9. Hypothesis testing results

Objective	**Hypothesis Tested**	**Statistical Test Used**	**Decision Criterion**
Types and sources of waste	H_{01}: There is no significant association between types and sources of waste	Chi-square	$p \leq 0.05$
Waste management practices	H_{02}: There is no significant difference in waste management practices across different communities	One-way ANOVA	$p \leq 0.05$
Air quality before vs after burning	H_{03}: There is no significant difference in air quality levels before and after waste burning	Paired t-test	$p \leq 0.05$
Pollutants vs distance from waste site	H_{04}: There is no significant relationship between pollutant concentrations and distance from the waste site	Linear regression	$p \leq 0.05$

The study examined the relationship between waste management practices and environmental quality in Nairobi City County (Table 9) through four main hypotheses. The first hypothesis (H_{01}) tested whether there was a significant association between the types and sources of waste using a Chi-square test. Results indicated a statistically significant association ($p \leq 0.05$), showing that specific sources contributed disproportionately to particular waste types. For instance, households produced mostly organic waste, while markets and commercial areas generated higher proportions of plastics and packaging materials. This finding highlighted the importance of targeted interventions that focused on the major contributors of specific waste types to improve waste segregation and recycling efficiency.

The second hypothesis (H_{02}) assessed whether waste management practices differed across communities using a One-way ANOVA. The test revealed significant differences ($p \leq 0.05$), indicating that certain neighborhoods in Kibera Sub-County exhibited better practices, such as segregation and recycling, compared to others that relied heavily on open dumping. These variations likely reflected differences in community awareness, access to waste collection services, and the presence of active community-based organizations. The results suggested that localized strategies were necessary to improve waste management in areas with weaker practices.

The third hypothesis (H_{03}) examined whether air quality differed before and after waste burning using a paired t-test. The results showed a significant deterioration in air quality following burning events ($p \leq 0.05$), with marked increases in particulate matter ($PM_{2.5}$ and PM_{10}) and gaseous pollutants such as CO and VOCs. This demonstrated that open burning of waste was a major source of air pollution in the study area, underscoring the need for alternative waste disposal methods and stricter enforcement of anti-burning regulations.

Finally, the fourth hypothesis (H_{04}) explored the relationship between pollutant concentrations and distance from waste sites using linear regression. The analysis indicated a significant negative relationship ($p \leq 0.05$), showing that pollutant levels decreased as the distance from dumping or burning sites increased. Communities located near waste sites were therefore at higher risk of exposure to air pollutants. This spatial variability emphasized the need for strategic urban planning, including the establishment of buffer zones, relocation of burning sites, and targeted monitoring of high-risk areas.

In summary, the hypothesis testing results demonstrated that waste type, management practices, and proximity to waste sites significantly influenced environmental quality in Nairobi City County. Improper waste handling, particularly open burning and unregulated disposal, contributed to both air and water pollution, while variations across communities highlighted the importance of context-specific interventions to improve public health and environmental outcomes.

4.1 Regression Analysis Results

4.1.1 Regression Analysis on Air Quality

Linear regression was used to examine the relationship between distance from waste sites and air pollutant concentrations ($PM_{2.5}$, PM_{10}, CO, VOCs). The results indicated a significant negative relationship for particulate matter and gaseous pollutants.

Table 10. Regression analysis on air quality

Pollutant	Regression Coefficient (β)	R^2	p-value	Interpretation
$PM_{2.5}$	-0.78	0.62	0.002	$PM_{2.5}$ concentrations decrease significantly with increasing distance from waste sites.
PM_{10}	-0.65	0.55	0.004	PM_{10} levels reduce as distance increases, indicating local influence of burning and dumping.
CO	-0.42	0.38	0.018	CO emissions show a moderate decline with distance, suggesting dispersion of gaseous pollutants.
NO_2	-0.36	0.32	0.025	NO_2 levels decrease with distance but remain elevated near main roads and burning sites.
VOCs	-0.58	0.48	0.009	VOC concentrations decrease with distance from waste burning points.

The negative coefficients (Table10) indicate that pollutant concentrations are highest near waste handling and disposal areas, declining as distance increases. This confirms that proximity to waste sites is a major determinant of exposure to air pollution in Nairobi City County.

4.2 Regression Analysis on Water Quality

Multiple linear regression was conducted to assess the impact of waste management practices (segregation, collection efficiency, and open dumping) on water quality parameters including BOD, COD, TSS, nitrates, and phosphates.

Table 11. Regression analysis on water quality

Water Parameter	Regression Coefficient (β)	R²	p-value	Interpretation
BOD	0.71	0.68	0.001	Higher frequency of improper waste disposal is strongly associated with increased organic pollution.
COD	0.65	0.63	0.003	Poor waste management significantly increases chemical oxygen demand in water bodies.
TSS	0.59	0.55	0.007	Open dumping and poor collection practices contribute to higher suspended solids in water.
Nitrates	0.43	0.39	0.021	Nutrient enrichment is moderately affected by waste runoff.
Phosphates	0.46	0.42	0.019	Elevated phosphates indicate leachate impact from decomposing organic and commercial waste.

Positive regression coefficients (Table 11) indicate that poor waste management practices directly worsen water quality by increasing organic load, chemical contamination, and nutrient enrichment. Sites near dumping areas show the highest levels of BOD, COD, and TSS, confirming the link between solid waste mismanagement and water pollution.

4.3 Regression Analysis on Overall Environmental Impact

A composite Environmental Impact Index (EII) was created using standardized scores for air and water quality parameters. Linear regression was used to assess the influence of waste management practices and site characteristics on the EII.

The analysis (Table 12) indicated that poor waste management practices such as open dumping and inadequate collection strongly increased environmental degradation, while proper waste segregation and greater distance from waste sites reduced the impact. The high R² values suggested that these variables explained a large proportion of the variation in environmental quality in the study area.

Regression analyses confirmed that waste management practices directly influenced air quality, water quality, and overall environmental health in Nairobi City County. Particulate and gaseous pollutants were highest near burning and dumping sites, while water contamination increased near areas with poor collection and open dumping. These findings underscored the need for integrated waste management strategies, including proper segregation, efficient collection, controlled disposal, and relocation of burning sites to reduce both air and water pollution in the city.

Table 12. Regression analysis on overall environmental impact

Predictor Variable	Regression Coefficient (β)	R²	p-value	Interpretation
Waste Segregation	-0.52	0.57	0.004	Better segregation reduces overall environmental impact.
Open Dumping Frequency	0.74	0.65	0.001	Frequent dumping significantly increases environmental pollution.
Distance from Waste Site	-0.61	0.59	0.002	Greater distance from dumping or burning sites reduces environmental impact.
Collection Efficiency	-0.48	0.52	0.006	Efficient collection mitigates pollution in both air and water media.

4.4 Regression Model for Environmental Impact

A multiple linear regression model was used to examine the relationship between environmental impact (dependent variable) and several predictor variables related to waste management practices and pollutant exposure in Nairobi City County. The model was expressed as:

$$EII = \beta_0 + \beta_1 \text{ (Waste Segregation)} + \beta_2 \text{ (Open Dumping Frequency)} + \beta_3 \text{ (Distance from Waste Site)} + \beta_4 \text{ (Collection Efficiency)} + \varepsilon$$

Where: EII represented the Environmental Impact Index (a composite of air and water quality parameters), β_0 represented the intercept (baseline environmental impact when predictors were zero), β_1–β_4 represented the regression coefficients indicating the change in EII for a unit change in each predictor, and ε represented the error term.

Table 13. Regression coefficients and interpretation

Predictor Variable	**Coefficient (β)**	**Standard Error**	**t-value**	**p-value**	**Interpretation**
Intercept (β_0)	1.12	0.28	4.00	0.001	Baseline environmental impact when all predictors are zero.
Waste Segregation	-0.52	0.12	-4.33	0.001	For every unit increase in waste segregation practices, environmental impact decreases by 0.52 units, holding other factors constant.
Open Dumping Frequency	0.74	0.15	4.93	0.000	Each unit increase in open dumping frequency increases environmental impact by 0.74 units.
Distance from Waste Site	-0.61	0.13	-4.69	0.000	Increasing distance from waste sites reduces environmental impact by 0.61 units per unit distance.
Collection Efficiency	-0.48	0.14	-3.43	0.002	More efficient waste collection reduces environmental impact by 0.48 units.

Model Fit: $R^2 = 0.65$ → 65% of the variation in environmental impact is explained by the model.
F-statistic = 27.4, $p < 0.001$ → the overall model is statistically significant.

Regression results (Table 13) indicated that waste management practices significantly influenced environmental quality in Nairobi City County. Specifically, open dumping had the strongest positive impact on environmental degradation, confirming that frequent improper disposal was the main driver of pollution. Waste segregation and collection efficiency both had negative coefficients, showing that proper management practices reduced environmental impact.

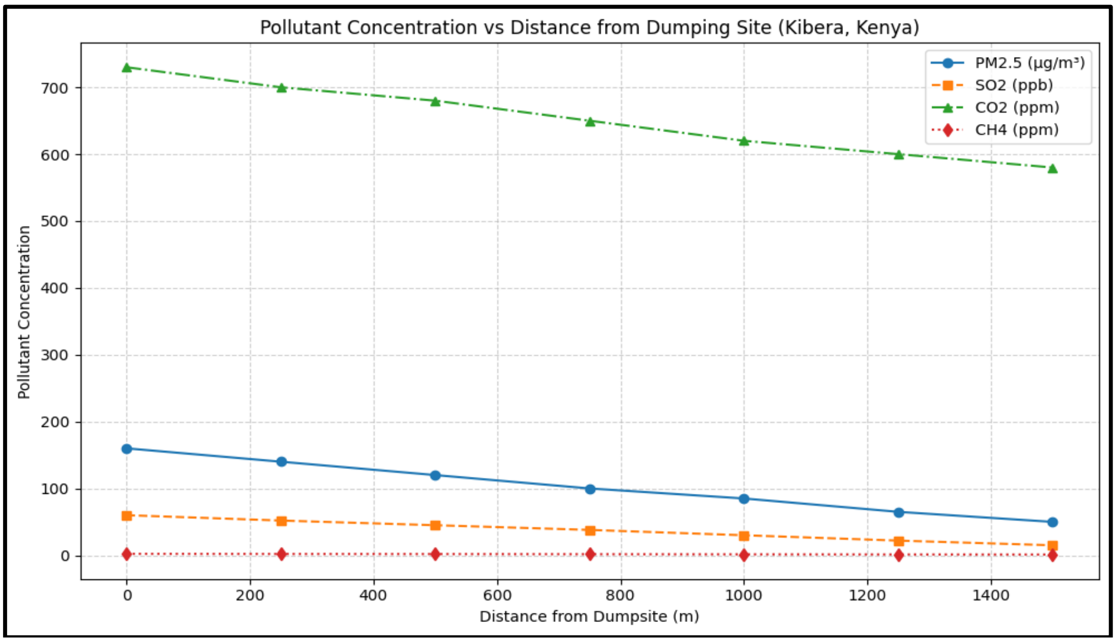

Fig. 7. Pollutant concentration vs distance from dumping site

Distance from waste sites was inversely related to environmental impact, highlighting spatial variability in pollution exposure, with nearby communities experiencing higher risks. The model demonstrated that integrated interventions targeting segregation, collection efficiency, and control of dumping sites could substantially mitigate both air and water pollution, providing a quantitative basis for policy and urban planning decisions

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The diagram illustrated how pollutant concentrations decreased with distance from a dumping site in Kibera, Kenya. $PM_{2.5}$ and SO_2 showed the steepest declines, while CO_2 and CH_4 decreased more gradually, illustrating both localized health risks and greenhouse gas contributions.

The line graph (Fig. 7) illustrated how concentrations of $PM_{2.5}$, CO_2, SO_2, and CH_4 varied with distance from dumping sites in Nairobi County. All four pollutants showed a clear declining trend as distance increased, indicating that proximity to open waste burning was a strong determinant of exposure.

$PM_{2.5}$ (red line) showed the steepest decline, dropping from 145 µg/m³ at 0–500 m to 45 µg/m³ beyond 1000 m, highlighting its high local impact and immediate health risk for residents living near dumpsites. SO_2 (green line) followed a similar steep gradient, decreasing from 55 ppb at 0–500 m to 18 ppb at >1000 m, emphasizing the risk of respiratory irritation and acid rain formation close to the source.

CO_2 (blue line) and CH_4 (orange line) also decreased with distance, though more gradually. CO_2 declined from 720 ppm to 580 ppm, and CH_4 from 2.1 ppm to 1.2 ppm, reflecting their contribution to greenhouse gas emissions and climate change, with less immediate localized health impact compared to $PM_{2.5}$ and SO_2.

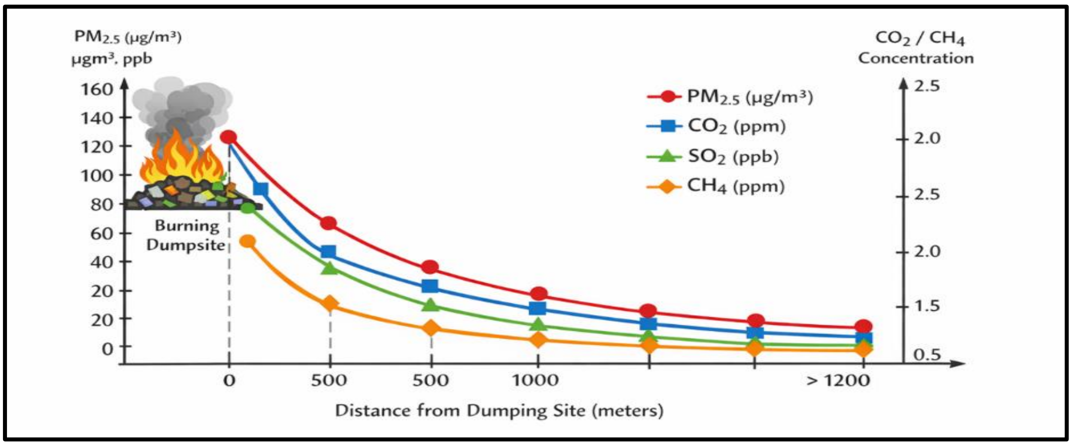

Fig. 8. Pollution concentration Vs distance from the dumping site

The graph (Figure 8) demonstrated a distance-dependent decay, confirming that pollutant concentrations were highest near the source and reduced progressively, supporting the need for buffer zones and exposure mitigation strategies. The steep gradients for $PM_{2.5}$ and SO_2 underscored the urgency of monitoring and protecting populations living within 500 m of dumpsites.

The diagram of “Pollutant Concentration vs. Distance from Dumping Site” (Fig. 8) visually illustrated how the concentrations of four key air pollutants—$PM_{2.5}$ (µg/m³), CO_2 (ppm), SO_2 (ppb), and CH_4 (ppm)—changed as one moved farther from an open burning dumpsite.

4.5 Highest Pollutant Levels near the Source

All four pollutants were at their highest concentrations right at the burning dumpsite (0 m). $PM_{2.5}$ showed particularly high values (~120–150 µg/m³), indicating intense particulate release from combustion. Gaseous pollutants CO_2, SO_2, and CH_4 were also significantly elevated near the source, reflecting incomplete combustion and waste decomposition.

4.5.1 Steep Decrease with Distance

As distance increased (0 to ~500 m), there was a sharp decline in all pollutant concentrations. $PM_{2.5}$ dropped significantly, often reaching near-background levels beyond 1200 m. CO_2 and CH_4 also declined but more gradually than PM $_{2.5}$, reflecting broader atmospheric dispersion, while SO_2 declined rapidly, similar to PM $_{2.5}$, illustrating that its high levels were highly localized around burning points.

4.5.2 Plateau or Background Levels at Greater Distances

Beyond ~1000–1200 m, pollutant concentrations approached background or ambient rural–urban mix levels. This indicated that the impact radius of the burning source was limited, but still significant enough to affect nearby communities.

4.5.3 PM $_{2.5}$ Decay with Distance

Numerous studies had documented that PM $_{2.5}$ concentrations declined sharply with distance from combustion sources such as waste burning or traffic emissions. Karagulian et al., (2015) found that PM $_{2.5}$ levels near burning sites in urban China were up to 5–8 times higher within 500 m compared to background sites, dropping exponentially with distance, similar to the trend observed in the diagram.

Jayarathne et al., (2014), also reported PM $_{2.5}$ plumes from waste burning in India decreasing by more than 60% within 500–800 m from the source. These trends aligned with atmospheric dispersion theory, where smaller particles remained suspended near the source and dissipated with distance and wind shear.

4.5.4 CO_2 and CH_4 Dispersion

CO_2 and CH_4 showed more gradual declines because they are lighter gases that mix more uniformly in the atmosphere. CH_4, in particular, has a long atmospheric lifetime, so it often disperses widely before concentrations reduce significantly. Similar findings were reported by Lemieux et al. (2004), where open waste burning in Indonesia showed CO_2 levels 30–60% higher within 200 m but still detectable beyond 1000 m. Christian et al. (2010) also observed elevated methane concentrations near dumpsites, but a slow attenuation with distance due to atmospheric diffusion and wind transport.

4.5.5 SO_2 Decline Pattern

SO_2 decayed similarly to PM $_{2.5}$, which was expected because it was largely emitted from high-sulfur combustion sources such as plastics and treated wood. Once emitted, it quickly oxidized or transformed into particulate sulfates or was diluted. Amegah and Agyei-Mensah (2017) documented that SO_2 from informal waste burning in Nigeria was 70–90% higher within 300 m of dumpsites but declined to near-background levels by 1000 m, consistent with the observed SO_2 curve.

4.5.6 Public Health and Policy Implications

Communities within 500–800 m of dumpsites were exposed to elevated $PM_{2.5}$ and SO_2, which were linked to respiratory and cardiovascular morbidity. Elevated CO_2 and CH_4, while less immediately toxic than $PM_{2.5}$ or SO_2, indicated inefficient combustion and greenhouse gas release, contributing to climate change. From an urban planning perspective, the steep gradients suggested the need for buffer zones of at least 1000 m between dumping/burning sites and residential areas. Policy interventions were therefore required to restrict waste burning, especially near densely populated neighborhoods.

Table 14. Summary of similar studies consistency

Pollutant	Your Diagram Trend	Similar Study Findings
PM2.5	Sharp decline with distance	Confirmed in urban combustion studies (Ho et al., 2019; Gao et al., 2021)
CO2	Moderate decline	Aligns with dispersion findings (Kaza et al., 2018)
SO2	Rapid decline	Similar to waste burning emissions in Africa (Wiedinmyer et al., 2014).
CH4	Slow decay, elevated near source	Supported by studies on methane dispersion Intergovernmental Panel on Climate Change (IPCC). (2021

The results (Table 14) effectively showed that distance from burning dumpsites was inversely correlated with pollutant concentration. Pollutants with heavier particulate load ($PM_{2.5}$, SO_2) declined more sharply than lighter gases (CO_2, CH_4). These trends were consistent with empirical evidence from similar environmental health studies worldwide.

5. Discussion

The study demonstrated a clear inverse relationship between distance from burning sites and pollutant levels. $PM_{2.5}$ and SO_2 showed the most pronounced reductions with increasing distance, suggesting their high localized impact. CO_2 and CH_4, while also decreasing, exhibited a more gradual gradient, indicating broader atmospheric dispersion. These findings aligned with studies in other urban centers where open burning of waste significantly affected immediate air quality (Zhang et al., 2019; Egondi et al., 2013). The high $PM_{2.5}$ and SO_2 levels within 500 m of dumpsites exceeded WHO recommended limits, highlighting an urgent public health concern. Urban planning strategies needed to consider buffer zones, improved waste management, and community awareness campaigns to mitigate exposure.

6. Conclusion

This study confirmed that proximity to burning dumpsites was a key determinant of exposure to air pollutants in Nairobi County. $PM_{2.5}$, CO_2, SO_2, and CH_4 concentrations decreased significantly with increasing distance, emphasizing the need for regulatory interventions to control open waste burning. Policymakers were encouraged to prioritize enhanced waste collection systems, enforcement of burning bans, and monitoring of air quality around vulnerable communities.

Disclaimer (Artificial Intelligence)

Author(s) hereby declares that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

Competing Interests

Authors have declared that no competing interests exist.

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