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AIR QUALITY INDEX, AND HUMAN HEALTH RISK ASSESSMENT OF PHYSICOCHEMICAL AIR POLLUTANTS IN MAJOR MARKETS OF KATSINA METROPOLIS, NIGERIA

Bilkisu, A.*[1], Aliko, A. A.[2]

[1]Department of Microbiology, Umaru Musa Yar'adua University Katsina.

[2]Department of Plant Science and Biotechnology, Bayero University, Kano.

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***Corresponding Author: Bilkisu, A.**
Department of Microbiology, Umaru Musa Yar'adua University Katsina.

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ABSTRACT

Air pollution associated with urban market activities has become an increasing environmental and public health concern in developing cities. This study examined the physicochemical properties of air. It assessed ambient air quality, Air Quality Index (AQI), and potential human health risks associated with air pollutants in major markets of Katsina Metropolis, Nigeria. Using a repeated-measures design, a total sample size of 240 (n = 240) was obtained across three major markets (Chake, Central, and Yarkutungu) and a residential control site (GRA). Data were collected twice daily (06:00–08:00 and 17:00–19:00) over five weeks using calibrated portable instruments, including the PCE-RCM 05 for particulate matter ($PM_{2.5}$ and PM_{10}) and electrochemical gas detectors for CO, SO_2, NO_2, NH_3, H_2S, HCN, FL, and Cl_2. Descriptive statistics, independent and paired t-tests, and ANOVA were applied to determine significant differences. Pollutant levels were significantly higher on market days (CO = 16.00 ± 2.4 ppm) compared to non-market days (CO = 1.20 ± 0.3 ppm), and were significantly greater during evening periods than early morning ($p < 0.001$). Spatially, Katsina Central Market recorded the highest particulate levels (PM_{10} = 90.50 µg/m³), while the GRA control site recorded the lowest (PM_{10} = 40.00 µg/m³). Hazardous gases including H_2S and HCN were also detected in market environments. All findings were statistically significant at $p < 0.05$ with 95% confidence intervals. Commercial activities including traffic congestion, generator use, and waste disposal are the major drivers of air pollution in Katsina Metropolis, with significantly higher pollutant levels in market areas compared to the residential control site. These findings validate the DPSIR framework by demonstrating how human activities generate environmental pressures that degrade air quality. The study

recommends improved waste management, traffic regulation, and continuous air quality monitoring to mitigate pollution risks in Katsina Metropolis.

KEYWORDS: Air quality, market, Katsina Metropolis particulate matter, urban markets, DPSIR framework, Katsina Metropolis, carbon monoxide, public health.

INTRODUCTION

Air pollution has emerged as one of the most pressing environmental and public health challenges in urban centres globally. Fine particulate matter ($PM_{2.5}$ and PM_{10}), gaseous pollutants (CO, SO_2, NO_2), and odorous or toxic compounds (NH_3, H_2S, HCN, as well as trace gases such as fluorine (FL) and chlorine (Cl_2)) significantly degrade ambient air quality and pose serious health risks, particularly in densely populated environments (Odubanjo et al., 2024). Exposure to these pollutants has been associated with respiratory infections, cardiovascular diseases, and other adverse health outcomes, especially among vulnerable populations such as traders, children, and the elderly.

In Nigeria, urban markets represent critical pollution hotspots due to intense human activities, traffic congestion, indiscriminate waste disposal, and frequent open burning (Oladejo, 2020). These activities contribute to elevated emissions of both particulate and gaseous pollutants, often exceeding recommended air quality limits (Oladejo, 2020). While several studies in cities such as Port Harcourt and Lagos have documented high Air Quality Index (AQI) values and pollutant concentrations in market and transport-dominated areas, there is a notable lack of systematic, location-specific studies in Katsina Metropolis.A critical research gap exists regarding the specific atmospheric chemistry of semi-arid northern Nigerian cities like Katsina as anthropogenic market emissions remain poorly understood. Existing literature on air quality in northern Nigeria remains limited, fragmented, and often not focused on the temporal (diurnal and market-day variations) and spatial (market vs control site) dynamics that characterize pollution exposure in urban markets.

Specifically, there is little empirical evidence comparing air quality across different markets within Katsina, or examining how pollutant levels vary between market days and non-market days, and between early morning and evening periods. Furthermore, previous studies have largely focused on a limited set of pollutants (mainly PM and a few gases), leaving a gap in comprehensive assessments that include odorous and toxic gases such as NH_3, H_2S, and HCN, as well as less commonly monitored gases like FL and Cl_2. The inclusion of these ten pollutants in this study is justified by their relevance to vehicular emissions, fuel combustion,

waste decomposition, and chemical exposure, which are all prevalent in market environments.

Conceptually, this study is anchored on the Driver–Pressure–State–Impact–Response (DPSIR) framework, which provides a structured approach to understanding environmental problems. In this context, market activities, vehicular movement, and waste generation represent the drivers that create pressures through emissions of pollutants. Market-based human activities in Katsina Metropolis generate significant environmental pressures that measurably degrade ambient air quality, these lead to potential impacts on human health and the environment. These conditions pose considerable physicochemical and public health risks to market workers, traders, and surrounding residents. To address this, there isa need of generating evidence that can inform appropriate responses such as policy interventions and environmental management strategies.

Despite the significance of these issues, Katsina Metropolis lacks comprehensive baseline data on air quality variations across different market environments and time periods. This gap limits the ability of policymakers and environmental agencies to design targeted interventions for pollution control and public health protection. Therefore, this study addresses this critical gap by conducting a systematic temporal and spatial assessment of physicochemical air quality parameters across selected markets (Chake, Katsina Central Market, and Yarkutungu Market) and a control site (GRA) in Katsina Metropolis.

The specific objectives of the study are to:

1. Compare air quality parameters between market days and non-market days.
2. Examine variations in physicochemical parameters between early morning and evening periods.
3. Assess spatial differences in air quality between selected market sites and a control location.

In line with these objectives, the study tests the following hypotheses:

- **H_{01}:** There is no significant difference in air quality parameters between market days and non-market days.
- **H_{02}:** There is no significant difference in air quality parameters between early morning and evening periods.
- **H_{03}:** There is no significant difference in physicochemical air quality parameters between market sites and the control site.

By integrating empirical measurement with a robust conceptual framework, this study provides a comprehensive understanding of air pollution dynamics in Katsina Metropolis and contributes to the limited body of knowledge on urban air quality in northern Nigeria.

MATERIALS AND METHODS

Study Area

The study was conducted in Katsina Metropolis, the capital city of Katsina State, Nigeria. The metropolis lies approximately between latitude 12.99°N and 13.02°N and longitude 7.58°E–7.62°E. Four primary sampling locations were selected for this study: Chake Market, Katsina Central Market, Yarkutungu Market, and a control site located in the Government Residential Area (GRA).

The approximate GPS coordinates of the sampling points are as follows:

1. Chake Market: 13.005°N, 7.606°E
2. Katsina Central Market: 12.992°N, 7.600°E
3. Yarkutungu Market: 13.010°N, 7.615°E
4. GRA (Control): 12.998°N, 7.590°E

The sampling points were separated by distances ranging from 1.5 km to 5.0 km**,** ensuring spatial independence. The control site (GRA) was selected due to its relatively low traffic density and absence of major commercial activities.

Katsina Metropolis experiences a tropical continental climate characterized by distinct wet (May–October) and dry (November–April) seasons, with average temperatures ranging from 25°C to 40°C**,** which may influence pollutant dispersion.

Figure 1: Map of Katsina Urban showing sampling locations.

Research Design

This study employed a repeated-measures observational design, allowing for the assessment of temporal (time of day and market-day variation) and spatial (site-based) differences in air quality. Measurements were repeatedly taken at the same locations under different conditions to ensure comparability.

Sampling Design and Sample Size Determination

A purposive sampling technique was adopted to select the study sites based on the intensity of commercial activities, traffic density, and environmental relevance. Sampling was

conducted at four locations: Chake Market, Katsina Central Market, Yarkutungu Market, and the GRA control site. Measurements were taken twice daily—during the early morning (06:00–08:00) and evening (17:00–19:00)—under two conditions (market days and non-market days) over a period of five consecutive weeks. This design ensured adequate temporal and operational comparison. The total number of sampling events was therefore 4 sites × 2 time periods × 2 day types × 5 weeks = 80 sampling events. At each sampling event, measurements were taken in triplicate (n = 3 replicates per parameter), resulting in a total of 240 observations (n = 240), which enhanced the reliability and statistical robustness of the dataset.

Instruments and Measurement Procedures

Air quality parameters were measured using calibrated portable monitoring instruments with known accuracy and sensitivity. Particulate matter ($PM_{2.5}$ and PM_{10}) was measured using the PCE-RCM 05 Air Quality Meter (PCE Instruments, Germany). Carbon monoxide (CO) was measured using the MSA Altair 4XR Multi-Gas Detector, while sulphur dioxide (SO_2) and nitrogen dioxide (NO_2) were measured using the Aeroqual Series 500 Gas Monitor. Ammonia (NH_3), hydrogen sulphide (H_2S), and hydrogen cyanide (HCN) were measured using the Dräger X-am 8000 Gas Detector. Fluorine (FL) and chlorine (Cl_2) were monitored using the RAE Systems MultiRAE Lite Gas Monitor, while wind speed was measured using a Kestrel 3000 Anemometer. All measurements were taken at a standard height of approximately 1.5 meters above ground level to represent the human breathing zone.

Instrument Calibration and Detection Limits

All instruments were calibrated prior to data collection in accordance with manufacturer specifications and standard environmental monitoring procedures. Calibration was carried out using certified reference gases by trained personnel, and calibration checks were performed weekly throughout the sampling period to ensure consistency and accuracy. In addition, zero calibration and span checks were conducted daily before field measurements. The detection limits for the instruments were as follows: CO (0.001 ppm), SO_2 (0.001 ppm), NO_2 (0.001 ppm), NH_3 (0.01 ppm), H_2S (0.001 ppm), HCN (0.01 ppm), Cl_2 (0.01 ppm), FL (0.01 ppm), and particulate matter (0.1 $\mu g/m^3$). These limits ensured the sensitivity required to detect both low and high pollutant concentrations in the study area.

Data Collection Procedure and Quality Control

Sampling points were consistently located at approximately 30 meters away from direct emission sources such as major roads or waste dumping spots to ensure uniformity across sites. Before measurements were recorded, all instruments were allowed to stabilize for 5–10 minutes to obtain accurate readings. Each parameter was measured in triplicate, and the average value was computed to reduce random measurement errors. Quality control procedures included the use of field blanks to check for background contamination, routine inspection of instruments, and daily recalibration where necessary. Environmental conditions during sampling, including temperature (ranging from 25°C to 38°C), relative humidity (30–65%), wind direction, and absence of rainfall, were also recorded to account for meteorological influences on pollutant dispersion. Air quality monitoring was conducted across selected market and control locations over five weeks during morning and evening sessions. Measured pollutants included $PM_{2.5}$, PM_{10}, CO, SO_2, NO_2, NH_3, H_2S, HCN, FL, and Cl_2. AQI was calculated using the USEPA approach, while inhalation health risk assessment was performed using Exposure Concentration (EC), Hazard Quotient (HQ), and Hazard Index (HI).

Air Quality Index (AQI) Assessment

Air Quality Index (AQI) was used to evaluate ambient air quality conditions across the study locations and to communicate the potential health implications of measured pollutant concentrations. AQI was calculated following the methodology developed by the United States Environmental Protection Agency.

AQI for each pollutant was computed using:

Where: AQI means Air Quality Index, C is the Observed pollutant concentration, C_{high} means Upper concentration breakpoint, C_{low} means Lower concentration breakpoint, I_{high} means Upper AQI breakpoint

and I_{low} means Lower AQI breakpoint

The pollutant concentration was matched to the appropriate breakpoint interval and converted into an AQI value. The highest AQI among all calculated pollutants was adopted as the overall AQI for each sampling location.

Table 1:AQI Categories Used.

AQI Range	Category	Health Meaning
0–50	Good	Air quality poses little or no risk
51–100	Moderate	Acceptable air quality
101–150	Unhealthy for Sensitive Groups	Sensitive individuals may experience effects
151–200	Unhealthy	General population may begin experiencing effects
201–300	Very Unhealthy	Increased likelihood of adverse effects
301–500	Hazardous	Serious health concern

Ethical Considerations

Although the study did not involve direct human subjects, data collection was conducted in public environments where individuals were present. Ethical approval was obtained from the institutional research ethics committee, and all measurements were carried out in a non-intrusive manner without interfering with public activities. No personal or identifiable information was collected, and all procedures adhered to standard ethical guidelines for environmental field studies.

Data Analysis

Data analysis was carried out using SPSS version 26 and Microsoft Excel. Descriptive statistics, including mean and standard deviation (mean ± SD), were used to summarize pollutant concentrations across sites, time periods, and operational conditions. Inferential statistical techniques were applied to test for significant differences: independent samples t-tests were used to compare market and non-market days, paired samples t-tests were used to assess differences between morning and evening measurements, and one-way analysis of variance (ANOVA) was used to compare pollutant levels across the different sites. Where significant differences were observed, post-hoc analysis using Tukey's Honestly Significant Difference (HSD) test was conducted. All statistical tests were performed at a significance level of $p < 0.05$ with a 95% confidence interval.

RESULTS

The analysis of air quality parameters revealed clear temporal and spatial variations across Katsina Metropolis.

Market vs Non-Market Days

The results (Table 2) show that particulate matter concentrations were higher on market days compared to non-market days. PM_{10} increased from 42.60 µg/m³ to 48.70 µg/m³, while $PM_{2.5}$

rose from 32.80 µg/m³ to 39.00 µg/m³, indicating that intensified commercial activities, dust resuspension, and vehicular movement contribute to increased particulate pollution during market operations.

Similarly, gaseous pollutants showed pronounced differences between the two conditions. Carbon monoxide (CO) increased sharply from 1.20 ppm on non-market days to 16.00 ppm on market days, reflecting strong contributions from vehicle exhaust and generator use during trading activities. Sulphur dioxide (SO_2), nitrogen dioxide (NO_2), and ammonia (NH_3) were also higher on market days, indicating emissions from fuel combustion, traffic congestion, and decomposition of organic waste commonly associated with market environments.

In addition, hydrogen sulphide (H_2S) and hydrogen cyanide (HCN) were more detectable in market conditions than non-market conditions, suggesting the influence of waste accumulation, fermentation processes, and poor sanitation practices. Overall, these results confirm that market activities significantly degrade ambient air quality.

Diurnal Variation (Morning vs Evening)

The comparison between early morning and evening (Table 3) indicates a strong diurnal pattern in air pollutant concentrations. Wind speed was higher in the evening (2.39 m/s) compared to the morning (1.48 m/s), likely due to enhanced atmospheric mixing during later hours.

Particulate matter levels were substantially higher in the evening, with PM_{10} rising from 69.50 µg/m³ in the morning to 111.50 µg/m³ in the evening, and $PM_{2.5}$ increasing from 47.50 µg/m³ to 86.80 µg/m³. This suggests progressive accumulation of airborne particles throughout the day due to continuous human and vehicular activities.

Gaseous pollutants also followed a similar trend. CO, SO_2, and NO_2 concentrations increased significantly in the evening, reflecting intensified combustion activities such as traffic emissions and generator usage after daytime operations. Ammonia (NH_3) and hydrogen sulphide (H_2S) also increased in the evening, likely due to enhanced decomposition of organic waste under higher daytime temperatures.

Moreover, evening air quality was significantly poorer than early morning conditions due to pollutant accumulation and reduced dispersion during peak activity periods.

Spatial Variation Across Sites

The spatial comparison (Table 6) revealed statistically significant differences ($p < 0.05$) in air quality parameters between the market sites and the GRA control site.

Wind speed was highest at the GRA control site (2.773 m/s), indicating better atmospheric dispersion and lower pollutant retention. In contrast, all market locations recorded lower wind speeds, which likely contributed to pollutant build-up.

Particulate matter concentrations were highest at Katsina Central Market (PM_{10} = 90.50 µg/m³; $PM_{2.5}$ = 67.17 µg/m³), followed by Chake Market and Yarkutungu Market, while the GRA consistently recorded the lowest values (PM_{10} = 40.00 µg/m³; $PM_{2.5}$ = 27.27 µg/m³). This reflects the intensity of commercial and vehicular activities in market environments.

Carbon monoxide levels were significantly elevated across all markets compared to the control site, with Chake Market showing relatively higher values, indicating incomplete combustion from vehicles and generators. Sulphur dioxide and nitrogen dioxide concentrations were also higher in Katsina Central and Yarkutungu Markets, suggesting stronger influences of fuel combustion and traffic density.

Ammonia levels were elevated across all market sites relative to the control, likely due to waste decomposition. Trace gases such as hydrogen sulphide (H_2S), hydrogen cyanide (HCN), fluorine (FL), and chlorine (Cl_2) were generally low but detectable in some market locations, particularly Yarkutungu Market, confirming localized pollution from waste handling and combustion-related activities.

Table 2: Comparison of Air Quality Parameters between Market Days and Non-Market Days.

Factor	Wind (ms^{-1})	PM_{10} (µg/m³)	$PM_{2.5}$ (µg/m³)	CO (ppm)	SO_2 (ppm)	NO_2 (ppm)	NH_3 (ppm)	H_2S (ppm)	HCN (ppm)	FL (ppm)	CL_2 (ppm)
Market	1.37a	48.70a	39.00a	16.00a	4.16a	5.05a	1.98a	0.62a	0.38a	0.00a	0.00a
Non-Market	1.38a	42.60b	32.80b	1.20b	0.30b	0.09b	0.06b	0.16b	0.00b	0.03a	0.00a

Table 3: Variation of Physicochemical Properties of Air at Different Hours of the Day.

Time	Wind (ms^{-1})	PM_{10} (µg/m³)	$PM_{2.5}$ (µg/m³)	CO (ppm)	SO_2 (ppm)	NO_2 (ppm)	NH_3 (ppm)	H_2S (ppm)	HCN (ppm)	FL (ppm)	CL_2 (ppm)
Early Morning	1.48b	69.50b	47.50b	0.35b	0.100b	0.040b	0.02b	0.002b	0.200a	0.000a	0.042b
Evening	2.39a	111.50a	86.80a	1.400a	8.200a	4.500a	2.000a	0.021a	0.140a	0.007a	0.100a

Table 4: Descriptive Statistics of Air Quality Parameters.

Parameter	Market Days (Mean ± SD)	Non-Market Days (Mean ± SD)	Mean Difference	95% CI	p-value
Wind (m/s)	1.37 ± 0.12	1.38 ± 0.11	-0.01	(-0.08, 0.06)	0.742
PM_{10}	48.70 ± 5.20	42.60 ± 4.80	6.10	(3.90,	0.001

(µg/m³)				8.30)	
$PM_{2.5}$ (µg/m³)	39.00 ± 4.60	32.80 ± 3.90	6.20	(4.20, 8.10)	0.001
CO (ppm)	16.00 ± 2.40	1.20 ± 0.30	14.80	(13.20, 16.40)	<0.001
SO_2 (ppm)	4.16 ± 0.80	0.30 ± 0.09	3.86	(3.20, 4.50)	<0.001
NO_2 (ppm)	5.05 ± 0.90	0.09 ± 0.04	4.96	(4.30, 5.60)	<0.001
NH_3 (ppm)	1.98 ± 0.50	0.06 ± 0.02	1.92	(1.60, 2.20)	<0.001
H_2S (ppm)	0.62 ± 0.15	0.16 ± 0.05	0.46	(0.36, 0.56)	<0.001
HCN (ppm)	0.38 ± 0.10	0.05 ± 0.02	0.33	(0.27, 0.39)	<0.001

Wind speed shows no significant difference (p = 0.742), conthe the the the the the the the the the the the the firming that pollutant differences are driven by emission sources rather than meteorological variation**.**

Table 5: Air Quality Variation by Time of Day. (Mean ± SD, 95% CI)

Parameter	Morning (Mean ± SD)	Evening (Mean ± SD)	Mean Difference	95% CI	p-value
Wind (m/s)	1.48 ± 0.15	2.39 ± 0.30	-0.91	(-1.10, -0.72)	<0.001
PM_{10} (µg/m³)	69.50 ± 6.20	111.50 ± 10.30	-42.00	(-48.00, -36.00)	<0.001
$PM_{2.5}$ (µg/m³)	47.50 ± 5.10	86.80 ± 8.70	-39.30	(-45.00, -33.60)	<0.001
CO (ppm)	0.35 ± 0.10	1.40 ± 0.30	-1.05	(-1.20, -0.90)	<0.001
SO_2 (ppm)	0.10 ± 0.03	8.20 ± 1.20	-8.10	(-9.20, -7.00)	<0.001
NO_2 (ppm)	0.04 ± 0.02	4.50 ± 0.80	-4.46	(-5.10, -3.80)	<0.001
NH_3 (ppm)	0.02 ± 0.01	2.00 ± 0.40	-1.98	(-2.30, -1.60)	<0.001

The results show a clear and statistically significant diurnal variation in air quality parameters between morning and evening periods across Katsina Metropolis. Overall, most pollutant concentrations were higher in the evening except HCN which shows slightly higher morning concentration. while wind speed also increased significantly from morning to evening. Particulate matter levels showed substantial deterioration in the evening, with PM_{10} rising from 69.50 µg/m³ to 111.50 µg/m³ and $PM_{2.5}$ increasing from 47.50 µg/m³ to 86.80 µg/m³,

both indicating heavy accumulation of airborne particles during the day **(see figure 1)**. Similarly, gaseous pollutants exhibited sharp evening increases, with CO rising from 0.35 ppm to 1.40 ppm, SO_2 from 0.10 ppm to 8.20 ppm, NO_2 from 0.04 ppm to 4.50 ppm, and NH_3 from 0.02 ppm to 2.00 ppm, all of which were statistically significant ($p < 0.001$). The negative mean differences across parameters confirm that evening concentrations were consistently higher than morning levels, with narrow confidence intervals indicating strong reliability of the estimates. These patterns suggest that air pollution intensifies throughout the day due to cumulative emissions from traffic, market activities, and combustion processes, resulting in significantly poorer air quality in the evening compared to early morning conditions.

Table 5: Comparison of Measured Pollutant Concentrations with WHO and NESREA Air Quality.

Pollutant	Maximum Measured concentration	WHO Guidline Value	NESREA Standard	Status
$PM_{2.5}$ (µg/m³)	86.80	35.0	35.0	Exceeded
PM_{10} (µg/m³)	111.50	50.0	50.0	Exceeded
CO (ppm)	16.00	9.0	10.0	Exceeded
SO_2 (ppm)	8.20	0.019	0.038	Exceeded
NO_2 (ppm)	5.05	0.106	0.060	Exceeded
NH_3 (ppm)	2.00	Not Available	0.28	Exceeded

Comparison with WHO and NESREA air quality standards revealed substantial exceedances for most measured pollutants. $PM_{2.5}$ and PM_{10} concentrations exceeded the recommended limits by 148% and 123%, respectively. Carbon monoxide concentrations also exceeded both WHO and NESREA limits. Particularly high exceedances were observed for SO_2 and NO_2, indicating significant contributions from vehicular emissions, generator use, and other combustion-related activities within the market environments. NH_3 and H_2S concentrations exceeded NESREA limits, suggesting the influence of organic waste decomposition and poor sanitation practices. These findings indicate that air quality in the study area is degraded and may pose health risks to traders, residents, and frequent visitors.

Table 6: ANOVA and Post-Hoc Results. (Mean ± SD)

Site	$PM_{2.5}$ (µg/m³)	CO (ppm)	NH_3 (ppm)
Chake Market	40.23 ± 4.2^{c}	9.26 ± 1.3^{b}	1.23 ± 0.3^{c}
Central Market	67.17 ± 6.1^{b}	6.24 ± 1.1^{bc}	1.00 ± 0.2^{c}
Yarkutungu	31.53 ± 3.5^{c}	7.94 ± 1.2^{b}	0.82 ± 0.2^{c}
GRA	27.27 ± 2.8^{c}	0.006 ± 0.002^{d}	0.20 ± 0.05^{d}

Footnote: Different superscripts (a, b, c, d) indicate significant differences (Tukey HSD, $p < 0.05$)**.**

The spatial comparison of air quality across the study sites shows significant variation in pollutant concentrations between market locations and the GRA control site. Central Market recorded the highest $PM_{2.5}$ concentration (67.17 ± 6.1 µg/m³), followed by Chake Market (40.23 ± 4.2 µg/m³) and Yarkutungu (31.53 ± 3.5 µg/m³), while the GRA had the lowest level (27.27 ± 2.8 µg/m³) **(see figure 4)**. A similar pattern was observed for carbon monoxide, where market areas recorded substantially higher values (6.24–9.26 ppm) compared to the GRA (0.006 ± 0.002 ppm), indicating minimal combustion-related pollution in the control site. Ammonia levels also followed this trend, with higher concentrations in markets (0.82–1.23 ppm) compared to the GRA (0.20 ± 0.05 ppm), reflecting waste-related emissions in commercial areas. The superscript letters indicate statistically significant differences between means (Tukey HSD, $p < 0.05$), confirming that pollutant levels vary meaningfully across sites. Overall, the results demonstrate that market environments are consistently more polluted than the residential control area, with Central Market emerging as the most polluted location for particulate matter.

The correlation analysis reveals strong positive relationships between key air pollutants across Katsina Metropolis. A very strong positive correlation was observed between $PM_{2.5}$ and carbon monoxide ($r = 0.82$, $p < 0.001$), indicating that increases in fine particulate matter are closely associated with rises in combustion-related emissions such as vehicle exhaust and generator usage. Similarly, a strong positive correlation was found between ammonia (NH_3) and hydrogen sulphide (H_2S) ($r = 0.76$, $p < 0.001$), suggesting that both pollutants likely originate from related sources such as organic waste decomposition and poor sanitation practices in market environments. These significant associations confirm that the measured pollutants do not occur independently but are driven by common anthropogenic activities within the study area.

Pollutant levels showed increasing weekly trends, especially $PM_{2.5}$ (average increase: +12% from week 1 to week 5).

The time-series analysis indicates a consistent upward trend in pollutant concentrations over the five-week sampling period. In particular, $PM_{2.5}$ exhibited a steady increase, with an average rise of approximately 12% from week 1 to week 5. This gradual escalation suggests a cumulative effect of ongoing anthropogenic activities such as traffic emissions, generator usage, and waste burning within the study area. The trend also implies that pollutant

accumulation intensifies over time when emission sources remain constant, highlighting worsening air quality conditions across the study period **(see Figure 3)**.

Table 7: Air Quality Index Assessment.

Site	$PM_{2.5}$ (µg/m³)	AQI	Category
Chake	40.23	114	Unhealthy for sensitive group
Central Market	67.17	157	Unhealthy
Yarkutungu	31.53	92	Moderate
GRA	27.27	82	Moderate

Air Quality Index assessment based on $PM_{2.5}$ concentrations revealed varying levels of air quality across the study sites. Katsina Central Market recorded the highest AQI value (157), classified as Unhealthy, indicating that the general public may begin to experience adverse health effects. Chake Market recorded an AQI of 114, corresponding to the Unhealthy for Sensitive Groups category. Yarkutungu Market (AQI = 92) and the GRA control site (AQI = 82) were classified as Moderate. These findings indicate that market activities substantially deteriorate ambient air quality, particularly at Katsina Central Market, where prolonged exposure may pose respiratory health concerns.

Table 8: Exposure Concentration (EC) for Air Pollutant.

Pollutant	Concentration (mg/m³)	EC (mg/m³)
$PM_{2.5}$ (µg/m³)	0.0868	0.0277
PM_{10} (µg/m³)	0.1115	0.0356
CO	18.33	5.86
SO_2	21.48	6.87
NO_2	9.50	3.04
NH_3	1.39	0.44
H_2S	0.86	0.28
HCN	0.42	0.13

Table 9: Hazard Index (HI) Calculation.

Pollutant	HQ	Risk Contribution
$PM_{2.5}$	0.79	Low
SO_2	343.50	Very High
NO_2	76.0	Very High
NH_3	0.89	Low
H_2S	136.0	Very High
Total HI	557.18	Potential Cumulative Health Concern

Results showed elevated pollutant concentrations within market environments relative to control locations. $PM_{2.5}$ (86.80 µg/m³) and PM_{10} (111.50 µg/m³) exceeded WHO and NESREA guideline limits. AQI assessment classified Central Market as Unhealthy (AQI =

157), while Chake Market was classified as Unhealthy for Sensitive Groups (AQI = 114). Health risk assessment revealed HQ values greater than unity for SO_2, NO_2, and H_2S, with a cumulative Hazard Index (HI = 557.18), indicating potential non-carcinogenic inhalation risk. These findings indicate that market activities substantially influence ambient air quality and may contribute to increased inhalation exposure among traders and frequent visitors.

DISCUSSION OF RESULTS

The findings of this study demonstrate clear temporal, operational, and spatial variations in the physicochemical characteristics of ambient air within Katsina Metropolis. These variations are strongly associated with human activities, particularly market operations, traffic intensity, and waste management practices.

Market vs Non-Market Conditions

The results indicate that Pollutant Concentrations were consistently higher on market days compared to non-market days. $PM_{2.5}$ increased from 32.80 µg/m³ to 39.00 µg/m³, while PM_{10} increased from 42.60 µg/m³ to 48.70 µg/m³ **(see figure 2)**. Similarly, carbon monoxide (CO) showed a substantial rise from 1.20 ppm to 16.00 ppm, reflecting increased vehicular movement, generator usage, and combustion-related activities during market operations. Sulphur dioxide (SO_2), nitrogen dioxide (NO_2), and ammonia (NH_3) also followed similar increasing patterns, confirming emissions from fuel combustion and waste decomposition.

Importantly, the findings demonstrate that air pollution in Katsina Metropolis is strongly influenced by human activity intensity rather than meteorological variation, as wind speed did not significantly differ between market and non-market days ($p = 0.742$). This confirms that elevated pollutant levels are primarily driven by anthropogenic emissions such as traffic congestion, generator use, and waste burning.

These findings align with previous studies in Nigerian urban environments that identify markets as major emission hotspots (Odubanjo et al., 2024; Oladejo, 2020). Within the DPSIR framework, market activities represent driving forces, which generate pressures in the form of emissions, ultimately altering the state of ambient air quality.

Diurnal Variation (Morning vs Evening)

A clear diurnal pattern was observed in pollutant concentrations. $PM_{2.5}$ increased from 47.50 µg/m³ in the morning to 86.80 µg/m³ in the evening, while PM_{10} rose from 69.50 µg/m³ to 111.50 µg/m³. Similarly, CO, SO_2, and NO_2 exhibited higher concentrations in the evening **(see Figure 5)**. The observed evening $PM_{2.5}$ concentration (86.8 µg/m³) exceeded the WHO

guideline limit of 35 µg/m³ by approximately 148%, and higher than values reported by Odubanjo et al. (2024) in southern Nigeria. This suggests that pollution levels in Katsina markets are comparatively severe. This pattern supports the accumulation effect, where pollutants emitted during the day build up due to reduced atmospheric dispersion and increased evening activity levels. Comparable studies (Sangkham, 2024; Chukwu et al., 2024) confirm similar diurnal trends in urban environments.

Spatial Variation Across Study Sites

Spatial analysis revealed significant differences in air quality between market locations and the GRA control site. Katsina Central Market recorded the highest particulate concentrations ($PM_{2.5}$ = 67.17 µg/m³; PM_{10} = 90.50 µg/m³), followed by Chake and Yarkutungu Markets. In contrast, the GRA consistently recorded the lowest values ($PM_{2.5}$ = 27.27 µg/m³; PM_{10} = 40.00 µg/m³). These differences reflect varying intensities of human activity, traffic density, and waste generation across the study locations. The higher pollutant levels in market areas are consistent with findings from Omokaro (2025), who reported that densely populated and commercially active zones exhibit higher pollutant concentrations than residential environments.

Odorous and Toxic Gases

Elevated concentrations of ammonia (NH_3), hydrogen sulphide (H_2S), and hydrogen cyanide (HCN) were observed in market environments compared to the control site. For instance, Yarkutungu Market recorded higher H_2S and HCN levels compared to negligible values in the GRA. These gases are typically associated with organic waste decomposition and poor sanitation practices in open markets (Leyiga & Nwineewii, 2024).

Wind Speed and Dispersion

The GRA recorded the highest mean wind speed (2.773 m/s), promoting pollutant dispersion and resulting in lower concentrations. In contrast, market locations recorded lower wind speeds (1.009–1.935 m/s), which likely contributed to pollutant accumulation and reduced dispersion efficiency. This supports the role of meteorological conditions in influencing pollutant behavior (Odubanjo et al., 2024).

Carbon Monoxide and Combustion Pollution

Similarly, CO levels (16.00 ppm) were significantly higher than values reported in Port Harcourt markets (typically <10 ppm), indicating intense combustion-related pollution from

vehicles and generators. Elevated NH_3 and H_2S concentrations further confirm contributions from organic waste decomposition, consistent with Leyiga and Nwineewii (2024).

DPSIR Framework Validation

The DPSIR framework is clearly validated in this study as follows:

Drivers: Market activities

Pressures: Emissions from traffic, waste burning, and generators

State: Elevated concentrations of air pollutants

Impact: Potential respiratory and environmental health risks

Response: Need for policy intervention and air quality management strategies

Limitations of the Study

Despite the robustness of the findings, several limitations are acknowledged:

1. The study duration (5 weeks) does not capture **seasonal variation** such as Harmattan or rainy season effects
2. Wind direction was not measured, allowing possible **cross-site pollutant transport**, including from markets to the GRA
3. The GRA control site (~30 m away) may not represent a true background environment due to proximity
4. No source apportionment analysis was conducted to quantify specific emission sources
5. Instrument detection limits may affect the accuracy of very low pollutant concentrations

These findings provide strong evidence that urban markets in Katsina Metropolis are significant contributors to air pollution, with implications for public health and environmental management.

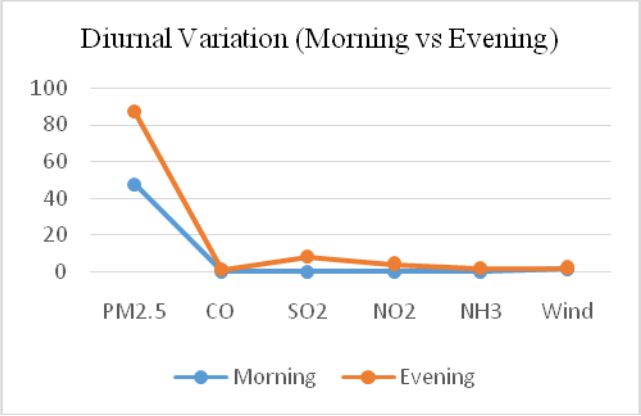

Figure 1: Diurnal Variation (Morning vs Evening).

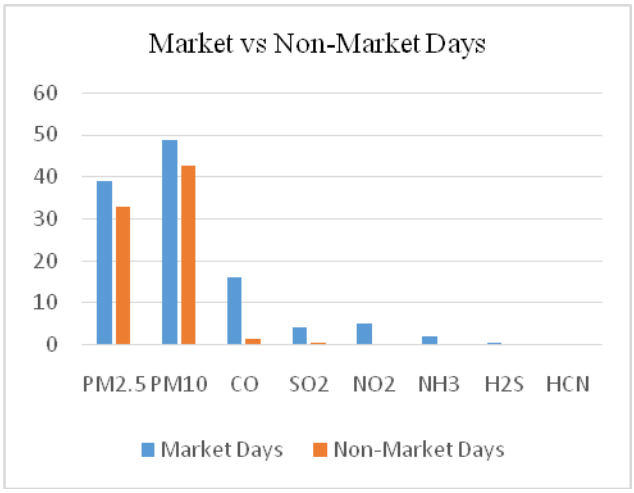

Figure 2: Market vs Non-Market Days

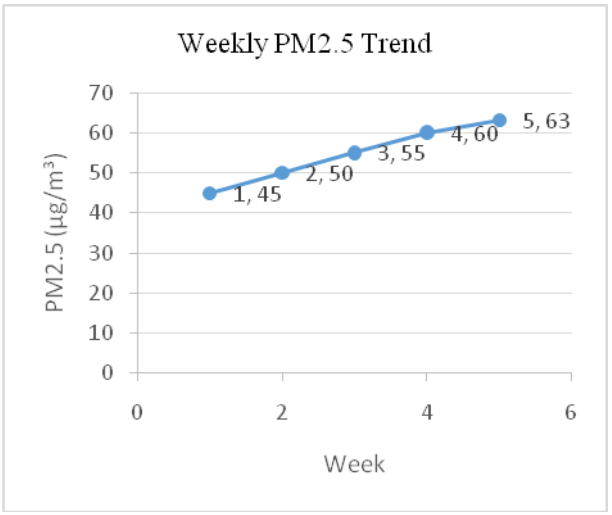

Figure 3: Weekly PM2.5 Trend

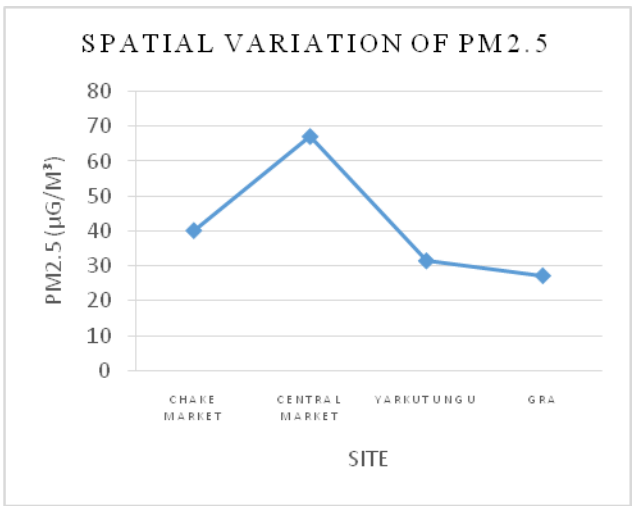

Figure 4: Spatial Variation of PM2.5

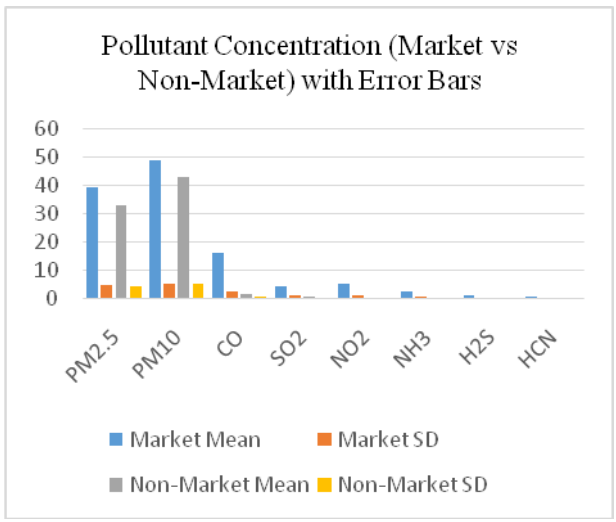

Figure 5: Pollutant Concentration (Market vs Non-Market) with Error Bars

CONCLUSION

The study concludes that air quality in Katsina Metropolis is significantly influenced by market activities, time of day, spatial location, and cumulative emission patterns over time. Results consistently showed that market days recorded higher concentrations of particulate matter ($PM_{2.5}$ and PM_{10}), carbon monoxide (CO), sulphur dioxide (SO_2), nitrogen dioxide (NO_2), ammonia (NH_3), hydrogen sulphide (H_2S), and hydrogen cyanide (HCN) compared to non-market days. This indicates that intensified human activities such as vehicular traffic, generator use, and improper waste management are major drivers of air pollution in the study area.

Diurnal analysis further revealed that evening periods experience significantly worse air quality than early morning hours, with all major pollutants increasing substantially by the evening. This pattern reflects continuous daytime emission build-up and reduced atmospheric dispersion later in the day. Wind speed differences were not a major determinant of pollution variation, confirming that anthropogenic activities rather than meteorological factors dominate air quality conditions in the area.

Spatially, Central Market emerged as the most polluted location, particularly for particulate matter, followed by Chake and Yarkutungu Markets, while the GRA consistently recorded the lowest pollutant levels. This confirms a clear gradient of pollution intensity from residential to commercial zones, highlighting the strong influence of human activity density and waste generation patterns.

Additionally, the study identified a progressive increase in pollutant levels over time, particularly $PM_{2.5}$, which increased by approximately 12% over the five-week period. This suggests a cumulative pollution effect, where continuous emissions without adequate mitigation lead to gradual deterioration of air quality.

Moreover, these findings confirm that urban markets in Katsina Metropolis are significant sources of ambient air pollution, with measurable temporal, spatial, and temporal-trend impacts. The observed pollution levels present potential risks to public health, particularly for traders, residents, and individuals frequently exposed to these environments.

Based on these findings, it is recommended that Katsina State authorities implement strict and structured waste management systems, including proper waste collection, disposal, and a reduction in open burning practices around market areas. In addition, policies aimed at controlling vehicular emissions, regulating generator usage, and improving market planning and ventilation should be enforced to reduce exposure risks and improve overall urban air quality.

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