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RESEARCH ARTICLE

ANALYSIS OF AIR QUALITY IN DIFFERENT ACTIVITIES HOTSPOTS IN RELATION TO VEHICULAR EMISSION IN YOLA METROPOLIS, NIGERIA

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ABSTRACT

The study analysed air quality in Yola Metropolis in relation to vehicular emission. The study combined air quality monitoring and Air Quality Index (AQI) assessments to analyze data on key vehicular pollutants (namely $PM_{2.5}$, CO, NO_2, and SO_2) from 13 monitoring locations. First, an attempt was made to clarify daily temporal variation of vehicular pollutant where findings revealed that average pollutants concentration was usually low during the morning hours but experiences rise in the evening. Findings also showed that the overall concentrations of CO, NO_2 and $PM_{2.5}$ have health effects on the public while SO_2 was considered satisfactory. Findings also revealed that most of the activity hotspots have high pollutant concentration, hence, the risk of adverse health outcome. In conclusion, high pollutants concentration prevails in most of the activity hotspots of the Metropolis and prolonged exposure to such pollutants possesses health risk. The study therefore recommends the need to introduce stricter emission standards for petrol-vehicles so as to reduce higher emissions; moderating automobile dependency and prioritizing HOVs to alternate the low carrying capacity public transports; need to consider active transport by engendering a walkable environment; supporting tree planting programs in the Metropolis among others things.

Keywords: Air quality, vehicular emission, air pollution, health risk, Yola metropolis

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1.0. INTRODUCTION

Air quality is a critical environmental and public health concern, particularly in a growing urban area. In many cities of the developing world (including Nigerians), increased population growth, traffic congestions among other things have contributed to the rising levels of air pollution. Air quality deterioration poses significant threat to public health and environmental sustainability, particularly in urban areas of developing countries. Exposure to elevated concentration of air pollutants such as CO, SO_2, NO_2, and $PM_{2.5}$ has been linked to respiratory and cardiovascular diseases (World Health Organization [WHO], 2025; United State Environmental Protection Agency [USEPA], 2025). WHO, 2021; Chen *et al.*, 2022). In response to these risks, WHO (2021) and the Nigeria's Natioal Environmental Standards and Regulation Enforcement Agency (NESREA, 2014) have established ambient air quality guidelines to protect human health.

Yola Metropolis, the capital city of Adamawa state, has experienced significant urban expansion in recent years, which is accompanied by increased vehicular emissions and other pollutant sources (Zemba & Tukur, 2020). Despite these pollutant sources, routine air quality monitoring in the Metropolis remains limited, hence limited data exist on the ambient air quality conditions. There is significant lack of comprehensive, consistent air quality data in Nigeria stemming from insufficient monitoring stations, outdated equipment, budget constraint, and fragmented systems despite clear evidence of severe pollution from sources most especially vehicle emissions (None *et al*., 2025; Olise *et al*., 2025; Ajayi, 2022). Similarly, lack of data availability severely restricts research on transport-related studies in less developed nations (Metta, 2019). This study therefore analyses the air quality in Yola Metropolis by assessing key atmospheric pollutants and comparing the findings with established air quality standards.

2.0. CONCEPTUAL FRAMEWORK

Conceptual Link between Vehicle Emissions Air Quality and Public Health

Vehicular emissions, which result from rapid urbanization and increased vehicular traffic, particularly in urban centres increases the risk of adverse health outcome. Extensive evidence has shown strong associations between air pollution exposure and several diseases, such as respiratory and cardiovascular, and issues pertaining to child development (Chen *eta al*., 2022) and to some extent even death (WHO 2021; USEPA 2021). According to WHO (2021), poor air quality is strongly linked to: respiratory diseases (asthma, bronchitis, reduced lung function); cardiovascular diseases (hypertension, heart attack, stroke); Premature mortality and Increased hospital admissions and health costs. Thus, degrading air quality acts as a mediating factor between vehicle emission and public health risk. The conceptual framework (Figure 1) is presented as a flow chart diagram illustrating the pathway through which vehicle emission influence air quality and consequently, public health risk in an urban environment. The diagram begins with:

i. **Vehicle Emission Sources:** Urban transport systems are the major source of air pollution, such emission sources include motorcars, motorcycle, buses, and trucks. These sources generate pollutants such as Particulate Matter ($PM_{2.5}$ and PM_{10}) Nitrogen-oxide (NO_2), Carbon-monoxide (CO), Sulphur-dioxide (NO_2) among others. Factors such as traffic

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congestion, poor vehicle maintenance, fuel quality, and road conditions intensify emission levels.

ii. **Ambient Air Quality Degradation:** Vehicle emissions the accumulation of pollutants in the urban atmosphere, leading to deterioration of ambient air quality. When pollutant concentration exceeds WHO Air Quality Guidelines and Nigeria's National Ambient Air Quality Standards, the air becomes unsafe for human exposure. Poor air quality is influenced by meteorological conditions (such as wind speed, temperature, and atmospheric stability) and urban characteristics (traffic volume, road density and land use pattern) act as modifying factors within this stage.

iii. **Human Exposure Pathways (Interface):** This stage illustrates how urban residents are exposed to polluted air through inhalation during daily activities, prolonged exposure near roads, particularly those living or walking close to major roads, transport hubs, and commercial areas. Vulnerable groups such as children, the elderly, people with pre-existing respiratory or cardiovascular conditions as well as roadside traders and traffic workers experiences high exposure level.

iv. **Public Health Risk (Outcome):** Prolonged or repeated exposure to vehicle-related air pollution increases the risk of adverse health outcomes, including respiratory illnesses, (asthma, bronchitis), cardiovascular diseases (hypertension, heart disease, stroke), premature mortality and Increased hospital admissions and health costs (WHO, 2021).

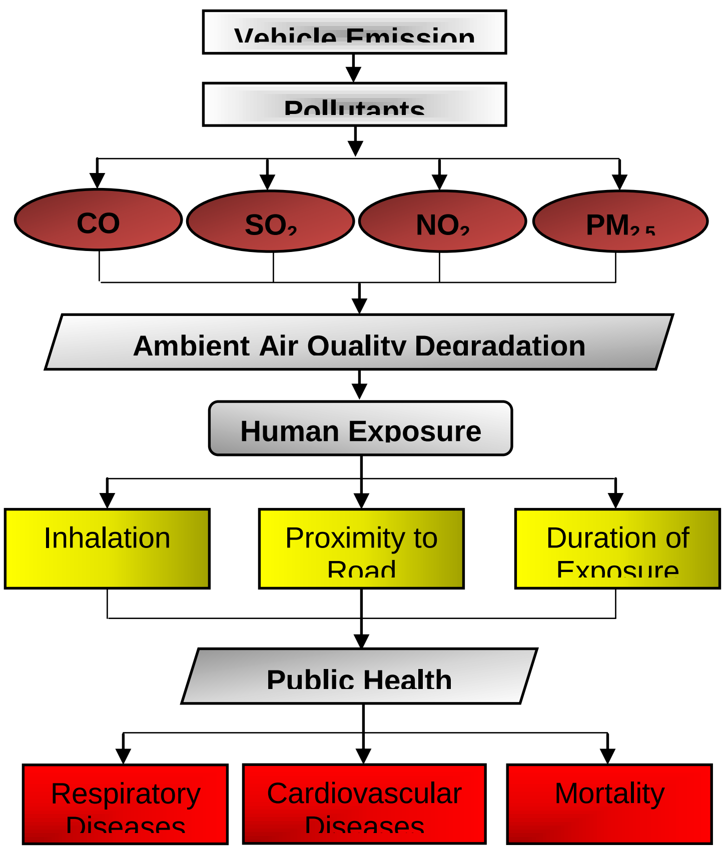

Figure 1: Conceptual Link between Vehicle Emissions Air Quality and Public Health

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3.0. MATERIALS AND METHODS

3.1. Description of the Study Area

Yola Metropolis (also referred to as Greater Yola), is the capital city of Adamawa State, North-eastern Nigeria. It is made up of twin cities of Yola and Jimeta and to some extent constituted some part of Girei Local Government Area. Since the creation of Gongola state, and subsequently Adamawa state, Yola and its twin settlement, Jimeta, (6 Kilometers due North) became the capital of Adamawa state and local government headquarters Yola North and Yola South local government areas respectively (Tukur & Barde, 2014). Yola Metropolis is located between 9^o 10' N and 9^o 30' N latitude and 12^o 20' E and 12^o 50' E longitude and it covers an area of about 1,982.49 Km^2.

Relatively, Yola Metropolis is bounded by Song LGA in the North, Fufore LGA on the South and Demsa LGA in the west (Figure 2). The study area has a projected population of 838,300 in 2022, which is roughly 16% of the entire population of the state, with Fulani and Hausa being the major languages spoken. The male gender accounted for 354,944 people, while the female gender accounted for 389,602. In terms of population density, the study area has the highest in the state, with 1,127 people per square kilometer (Dasin *et al.*, 2020). The study area has been experiencing an increasing population explosion since it assumed a status of Adamawa State capital in 1976 (Ilesanmi, 2020).

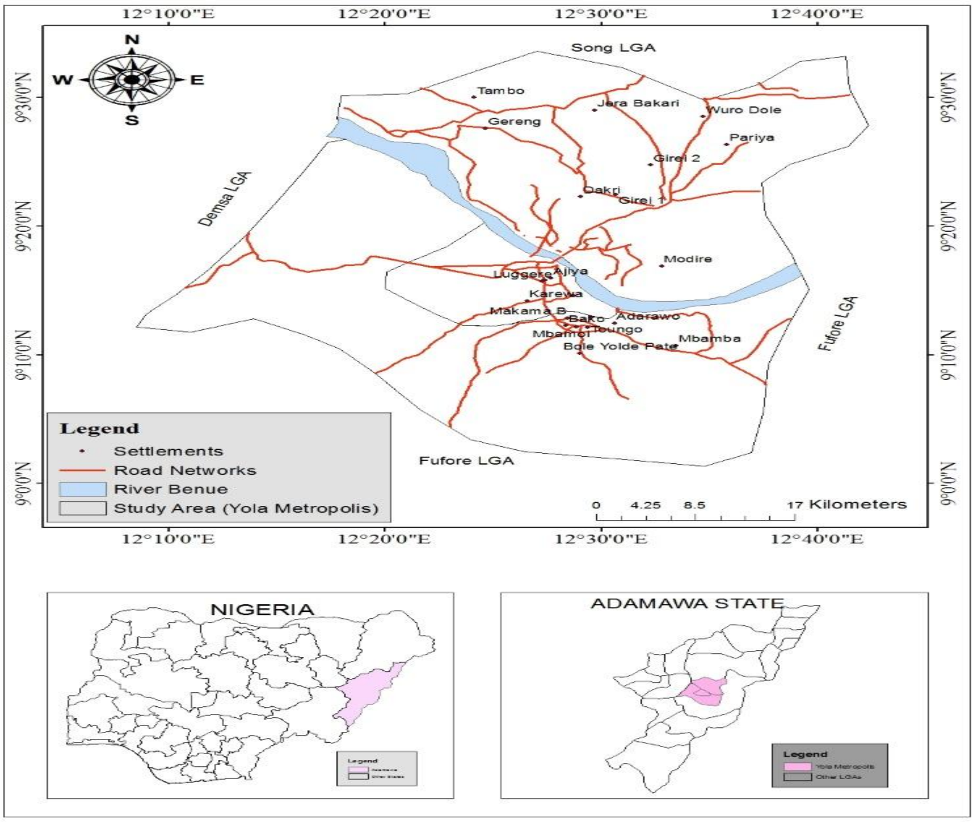

Figure 2: Yola Metropolis

Source: Geography Dept GIS Laboratory, Modibbo Adama University, Yola, (2023).

3.2. Methods of Data Collection

Types and Sources of Data

Field measurement was used to obtain data on atmospheric air pollutants namely Particulate Matter ($PM_{2.5}$), Carbon-monoxide (CO), Nitrogen-dioxide (NO_2), and Sulphur-dioxide (SO_2) using gas monitoring devices. The Gas-monitors/detectors were obtained from Adamawa State Ministry of Environment. Similarly, secondary data on Air Quality Standard were also utilised via several agencies including Federal Environmental Protection Agency of Nigeria (FEPA), international agencies such as Environmental Protection Agency (EPA), United States Environmental Protection Agency. (US-EPA) as well as World Health Organization (WHO). Additionally, data from Google Earth map was also used as input via the Geographic Information System (GIS) to generate coordinates of the selected sample points.

3.3. Procedure for Data Collection

Air quality parameters which include $PM_{2.5}$, CO, NO_2 and SO_2 were collected using Hinerway CW-HAT200 and Altier 5x Gas-monitors/detectors. The Gas-monitors automatically records the concentration of the targeted pollutant in the atmosphere using in-situ sensing mechanism. GPS was also used as an assisting tool to record the geographical location of the sampled locations, when ready to use, the gas analyzer was switched on and held at a ground level (at 10-15 centimeter above ground level) in relation to traffic of the sampling points and was recording the targeted pollutant concentration levels in either Micrograms per cubic meter ($\mu g/m^3$) or Parts Per Million (Ppm) calibration.

Based on observation during reconnaissance survey, thirteen (13) sample points (irrespective of residential boundaries) were purposely selected as the locations for measuring the air quality pollutions. As listed in Table 8, these locations represent the prevalent socioeconomic activities hotspots such as main city market, transport bus stations and corridors, major road intersections among others. The samples were collected from September to October 2024 on daily basis at each sample unit 4x daily between time interval of 07.00-09.00Hrs, 09.00-11.00Hrs, 11.00-13.00Hrs, 13.00-15.00Hrs, 15.00-17.00Hrs period.

Table 8: Air Quality Detection Sample Points

S/N	Sample Points	Location Name	Coordinates
1	**A**	A. A. Lawal Junction	9° 14′ 20.8″ N 12° 27′ 20.1″ E
2	**B**	Airport R/about	9° 16′ 39.6″ N 12° 25′ 27.5″ E
3	**C**	Bank Rd R/about	9° 15′ 54.8″ N 12° 26′ 48.7″ E
4	**D**	By-pass Market	9° 17′ 13.1″ N 12° 25′ 57.2″ E
5	**E**	Jambutu By-pass	9° 16′ 51.9″ N 12° 24′ 58.2″ E
6	**F**	Jimeta Market	9° 16′ 35.5″ N 12° 26′ 13.9″ E
7	**G**	Jippu Jam R/about	9° 12′ 44.7″ N 12° 27′ 54.5″ E
8	**H**	MAU Yola Gate	9° 20′ 30.9″ N 12° 30′ 26.7″ E
9	**I**	MAUTH Junction	9° 11′ 47.8″ N 12° 29′ 24.0″ E
10	**J**	Mubi R/about	9° 16′ 45.9″ N 12° 27′ 05.0″ E
11	**K**	Police R/about	9° 15′ 29.9″ N 12° 27′ 20.5″ E
12	**L**	Vinikilang Junction	9° 18′ 03.5″ N 12° 28′ 32.2″ E
13	**M**	Yola Market	9° 12′ 20.1″ N 12° 28′ 59.1″ E

Source: Field Survey (2024).

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3.4. Methods of Data Analysis

The data collected were mainly subjected to descriptive and Air Quality Index (AQI assessment. Air Quality Index (AQI) of the pollutants were determined in order to evaluate the health risk which the public are exposed due to atmospheric pollution of the areas of interest. In analysing the air quality, statistical mean was used to measure the concentration of the air pollutants while the AQI was calculated by converting the measured pollutants concentrations (average mean) to uniform index which is based on the health effects associated with such pollutants. The health benchmark used for calculating the Air Quality Index (AQI) are pollutants specific and are established by the EPA through the national ambient air quality standards. This was automatically done using an AQI calculator (airnow.gov, USEPA, 2014), Nigerian National Ambient Air Quality Standard (NAAAQS) and WHO (2021) Air Quality Guidelines (Table 1 and 2).

Table 1: National Ambient Air Quality Standard (NAAAQS)

Pollutant	Pollutants Concentration Limits			
	Averaging Time	**Nigeria (NAAAQS)**	**Averaging Time**	**WHO (AQG)**
CO	1 Hr.	10ppm (11.4 μg /m^3)	1 Hr.	35 μg/m^3
	8 Hr.	20ppm (24.7μg /m^3)	8 Hr.	10 μg/m^3
	-	-	24 Hr.	4 μg/m^3
SO_2	1 Hr.	0.01ppm (260μg/m^3)	10 Min.	500 μg/m^3
	24 Hr.	0.1ppm (0.0282μg /m^3)	24 Hr.	40 μg/m^3
NO_2	1 Hr.	0.04ppm (22.8μg/m^3)	1 Yr.	10 μg/m^3
	24 Hr.	0.06ppm (0.112μg /m^3)	24 Hr.	25 μg/m^3
$PM_{2.5}$	1 Hr.	250μg/m^3	24 Hr.	15 μg/m^3

Source: FEPA (2016) and WHO (2021)

Table 2: The Air Quality Index (AQI) Colour Table

AQI Levels of Health Concern	Numerical Value	Remark
Good	0-50	Air quality is considered satisfactory, and air pollution poses little or no risk.
Moderate	51-100	Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution.
Unhealthy for sensitive Group	101-150	Members of sensitive groups may experience health effects. The general public is not likely to be affected.
Unhealthy	151-200	Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects.
Very Unhealthy	201-300	Health alert: everyone may experience more serious health effects.
Hazardous	> 300	Health warnings of emergency conditions. The entire population is more likely to be affected.

Source: USEPA, (2014)

Additionally, concentration of pollutants in the atmosphere was established in various unit of measurements to analyse and present results (Canadian Centre for Occupational Health and Safety [CCOHS] 2021). This study adopted specifically the method of converting Micrograms per cubic meter (μg /m^3) to Part per Million (Ppm), Ppm to Part per Billion (Ppb) and vice versa (Formulas 1 2, 3 and 4):

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$$XPpm = (Y\ \mu g/m^3)(24.45)/(Molecular\ Weight)$$ ---------------------------- (1)

Or

$$Y\ \mu g/m^3 = (X\ Ppm)(Molecular\ Weight)/(24.45)$$ ---------------------------- (2)

The conversion equation is based on 25^0C and 1 Atmosphere.

$$Ppb = X\ Ppm \times 1000$$ -- (3)

Or

$$Ppm = X\ Ppb\ /\ 1000$$ -- (4)

4.0. PRESENTATION OF RESULTS AND DISCUSSIONS

4.1. Daily Temporal Variation of Vehicular Pollutant Concentration

The mean temporal variation of vehicular exhaust pollution concentration in the atmosphere with reference to four air pollutants which include CO, SO_2, NO_2, and $PM_{2.5}$ (all converted to micrograms per cubic meter [$\mu g/m^3$]) as presented in Figures 3, 4, 5 and 6 revealed greater variation between the sample pollutants, but the average concentration of each of the four (4) pollutants analysed was usually low during the morning hours of 7:00 to 9:00 am but experiences rise in pollutant concentration in the evening period (especially at 16:00 to 18:00). This finding was in line with the views of Zakaria *et al.* (2021) that the low concentration in the morning was because the atmosphere is still fresh and the air has not been saturated by vehicle exhaust and other air pollution sources at the time. While the evening period experiences high pollution because the atmosphere is saturated by different sources of pollutants ranging from vehicle exhaust, generators and other air pollution sources due to various human activities making the air quality unhealthy and above US and Nigerian NAAQS as well as WHO Air Quality Guidelines (AQG).

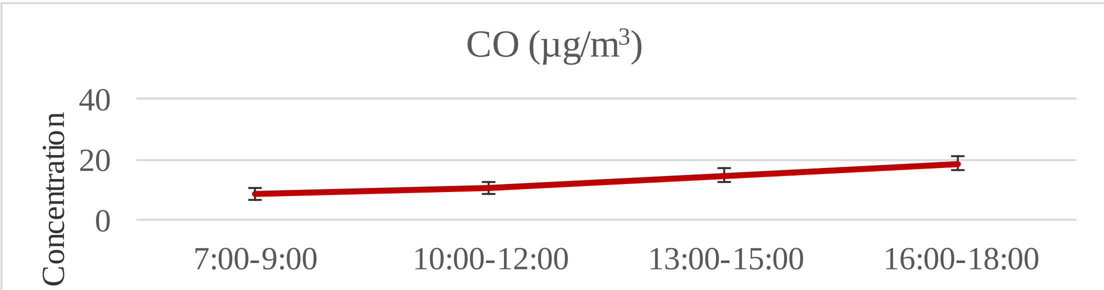

Figure 3: Mean Temporal Variation of CO Concentration

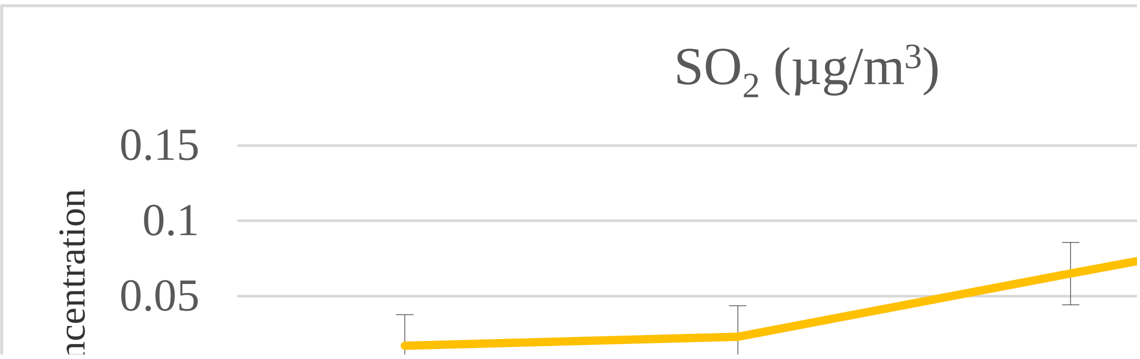

Figure 4: Mean Temporal Variation of SO_2 Concentration
Source: Authors' Field Survey (2024).

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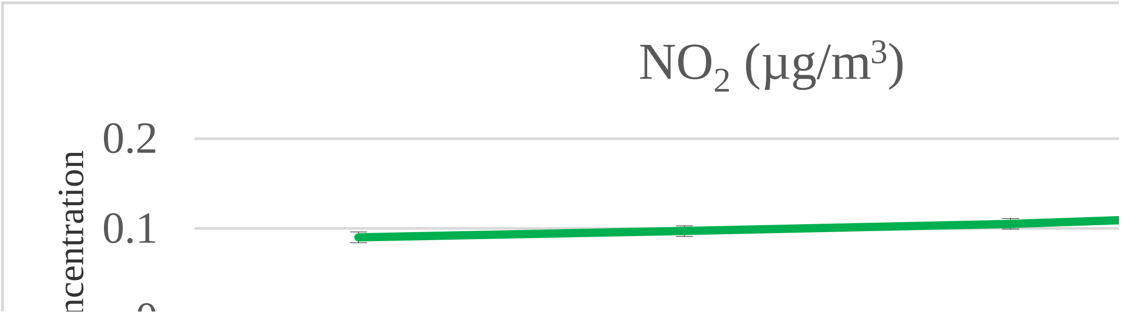

Figure 5: Mean Temporal Variation of NO_2 Concentration
Source: Authors' Field Survey (2024)

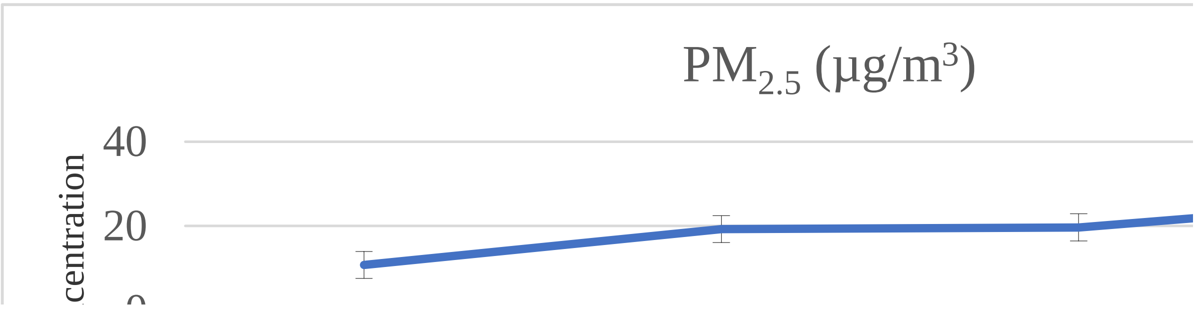

Figure 6: Mean Temporal Variation of $PM_{2.5}$ Concentration
Source: Authors' Field Survey (2024).

4.2. The Assessment of Overall Mean Value of Pollutants Concentration

Evaluation of the average ambient air quality for the study area presented in Figure 7 revealed that the overall mean value of 13.01 Ppm (14.9 µg /m^3) for CO was high above the Nigerian (NAAAQS) pollution concentration limit of 11.4 µg /m^3 (10ppm) per hour. Similarly, the result also showed NO_2 with 0.102375 Ppm (0.2 µg /m^3) was above the Nigerian (NAAAQS) pollution concentration limit of 0.0282µg /m^3 (0.1ppm) in 24 hours. While SO_2 with value of 0.05275 Ppm (0.05957 µg /m^3) and NO_2 with 0.102375 Ppm (0.2 µg /m^3) was slightly below the Nigerian (NAAAQS) pollution concentration limit of 0.112µg /m^3 (0.06ppm). Whereas, the overall mean values of $PM_{2.5}$ (20.5617 in µg/m^3) was found to be lower than the Nigerian (NAAAQS) mean pollution concentration limit of 250 µg/m^3 per hour. However, the implication of this findings based on WHO Global Update (2021) indicates that long term exposure to particulate matter concentration in the air above 10µg/m^3 can cause health problems such as Lungs Cancer, Heart Disease, Lungs Disease, and Asthma Attacks.

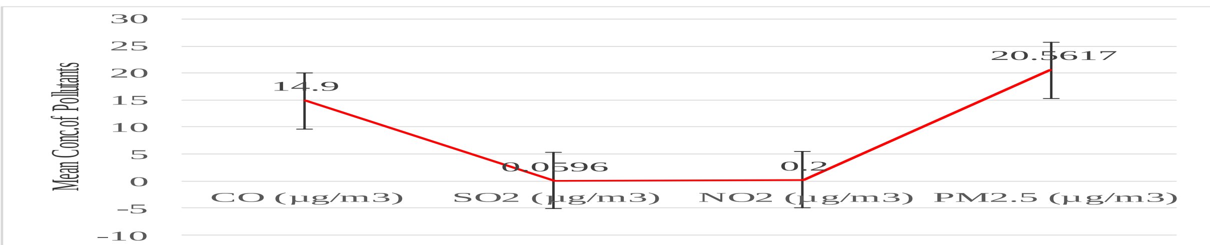

Figure 7: The Overall Mean Value of Pollutants Concentration in Yola Metropolis
Source: Authors' Field Survey (2024).

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4.3. Evaluation of Air Quality Index (AQI) for the Sampled Pollutants

AQI for the sampled pollutants was determined in order to evaluate the health risk the public will be exposed due to atmospheric pollution. It shows how clean or polluted the air condition is, and what associated health effects might be a concern to the public (AirNow, 2016; USEPA, 2014). The mean concentration of pollutants along with the calculated AQI values (presented in Table 3) shows that CO was considered unhealthy and that everyone may begin to experience health effects, household members of sensitive groups may experience more serious health effects and especially people with heart diseases are the group most at risk. NO_2 was considered unhealthy for sensitive groups and household members of sensitive groups may experience health effects.

For example, people with asthma or other respiratory diseases, the elderlies and children are the groups most at risk. The concentration of $PM_{2.5}$ on the other hand was moderate. People with asthma or other respiratory diseases, the elderlies and children are the groups most at risk. Also, unusually sensitive people should consider reducing prolong or heavy exertion. SO_2 was the only pollutant found to be good in terms of air quality and was considered satisfactory, and poses little or no risk to the general public. Khreis (2020), in support of this finding stated that vehicle and truck air pollution in urban cities is a major public health issue because it can induce lung and heart diseases.

Table 3: AQI for the Study Area

Pollutants	**Concentration ($\bar{x}$)**			**AQI**	**AQI Color & Level of Health Concern**
	Ppm	**Ppb**	**μg /m^3**		
CO	13.9	13,010	14.9	159	Unhealthy
SO_2	0.05275	52.75	0.059	71	Good
NO_2	0.10237	102.37	0.2	101	Unhealthy for sensitive groups
$PM_{2.5}$	-	-	20.56	72	Moderate

Source: Authors' Field Survey (2024).

4.4. High Pollutants Concentration Hotspot in Yola Metropolis

High pollutants concentration hotspot in Yola Metropolis presented in Table 4 and Figure 8 shows condition pollutants were CO and $PM_{2.5}$ where AQI level of health concern for CO at Jimeta Market was considered hazardous indicating greater health risk on the entire population. CO at Jambutu By-pass, Vinikilang Junction and at Yola Market was considered very unhealthy signifying health alert and that everyone may experience more serious health effects. On the other hand, CO at Airport R/about and as well at Mubi R/about was considered unhealthy and that everyone may begin to experience health effects, also in addition, members of sensitive groups may experience more serious health effects Similarly, $PM_{2.5}$ at By-pass Market was unhealthy but in contrast, CO was considered unhealthy for sensitive group at this same location. The result implies that poor air quality in some of the key activity areas has a direct physical impact on some households living in such areas, most especially in the high-density neighbourhoods (as presented in Figure 30).

This indicates that household members of sensitive groups may experience health effects while the general public is not likely to be affected. It is of utmost important to note that any pollutants concentration that exceeds the air quality limit in any location is considered unhealthy. By implication, even if CO is considered normal for such a location while $PM_{2.5}$ is slightly beyond the air quality limit for that same location, such location is considered unhealthy irrespective of the

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acceptable CO concentration (EPA, 2018). This was due to the fact that there is no pollutant that is considered safe for human being and that prolonged exposure of individuals/household to such conditioned pollutants at any locations is highly risky and should be avoided (EPA, 2018). In essence, the disproportionate direct exposure of certain population groups to air pollution is highly risky.

Table 4: Locations with High Pollutants Concentration

Location Name	Condition Pollutants	Mean Value	AQI	AQI Colour & Remark
Airport R/about	CO (ppm)	13.16	161	Unhealthy
By-pass Market	CO (ppm)	11.32	130	Unhealthy for Sensitive Group
	$PM_{2.5}$ (μg/m^3)	95.3	171	Unhealthy
Jambutu By-pass	CO (ppm)	16.39	206	Very Unhealthy
Jimeta Market	CO (ppm)	33.17	327	Hazardous
Mubi R/about	CO (ppm)	13.84	172	Unhealthy
Vinikilang Junction	CO (ppm)	21.10	237	Very Unhealthy
Yola Market	CO (ppm)	17.36	212	Very Unhealthy

Source: Authors' Field Survey (2024).

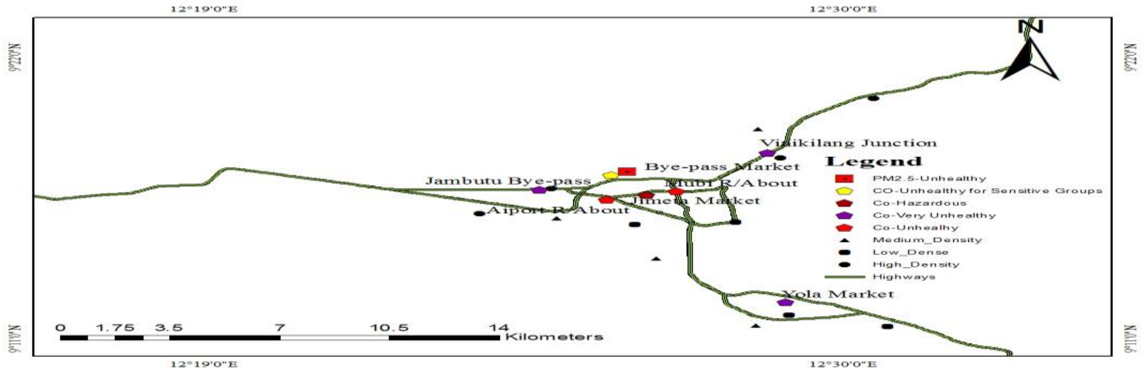

Figure 8: Locations with High Pollutants Concentration
Source: Authors' Field Survey (2024).

5.0. CONCLUSION AND RECOMMENDATIONS

The research study aimed to analysed air quality in different activities hotspots of Yola Metropolis in relation to vehicular emission, Adamawa State, Nigeria. Firstly, an attempt was made to clarify daily temporal variation of vehicular pollutant and it was revealed that the average concentration of the four pollutants analysed was usually low during the morning hours but experiences rise in pollutant concentration in the evening period (especially at 16:00 to 17:00). Findings with regard to the health risk of vehicular emission showed that the overall concentrations of CO, NO_2 and $PM_{2.5}$ have health effects whereas SO_2 was considered satisfactory, hence poses little or no risk. Findings also revealed that most of the activity's hotspot locations were considered very unhealthy due to high pollutant concentration most especially CO and $PM_{2.5}$, hence, posing more serious health effects.

In conclusion, it is also clear that high pollutants concentration prevails in most of the activity hotspots of the Metropolis and prolonged exposure to such pollutants possesses high risk. The finding based on WHO Global Update, (2020) indicates that long term exposure to such pollutants particularly Particulate Matter (PM) concentration in the air above 10μg/m^3 can cause health problems such as lungs cancer, heart disease, and asthma attacks. By implication, even if CO is considered normal for a certain location while $PM_{2.5}$ is slightly beyond the air quality limit for that same location, such location is considered unhealthy irrespective of the acceptable CO concentration (EPA, 2018). This was due to the fact that there is no pollutant that is considered safe for human being and that prolonged exposure of individuals/household to such conditioned pollutants at any locations is highly risky and should be avoided (EPA, (2018). Based on the study findings, the following recommendations were put forward:

I. Government and policy makers, through Federal/State Ministry of environment and other related agencies to introduce stricter emission standards for petrol-vehicles like catalytic converters in petrol vehicles so as to reduce CO emissions;
II. Moderating automobile dependency and prioritizing Higher Occupant Vehicle (HOV) to alternate the low carrying capacity public transports in the Metropolis;
III. The need for Federal/State Ministry of transport to offer consideration for active transport by engendering a walkable environment which will in turn foster active travelling as well as cycling, which consequently would improve urban environments and as well erase the ideology of perceiving active travel particularly in developing countries, often as a necessity rather than a choice.
IV. Supporting tree planting programs to serve as carbon sinks especially near activity hotspots in the Metropolis to help reduce human exposure to carbon monoxide (CO), as trees absorb carbon-related gases.

Data Availability Statement

Data for this article are analyzed in the main Text. Details of the laboratory results can be made available by the authors on request.

Conflict of Interest

The authors declare no conflict of interest.

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