KADUNA JOURNAL OF GEOGRAPHY
2026, VOL. 8, No. 1, 22-28
https://doi.org/10.47514/kjg.2026.08.01.003

Research Article

Assessment of the Impact of Vehicular Carbon Dioxide Emissions on Climate Change in Zaria Metropolis, Kaduna State, Nigeria

Muhammed, A. Y. [a], Habila S. K. [b], Mustapha, M. [a], Balarabe, M. [a], Abdullahi S. Y. [c]

[a] Kaduna State University, Kaduna State, Nigeria. [b] Ahmadu Bello University, Zaria, Nigeria. [c] Nuhu Bamalli Polytechnic, Zaria, Nigeria

ABSTRACT
Urban transport is one of the key contributors to greenhouse gas emissions in rapidly developing cities. In Zaria metropolis, three nodes are identified to be hotspots for carbon dioxide (CO_2) and other greenhouse gas emissions. They are: Kofar Doka Cloverleaf, PZ Junction, and Flyover at Kwangila. This study assessed CO_2 emission levels at the three designated spots. Temperature rise at the spots was attributed to the increased CO_2 emission. A multi-user instrument for measuring greenhouse gases Multi-Gas Analyser (Model: Testo 350 Portable Emission Analyser), was used to measure the CO_2 levels. The analyser was calibrated before each session to ensure accuracy. Surface temperature conditions from NiMET; standards from NESREA, and the WMO, were compared with the data collected from the field, and correlation and regression analysis were carried out. Findings indicated the concentrations of carbon dioxide above the world average. They are: 455 ppm, 586 ppm, and 620 ppm for Kofar Doka, PZ, and Kwangila, respectively. Findings further revealed a significant correlation between vehicular density and carbon dioxide concentration at ($r = 0.81$, $p < 0.05$) and CO_2 concentration, and a moderate correlation ($r = 0.67$, $p < 0.05$) between mean temperature and CO_2 levels, revealing significant local warming effects. The study concluded that vehicular emissions highly increase the climate change vulnerability in the transport sector of Zaria Metropolis. The study therefore recommended the provision of efficient public transport systems, emission testing, and urban greening to mitigate impacts.

ARTICLE HISTORY
Submitted 29 November 2025
Accepted 20 January 2026
Published 27 February 2026

GUEST EDITOR
A. M. Ahmed

KEYWORDS
carbon dioxide, emission, temperature, vehicular density

1 Introduction

Climate change is seen as our planet's biggest existential threat (Natural Resources Defense Council [NRDC], 2022). Globally, anthropogenic greenhouse gas (GHG) emissions, especially carbon dioxide (CO_2), are the primary drivers of global warming (Olajire, 2011; Intergovernmental Panel on Climate Change [IPCC], 2022). According to multiple sources, carbon dioxide is the leading contributor of greenhouse gases, contributing as high as 76% of the total Environmental Protection Agency [EPA], 2022; Zubair, 2023). Zubair (2023) further reported that the major sources of greenhouse gases are: the transport sector, the industrial sector, and domestic uses, among others.

Studies have shown that there is a strong connection between rapid urbanisation and increased transportation in Nigeria and across the globe, and in turn, increased carbon dioxide and other greenhouse gas emissions (Ndoke et al., 2006; PerkinElmer, 2025). Zaria Metropolis, a major educational and commercial centre in northern Nigeria, is characterised by high vehicular traffic density, narrow road corridors, and increasing congestion (Sani et al., 2025), particularly around Kwangila Flyover, PZ Roundabout, and Kofar Doka. These factors make it a significant emission hotspot.

Previous studies, such as Sadiq (2022) and Ahmed et al. (2022), revealed that poor vehicular maintenance, aged fleets, and the use of low-quality fuels contribute significantly to elevated CO_2 and particulate matter levels in urban centres. Sadiq (2022) further found that carbon dioxide emissions from urban transport in Kano metropolis are above the global maximum average, which triggers the increased temperature in the local microclimate of metropolitan Kano and exposes the public to negative health impacts.

This study, therefore, assessed the concentration and spatial variation of carbon dioxide emissions in three selected hotspots in Zaria Metropolis. The study evaluates the correlation between traffic density and temperature rise, and discusses the implications for local climate change. The result of the study is also compared with the international recommendation set by the World Meteorological Organisation and the national standard set by the National Environmental Standard Regulation and Enforcement Agency to highlight the potential risks.

2 Materials and Methods

2.1 Study Area

Zaria is located between Latitude 11ºC4' to 11ºC11' North of the Equator and Longitude 7ºC12' to 7ºC42' East of the Greenwich. Zaria is about 160 km southwest of Kano (Ibrahim, 2024). See Figure 1. The climate of Zaria is tropical savanna (Koppen's classification *Aw*) with warm weather year-round, a wet season lasting from April to October, and a dry season from November to March (Auwal, 2019). The climate is influenced by the tropical

Corresponding Author: Muhammed, A. Y. abdulkadir.yahaya@kasu.edu.ng Kaduna State University, Kaduna State, Nigeria.

continental air mass that carries dust from the Sahara and tropical maritime air mass that carries moisture from the Atlantic Ocean. The mean annual rainfall is about 1100mm, and the daily temperature is from 16 °C to 32 °C depending on the time and season (Oluwatoyin, 2013). This has increased to above 35 °C recently (NiMET, 2025).

Owing to its interior location of about 670km north of the Atlantic Ocean, Zaria metropolis experiences a Tropical Continental Climate characterized by distinct wet and dry seasons subject to the movement of the Intertropical Discontinuity (ITD) associated with Tropical Continental and Tropical Maritime air masses. The former air mass originates from the Sahara Desert and is therefore dry, bringing dusty and hazy conditions known as 'harmattan' to the region in the dry season, while the latter air mass originates from the Atlantic Ocean and is hence moist and rain-bearing. The humidity also drops to less than 15% in December/January (dry season). After that, the South Westerly Monsoon winds (Tropical Maritime Air mass) laden with moisture bring the rain accompanied by thunderstorms and squalls with heavy fall of high intensities. Humidity during the wet season reaches up to 82%, especially in August/September (Abbas, 2018).

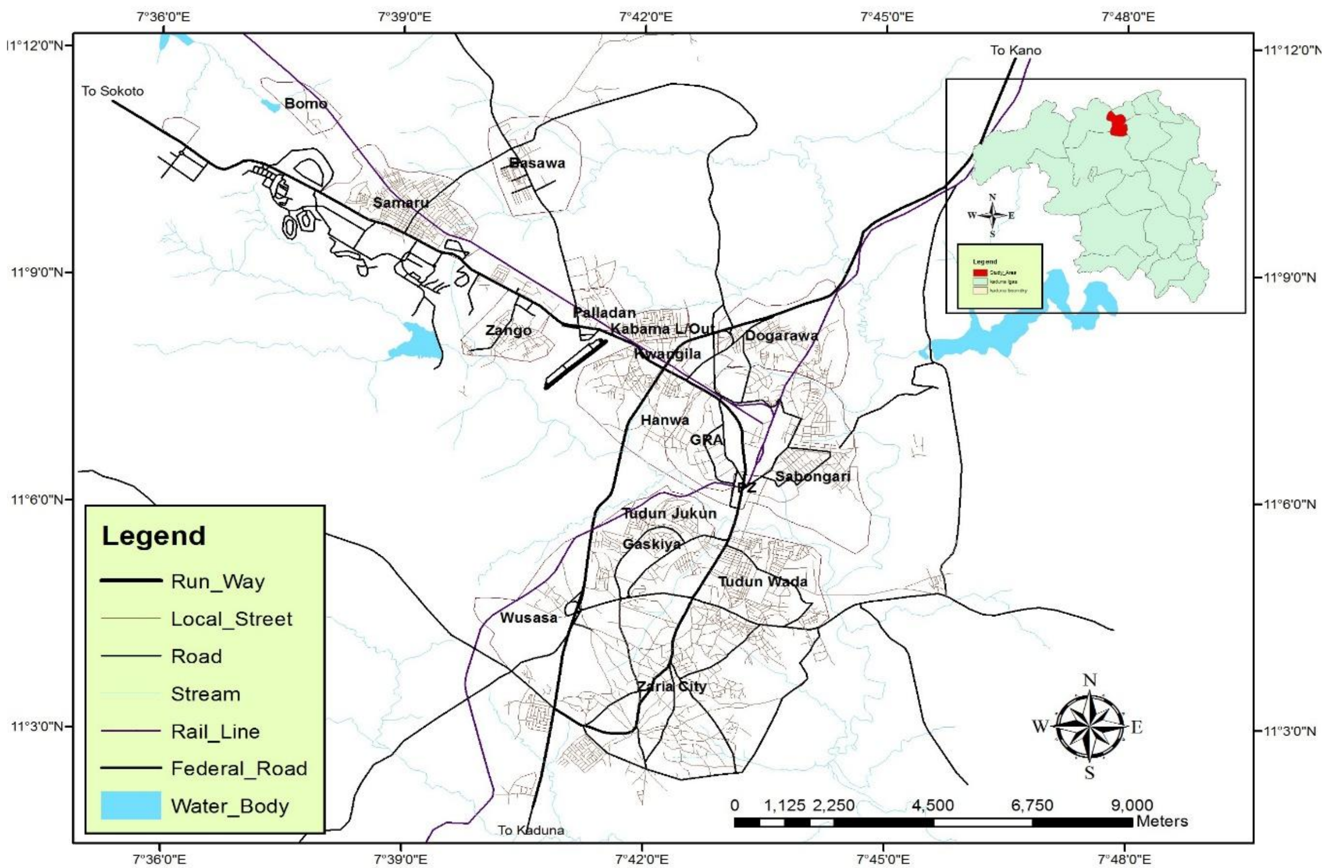

Figure 1: Zaria Metropolis in the Context of Kaduna State
Source: Adapted from the Administrative Map of Kaduna State, 2024

Zaria receives an average of 3840 hours of sunshine per year, and daylight ranges from 11 hours 28 minutes to 12 hours 45 minutes per day. Zaria usually has the most precipitation in July, August, and September, with an average of 24 rainy days and 184 mm (7.2 inches) of precipitation per month. The driest months in Zaria are January, November, and December. The sunniest months in Zaria are March, May, and July, when the sun shines an average of 10 hours 53 minutes a day. The least sunny months in Zaria are January, February, and August, which receive an average of 9 hours and 40 minutes of sunshine daily. Zaria experiences the highest level of ultraviolet (UV) radiation in April, July, and August, when the maximum UV index can reach values of 12 - 13, which corresponds to the Extreme category of sun exposure (Copernicus Climate Change Service and Information, 2022).

2.2 Data Sources

At least sixty (60) observation units, shared at twenty (20) per spot, were conducted. Each of the three hotspot units represents a time-averaged carbon dioxide reading, alongside the corresponding traffic counts and microclimatic measures. The analysis used a common p-value of 0.05 or 95% confidence level. Pearson correlation analysis with a uniform significance threshold of p = 0.05. Data collection involved direct field measurements using a portable digital instrument and observation technique.

The instrument used was a Multi-Gas Analyser (Model: Testo 350 Portable Emission Analyser), capable of detecting CO_2 concentration in parts per million (ppm) with a precision of ±50 ppm. The analyser was calibrated before each session to ensure accuracy.

Field sampling targeted three high-traffic nodes: Kwangila Flyover, PZ Area, and Kofar Doka. At each node, measurements were taken over six days, during peak and off-peak periods, to capture temporal variability. The raw vehicle tallies across all sampling events exceeded 1,000 vehicles; however, individual vehicles are not independent observations for the purposes of correlation analysis because the measured dependent variable (CO_2 concentration) is a site- and time-aggregated environmental reading. This practice follows established environmental monitoring protocols where the unit of analysis is the sampling instance rather than each mobile source (EPA, 2022; Raheem et al., 2024). Using these aggregated observations preserves independence across data points and provides robust inputs for Pearson correlation.

Each site was monitored for three days per week over two weeks (13^{th} -27th October, 2025), during morning (7–10 am), afternoon (12–3 pm), and evening (5–8 pm) peaks. For each session, five readings were taken at 10-minute intervals and averaged.

Traffic density was also recorded manually using a traffic count method (vehicles/hour), and meteorological parameters (temperature, humidity, wind speed, and rainfall records were obtained from NiMET (2024–2025) climate forecast reports.

The concurrent mean surface air temperature was recorded by a weather-grade thermistor at 1.5 m height.

2.3 Data Analysis

Data cleaning involved the removal of obvious instrument anomalies and the application of a two-pass calibration against a standard reference gas. Pearson correlation was computed in SPSS (v26) between pairwise variables (vehicle density ↔ CO_2; CO_2 ↔ temperature).

3 Results and Discussion

Table 1: The Mean CO_2 Concentrations, Vehicular Density, and Average Surface Temperature

Location	Average CO_2 (ppm)	Traffic Volume (veh/hr)	Mean Temperature
Kwangila Flyover	620	685	38.2
PZ Roundabout	586	610	37.6
Kofar Doka	455	380	35.9
Average	553	558	37.2

From Table 1, the mean concentration across all sites was 553 ppm, which exceeds the pre-industrial baseline of 280 ppm and the WMO (2021) recommended urban outdoor range of 450 ppm and 400 ppm, NESREA's (2010) standard. The highest levels were observed at Kwangila Flyover and PZ Roundabout, confirming these areas as critical CO_2 "hotspots" in Zaria Metropolis. These are also the areas Sani (2017) described as most congested in the metropolis.

This pattern supports the findings of Ahmed et al. (2022), who reported elevated CO and NO_2 concentrations in these corridors, attributing them to heavy traffic, low vehicle maintenance standards, and poor ventilation during congestion. Similar observations were reported in Ucheje and Okolo (2023) in their Nigerian study and Raheem et al. (2021) in Bauchi, where transport emissions accounted for over 50 % of urban CO_2 build-up.

Table 2: Relationship Between CO_2 and Meteorological Variables (Temperature) /Vehicular Density

Correlation analysis (Pearson's r, N = 60, p = 0.05)

Variables compared	Pearson's r	p-value	Interpretation
Conc. CO_2 vs Vehicle Density (veh/hr)	0.81	0.05	Strong positive correlation
Conc. CO_2 vs Mean Temperature (°C)	0.67	0.05	Moderate positive correlation

From Table 2, a-10-minute observation in each corridor was made in the three hotspots. The observation was accompanied by the traffic count to get the average and correlate with the carbon dioxide concentration. A weather-grade portable instrument for measuring temperature was used to record the potential temperature increase at sites with a height of 1.5 meters.

The r = 0.81 result reveals that approximately 65.6% of the variance in CO_2 concentration can be statistically associated with vehicle density ($r^2 = 0.656$), and the r = 0.67 indicates that 44.9% of the variance in temperature can be associated with CO_2 variation ($r^2 = 0.449$) recognising that association is not causation, but that these relationships are both substantive and policy-relevant (EPA, 2022; Ucheje & Okolo, 2023).

Or correlation analysis showed strong positive relationships between CO_2 concentration and mean surface temperature ($r = 0.81$, $p < 0.005$) and between CO_2 and traffic volume ($r = 0.67$, $p < 0.005$). Relative humidity and wind speed, however, had weak and statistically insignificant relationships ($r = –0.19$ and $–0.11$, $p > 0.005$), suggesting limited dispersion effect during the dry season.

These results are consistent with NiMET (2024) climate reports, which indicated rising mean daily temperatures in Zaria (now averaging 38°C, up from 34–35°C in 2015–2020). Elevated temperature promotes photochemical reactions and atmospheric stagnation, reducing pollutant dispersion and leading to localized heat accumulation, an indication of the urban heat island effect.

Furthermore, areas such as Magume, Gaskiya, Kofar Doka, and Kwangila, which were frequently affected by flood episodes in 2025, showed high CO_2 accumulation even under lower traffic counts, likely due to potholes and damaged pavements slowing vehicle flow, thus increasing idling emissions. This relationship between climate-induced road degradation and CO_2 build-up mirrors observations by the World Bank (2015) and IPCC (2022) on how infrastructure vulnerability amplifies emission persistence in developing cities.

3.1 Socioeconomic and environmental implications

High CO_2 concentrations in urban transport corridors have far-reaching implications for Zaria's environment and residents. Prolonged exposure aggravates respiratory and heat-related illnesses, as reported by Sadiq (2022), Ucheje and Okolo (2023), particularly among roadside vendors, commuters, and transport operators. The congested spots (Kwangila Flyover and PZ Roundabout), as found by Sani (2017), are the most exposed to the gases because of vehicle idling in the queue.

Economically, poor air quality increases vehicle maintenance costs and reduces worker productivity, especially for commercial tricycle (*Keke*) and motorcycle (*Achaba*) operators who spend extended hours in traffic. This corresponds with the vulnerability patterns identified in earlier objectives, where low-income commuters depend on high-emission transport modes, reinforcing transport poverty as noted by EPA (2022).

Environmentally, the continuous rise in transport-related CO_2 emissions contributes to local climate alteration, affecting rainfall distribution and exacerbating flooding risks along low-lying roads such as Magume–Gaskiya. The IPCC Report (2022) and NESREA (2010) underscore that even minor increases in localized CO_2 concentrations can intensify microclimatic variability, especially in inland urban basins like Zaria Metropolis (Sani et al., 2025).

The overall mean CO_2 concentration of 553 ppm markedly exceeds commonly cited ambient safety benchmarks (WMO; NESREA ambient guidance and EPA contextual thresholds) and indicates persistent transport-related enhancement of CO_2 within the urban canopy (NESREA, 2010; WHO, 2021; EPA, 2022). The highest concentrations were recorded at Kwangila Flyover and PZ Junction nodes, with the greatest vehicle throughput and frequent idling due to intersection queuing. Smaller values at Kofar Doka likely reflect local ventilation and lower sustained congestion.

3.2 Correlation analysis: rationale and computed relationships

To quantify relationships between vehicular activity, CO_2 concentration, and temperature, Pearson's correlation coefficients were computed using the $N = 60$ observation units. Two primary hypotheses were tested:

H_1: Vehicle density is positively correlated with measured CO_2 concentration.

H_2: CO_2 concentration is positively correlated with mean surface air temperature (i.e., higher local CO_2 relates to warmer local conditions).

Pearson's r is appropriate given the continuous nature of the variables and the normality approximation of aggregated means. All tests were evaluated at $p = 0.05$ (two-tailed), which is the uniform significance threshold adopted in this study.

The strong correlation ($r = 0.81$) between vehicle density and CO_2 concentration confirms that vehicle throughput and related traffic conditions (idling, stop-start movement) are principal drivers of urban CO_2 enhancement in Zaria Metropolis. This finding is consistent with Ucheje and Okolo (2023), who reported that vehicular activity explains the majority of urban emission variability in Nigerian cities, and with Raheem et al. (2024), who demonstrated that road geometry and congestion (e.g., speed bumps, intersections) significantly increase instantaneous CO_2 emissions.

The moderate correlation ($r = 0.67$) between CO_2 concentration and temperature suggests that elevated local greenhouse gas burdens co-occur with higher near-surface temperatures, a pattern that reflects both the greenhouse trapping mechanism (EPA, 2022) and urban heat island amplification. Locally, this relationship has two practical implications. First, increased temperatures accelerate thermal degradation of pavement materials, thereby shortening road service life and increasing maintenance costs (Raheem et al., 2024; Ucheje & Okolo, 2023; World Bank, 2015). Second, higher temperatures raise ambient energy demand (e.g., for cooling), which may indirectly feed back into higher emissions where electricity generation relies on fossil fuels (Sadiq, 2022).

4 Conclusion

This study provides empirical evidence that vehicular CO_2 emissions in Zaria Metropolis are well above permissible environmental standards. The strong positive relationship between vehicular density and CO_2 concentration confirms that transport is a dominant contributor to greenhouse gas emissions and urban warming. The comparison with NESREA and WMO recommendations highlights a deviation of 35.7%, indicating significant environmental degradation.

These emissions not only contribute to global climate change but also have localised effects on temperature, air quality, and infrastructure sustainability. The data demonstrate that high traffic areas such as Kwangila and PZ are hotspots of both carbon emissions and heat accumulation.

The study recommended the following:

i. Regular Emission Testing: NESREA and the Kaduna State Environmental Protection Agency should enforce annual vehicle emission tests to ensure compliance with CO_2 limits.

ii. Promotion of Public Transport: Adoption of energy-efficient buses and non-motorised transport should be prioritised to reduce individual vehicle use.

iii. Urban Greening: Increasing tree cover along major roads can absorb atmospheric CO_2 through sequestration and mitigate heat accumulation.

iv. Awareness Campaigns: Public education on the impacts of vehicular emissions should be intensified through local radio and social media platforms.

v. Integration of Climate Data in Urban Planning: NiMET data on temperature and CO_2 trends should guide future road and urban development projects.

References

Abbas, S. (2018). Factors Influencing the Pattern of Residential Property Values in the Zaria Urban Area, Nigeria. Dutse Journal of Pure and Applied Sciences (DUJOPAS), 4(2): 169-177.

Ahmed, J. M., Dogo, B., Baba, S. U., Abdulkadir, Y.M. (2022). Assessment of Vehicular Emissions on Ambient Air Quality in Zaria Metropolis. Science World Journal 17(2), 221-226.

Auwal, S. A. (2019). An Assessment of Domestic Water Supply in Traditional Cities of Northern Nigeria. An Example of Zaria City. An Unpublished Undergraduate Project, Department of Geography, Ahmadu Bello University, Zaria, Nigeria.

Copernicus Climate Change Service and Information (2022). https://doi.org/10.1175/BAMS-D-21-0315.1/ijepr.13/vol11n14362.

EPA. (2022). Overview of Greenhouse Gases: Carbon Dioxide Emissions. United States Environmental Protection Agency.https://www.epa.gov/ghgemissions/overview-greenhouse-gases.

Federal Government of Nigeria (2021). Updated Nationally Determined Contribution (NDC). UNFCCC. https://www4.unfccc.int

Ibrahim, Z. J. (2024). Assessing the Role of Media in Creating Awareness about Climate Change in Zaria Metropolis. An Undergraduate Project, Department of Geography, Ahmadu Bello University, Zaria

IPCC (2022). Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. https://www.ipcc.ch/report/ar6/wg2/

Natural Resources Defense Council [NRDC] (2022). What Are the Effects of Climate Change? https://www.nrdc.org

Ndoke, P. N., Akpan, U.G. & Kato, M.E. (2006). Contributions of Vehicular Traffic to Carbon-Dioxide Emissions in Kaduna and Abuja, Northern Nigeria. Leonardo Electronic Journal of Practices and Technologies, 5(9), 81-90.

NESREA. (2010). National Environmental (Air Quality Control) Regulations. Federal Ministry of Environment, Abuja. https://www.nesrea.gov.ng

Nigerian Meteorological Agency (NiMET) (2025). NCAT, Zaria Weather Station.

Nigerian Meteorological Agency (NiMET) (2024). State of the Climate in Nigeria. A Publication of NiMET.

Nigerian Meteorological Agency (NiMET) (2025). The Role of Early Warnings Towards A Climate Resilient Aviation Industry for Sustainable Socioeconomic Development. A Publication of NiMET.

Olajire, A. A., Azeez, L., Oluyemi, E.A. (2011). Chemosphere Exposure to Hazardous Air Pollution along Oba Akran Road, Lagos, Nigeria. Chemosphere, 84, 1044-1051.

Oluwatoyin, O. (2013). Problems and Prospect of Domestic Water Supply in Zaria Local Government Area. Kaduna State. Unpublished MSc. Thesis, submitted to the Department of Geography Ahmadu Bello University, Zaria, Nigeria.

PerkinElmer (2025). Environmental Testing Solutions. https://www.perkinelmer.com

Raheem, I. O., Buhari, F.M., Salihu, A., Abdulkareem, M.N., & Aremu, B.G. (2024). Assessment of CO2 Emission Due to Speed Bumps on Selected Highways in Bauchi State. FUDMA Journal of Sciences, 9(3), 91-98. https://fjs.fudutsinma.edu.ng/index.php/fjs/article/view/2477

Sadiq, A. A. (2022). Effect of Particulate Emissions from Road Transportation Vehicles on Health of Communities in Urban and Rural Areas, Kano State, Nigeria (Google Books Record). https://books.google.com/books?id=H5Yk0AEACAAJ .

Sani, A. S. (2017). Spatial Analysis of Road Network and Traffic Congestion in Zaria, Kaduna State, Nigeria. A Masters Dissertation. Kampala University Uganda.

Sani, A. S., Hari, I. & Ahmed, A. (2025). A Review of Global Road Transportation and Climate Change: Mitigation Strategies and Adaptation Challenges in Developing Countries. ATBU Journal of Science, Technology and Education, 13(2), atbuftejoste.com.ng

Ucheje, O. O. & Okolo, O. J. (2023). Contribution of Vehicular Emissions to Climate Change in Nigeria. A Closer Look. International Journal of Environment and Pollution Research, 11(1), 43-62. https://doi.org/10.37745/ijepr.13/vol11n14362

World Bank (2015). Enhancing the Climate Resilience of Africa's Infrastructure: The Roads And Bridges Sector. https://www.worldbank.org/en/tropic/transport/publication/enhancing-the-climate-resilience-of-africas-infrastructure-the-roads-and-bridges-sector

World Health Organisation (WHO) (2022). Ambient (outdoor) Air Pollution: Health Impacts WHO https://www.who.int

World Meteorological Organisation (WMO) (2023). State of Greenhouse Gases in the Atmosphere. World Meteorological Organisation Bulletin No. 72.wmo.int/news/media-cent

Zubair, M., Chen, S., Ma, Y., & Hu, X. (2023). A Systematic Review on Carbon Dioxide (CO2) Emission Measurement Methods under PRISMA Guidelines: Transportation Sustainability and Development Programs. Sustainability, 15(6). https://doi.org/10.3390/su15064817.