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SPATIAL VARIABILITY OF $PM_{2.5}$ AND PM_{10} CONCENTRATIONS ACROSS URBAN LAND-USE TYPES IN JALINGO METROPOLIS, NORTHEASTERN NIGERIA: IDENTIFICATION OF POLLUTION HOTSPOTS AND IMPLICATIONS FOR AIR QUALITY MANAGEMENT.

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Abstract

Particulate matter (PM) in the atmosphere is one of the most pressing problems faced by the environment and public health in rapidly developing cities in developing nations. This study looks at how fine ($PM_{2.5}$) and coarse (PM_{10}) particulate matter vary across different land-use types in Jalingo Metropolis, northeastern Nigeria. The primary objectives are to identify pollution hot spots and to assess the relationship between land use and the levels of pollution. The APM 460 NL respirable dust sampler was used to measure PM at six sites: industrial, traffic, commercial, and residential. An average analysis on the $PM_{2.5}$ and PM_{10} for each site and drew comparisons with air quality guidelines internationally. The results indicated statistically significant differences in PM pollution levels among the areas of Jalingo. The levels of $PM_{2.5}$ varied between the lowest of 40.65 $\mu g\ m^{-3}$ at Shagari Quarters and the highest of 97.85 $\mu g\ m^{-3}$ at Nukai Timber Shed. The PM_{10} ranged from 26.53 to 81.58 $\mu g\ m^{-3}$. Mayogoi Market reported the lowest value, and the highest value was reported at Dinyavoh Stone Crushing Centre. The concentrations in industrial areas were the highest, followed by traffic-intensive sites, and residential and commercial areas were the lowest. Pollution levels were ranked as industrial, traffic, commercial, and residential. The air quality in all the sites was below the World Health Organization (WHO) 2021 standard for $PM_{2.5}$, indicating that poor air quality is prevalent across the city. The results indicate that the main sources of particulate pollution in Jalingo are industrial work, quarrying, vehicle emissions, and road dust. The city is provided with a set of baseline air quality data that will help inform sustainable management in the city while also identifying areas that require specific emission controls and continuing monitoring.

Keywords: $PM_{2.5}$, PM_{10}, spatial variability, land-use types, air pollution, urban environment, Jalingo Metropolis, Nigeria.

Introduction

Particulate matter (PM) in the atmosphere is one of the most significant pollutants affecting the urban environment and human health and has a global climate impact. Fine particles < 2.5 µm ($PM_{2.5}$) and < 10 µm (PM_{10}) are particulates of particular concern, as they can enter the human respiratory system and lead to heart, lung, and nerve damage. The $PM_{2.5}$ is a more dangerous pollutant because it can penetrate deeply into the lungs and into the bloodstream, whereas the PM_{10} impact is mainly on the upper airways. WHO (2026) states that long-term exposure to air pollution has also been linked to higher chances of developing asthma; heart disease; chronic lung disease; and early death.

Rapid urban growth in sub-Saharan Africa has led to more particulate pollution in many cities. Air quality has become poorer due to city growth, increased motor vehicle traffic, industrial activity, home energy consumption, open burning, and construction. The so-called problem is exacerbated in Nigeria due to the scarcity of monitoring of air quality and the absence of long-term data to manage the environment. The study conducted recently revealed that particulate pollution in some of the Nigerian cities can occasionally exceed the international standard and thus pose health and environmental risks (Odubanjo et al. 2024). The spatial variations in emissions are also reflected in the spatial variations in particulate concentrations, which also depend on land use, highlighting the need for local assessments for urban planning purposes.

The concentration of particulate matter varies from place to place in the city, depending, of course, greatly on land use and activities. Particulate concentrations are generally higher in industrial areas due to handling materials, fuel burning, quarrying, and manufacturing. Traffic corridors have emissions like vehicles, tire and brake wear, and road dust. In commercial areas, emissions are caused by transport, power generation, and business energy use. Residential areas typically have lower emissions unless industrial or heavy traffic is nearby (Mun et al. 2022, WHO 2025). Knowing these types of emissions and where they are found can help identify areas of high pollution and counteract them.

A study carried out in some developing countries has shown that land usage greatly affects the levels of PM2.5 and PM10 (Amegah et al., 2022). Particulate concentrations are significantly higher in industrial and high-traffic zones as compared to residential areas in many fast-growing areas of Nigeria, India, Ghana, etc. (Abulude et al. 2025; Ayensu-Ntim et al. 2025; Datta et al. 2026). This was also identified in other cities such as Abuja, Lagos, Port Harcourt, Enugu, and Kano, where pollutants included vehicle emissions, industry and dust, etc (Abiye et al. 2014). Nigerian national studies have also shown that pollution clusters and the degree of urbanization of an area are related to the activities of people in that area (Adeniji et al., 2026). The results stress the necessity of the local studies in identifying the sources of pollution and the patterns of the pollution in that area.

There are distinct weather conditions in Northeastern Nigeria that may exacerbate particulate pollution. During the dry season that is between September and May, seasonal Harmattan winds contribute much particulate matter to the air as well (Falaiye and Aweda, 2018).

These natural sources, in addition to the increase in urban population and anthropogenic emissions, have a significant impact on the air quality in urban areas such as Jalingo. Despite the expansion of the city of Jalingo and its economy, little information exists regarding the distribution of PM throughout the city. Previous studies focused on gas pollutants and emissions from roadways, leaving significant gaps in understanding variations in $PM_{2.5}$ and PM_{10} by land use in Jalingo.

Over the past 20 years, Jalingo has developed and urbanized. This has resulted in an increased number of vehicles, increased business development, small industries, buildings, and increased energy consumption (Oruonye 2014). These activities emit fine particle material, and reduce air quality. An understanding of the variation of particles by land use is significant for identification of pollution hotspots, exposure analysis and sustainable management.

This study looks at how $PM_{2.5}$ and PM_{10} levels vary across six types of land use in Jalingo Metropolis, Northeastern Nigeria. It makes comparisons between pollution levels in industrial, traffic, commercial and residential areas, identifies key hotspots and discusses the implications for urban air quality management. The results are intended to provide relevant baseline information for policy makers, urban planners and public health professionals in rapidly expanding northern Nigerian cities in relation to particulate pollution.

Materials and Methods

Study Area

The work was carried out in Jalingo Metropolis, the Capital of Taraba State, North-East Nigeria. Jalingo is situated between the latitudes 8°47′N and 9°01′N, and longitudes 11°09′E and 11°30′E and has an average altitude of c. 351 m above sea level. The climate experienced in the city is a tropical savannah type with clear-cut wet and dry seasons. Rainy season is generally April to October and dry season is from November to March. Mean annual rainfall ranges from 900 to 1,300 mm, and average temperatures vary between 24°C and 35°C.

Rapid urbanization, increasing vehicular traffic, commercial activities, construction works, quarry operations, and small-scale industrial activities have significantly contributed to environmental pollution in the metropolis. All these properties enable the study of spatial heterogeneity of atmospheric PM in urban areas at the sub-grid level across various land-use categories in Jalingo.

Particulate Matter Sampling

A respirable dust sampler (APM 460 NL) was placed on an elevated platform of 1.5 m high at a distance of 20 m away from obstructions and used to sample the dust from Dinyavoh Stone Crushing Centre (DS), Nukai Timber Shed (NT), Road Block Roundabout (RB), Government House Roundabout (GH), Mayogoi Market (MM) and Shagari Quarters (SQ) (Figure 1). The instrument separates airborne particulate matter into fine and coarse fractions using a cyclone separator and collection system.

Sampling was conducted at each site during the 2019 dry season. The sampler was positioned at an appropriate height above ground level to represent human exposure conditions and to minimize interference from immediate surface disturbances. Prior to sampling, filter papers were conditioned and weighed using a precision analytical balance. Following exposure, the filters were reconditioned and reweighed to determine the mass of particulate matter collected.

The total volume of air sampled was recorded directly from the sampler for each monitoring period.

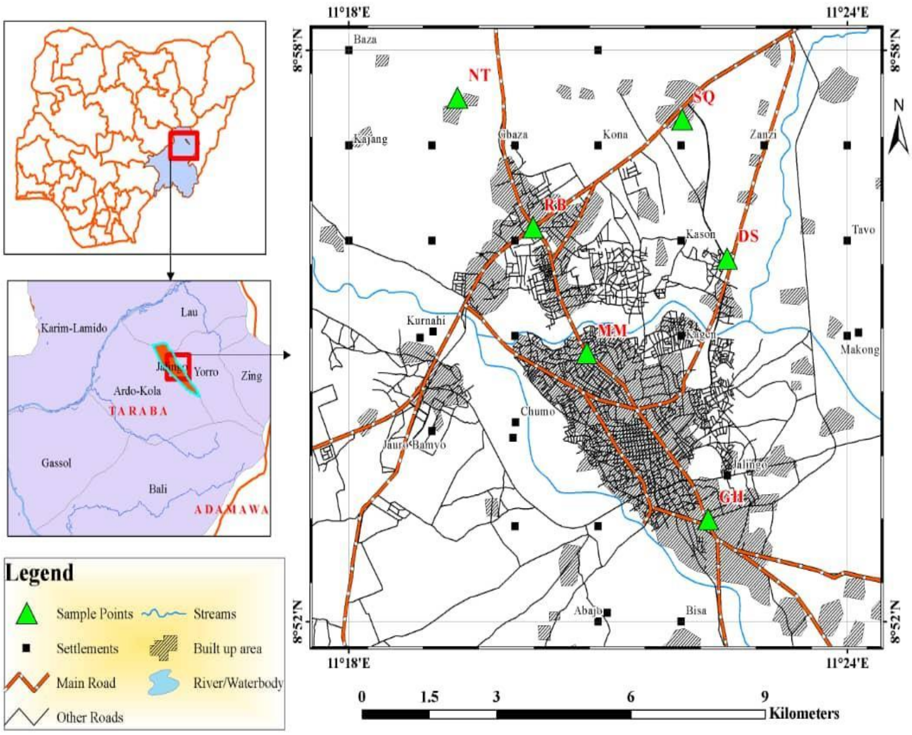

Figure 1: Map of Jalingo metropolis showing the sampling sites

Determination of $PM_{2.5}$ and PM_{10} Concentrations

The mass concentration of particulate matter was determined gravimetrically using the relationship:

$$Conc.(\mu g m^{-3}) = \frac{m_2 - m_1}{V} \times 10^6$$

Where m_1 and m_2 were for the initial and final mass of filter paper in grams, respectively. 10^6 was the conversion factor from grams to micrograms.

V represent the volume of sampled air in m^3 which is calculated from $V = \Phi \times t$,

Φ is average airflow rate in $\frac{m^3}{min}$ and

T is sampling time, in minutes.

Because of the proximity of residential houses and business offices to PM10 levels and, hence, human exposure. The probability of human health effects that exist was computed as the toxicity potential (TP) from the relation:

$$T\,P = \frac{observed\ mean\ mass\ of\ PM_{10}\ Concentration}{Permissible\ limit\ set\ by\ NAAQS}$$

TP> 1 is harmful to humans (Ediagbonya *et al*., 2013).

The sampling time was 8 hours per site for 4 samples (7.00 hrs-15.00 hrs).

Addressing spatial issues, land-use classification:

The sampling sites were classified into four categories of land use in order to be compared:

- Industrial: Dinyavoh Stone Crushing Centre and Nukai Timber Shed.
- Traffic: Road Block, Roundabout, and Government House Roundabout.
- Commercial: Mayogoi Market.
- Residential: Shagari Quarters.

In assessing spatial variability, the land-use categories with the highest mean concentrations of $PM_{2.5}$ and PM_{10}, as well as the land-use categories with the highest PM loads, were identified.

Data Analysis

Descriptive statistical analysis was employed to determine mean particulate concentrations and variability among sampling sites. Comparisons were made between the concentration of $PM_{2.5}$ and PM_{10} at the six stations and among the four land-use categories.

To assess compliance and potential health effects, the measured levels were compared to the WHO Air Quality Guidelines (2021) and the NAAQS.

Results

Geographical distribution of PM_{25} and PM_{10} for various land use types.

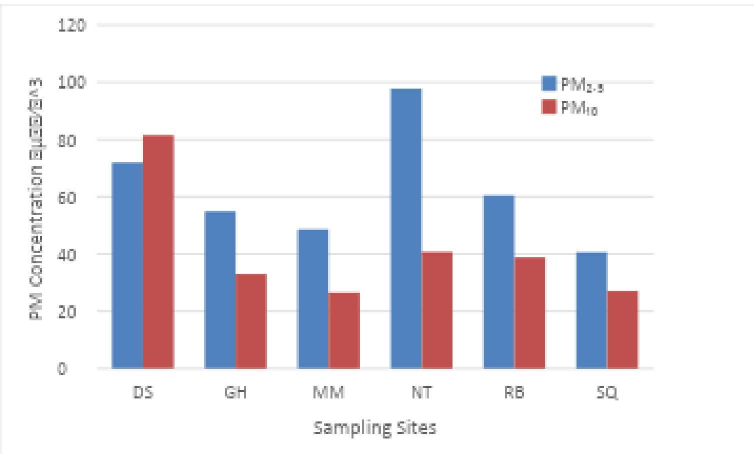

Figure 2: PM concentration vs. sampling sites

The $PM_{2.5}$ and PM_{10} sampling data shows variation at the different sampling locations. This data shows there is a lot of variation in the particulate pollution across Jalingo Metropolis. Table 1 shows the average concentrations of various particulate matters at each of the locations.

Table 1

Average $PM_{2.5}$ and PM_{10} concentrations across sampling points in Jalingo Metropolis

Site	Land-use Type	$PM_{2.5}$ (µg m^{-3})	PM_{10} (µg m^{-3})
Dinyavoh Stone (DS)	Industrial	71.87	81.58
Government House RD (GH)	Traffic	54.97	32.98
Mayogoi Market (MM)	Commercial	48.63	26.53
Nukai Timber Shed (NT)	Industrial	97.85	40.77
Road Block RD (RB)	Traffic	60.45	38.86
Shagari Quarters (SQ)	Residential	40.65	27.1

Table 1 indicates that the lowest $PM_{2.5}$ concentration was 40.65 µg m^{-3} for the Shagari Quarters and that the highest was found at the Nukai Timber Shed, where it reached 97.85 µg m^{-3}. The highest $PM_{2.5}$ concentration was recorded at Nukai Timber Shed, while the lowest concentration occurred at Shagari Quarters. For PM_{10}, concentrations ranged from 26.53 µg m^{-3} at Mayogoi Market to 81.58 µg m^{-3} at Dinyavoh Stone Crushing Centre.

The spatial ranking of $PM_{2.5}$ concentrations followed the order:

NT > DS > RB > GH > MM > SQ

whereas PM_{10} concentrations followed the order:

DS > NT > RB > GH > SQ > MM

The extent of variations in particulate pollution levels between land-use environments is clearly reflected in these patterns.

Land-Use Variation in Particulate Matter Concentrations

Particulate matter distribution was found to be different when the sampling points were grouped according to land-use categories. Industrial locations represented by Dinyavoh Stone Crushing Centre and Nukai Timber Shed recorded the highest particulate concentrations. Traffic-dominated locations, namely Road Block Roundabout and Government House Roundabout, exhibited intermediate concentrations, while commercial and residential areas generally recorded lower values.

Table 3

Land-use	Average $PM_{2.5}$	Average PM_{10}
Industrial	84.86	61.18
Traffic	57.71	35.92
Commercial	48.63	26.53
Residential	40.65	27.1

Table 3 reveals that industrial locations recorded the highest $PM_{2.5}$ and PM_{10} concentrations, whereas residential locations exhibited the lowest concentrations.

The industrial category had the highest mean concentration (84.86 µg m^{-3}), and the residential category had the lowest (40.65 µg m^{-3}). Likewise, the concentration of PM_{10} was the highest in industrial areas (61.18 µg m^{-3}) and the lowest in the commercial zone (26.53 µg m^{-3}).

The $PM_{2.5}$ and PM_{10} concentrations at each sampling site are shown in figure 2.

Identifying hotspots of particulate pollution.

Spatial distribution of particulate matter showed the presence of localized pollution hotspots in the metropolis. The Nukai Timber Shed turned out to be the highest hotspot for $PM_{2.5}$ concentration, with 97.85 µg/m³. With a total of 81.58 µg/m³, Dinyavoh Stone Crushing Centre recorded the most PM_{10}.

Road Block Roundabout was also noted for high levels of $PM_{2.5}$ (60.45 µg m^{-3}) and PM_{10} (38.86 µg m^{-3}). The results confirmed high pollution levels of $PM_{2.5}$ and PM_{10} in the most trafficked areas.

Shagari Quarters, on the other hand, recorded the least $PM_{2.5}$ concentrations, while the least PM_{10} was recorded in Mayogoi Market.

Comparison with Air Quality Guidelines

The measured particulate concentrations were then compared with the WHO Air Quality Guidelines (2021) and NAQS.

The sampling locations had all exceeded the WHO 24-hour guideline value for $PM_{2.5}$ (15 µg m^{-3}). The observed $PM_{2.5}$ levels were roughly 2.7–6.5 times over the acceptable threshold.

For PM_{10}, Dinyavoh Stone Crushing Centre reported values over the WHO-recommended value of 45 µg m^{-3}, and the other locations reported values below this limit. Nevertheless, all the locations were still within the Nigerian National Ambient Air Quality Standard of 150 µg m^{-3} for PM_{10}.

Toxicity Potential of Particulate Matter

TP values using the National Ambient Air Quality Standard for $PM_{2.5}$ showed that all areas of the sample demonstrated an increased risk of pollution. The Shagari Quarters toxicity potential was 1.16, and that of the Nukai Timber Shed was 2.80.

Toxicity potential was the highest at the Nukai Timber Shed (2.80), followed by the Dinyavoh Stone Crushing Center (2.05) and the Road Block Roundabout (1.73). The PM_{10} toxicity potentials, in contrast, ranged from 0.18 to 0.54 and were always less than unity at locations.

Heightened $PM_{2.5}$ toxicity implies that fine particulate pollution is ubiquitous throughout the city and that industrial and traffic-dominated areas are exposed to the highest pollution levels.

Permissible limit set by NAAQSfor fine particulates (µg/m3)	**Site**	**Mean conc. of Fine particulate (µg/m3)**	**Toxicity potential**	**Permissible limit set by NAAQSfor Coarse particulates (µg/m3)**	**Site**	**Mean conc. of Coarse particulate (µg/m3)**	**Toxicity potential**
35	DS	71.87	2.053	150	DS	81.58	0.544
	GH	54.97	1.571		GH	32.98	0.219
	MM	48.63	1.389		MM	26.53	0.176
	NT	97.85	2.795		NT	40.77	0.271
	RB	60.45	1.727		RB	38.86	0.259
	SQ		1.161		SQ	27.1	0.18

Discussion

The spatial distribution of $PM_{2.5}$ and PM_{10} concentrations in Jalingo Metropolis indicates clear control of land use, where industrial and traffic-based areas have more particulate pollution than commercial and residential areas. The mean $PM_{2.5}$ concentration ranged from 40.65 µg m^{-3} at Shagari Quarters to 97.85 µg m^{-3} at Nukai Timber Shed, while PM_{10} ranged from 26.53 µg m^{-3} at Mayogoi Market to 81.58 µg m^{-3} at Dinyavoh Stone Crushing Centre. This indicates that particulate pollution in Jalingo is not uniformly distributed but rather is concentrated around certain anthropogenic activity areas (AAs), in particular the industrial workshops, the activities associated to the quarries, and the traffic corridors.

As can be seen from Figure 2, fine particulate pollution in Jalingo is greatly affected by small-scale industrial activities as noted by the maximum $PM_{2.5}$ concentration recorded at the Nukai Timber Shed. Fine respirable particles can be emitted into the atmosphere by timber processing, sawing, sanding, welding, generator operation, vehicle movement, and potentially biomass-related activities. This pattern is consistent with the findings of Okudo et al. (2022), which indicated that particulate matter ($PM_{2.5}$ and PM_{10}) concentrations in Enugu Urban are different across industrial, commercial, and residential land-use zones. Industrial and high-activity zones have the most PM concentrations. For instance, the level of $PM_{2.5}$ in the Nukai Timber Shed was below the upper limit of the PM level recorded in Enugu Urban, which was 153.23 µg/m^3, although it was still higher than what is expected in a clean urban area.

The highest concentration of PM_{10} was found at the Dinyavoh Stone Crushing Centre. The coarse dust that is created and resuspended from a quarry and is caused by several mechanical processes such as crushing, grinding, and the transported dust is considered to be the major contributor. The finding of this study is in line with studies that have been carried out on the quarry environment in Nigeria, which have pointed out that the dust caused by stone crushing is one of the leading causes of PM_{10} and $PM_{2.5}$ pollution (Bada et al. 2021). The PM_{10} concentration at Dinyavoh is lower than the concentrations of some very active quarry and urban-industrial sites but its dominance over the other Jalingo sites indicates that it is the dominant coarse-particle hotspot in the metropolis.

Traffic-dominated sites, Road Block roundabout and Government House roundabout, also had high levels of particulate. Road Block Roundabout had higher $PM_{2.5}$ and PM_{10} concentrations than Government House Roundabout, likely due to increased road traffic and commercial transport, as well as more tricycle traffic and road dust resuspension and stop-vehicle emissions. This coincides with some more recent studies involving Port Harcourt, Abuja, and other cities in Nigeria, which discovered that the air quality in high-traffic regions is worse than in low-traffic regions. Seasonal monitoring of $PM_{2.5}$ and PM_{10} in Abuja from 2021 to 2022 showed significant variations among urban activity intensity and inter-seasons. These studies provide evidence that both traffic and weather are influential in the accumulation of particulate matter in the cities of Nigeria (Adeniji et al. 2026; Karagulian et al. 2015).

The levels of Jalingo are relatively high compared with the levels of another city in the northeastern region of Nigeria, namely, Yola. Adediran et al. (2024) reported that during the dry-hot season, $PM_{2.5}$ and PM_{10} in Yola were highest, with commercial land use having an average concentration of approximately 21.44 µg m^{-3} and 44.62 µg m^{-3}, respectively. In the current study, all the Jalingo sites have exceeded the Yola $PM_{2.5}$ value, particularly the Nukai Timber Shed, Dinyavoh Stone Centre, and Road Block Roundabout. This discrepancy could be attributed to more intense industrial activities, the presence of quarry dust, traffic density at the site, and/or sampling timing. Both cities, however, have the common feature that increased particulate levels are generally observed during dry seasons when the scavenging effect of rainfall is reduced, and the resuspension effect of dust is enhanced.

The results are also consistent with general observations in Northern Nigeria, where PM_{10} is also affected by Harmattan dust, unprotected surfaces, and resuspension of road dust. A recent national-scale assessment of air pollutants over Nigeria showed that PM_{10} levels are relatively high in northern Nigeria, associated with the transport of Saharan dust, the Harmattan wind, and dry-season resuspension of dust, while $PM_{2.5}$ hotspots exist more persistently in southeastern Nigeria and in the Niger Delta region, associated with industrial emissions and secondary aerosol formation (Adenije et al., 2026). The Jalingo pattern was consistent with this interpretation, with PM_{10} being highest at the stone-crushing site, and $PM_{2.5}$ more strongly linked to industrial workshops and traffic-related combustion sources.

The $PM_{2.5}$ values in Jalingo are higher than the values reported in Yenagoa, where $PM_{2.5}$ ranged from 11.1 to 26.2 $\mu g\ m^{-3}$ (Ediagbonya et al., 2013) when compared with the cities in the South of Nigeria. This indicates that the fine-particle exposure risk in Jalingo's industrial and traffic microenvironments may be higher than in certain less industrialized southern urban areas. The PM values for Jalingo, however, are lower than values reported in some highly polluted eastern Nigerian urban areas, for which $PM_{2.5}$ was reported to be between 99.30 and 124.70 $\mu g\ m^{-3}$ and PM_{10} between 138.70 and 168.00 $\mu g\ m^{-3}$. Therefore, it may be described as moderately to highly polluted, particularly at industrial and traffic sites, depending on the type of land use.

The land-use ranking that was observed in Jalingo can be summarized as industrial, traffic, commercial, and residential. International evidence from swiftly evolving cities shows that particulate pollution hotspots can be found in industrial zones, road junctions, markets, and transport corridors (Amegah et al., 2022). In Dar es Salaam, Tanzania, studies showed that microenvironments contained varying PM2.5 and PM10 levels of particulate matter, which were the result of a combination of factors, including traffic, commerce, road dust, and weather (Lema et al. 2023).

The lowest concentrations of PM2.5 found in Jalingo, along with the highest concentrations found in Jalingo, were still over the WHO 2021 24-hour guideline of 15 $\mu g/m^3$. This shows that the least polluted area of Jalingo is still not safe from high levels of PM2.5. The exceedances at all sites do not appear to be a localized industrial outbreak but instead a regional air quality issue at the level of the metropolitan area. The Dinyavoh Stone Crushing Centre was the most significant coarse-particle hotspot, with a PM_{10} concentration exceeding the WHO 2021 24-hour guideline of 45 $\mu g/m^3$.

In conclusion, the results show that the sources of particulate pollution in Jalingo are mostly related to industrial processing, quarrying, vehicles, commercial activity, road dust, and seasonal atmospheric conditions. Results are reasonably comparable with studies conducted in other urban centers such as Yola, Enugu, Abuja, Yenagua, Port Harcourt, Lagos, Dar es Salaam, and other locations but also indicate that Jalingo has its own local pollution structure. The key policy recommendations are as follows: ensure dust is suppressed at stone crushing works; limit emissions from timber and workshop areas; pave and clean roads; regulate open burning; and monitor air-quality levels at traffic and industrial emission sources continuously for $PM_{2.5}$ and PM_{10}.

Conclusion

The aim of this study was to determine the spatial variability of $PM_{2.5}$ and PM_{10} levels of various land-use categories in Jalingo Metropolis, northeastern Nigeria. Results showed considerable spatial variability in PM distribution, with PM concentration at industrial and traffic areas being significantly higher than commercial and residential areas. The highest concentration of $PM_{2.5}$ was recorded at Nukai Timber Shed (97.85 μg m^{-3}), and the highest concentration of PM_{10} was recorded at Dinyavoh Stone Crushing Centre (81.58 μg m^{-3}), indicating these to be the major particulate pollution hotspot areas of the metropolis.

The measured gradient in pollution (industrial > traffic > commercial > residential) highlights the major contribution of industrial sources, quarry activities, traffic exhaust, and resuspension of road dust to urban air quality. All the $PM_{2.5}$ samples from the walking surveys exceeded the WHO recommended levels. These results show that air quality in these areas is harmful and poses health risks. These results underscore the increasing problem of particulate pollution in the fast-urbanizing cities of Northeastern Nigeria and offer a valuable reference point for future air quality planning and policy-making.

To curb the pollution of particulate matter and safeguard public health in Jalingo Metropolis, the following measures for mitigation have been recommended: Routine monitoring of air quality, improved traffic emission management, and dust control at industrial and quarry operations.

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Authors' contributions

All authors read and approved the final manuscript.

Data availability

No datasets were generated or analyzed during the current study.

Declarations

Ethics approval and consent to participate

Not applicable. This study did not involve human or animal subjects.

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Competing interests

The authors declare that they have no competing interests.

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