ASSESSMENT OF CARBON MONOXIDE, NITROGEN DIOXIDE AND AEROSOL IN LOKOJA, KOGI STATE, NIGERIA

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AN UNDERGRADUATE PROJECT SUBMITTED TO THE DEPARTMENT OF ENVIRONMENTAL MANAGEMENT AND TOXICOLOGY, FACULTY OF LIFE SCIENCES, UNIVERSITY OF BENIN, BENIN CITY, EDOSTATE, NIGERIA; IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR AWARD OF BACHELOR OF SCIENCE (B.Sc.) DEGREE IN ENVIRONMENTAL MANAGEMENT AND TOXICOLOLGY

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CERTIFICATION

This is to certify that this research titled "**ASSESSMENT Of CO, NO_2, AEROSOL IN LOKOJA, KOGI STATE, NIGERIA**" was carried out by ALAO, Amana Seneire (**MISS**) with Matriculation Number LSC1906673 and presented to the Department of Environmental Management and Toxicology, Faculty of Life Sciences, University of Benin, Benin City, Edo state in partial fulfilment of the requirements for the award of Bachelor of Science (B. Sc.) in Environmental Management and Toxicology. It was conducted under suitable conditions, was carefully supervised and subsequently approved as having met the requirements for the award of Bachelor of Science degree in Environmental Management and Toxicology.

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HEAD OF DEPARTMENT	

DECLARATION

I, **ALAO**, Amana Seneire(**MISS**) declares that **ASSESSMENT Of CO, NO_2, AEROSOL IN LOKOJA, KOGI STATE, NIGERIA** is my own work and that all sources that I have used or quoted have been acknowledged by means of complete references and that this work has not been submitted before for any other degree at any other university.

ALAO AMANA SENEIRE (MISS)

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DEDICATION

This Project is dedicated to God Almighty whose grace has brought me thus far and my parents Mr and Mrs. Idris Alao whose love and unending support has been the greatest encouragement all through this programme.

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My eternal gratitude goes to Allah for his mercy and love which never comes to an end nor ceases.

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ABSTRACT

Air pollution remains a critical environmental and public health challenge in rapidly urbanizing regions. This study employs Sentinel-5P satellite data and Google Earth Engine (GEE) to analyze the spatial and temporal trends of carbon monoxide (CO), nitrogen dioxide (NO_2), and aerosols in Lokoja, Nigeria, from 2019 to 2024. As a major transit hub, Lokoja experiences significant pollution from vehicular emissions, industrial activities, and biomass burning, necessitating comprehensive monitoring. Results reveal dynamic fluctuations in pollutant concentrations, with CO levels peaking in 2024 due to increased fossil fuel combustion, while NO_2 concentrations spiked in 2021 before a gradual decline, suggesting the influence of regulatory interventions and shifts in energy consumption. Aerosol trends indicate seasonal variations, with pronounced increases post-2021 linked to dry-season biomass burning and industrial expansion. A paired sample t-test confirmed statistically significant year-to-year differences in pollutant levels, reinforcing the role of economic, policy, and environmental factors in air quality dynamics. This study underscores the importance of integrating satellite-based remote sensing with ground validation for enhanced air quality assessments. Findings provide critical insights for policymakers, advocating for emission control strategies, sustainable urban planning, and targeted mitigation efforts to safeguard public health and environmental sustainability in emerging urban centers.

CHAPTER ONE

INTRODUCTION

BACKGROUND OF STUDY

Air quality refers to the condition of the air within our surroundings and is determined by measuring the concentration of pollutants in the atmosphere (Manisalidis *et al.,* 2020). Good air quality means the air is clean and contains low levels of harmful pollutants. In contrast, poor air quality indicates high levels of contaminants that pose risks to human health, ecosystems, and the environment (Spiegel *et al.,* 2019).

Air pollution, especially from aerosols and gases like CO_2, contributes to global warming by trapping heat in the atmosphere (Spiegel and Maystre 2020; Wuebbies *et al* 2017). Particulate matter from industrial emissions and vehicles influences cloud formation and precipitation patterns, leading to unpredictable climate effects (Myhre *et al* 2013). Pollutants such as nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) combine with water vapor to form acidic compounds, which fall as acid rain (Okeoma *et al.*, 2023). This affects soil acidity, damages crops, corrodes buildings, and acidifies water bodies, harming aquatic life. (Mehta 2010; Liuz *et al* 2022). Certain pollutants, including nitrogen oxides (NO_x), contribute to the degradation of the ozone layer, which protects the Earth from harmful ultraviolet (UV) radiation. (Randeniya *et al* 2002).

Exposure to pollutants such as aerosols (particulate matter), NO_2, and CO is associated with respiratory conditions like asthma, bronchitis, and other chronic lung diseases. (WHO, 2022; Croft *et al*, 2019; I Q Air, 2020). Particles can penetrate deep into the lungs and bloodstream, causing inflammation and long-term damage, these long-term exposure to pollutants can lead to heart disease, high blood pressure, and an increased risk of strokes. (Zhang *et al* 2013; Samoli *et* *al* 2005; Ostro *et al* 2006; Lewis *et al* 2005). Fine particulate matter ($PM_{2.5}$) and carbon monoxide (CO) are especially harmful to the cardiovascular system (Basith *et al.*, 2022). Studies link prolonged exposure to air pollutants to an increased risk of cancers, particularly lung cancer, due to the carcinogenic properties of certain pollutants. (Hamra *et al* 2014; pope *et al* 2020; IARC 2012; Turner *et al* 2014). Neurotoxic effects of pollutants have also been observed, impacting brain development and function. (Fonken *et al*. 2011; Russ et al. 2019; Lee et al. 2019).

Techniques like satellite imaging and LIDAR (Light Detection and Ranging) allow scientists to measure pollutant levels across vast regions. (Veefkind *et al* 2012; Kim *et al* 2020; Burke *et al* 2021). Remote sensing involves using satellite or airborne sensors to collect data on air pollutants over a large area without direct contact (Mertikas *et al.*, 2021). Remote sensing technology plays a key role in detecting and monitoring major air pollutants such as aerosols, nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and carbon monoxide (CO) (Sharma *et al.*, 2024). Aerosols, which include tiny particles from sources like dust, smoke, and industrial pollution, affect air quality and the climate. By measuring how these particles interact with light, instruments like MODIS and VIIRS can assess aerosol concentrations and their impacts on health and the environment (Osgouei *et al*, 2022). NO_2, primarily released from vehicle emissions and industrial activities, contributes to respiratory issues and the formation of ground-level ozone. Sensors like TROPOMI and OMI measure NO_2 by detecting the wavelengths it absorb, providing important data for urban air quality management. Remote sensing is invaluable for air quality monitoring, offering wide coverage, continuous data collection, and high spatial and temporal resolution. Without extensive ground equipment, it can detect multiple pollutants (e.g., aerosols, NO_2, SO_2, CO) across large areas, including remote locations (Yang *et al.*, 2022).

This technology enables real-time assessments, early health warnings, and informed decision-making for policy, as well as emergency response to pollution events like wildfires. Additionally, it provides standardized, comparable data that supports climate and environmental studies and enhances global collaboration on air quality issues. While remote sensing is valuable for air quality monitoring, it has limitations in providing localized, specific data. Satellite sensors may have low spatial resolution for small areas, rely on clear weather, and lack precise vertical resolution to distinguish ground-level pollutants (Yang *et al.*, 2022). They effectively detect certain pollutants (e.g., NO_2, SO_2) but struggle with others like VOCs and ground-level ozone. Data often needs calibration with ground sources, and satellite orbits can create temporal gaps, and missing short-term events. Additionally, interpreting data can be complex, and high initial costs and technical requirements can limit accessibility, especially for real-time monitoring and localized responses.

1.1 STATEMENT OF THE PROBLEM

Lokoja, a growing transit hub in Nigeria, faces rising air pollution due to urbanization and industrial activities. The emissions of vehicles and poorly regulated industrial emissions, especially from cement plants and small manufacturing companies, release pollutants like carbon monoxide, nitrogen oxides, sulfur dioxide, and particulates, which pose health risks. (Marlowe and Mansfield 2002). Additional pollution sources include waste burning, generator use, and construction dust, impacting air quality and increasing respiratory and cardiovascular health risks, particularly for vulnerable groups. (Adeoye *et al* 2015).

A major challenge in addressing air pollution in Lokoja is the lack of local data on pollutants like aerosols, nitrogen dioxide (NO_2), and carbon monoxide (CO), which pose significant health risks. Most air quality data in Nigeria focuses on larger cities like Lagos and Abuja (Kanee *et al* 2020), leaving rapidly growing cities like Lokoja under-researched despite rising pollution levels. Accurately assessing the risks to public health and the environment in Lokoja is challenging due to the lack of localized air quality data. Pollutants like nitrogen dioxide (NO_2), carbon monoxide (CO), and particulate matter are known to cause respiratory and cardiovascular diseases, particularly affecting vulnerable populations. Without local monitoring, it is difficult to understand the full scope of pollution and its specific sources, limiting effective interventions. A focused study on Lokoja's air quality could provide important insights, helping to identify health risks and inform local policies to mitigate pollution-related illnesses.

1.3 JUSTIFICATION

Located at the confluence of the Niger and Benue rivers, Lokoja serves as a central hub in Nigeria's transportation network, linking the northern and southern regions. This strategic location contributes to higher traffic and industrial activity, making Lokoja a relevant area for air quality studies. Lokoja's role as a transit hub exposes it to air pollution from vehicles, industrial sources, and small-scale businesses, which could impact air quality differently from other cities in Nigeria. The study's results can guide local authorities in addressing pollution from these unique sources.

This study is crucial for understanding the health impacts of air pollution on Lokoja's residents. With rising respiratory and cardiovascular disease rates linked to poor air quality, this research will provide valuable data for local and regional health interventions. Sentinel- 5P hasn't been used to assess the air quality in Lokoja, Kogi state, making it a limitation to the study. Without comprehensive local data, it is difficult to assess the full extent of exposure, limiting efforts to address air quality issues. To fill the gap, this study helps to provide comprehensive data on the air quality status of Lokoja adopting Sentinel-5P, as there are limited studies using traditional methods such as hand-held meters.

Since pollutants such as aerosols, NO_2, and CO are known to exacerbate respiratory conditions and other health issues, understanding their concentration levels in Lokoja will allow health officials to target preventative measures and reduce health risks for vulnerable populations, including children and the elderly. This study's findings can inform air quality management policies and regulatory enforcement by Nigeria's National Environmental Standards and Regulations Enforcement Agency (NESREA). Accurate local data will help establish relevant regulations and standards for Lokoja, leading to targeted environmental strategies.

By working with Nigeria's national air quality objectives and international standards (e.g., WHO air quality guidelines), this research provides a scientific basis for policy interventions to mitigate pollution and enhance environmental sustainability. Air quality studies in Nigeria often focus on larger cities like Lagos, with limited research on smaller but rapidly developing areas such as Lokoja. This research will contribute to a more comprehensive understanding of air quality trends across Nigeria, highlighting specific challenges and needs in midsized urban areas.

Findings from this study will add to the body of knowledge on air pollution in West Africa, where localized data on pollutant levels and sources is still scarce.

1.4. AIM OF THE STUDY

The study aims to assess CO, NO_2 and Aerosols concentration in Lokoja city.

1.5. OBJECTIVES OF THE STUDY

This research has the following objectives:

1. Assess the data for the selected air quality parameters for the years 2019-2024.
2. Determine CO, NO_2, and aerosol emissions concentration for the years under review.
3. Determine statistical significant difference in parameters across the years under review.

CHAPTER TWO

LITERATURE REVIEW

2.1. AIR POLLUTION

Air pollution is the presence of harmful substances in the air that can cause damage to human health, ecosystems, and the environment (Manisalidis *et al.,* 2020). These pollutants can be natural or manmade and include gases, liquids, or solids, such as particulate matter (PM), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon monoxide (CO), ozone (O_3), and volatile organic compounds (VOCs). Air pollution results from sources like industrial emissions, vehicle exhaust, agricultural activities, and household practices, and it can lead to respiratory and cardiovascular diseases, environmental degradation, and contribute to climate change (Manisalidis *et al.,* 2020).

2.2 AIR QUALITY

Air quality refers to the condition or cleanliness of the air in a given environment, determined by the concentration of pollutants such as particulate matter (PM), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon monoxide (CO), ozone (O_3), and volatile organic compounds (VOCs) (Fahim and Visockienė, 2024). Good air quality is characterized by low levels of harmful pollutants, while poor air quality indicates higher concentrations that can pose health risks to humans, animals, and ecosystems. Monitoring air quality is essential for assessing pollution levels and their impact on public health and the environment.

2.3. BENEFITS OF AIR QUALITY

Good air quality provides numerous essential benefits that impact human health, the environment, and even the economy (Fahim and Visockienė, 2024). These benefits extend to individuals, communities, ecosystems, and broader societal outcomes. Here is an expanded look at the benefits of good air quality:

IMPROVED HEALTH: Clean air is crucial for reducing the risk of a wide range of health problems. Air pollution is linked to respiratory issues like asthma, bronchitis, and chronic obstructive pulmonary disease (COPD), as well as cardiovascular diseases such as heart attacks, strokes, and hypertension (Fahim and Visockienė, 2024). Good air quality minimizes these risks, leading to fewer hospital visits, reduced healthcare costs, and longer, healthier lives. It also helps to lower the rates of lung cancer and respiratory infections, particularly among children and the elderly, who are more vulnerable to air pollution.

ENHANCED PRODUCTIVITY: Healthy air contributes directly to greater productivity in both work and education. Pollution can lead to increased absenteeism due to illness, decreased cognitive function, and even more significant impairments in physical performance. In contrast, cleaner air improves focus, reduces fatigue, and supports better physical and mental health, all of which contribute to better performance in workplaces, schools, and other productive activities. This benefit is especially important in rapidly urbanizing regions, where pollution is a growing concern.

BETTER ECOSYSTEM HEALTH: Clean air is vital for the health of ecosystems, supporting plant growth, animal health, and biodiversity. Pollutants like nitrogen oxides (NOx) and sulfur dioxide (SO_2) can harm plants, disrupt nutrient cycles, and weaken ecosystems, making them more susceptible to other environmental stresses. Good air quality ensures the flourishing of vegetation, which is critical for the survival of herbivores, predators, and other wildlife. Additionally, healthy ecosystems contribute to cleaner air, creating a feedback loop where biodiversity is maintained, and environmental stability is supported.

CLIMATE CHANGE MITIGATION: Air quality and climate change are closely linked. Pollutants like carbon dioxide (CO_2) and methane (CH_4) are not only harmful to human health but also act as greenhouse gases that contribute to global warming (Fahim and Visockienė, 2024). By improving air quality—such as reducing emissions from vehicles, industries, and agriculture—we can also mitigate climate change. Strategies that improve air quality often help reduce carbon footprints, lower greenhouse gas emissions, and reduce the negative impacts of climate change, such as extreme weather patterns, rising sea levels, and biodiversity loss.

ECONOMIC SAVINGS: Good air quality can result in substantial economic benefits. The reduced incidence of health problems directly lowers healthcare costs, including hospital admissions, treatments, and long-term care for pollution-related diseases. There are also savings in terms of environmental restoration, such as cleaning up contaminated water and soil or reducing the economic impacts of climate change. Additionally, cleaner air encourages a healthier, more productive workforce, which benefits national economies. In cities, a focus on air quality improvements can attract businesses, tourism, and investment by enhancing the city's reputation as a livable, healthy location.

LONGER LIFE EXPECTANCY: Reduced exposure to harmful air pollutants leads to a lower incidence of diseases and mortality, increasing life expectancy. Long-term exposure to air pollution is linked to premature death from conditions such as heart disease, respiratory illnesses, stroke, and cancer. Cleaner air means a lower burden of these diseases, allowing individuals to live healthier and longer lives. For many developing countries, improving air quality could lead to a significant increase in life expectancy by reducing pollution-related mortality rates.

PUBLIC HEALTH COST REDUCTION: Beyond individual health, good air quality alleviates the broader economic burden of treating pollution-related diseases. The healthcare system saves costs by preventing hospital admissions, reducing the need for treatments and medications, and minimizing long-term healthcare services for patients with chronic conditions. Furthermore, improved air quality reduces absenteeism from schools and workplaces, preventing the economic losses associated with productivity decline.

PROMOTION OF SUSTAINABLE DEVELOPMENT: As cities and countries pursue development, maintaining good air quality is essential for ensuring that this growth is sustainable. Policies that focus on clean energy sources, efficient transportation systems, and sustainable industrial practices help balance development needs with environmental stewardship. Sustainable development reduces the environmental and health costs associated with growth while providing long-term benefits for both people and the planet. Maintaining good air quality is not just an environmental concern—it is integral to public health, economic well-being, ecosystem stability, and climate resilience. The collective benefits of clean air promote a healthier, more prosperous society, enhance the livability of cities, and protect natural environments for future generations.

2.4. GLOBAL STUDIES ON AIR POLLUTION

Global studies on air pollution have revealed alarming trends regarding its widespread impact on human health, the environment, and the climate. Research from organizations such as the World Health Organization (WHO), the United Nations (UN), and various scientific journals has provided in-depth insights into the extent of air pollution and its consequences.

Health Impacts: Numerous global studies have highlighted the severe health risks associated with air pollution. According to the WHO, air pollution is responsible for about 7 million premature deaths annually, making it one of the leading causes of death worldwide (Tainio *et al.*, 2021). These deaths are primarily attributed to respiratory and cardiovascular diseases, such as asthma, chronic obstructive pulmonary disease (COPD), stroke, heart attacks, and lung cancer. Studies have also shown that air pollution exacerbates preexisting conditions like diabetes and respiratory infections, particularly affecting vulnerable populations such as children, the elderly, and individuals with chronic illnesses. One of the most notable studies, the Global Burden of Disease Study, published by the Institute for Health Metrics and Evaluation (IHME), found that exposure to fine particulate matter (PM2.5) is the leading environmental risk factor for early death (Burnett and Cohen, 2020). This study estimates that air pollution is responsible for around 4.2 million deaths annually due to diseases directly linked to air pollution, such as ischemic heart disease, stroke, and lung cancer.

Global research also underscores the significant economic costs associated with air pollution. The World Bank estimates that air pollution costs the global economy trillions of dollars each year in terms of healthcare costs, lost productivity, and environmental damage. In 2019, the World Bank estimated that air pollution caused a global economic loss of approximately 5% of global GDP due to healthcare costs and the loss of labor productivity. This includes the effects of both outdoor and indoor air pollution (Tainio *et al.*, 2021).

2.5 ENVIRONMENTAL IMPACT

Air pollution is a major driver of environmental degradation. Global studies on air quality have shown how pollutants like sulfur dioxide (SO_2) and nitrogen oxides (NO_x) contribute to acid rain, which harms soil quality, aquatic ecosystems, and plant life (Gurav *et al.*, 2024). Acid rain leads to soil and water acidification, reducing agricultural productivity, harming aquatic life, and altering natural ecosystems.

Additionally, pollutants like black carbon and ground level ozone (O_3) are powerful short-lived climate pollutants (SLCPs), which exacerbate global warming by trapping heat in the atmosphere. The Intergovernmental Panel on Climate Change (IPCC) reports that SLCPs contribute significantly to climate change, with black carbon alone accounting for up to 20% of global warming (Burnett and Cohen, 2020). Air pollution also negatively affects biodiversity by disrupting habitats, reducing the health of plants and animals, and contributing to the decline of species that depend on clean air and healthy ecosystems.

CLIMATE CHANGE AND AIR POLLUTION

Research also highlights the interconnection between air pollution and climate change. Many pollutants that degrade air quality, such as CO_2, methane (CH_4), and black carbon, are also greenhouse gases that contribute to global warming. According to the UN Environment Programme (UNEP), over 90% of urban areas worldwide exceed the air quality guidelines set by the WHO, exacerbating both air pollution and climate change simultaneously.

The Global Atmospheric Watch (GAW), operated by the World Meteorological Organization (WMO), has conducted studies on the rising levels of pollutants such as CO_2, methane, and aerosols (Carpenter *et al.*, 2023). These studies have shown that not only do pollutants harm air quality, but they also contribute to the intensification of extreme weather events, rising sea levels, and disruptions in ecosystems.

While many global studies on air pollution provide valuable insights, there are significant gaps in localized air quality data, especially in low and middle-income countries. Although cities like Lagos, Beijing, and New Delhi have comprehensive monitoring systems, many developing regions still lack sufficient data on pollutants. This data gap hampers the development of effective air quality management and policies.

However, new advancements in remote sensing and satellite based monitoring are helping to fill these gaps. Satellites provide high resolution global data on air pollutants such as nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon monoxide (CO), and particulate matter, offering a more comprehensive understanding of pollution patterns worldwide.

2.6 STATEMENT OF THE PROBLEM: MONITORING AIR QUALITY

Air pollution has become a critical environmental and public health issue globally, with significant consequences for both human health and the environment. In rapidly developing cities like Lokoja, Nigeria, where urbanization, industrialization, and vehicular traffic are on the rise, air quality is deteriorating at an alarming rate. However, one of the most significant challenges in addressing air pollution is the lack of accurate and localized data on air quality. Without reliable data, it becomes difficult to assess the full extent of pollution, its sources, and its impact on public health, making it challenging to implement effective mitigation measures.

In Lokoja, like many smaller cities, there is a lack of robust air quality monitoring systems that can provide real-time, accurate data on pollutants such as nitrogen dioxide (NO_2), carbon monoxide (CO), particulate matter (PM), and sulfur dioxide (SO_2), which are known to pose serious health risks. Most of the available data on air quality in Nigeria focuses on larger cities like Lagos and Abuja, leaving emerging urban centers under researched (Omodunni, 2024). This data gap hinders policymaking and the implementation of effective measures to protect public health and the environment.

The absence of comprehensive air quality monitoring leads to the risks of respiratory and cardiovascular diseases among residents, particularly vulnerable groups such as children, the elderly, and individuals with preexisting conditions (Manisalidis *et al.,* 2020). It also limits the ability to assess the environmental impact of pollution, including its effects on biodiversity, ecosystems, and the climate. Consequently, there is a pressing need for a more localized and efficient monitoring system in Lokoja to fill this knowledge gap and inform policies aimed at improving air quality.

2.7. METHODS FOR MONITORING AIR QUALITY

To address air pollution effectively, accurate and timely data is essential. Several methods are currently used for monitoring air quality, each with its advantages and limitations (Huang *et al.*, 2021). Among these methods, handheld meters and remote sensing are two key approaches that can be employed in both local and global contexts.

HANDHELD METERS

Handheld air quality meters are portable devices that measure specific air pollutants at a localized level. These meters are particularly useful for field measurements, providing real-time data on air quality in specific locations such as residential areas, industrial zones, or busy traffic intersections (Li *et al.*, 2020). Handheld meters typically measure a range of pollutants, including particulate matter (PM2.5 and PM10), **carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), and sulfur dioxide (SO_2).**

Advantages of Handheld Meters

1) Portability: Handheld meters are easy to carry and can be used in various locations, allowing for targeted air quality measurements.
2) Cost-effective: Compared to stationary air quality monitoring stations, handheld meters are relatively inexpensive and can be used in large numbers to gather widespread data.
3) Real-time Monitoring: Handheld meters provide immediate feedback on air quality, enabling rapid responses to pollution spikes and real-time decision making.
4) Localized Measurements: These devices allow for precise, location specific measurements, helping to identify pollution hotspots in urban areas.

Limitations of Handheld Meters

1) Limited Data Coverage: While handheld meters are useful for localized data collection, they cannot provide continuous, long-term monitoring across large areas.
2) Potential for Human Error: Data accuracy depends on the proper usage of the meters, and improper handling or calibration can lead to inaccurate readings.

3) Limited Scope: Handheld meters may measure only a limited number of pollutants compared to more advanced monitoring technologies, making it challenging to monitor a wide range of contaminants simultaneously.

Despite these limitations, handheld meters are valuable tools for gathering initial data on air quality in areas with limited resources or where continuous monitoring infrastructure is unavailable.

REMOTE SENSING

Remote sensing refers to the use of satellite or aerial sensors to collect data on the Earth's surface and atmosphere, providing large-scale monitoring of air quality. This method offers several advantages in assessing air pollution across wide geographical areas, including cities, countries, and continents (Li *et al.*, 2020). Remote sensing technologies can measure a variety of pollutants, including particulate matter (PM), nitrogen dioxide (NO_2), carbon monoxide (CO), ozone (O_3), and sulfur dioxide (SO_2), using sensors placed on satellites, drones, or aircraft.

Advantages of Remote Sensing

1) Wide Area Coverage: Remote sensing provides a comprehensive view of air quality across large areas, including regions that are difficult to access on the ground, such as remote or densely populated urban centers.
2) Continuous Data Collection: Satellites and other remote sensing technologies can collect data continuously or at regular intervals, providing a near real-time understanding of pollution trends and events.

3) High Spatial and Temporal Resolution: Modern sensors can capture data at a high resolution, allowing for detailed analysis of pollutant distribution at the local, regional, and global levels. This capability is essential for tracking changes over time and identifying pollution hotspots.
4) Detection of Multiple Pollutants: Remote sensing allows for the simultaneous measurement of a variety of pollutants, which is critical for obtaining a holistic understanding of air quality.
5) Nonintrusive and Cost-effective: Remote sensing reduces the need for ground based equipment, which can be expensive to set up and maintain. It can provide data without the need for onsite personnel or infrastructure.

Limitations of Remote Sensing:

1) Limited Accuracy for Small-scale Pollution: While remote sensing offers broad coverage, it may lack the spatial resolution to monitor localized pollution sources, especially in small urban areas or areas with complex topography.
2) Weather Dependence: Remote sensing can be affected by weather conditions, such as cloud cover or precipitation, which can obstruct satellite or aerial measurements, limiting the accuracy and frequency of data collection.
3) High Initial Costs: While satellite data is increasingly accessible, the initial setup and operational costs of launching and maintaining remote sensing satellites can be high. Additionally, the costs of processing and interpreting satellite data may require specialized expertise and software.

4) Data Validation Needs: Remote sensing data often needs to be validated and calibrated with ground based measurements to ensure accuracy, as atmospheric conditions can influence the readings.

2.8 APPLICATIONS OF REMOTE SENSING IN AIR QUALITY MONITORING

1) Global Monitoring: Remote sensing is an essential tool for global monitoring of air quality, as it allows for the tracking of pollution levels on a planetary scale. The NASA Earth Observing System (EOS) and the European Space Agency's (ESA) Copernicus program are examples of large-scale remote sensing initiatives focused on air quality monitoring.
2) Monitoring Regional Pollution: Remote sensing can track pollution trends across entire countries or regions, offering valuable insights into cross border pollution issues, such as Tran's boundary air pollution in Asia or Europe.
3) Real-time Alerts and Emergency Response: In cases of air pollution emergencies, such as industrial accidents or wildfires, remote sensing allows for rapid response by providing data on pollution levels and helping authorities make informed decisions on public health measures.

Both handheld meters and remote sensing play important roles in monitoring air quality, each with distinct advantages and limitations. Handheld meters are effective for localized, real-time monitoring and can be used in areas with limited infrastructure, whereas remote sensing offers large-scale, continuous monitoring with the ability to track pollution trends over time (Huang *et al.*, 2021). For effective air quality management, a combination of both methods is often ideal, as they complement each other in providing comprehensive data for policymaking, public health management, and environmental protection. In cities like Lokoja, a combination of these methods could fill the data gaps, enabling the development of targeted strategies to address air pollution and improve public health outcomes

CHAPTER THREE

METHODOLOGY.

3.1 STUDY LOCATION

Lokoja is the capital of Kogi State located in North-Central Nigeria, right at the point where the Niger and Benue Rivers meet, at latitudes 7.45°N–7.52°N and longitudes 6.41°E–6.45°E (Ifatimehin *et al.*, 2012; Federal University Lokoja, 2014). It is a strategically positioned city, located approximately 165 kilometers south of the Federal Capital Territory (FCT) and bordered by Koto-Karfe and Bassa to the west, Adavi to the south, and Kabba/Bunu to the east (Ifatimehin *et al.*, 2012; Federal University Lokoja, 2014; Adetunji and Isah, 2015). Lokoja plays an important role in connecting northern and southern Nigeria, which makes it significant for both trade and administration (Awodi *et al.*, 2021; Federal University Lokoja, 2014; Adetunji and Isah, 2015; Ebiloma, 2019).

The climate in Lokoja is tropical, meaning it has wet and dry seasons (Ifatimehin *et al.*, 2012; Adetunji and Isah, 2015; Ebiloma, 2019). The wet season lasts from late April to November, with rainfall peaking in July and September, while the dry season spans from December to March. During the hottest months (March and April), temperatures can exceed 40°C, although the yearly average ranges between 25°C and 35°C with an annual rainfall of about 1150 mm (Federal University Lokoja, 2014). The Niger and Benue Rivers contribute to high humidity levels and increase the likelihood of flooding during heavy rains, particularly in low-lying areas (Imam and Ojochenemi, 2024).

Geologically, Lokoja is situated at the transition between the Precambrian Basement Complex and sedimentary basins (Old rock formations meet newer sedimentary layers) (Tijani and Tijani, 2023). Its topography includes rugged landscapes, with Mount Patti standing at 700 meters above sea level (Tijani and Tijani, 2023; Odundun and Ogundoro, 2019). The city's soils, comprising sandy and clay deposits, influence water drainage, making certain areas prone to waterlogging and runoff during the rainy season, which worsen flooding risks (Odundun and Ogundoro, 2019).

Urbanization in Lokoja has led to rapid population growth, from 195,261 in 2006 to an estimated 886,000 in 2024 (Macrotrends, 2024). This growth has replaced traditional Guinea savanna and agricultural lands with urban structures (Awodi *et al.*, 2021). Markets like New Market and Kpata Market, along with educational institutions like Federal University Lokoja, have driven economic development (Imam and Ojochenemi, 2024; Awodi *et al.*, 2021). However, urbanization has come with challenges, including reduced agricultural activity and increasing environmental concerns (Imam and Ojochenemi, 2024; Awodi *et al.*, 2021).

Air quality in Lokoja is a growing issue due to urbanization and increased vehicular and industrial activities (Dukiya and Okhimamhe, 2013; Awodi *et al.*, 2021). The Abuja-Lokoja highway, a major transport route, contributes significantly to air pollution through emissions from heavy vehicular traffic (Awodi *et al.*, 2021). Study has shown that pollutants such as nitrogen dioxide (NO_2), carbon monoxide (CO), and particulate matter from vehicles and industries have affected air quality, impacting vegetation and public health (Awodi *et al.*, 2021).

The city's proximity to industrial activities and reliance on fossil-fuel-powered transport systems necessitate better air quality management strategies (Dukiya and Okhimamhe, 2013; Awodi *et al.*, 2021). Sustainable urban planning and stricter emission controls could help mitigate the negative impacts of air pollution on both the environment and public health (Imam and Ojochenemi, 2024).

3.2. MAP OF THE STUDY LOCATION

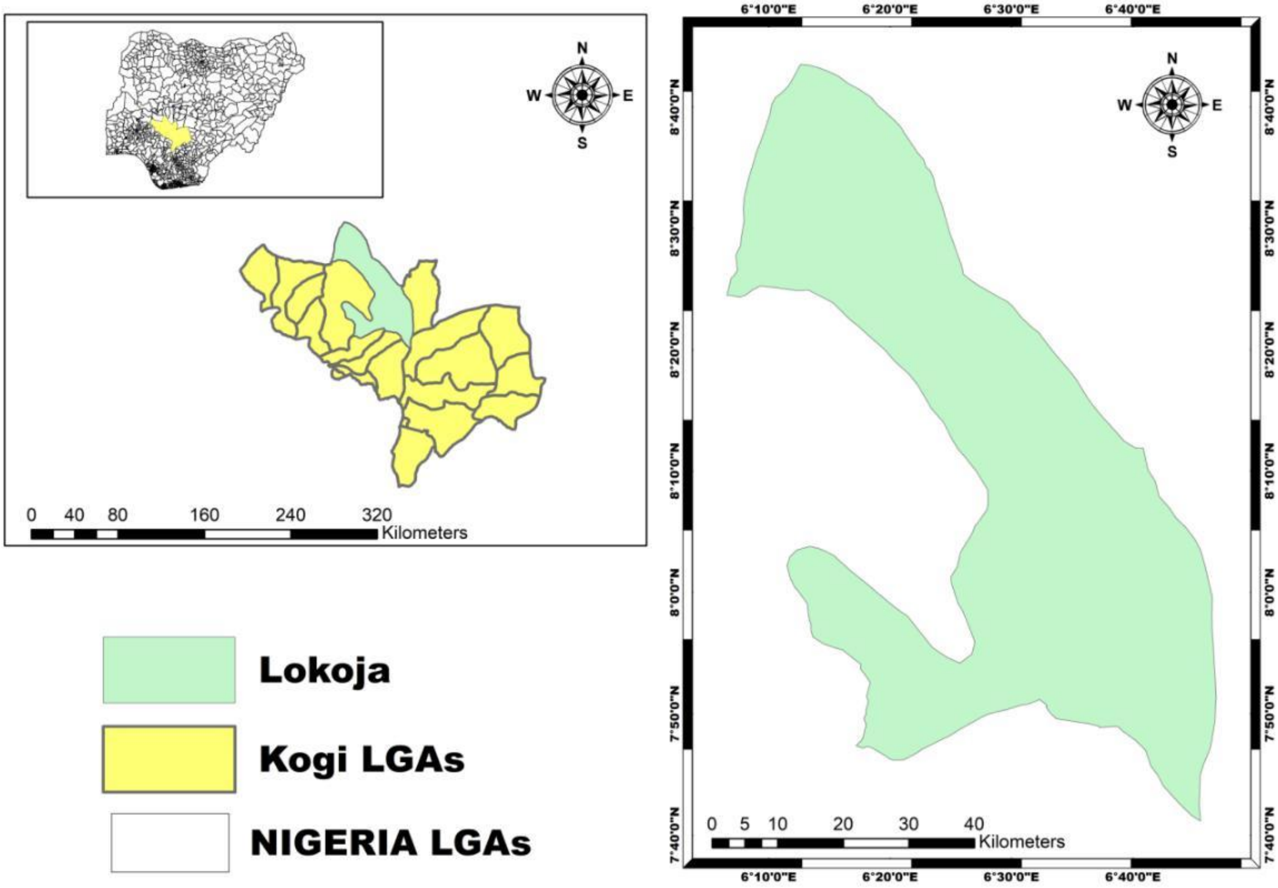

Figure 3.1: Map of Lokoja, Kogi State, North-Central Nigeria.

3.3 RESEARCH DESIGN

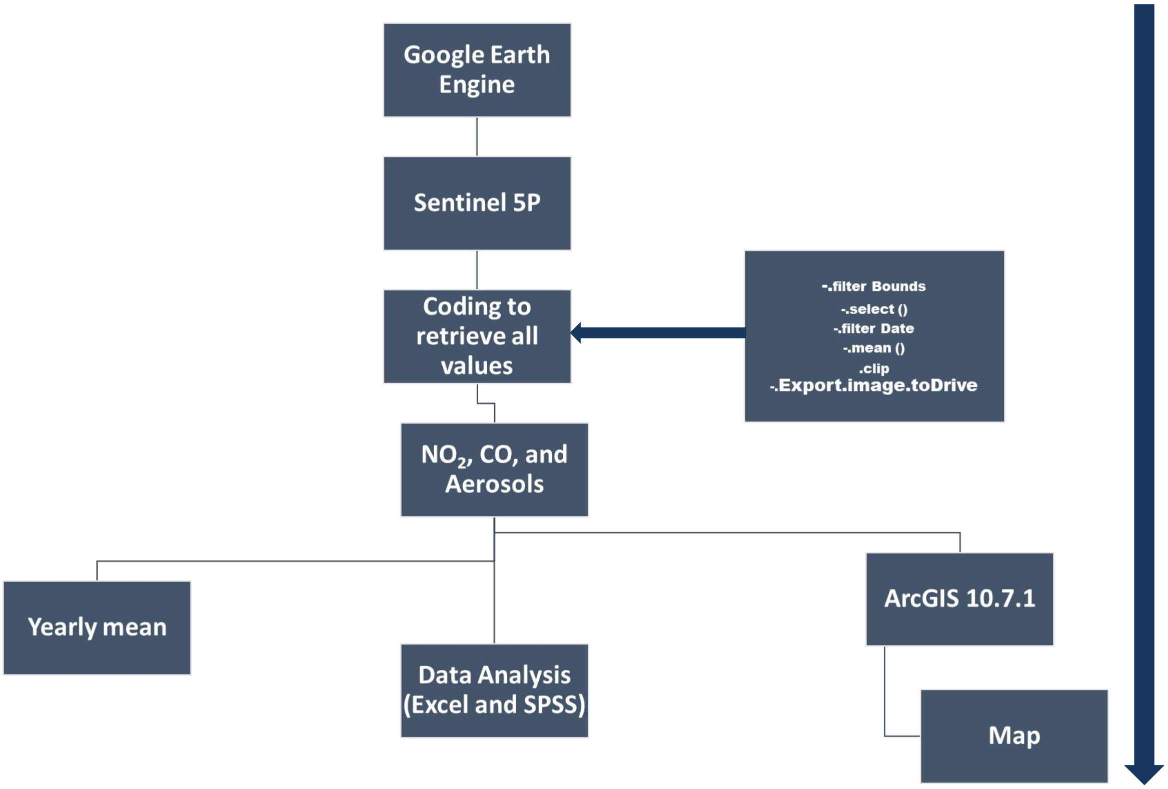

Figure 3.2: Schematic illustration of the research design

3.4 DATA SOURCE AND COLLECTION

This study examines Nitrogen dioxide (NO_2), Carbon monoxide (CO), and Aerosol pollution in Lokoja using data collected by Sentinel-5 Precursor, a satellite specifically designed to monitor atmospheric conditions. Sentinel-5P's high-resolution capabilities make it an excellent tool for observing pollution patterns across different locations and periods (ESA, 2018). The analysis spans the years 2019 to 2024, providing insights into yearly pollution trends in the region. Data collection and processing were conducted using Google Earth Engine (GEE), a cloud-based platform that efficiently handles large-scale environmental datasets.

DATA SOURCE

The Sentinel-5 Precursor (Sentinel-5P) satellite is a mission under the European Space Agency's (ESA) Copernicus Program, launched in October 2017 (ESA, 2018). It focuses on atmosopheric Instrument (TROPOMI) (ESA, 2018). Sentinel-5P provides high-resolution data on pollutants such as nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon monoxide (CO), ozone (O_3), methane (CH_4), and aerosols (Chandra and Singh, 2023).

TROPOMI detects ultraviolet (UV), visible, near-infrared, and short-wave infrared light, enabling it to measure key atmospheric constituents (ESA, 2018). Its spatial resolution (3.5×7 km^2) and daily global coverage allow precise monitoring of pollution hotspots and seasonal trends (Omrani *et al.*, 2020). The data is important for understanding the relationship between human activity, air quality, and climate change (Omrani *et al.*, 2020; Chandra and Singh 2023; Amaechi *et al.*, 2023). Studies leveraging Sentinel-5P include:

1. Chandra and Singh (2023), used it to monitor pollutant levels in Uttar Pradesh, India, before, during, and after the COVID-19 lockdown.
2. Amaechi *et al.* (2023), assessed the impact of Nigeria's fuel subsidy removal policy on pollutants in Abuja.

Sentinel-5P has been extensively used to:

1. Track air quality changes during major events such as lockdowns, revealing significant drops in NO_2 and CO (Behera *et al.*, 2021).
2. Support policy development by providing evidence for emission control measures (Omrani *et al.*, 2020).
3. Assist climate modeling by quantifying greenhouse gas concentrations and trends (Safarianzengir *et al.*, 2020).

3.5 DATA COLLECTION AND PROCESSING

Google Earth Engine (GEE) is a cloud-based geospatial analysis platform designed for large-scale environmental data processing. It integrates datasets like Sentinel-5P, providing tools for accessing, analyzing, and visualizing pollution data (Amaechi *et al.*, 2023). Researchers use GEE for:

1. Data Access and Processing: Sentinel-5P datasets, stored in GEE, allow researchers to filter by pollutant type, time, and geographic region.

2. Trend Analysis: GEE's tools enable analysis of temporal trends in pollutant concentrations. For example, Behera *et al.* (2021) tracked NO_2 reductions during COVID-19 lockdowns in India.

3. Spatial Mapping: GEE facilitates high-resolution mapping of pollutants, enabling the identification of hotspots, as seen in Amaechi *et al.*'s (2023) analysis of CO and aerosol reductions in Abuja.

Combining Sentinel-5P and GEE enhances research capabilities by leveraging the strengths of both tools. Sentinel-5P provides detailed, accurate, and frequent atmospheric measurements, while GEE simplifies data processing and analysis. The synergy between the two offers:

1. Accessibility: GEE eliminates the need for high computing power or storage, allowing researchers to access Sentinel-5P's global datasets efficiently (Behera *et al.*, 2021).
2. Speed: GEE processes large datasets quickly, making it ideal for time-sensitive studies such as disaster response or rapid policy evaluations (Singh and Rawat, 2024).
3. Scalability: Researchers can analyze global trends or zoom into specific areas, as demonstrated by Chandra and Singh (2023).
4. Visualization: GEE's mapping tools make it easier to communicate results to policymakers, urban planners, and the public (Amaechi *et al.*, 2023).
5. Policy Impact: Studies like those by Amaechi *et al.* (2023) demonstrate the policy relevance of combining Sentinel-5P's robust data with GEE's analysis tools to assess interventions like fuel subsidy removal.

This combination empowers researchers to perform comprehensive, scalable, and impactful analyses of air quality, climate dynamics, and policy impacts.

3.6 METHOD OF ANALYSIS

The data for the study were analyzed using Arc Map version 10.7.1, Google Earth Engine (GEE), and Microsoft Excel. GEE provided satellite imagery of the study area, Lokoja, Kogi State, displaying the concentrations of selected pollutants (CO, NO_2 and aerosols) in mol/m^2, except for Aerosols, which lack a standard SI unit. These raster images were imported into Arc Map, where irrelevant data were removed using shape files of the study area. The refined raster data were then edited and transformed into maps to illustrate the spatial distribution of pollutants. A color-coded grid system (green for mild, yellow for moderate, and red for severe concentrations) was used to represent the intensity of pollutants from 2019-2024.

Using Microsoft Excel, trends in pollutant concentrations were analyzed and presented in graphical form. This provided a clear understanding of changes in air quality across the study period.

3.7 WHY FOCUS ON DATA FROM 2019-2024?

The decision to begin data collection on January 1, 2029, was informed by the availability of Sentinel-5P datasets as outlined in the Earth Engine Data catalog. While data for the UV Aerosol Index became available starting from July 4, 2018, commencing analysis in 2019 ensures a full and consistent annual dataset for all parameters. This approach aligns with the goal of achieving comprehensive temporal coverage for the study period. This time frame also ensures comprehensive coverage of pollutant trends while accounting for potential influences coverage of pollutant trends while accounting for potential influences such as COVID-9 pandemic (2020-2022) and the removal of fuel subsidies in Nigeria (2023), both of which could have impacted air pollution levels.

3.8 WHY PIORITIZE THESE THREE POLLUTANTS (CO, NO_2 AND AEROSOLS)?

CO, NO_2 and Aerosols are the major pollutants that directly capture the impact of Lokoja's most significant emission sources: vehicular traffic congestions, industrial processes and biomass burning (Anyika *et al*., 2020; Ezeonyejiaku *et al*., 2022). They also align with global air quality standards and health impact assessments, providing reliable indicators of pollution trends in urban settings (Smith and Bolton, 2024). Since pollutants such as aerosols, NO_2, and CO are known to exacerbate respiratory conditions and other health issues, understanding their concentration levels in Lokoja will allow health officials to target preventative measures and reduce health risks for vulnerable populations, including children and the elderly. This study's findings can inform air quality management policies and regulatory enforcement by Nigeria's National Environmental Standards and Regulations Enforcement Agency (NESREA). Accurate local data will help establish relevant regulations and standards for Lokoja, leading to targeted environmental strategies.

The paired sample t-test is appropriate because it compares air pollutant concentrations between consecutive years while accounting for their dependence on each other. Air pollution levels are not independent across years since factors such as emission trends, regulatory changes, and environmental conditions influence between two related datasets is statistically significant.

By using a paired sample t-test, year- to – year variations in CO, NO_2 and Aerosol concentrations are analyzed while controlling for intra-year correlations. This approach reduces the impact of external variability and ensures that observed differences are due to actual changes in pollution levels rather than random fluctuations.

Table 3.1. NO_2, CO, and Aerosol datasets obtained from Sentinel 5P

Parameter Analyzed	**Image Collection**	**Minimum**	**Maximum**	**Band Used**	**Unit**
Carbon monoxide (CO)	**COPERNICUS/S5P/NRTIL3_CO**	**-34.43**	**0.0192**	**CO column number density**	**mol m^{-2}**
Nitrogen dioxide (NO_2)	**COPERNICUS/SP/NRTI/L3_NO2**	**-0.00051**	**0.0192**	**NO_2 column number density**	**mol m^{-2}**
Aerosol	**COPERNICUS/S5P/OFFL/L3_AER_AI**	**-21**	**39**	**Absorbing aerosol index**	

CHAPTER FOUR

RESULTS

4.1 CARBON MONOXIDE CONCENTRATION IN LOKOJA, KOGI STATE

Table 4.1.1 .Annual concentration of CO for 2019- 2024.

CO	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
MINIMUM	0.0479	0.0471	0.0467	0.0449	0.0435	0.0479
MAXIMUM	0.0523	0.0513	0.0517	0.0509	0.0473	0.0523
MEAN	0.0501	0.0492	0.0492	0.0497	0.0454	0.0501
STANDARD DEVIATION	0.00088	0.00079	0.00093	0.0011	0.00095	0.00065

The table4.1.1 presents CO concentration levels recorded annually, with minimum, maximum, and mean values.

The data show an increase in CO levels from 2019 to 2020, followed by fluctuations and a sharp increase in 2024.

The highest mean CO concentration (0.0544 mol/m²) was recorded in 2024, while the lowest (0.0459 mol/m²) was in 2019.

The standard deviation values indicate slight variations in CO levels, suggesting external factors like vehicular emissions and industrial activities influenced air quality.

The Monthly mean distribution of carbon monoxide concentration from 2019-2024 as depicted in Appendix 1 reveals that in 2019, The highest CO concentration was recorded in **February (0.069 mol/m²),** while the lowest occurred in **September (0.035 mol/m²).** The **mean CO concentration** for the year was **0.0459 mol/m².**

In 2020, the peak concentration was also in **February (0.072 mol/m²)**, marking the highest recorded monthly CO level across all study years. The lowest concentration was in **October (0.036 mol/m²),** with a **mean annual CO concentration of 0.0490 mol/m².**

In 2021, February recorded the highest CO concentration at **0.069 mol/m²**, while September had the lowest at **0.036 mol/m².** The **mean annual concentration** was **0.0487 mol/m²**

In 2022, the highest concentration occurred in **January (0.066 mol/m²),** while **September and October** had the lowest at **0.035 mol/m².** The **mean CO concentration** for the year was **0.0476 mol/m².**

In 2023, the peak CO level was observed **in February (0.062 mol/m²),** while the lowest was in **September (0.036 mol/m²).** The **mean annual concentration** was **0.0460 mol/m².**

While in 2024, the highest concentration occurred in February (0.068), while the lowest was in June (0.041). The mean CO concentration for the year was 0.0544.

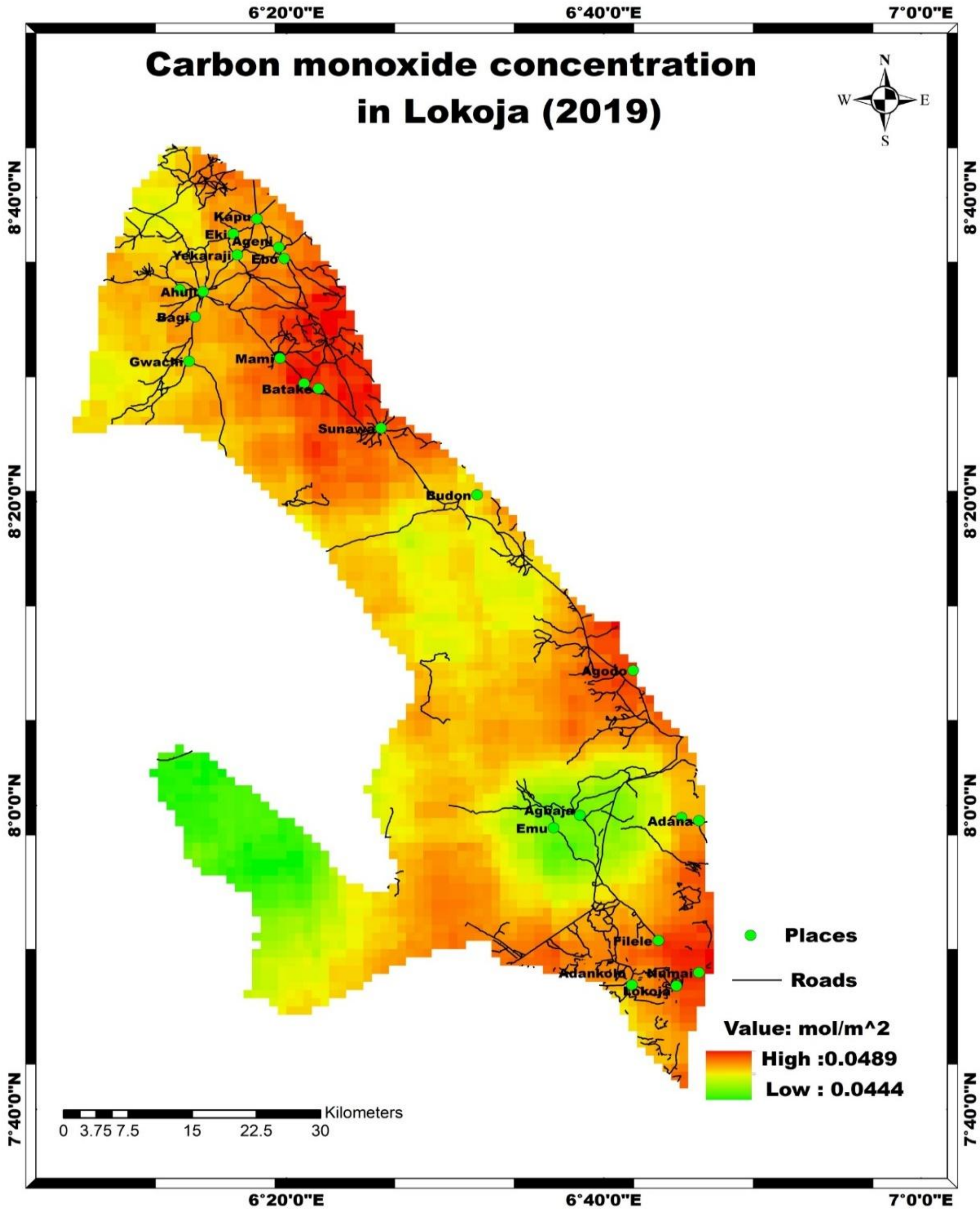

Figure 4.1.1: CO concentration in Lokoja, Kogi state for the year 2019

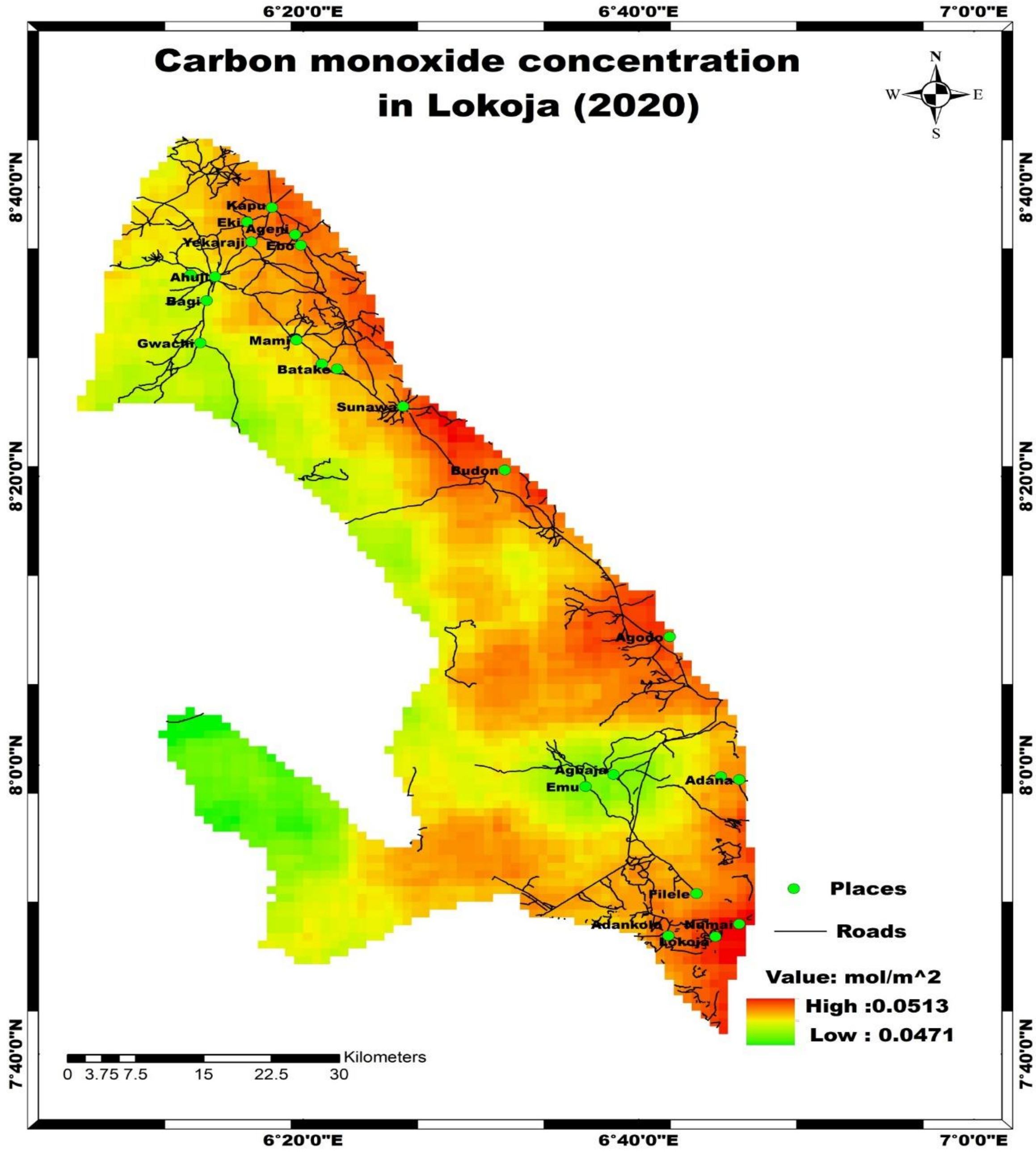

Figure 4.1.2: CO concentration in Lokoja, Kogi state for the year 2020

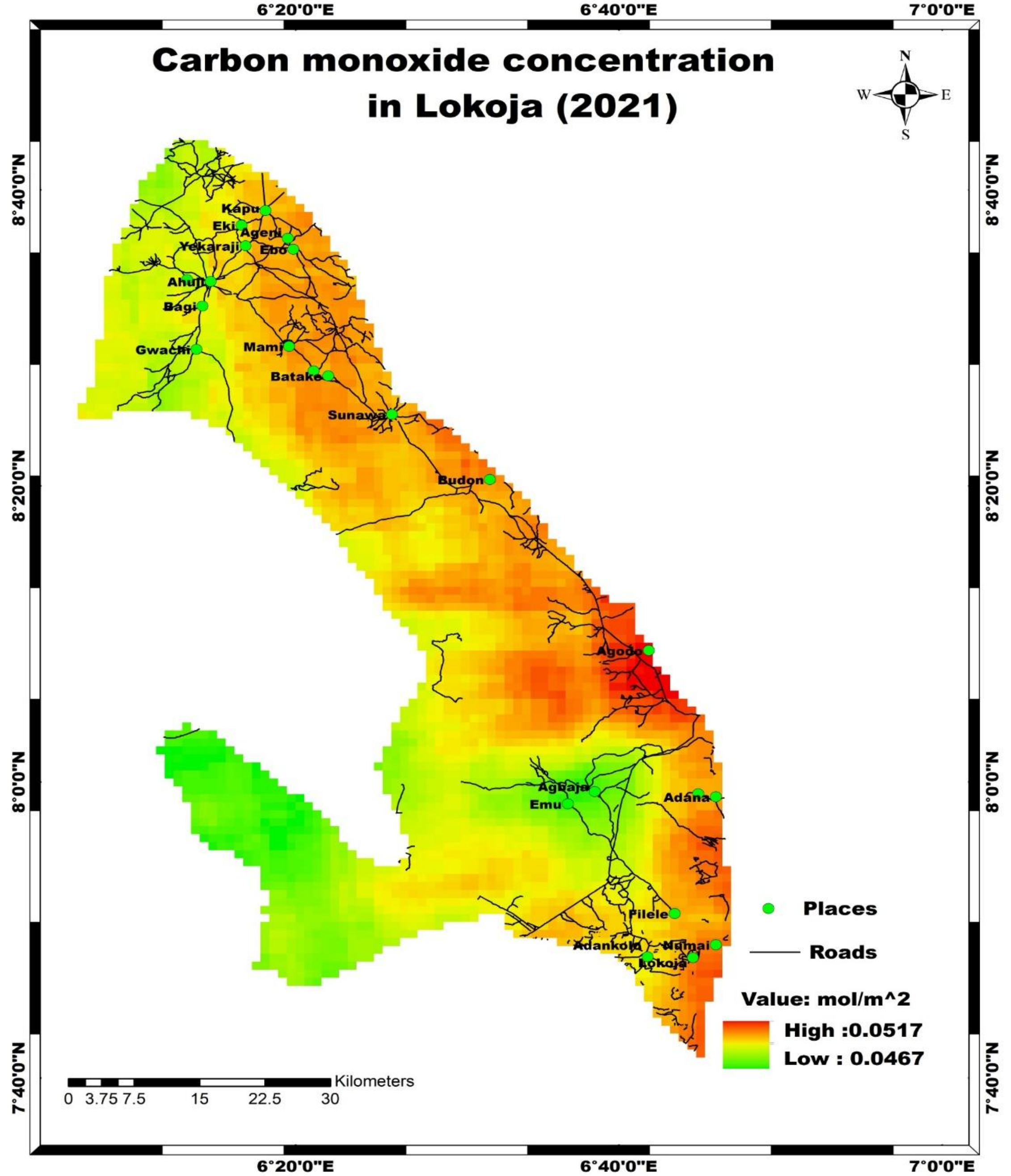

Figure 4.1.3: CO concentration in Lokoja, Kogi state for the year 2021

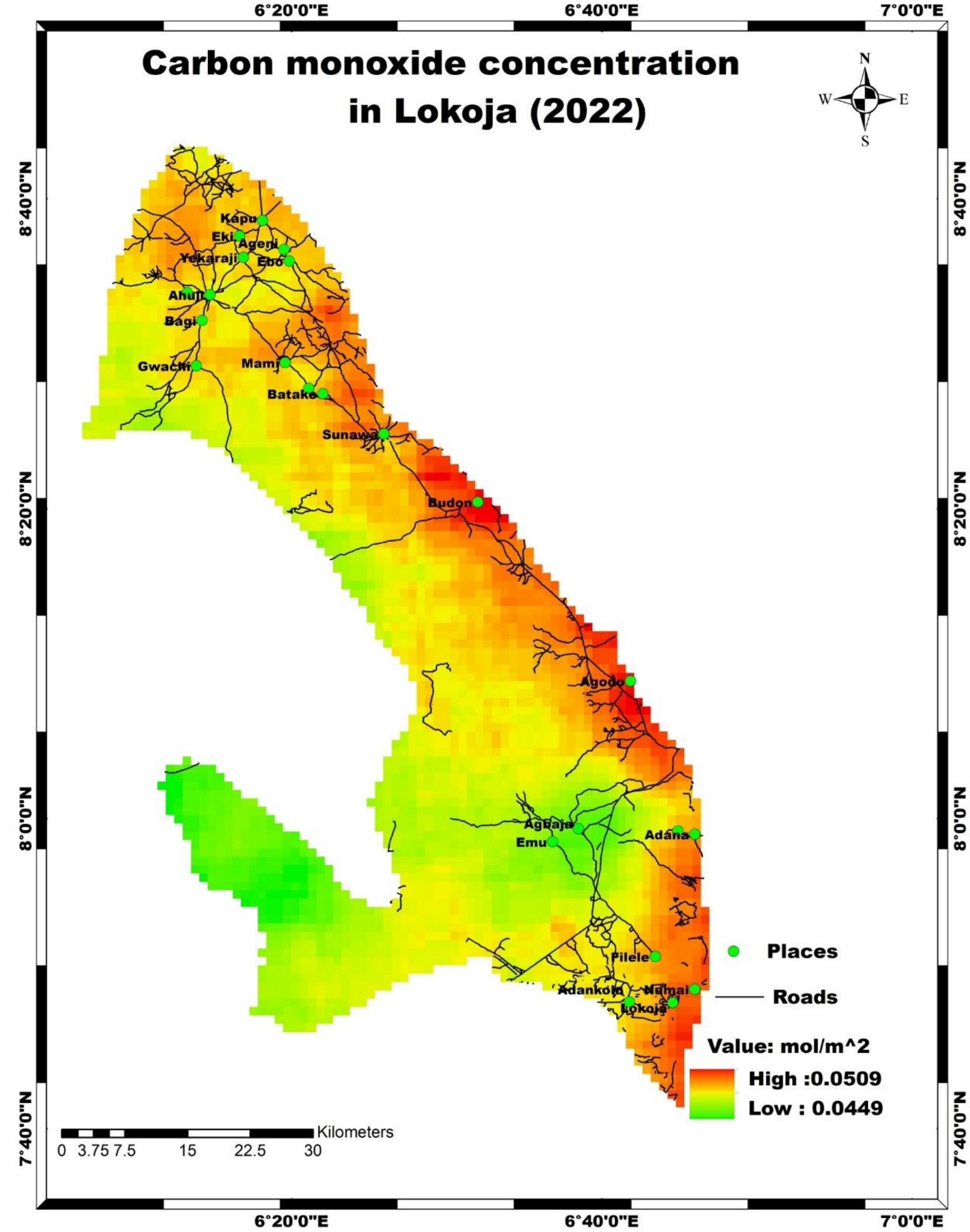

Figure 4.1.4: CO concentration in Lokoja, Kogi state for the year 2022

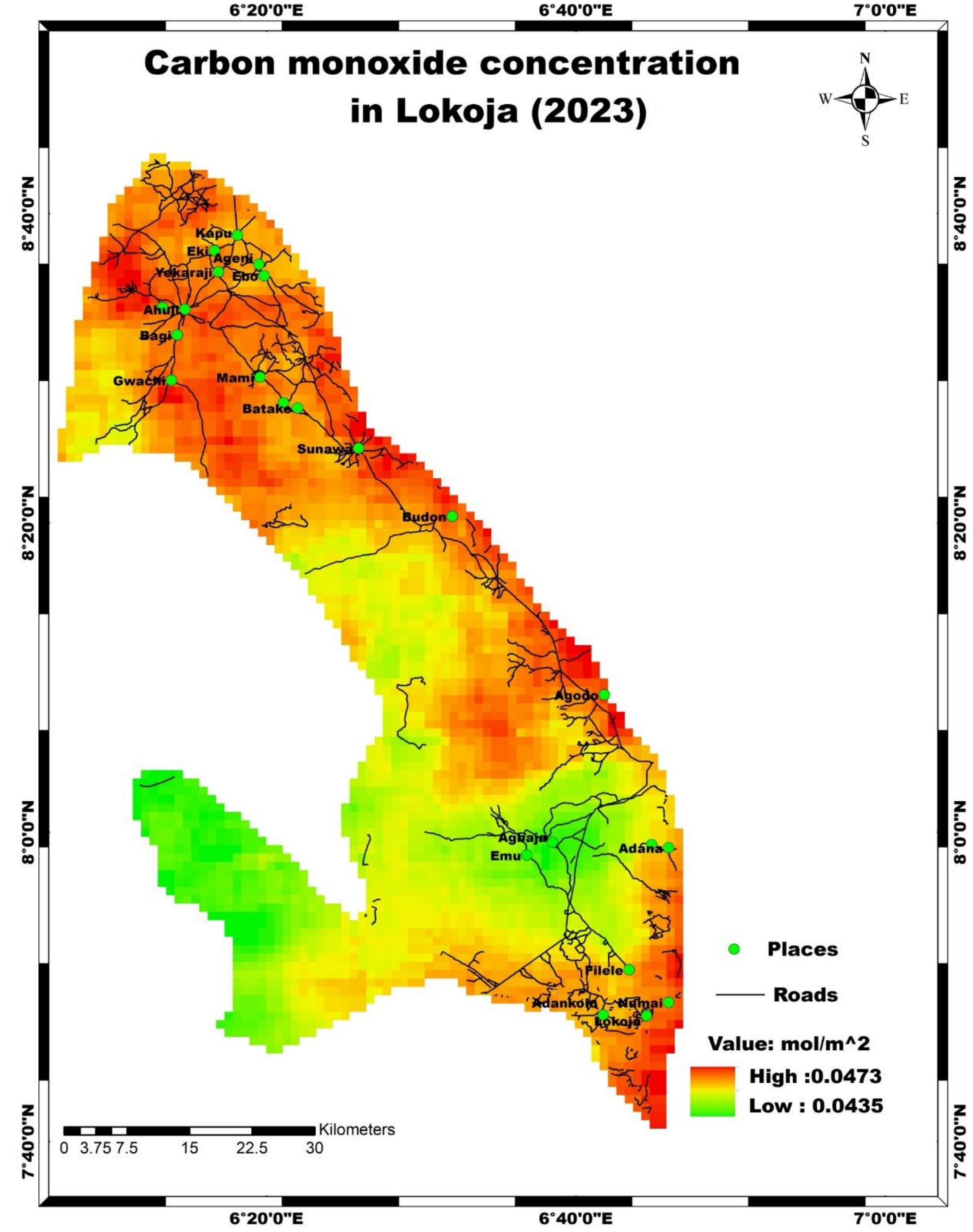

Figure 4.1.5: CO concentration in Lokoja, Kogi state for the year 2023

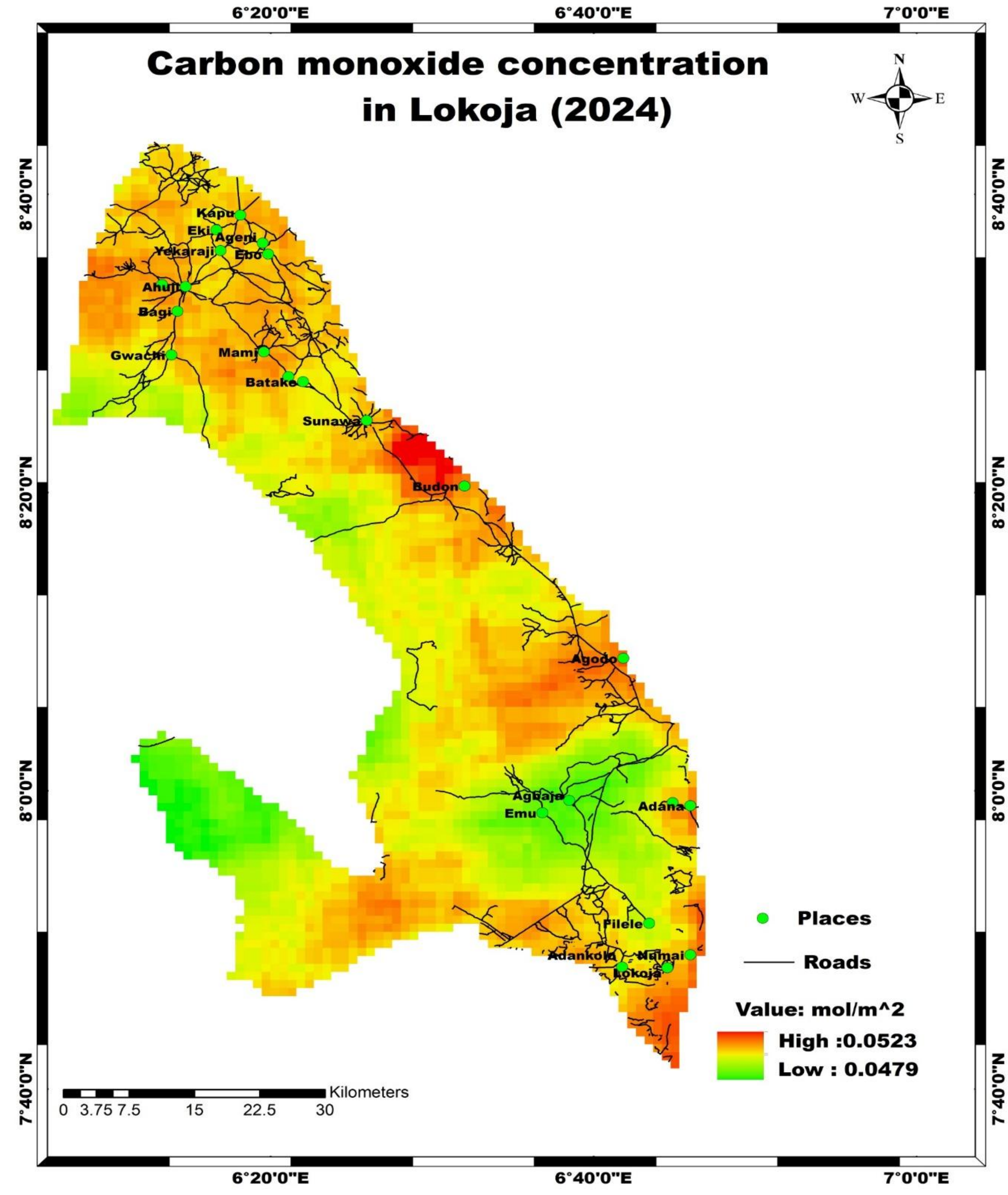

Figure 4.1.6: CO concentration in Lokoja, Kogi state for the year 2024

Based on the maps (Figures 4.1.1–4.1.6), the concentration of carbon monoxide (CO) in Lokoja has varied significantly from 2019 to 2024.

In 2019, High CO concentrations were observed in Mami, Batake, Sunawa, Agodo, and Numai, while Agbaja, Adana, and Emu recorded very low concentrations. In 2020, Areas such as Kapu, Mumai, and Lokoja experienced a notable increase in CO levels compared to the previous year, while other areas showed significantly lower concentrations. In 2021; Following the COVID-19 pandemic, CO concentrations were generally low across Lokoja, with Agodo being the only area with significant pollution. The number of highly polluted areas increased in 2022, with Budon and Agodo recording high CO levels, while other areas had moderate concentrations. In 2023; a notable increase in CO pollution was recorded in multiple areas, including Ahunji, Bagi, Gwachi, Sunawa, Batake, Yekaraji, Mami, Budon, Lokoja, Numai, and Agodo, while other locations had low concentration levels.

CO levels remained high in areas such as Gwachi, Mami, Bagi, Ahunji, Yekaraji, Ebo, Eki, Kapu, Aheni, Adankola, and Lokoja, while other locations maintained moderate or low CO concentrations as of 2024.

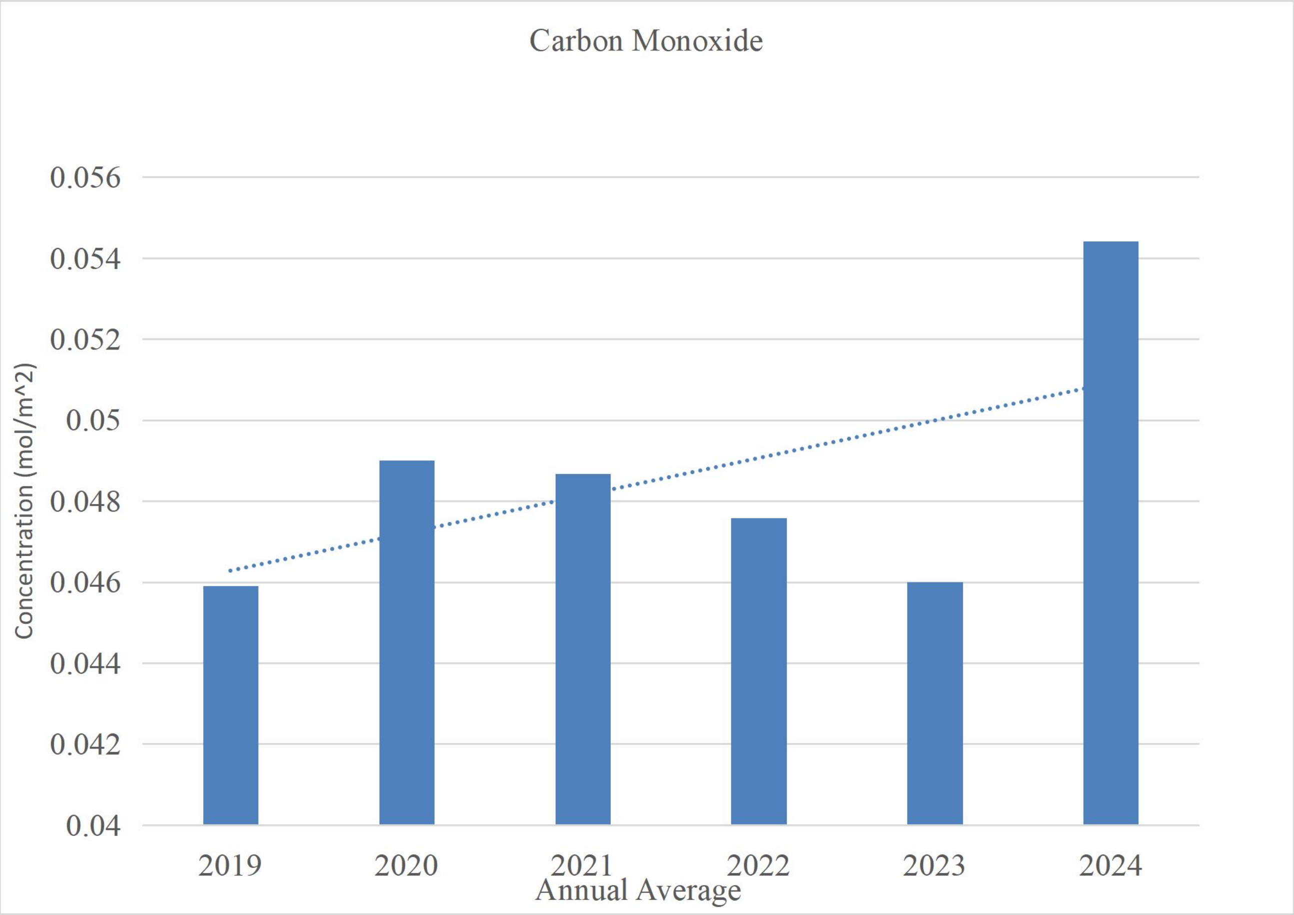

Figure 4.1.7: Trend of annual concentration of CO (2019-2024)

From figure 4.1.7; the annual variation of CO from 2019-2024 shows some difference the increment of the pollutant. From 2019 to 2020, there was an increase in the concentration of CO, then upon 2020 to 2021, there was a very slight difference in the change in the concentration level. As at 2021 to 2022, there was a slight decrease in the concentration of the pollutant; which then further decreased at 2023. Then as at 2024, there was a very sharp increase in the concentration of pollutant.

4.2. NITROGEN DIOXIDE CONCENTRATION IN LOKOJA, KOGI STATE

Table 4.2.1.Annual concentration of NO_2 for 2019- 2024.

NO	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
MINIMUM	0.0000513	0.0000529	0.0000588	0.0000589	0.0000581	0.0000561
MAXIMUM	0.0000679	0.0000724	0.000079	0.0000779	0.0000763	0.0000561
MEAN	0.0000596	0.00006265	0.0000689	0.0000684	0.0000684	0.0000561
STANDARD DEVIATION	0.0000021	0.0000024	0.0000025	0.0000024	0.0000024	0.0000026

From table 4.2.1.The lowest NO_2 concentration increased steadily from 2019 (0.0000513 mol/m²) to 2023 (0.0000581 mol/m²) before decreasing in 2024 (0.0000561 mol/m²). This indicates that air quality slightly worsened in the earlier years but improved in 2024. The peak NO_2 levels rose significantly from 2019 (0.0000679 mol/m²) to 2021 (0.000079 mol/m²), showing increased emissions. After 2021, NO_2 levels gradually declined, suggesting possible government interventions, environmental policies, or changes in fuel consumption. In 2024, the maximum concentration dropped to 0.0000561 mol/m², the lowest value recorded, which could indicate improvements in air pollution control. The average concentration increased from 2019 (0.0000596 mol/m²) to 2021 (0.0000689 mol/m²), showing higher pollution levels.

Between 2022 and 2023, the mean remained constant (0.0000684 mol/m²), suggesting stable pollution levels. In 2024, the mean dropped sharply to 0.0000561 mol/m², the lowest recorded level in the study period**.** This suggests a general improvement in air quality. The standard deviation values range between 0.0000021 and 0.0000026, indicating small fluctuations in NO_2 levels each year. Despite year-to-year changes, the variations in pollution levels remained relatively stable, meaning pollution trends were fairly predictable.

Monthly mean distribution of NO_2 concentration from 2019-2024 as depicted in Appendix 2. Reveals that in 2019**,** the highest NO_2 concentration was recorded in **February (0.000070 mol/m²)**, while the lowest occurred in **October (0.000042 mol/m²)**. The **mean NO_2 concentration** for the year was **0.0000548 mol/m²**. In 2020, the highest concentration was recorded in **February (0.0000655 mol/m²)**, while the lowest was in **May and October (0.000051 mol/m²).** The **mean NO_2 concentration** for the year was **0.0000563 mol/m².** In 2021, the highest concentration occurred in **January and March (0.0000725 mol/m²)**, while the lowest was in **August (0.000050 mol/m²)**. The **mean NO_2 concentration** for the year was **0.0000618 mol/m².**In 2022, the highest concentration occurred in January (0.000079), this happens to be the highest concentration level in the study years; while in July, there was a low concentration of 0.0000515. The mean NO_2 concentration for the year was 0.0000616.

In 2023, the highest concentration was in **January (0.000076 mol/m²),** while the lowest was in **October (0.0000525 mol/m²)**. The **mean NO_2 concentration** for the year was **0.0000613 mol/m².**

While in 2024, the highest NO_2 concentration was recorded in **January (0.0000735 mol/m²),** while the lowest was in **July (0.0000515 mol/m²).** The **mean NO_2 concentration** for the year was **0.0000597 mol/m².**

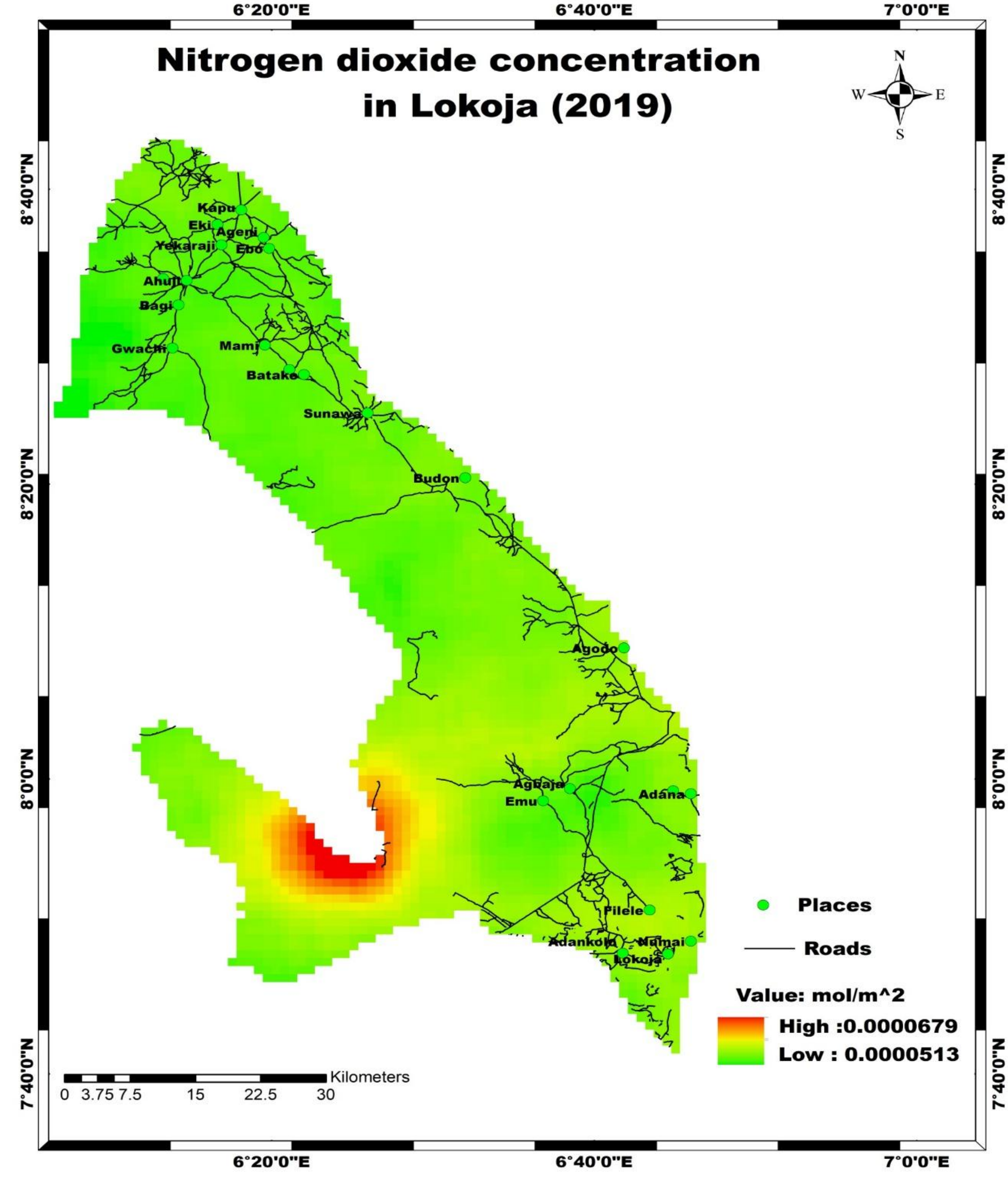

Figure 4.2.1: NO_2 concentration in Lokoja, Kogi state, for the year 2019

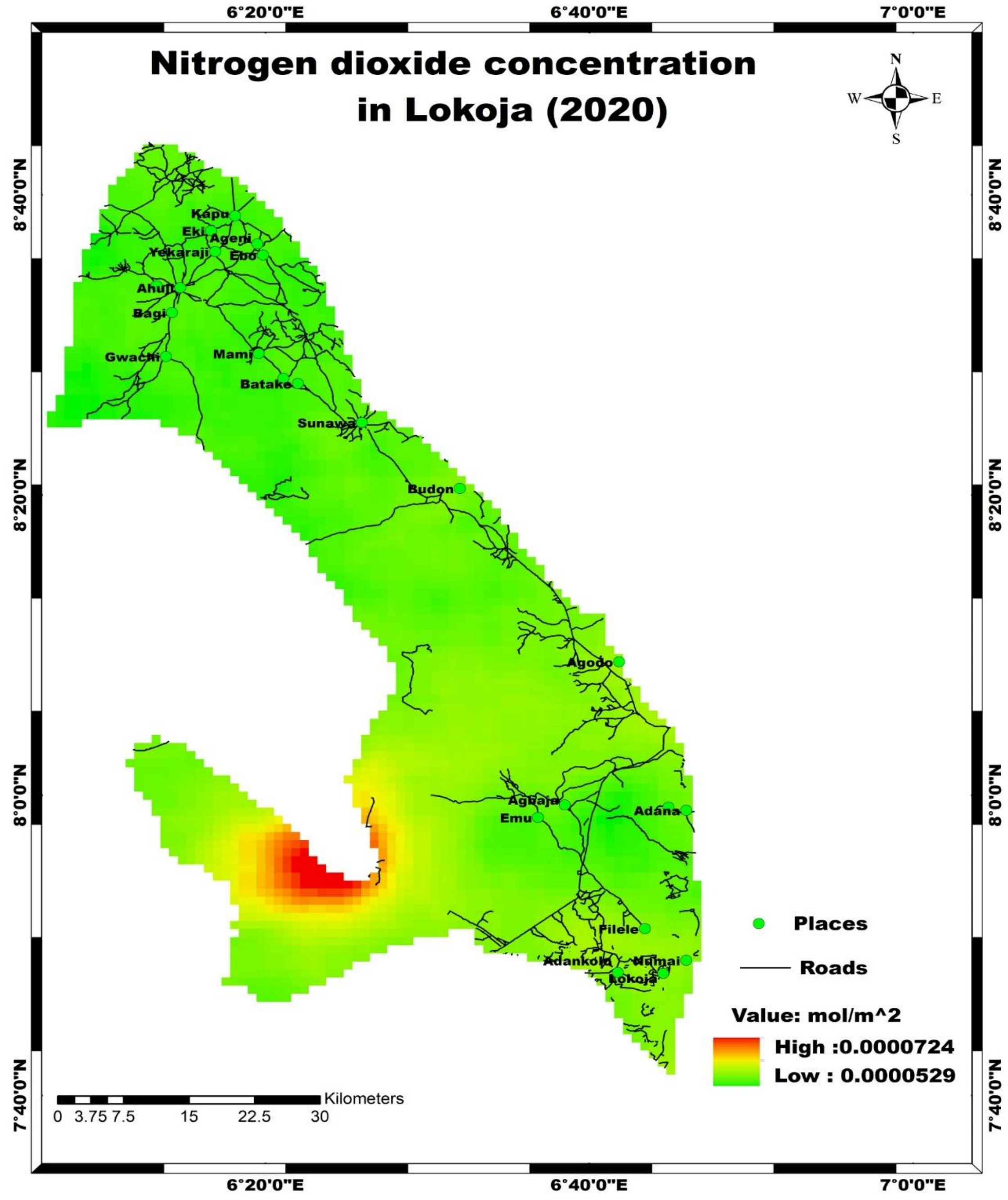

Figure 4.2.2: NO_2 concentration in Lokoja, Kogi state, for the year 2020

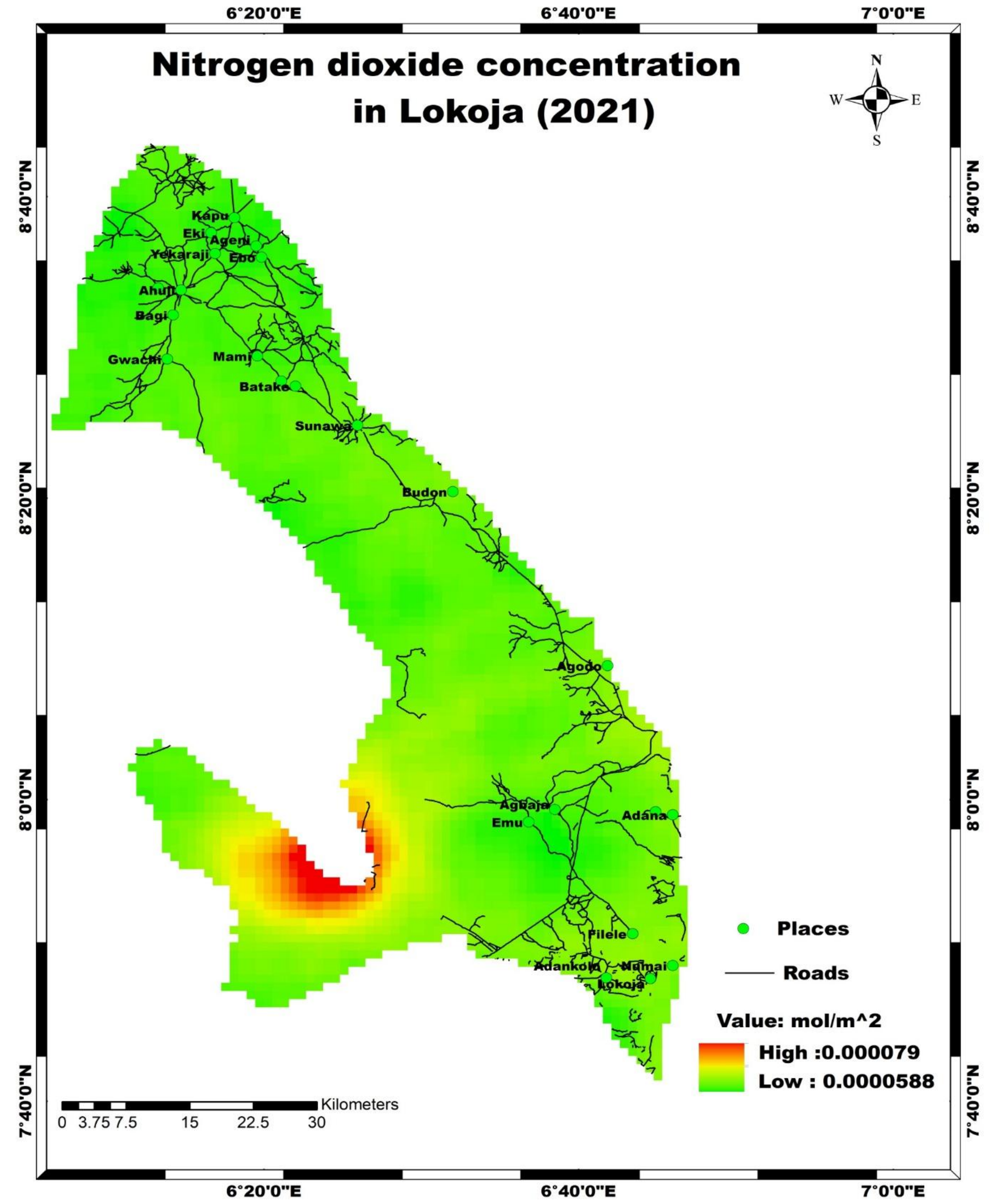

Figure 4.2.3: NO₂ concentration in Lokoja, Kogi state, for the year 2021

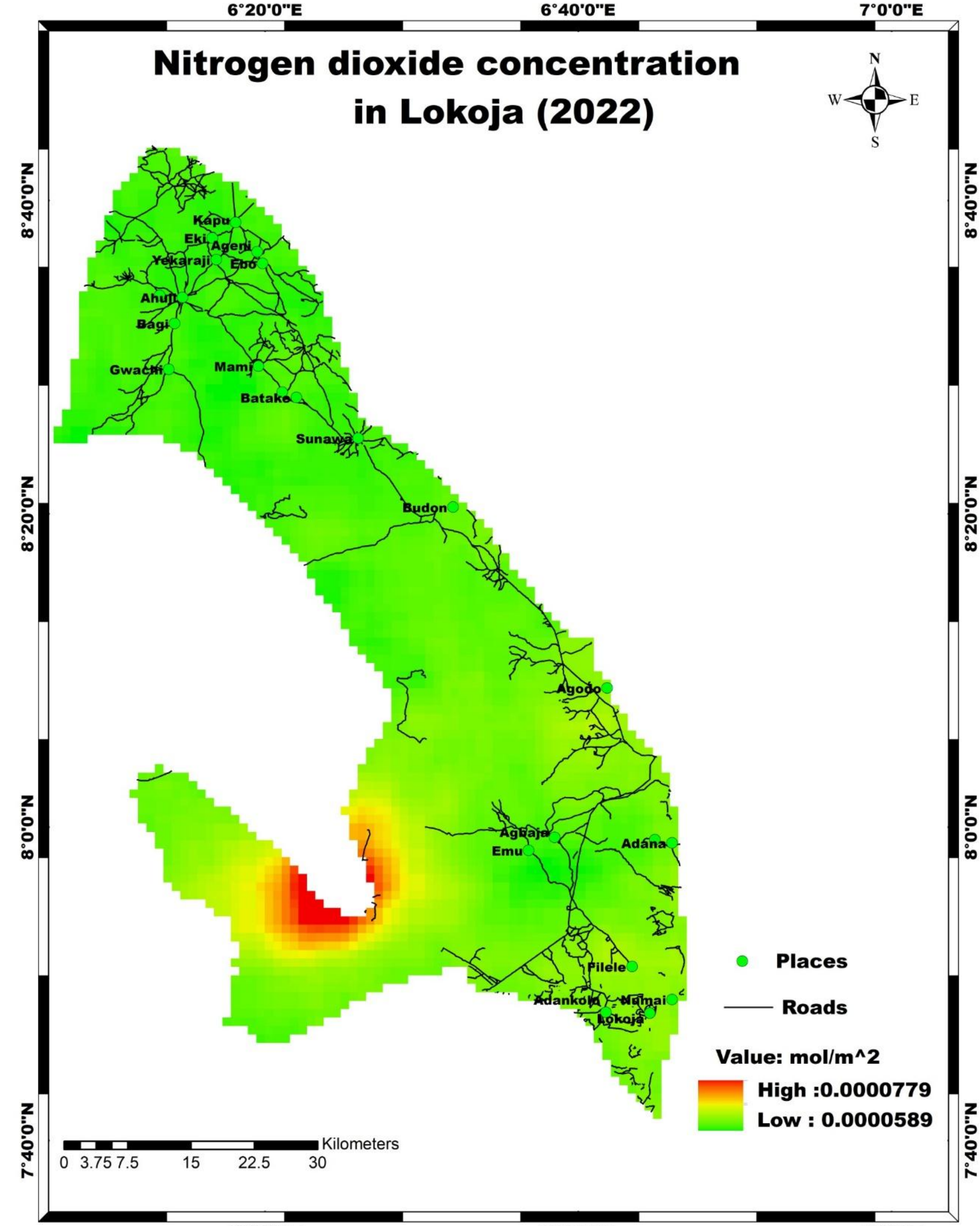

Figure 4.2.4: NO_2 concentration in Lokoja, Kogi state, for the year 2022

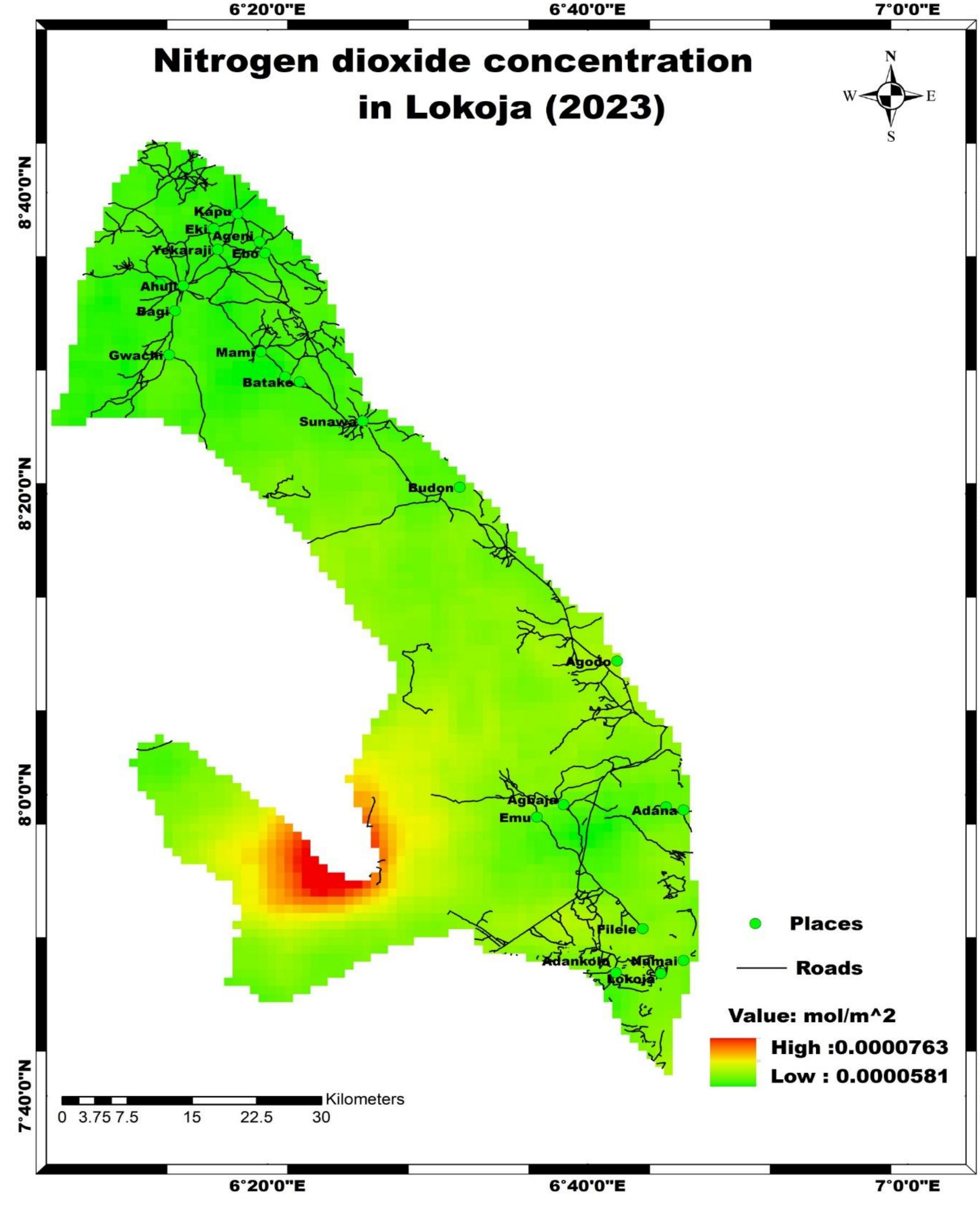

Figure 4.2.5: NO_2 concentration in Lokoja, Kogi state for the year 2023

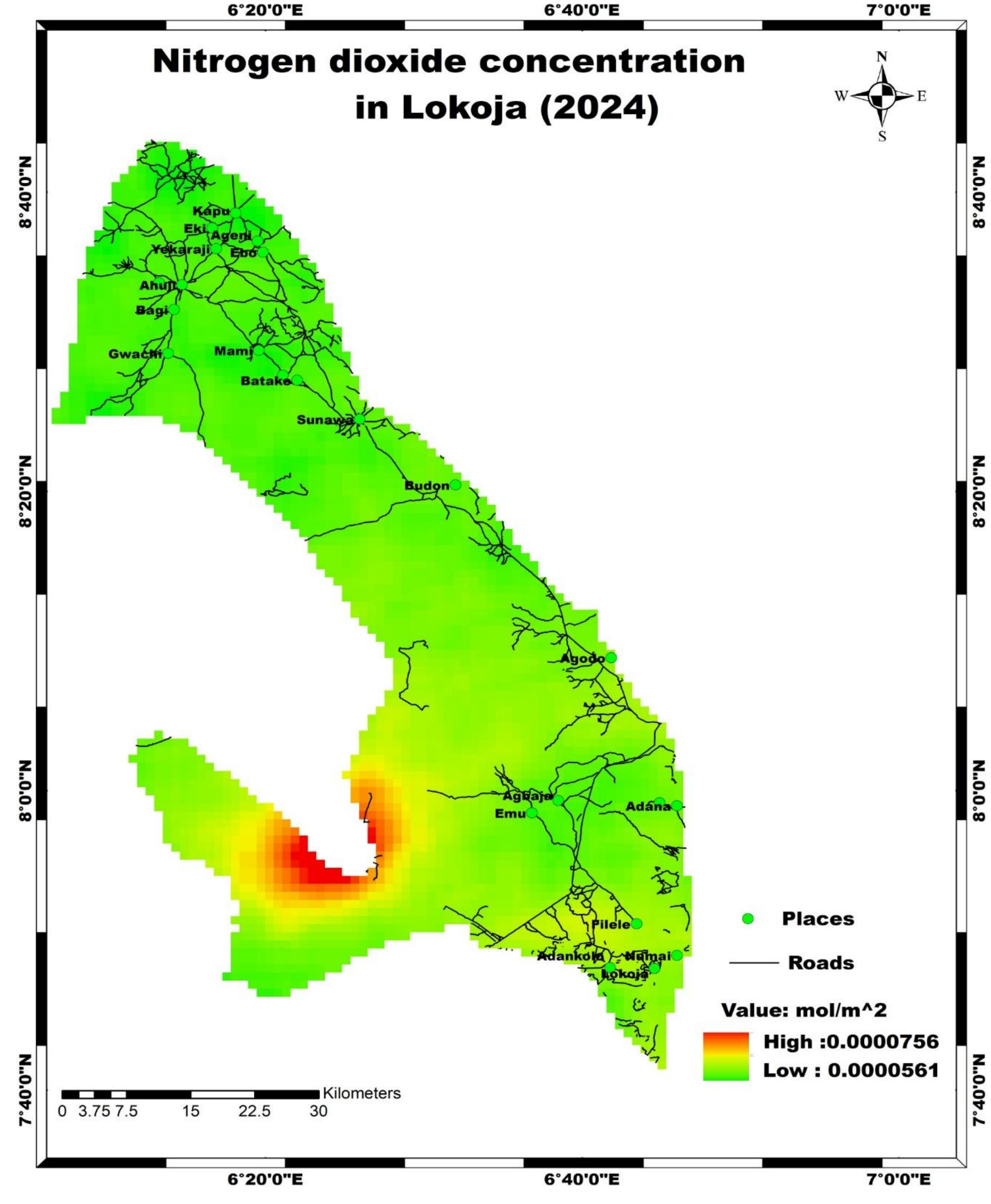

Figure 4.2.6: NO$_2$ concentration in Lokoja, Kogi state, for the year 2024

From the figure (4.2.1-4.2.6); it is evident that there is correlative significance from 2019-2024 in Lokoja.

There was a constant concentration level of NO_2 thereby making the level of NO_2 insignificant. Most areas are in a moderate or very low concentration level of NO_2.

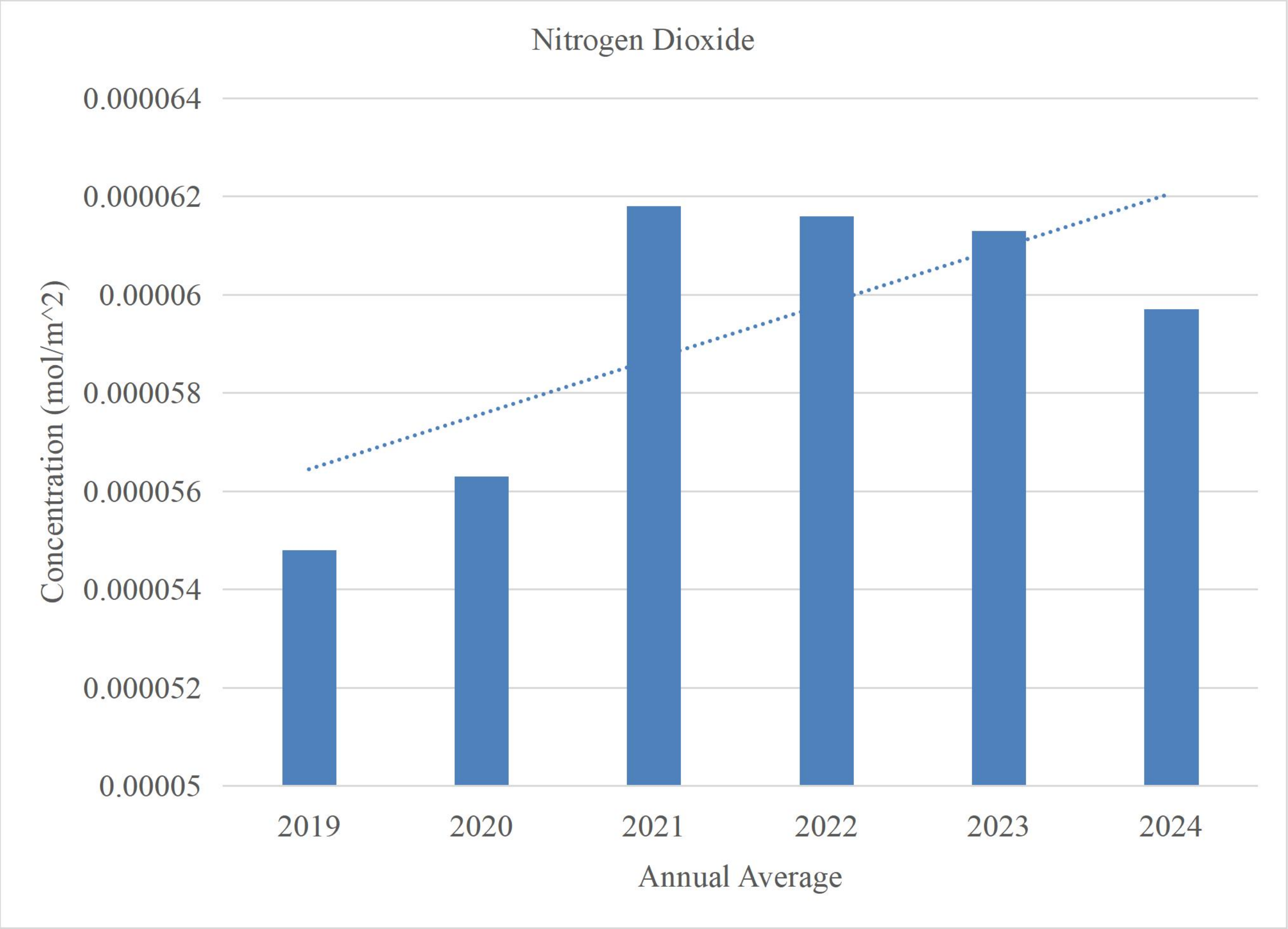

Figure 4.2.7: Trend of annual concentration of NO_2 (2019-2024)

The annual variation of NO_2 from 2019-2024 shows the varying concentration levels of the pollutants as the year passes. From 2019 to 2020, there is an increase in the concentration level of the pollutant. From 2020 to 2024, there was a sharp increase in the concentration level and that happens to be the highest peak level in all years. From 2021 to 2022, there was a very slight decrease in the concentration level. So, in subsequent years there was a slight decrease from 2022 to 2023 and then 2024.

4.3 AEROSOL CONCENTRATION IN LOKOJA, KOGI STATE

Table 4.3.1 . .Annual concentration of CO for 2019- 2024.

Aerosol	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
MINIMUM	-0.827	-0.909	-0.554	0.095	0.011	0.0428
MAXIMUM	-0.573	-0.713	-0.304	0.353	0.273	0.28
MEAN	-0.7	-0.811	-0.429	0.224	0.142	0.1614
STANDARD DEVIATION	0.053	0.0370	0.060	0.065	0.062	0.056

This table 4.3.1 presents the **annual concentration levels of aerosols** in Lokoja, Kogi State, **from 2019 to 2024** using the **minimum, maximum, and mean (average), and standard deviation values** for each year.

The minimum aerosol concentration values were negative from 2019 to 2021, indicating very low atmospheric aerosol presence in those years. In **2022,** suggesting a significant shift in aerosol levels.

In 2023 (0.011) and 2024 (0.0428) had positive values, indicating a continued trend of higher aerosol concentration compared to earlier years. Like the minimum values, the maximum aerosol concentrations were negative from 2019-2021, meaning aerosol presence was lower. A major shift occurred in 2022 (0.353), showing a sharp increase in aerosol concentration, possibly due to increased pollution sources.

In 2023 (0.273) and 2024 (0.28) maintained positive values**,** indicating continued high aerosol levels compared to the earlier years. Around 2019**-2021,** the mean values were negative (-0.7 to -0.429), showing low aerosol presence in the atmosphere.

Then in **2022,** the mean concentration rose **to 0.224**, marking a significant increase in aerosols.

In 2023 (0.142) and 2024 (0.1614) remained positive, suggesting that aerosol levels have stabilized but The standard deviation values range from 0.0370 to 0.065, showing moderate fluctuations in aerosol levels each year.

The highest variations were observed in 2022-2023, likely due to major environmental events such as biomass burning, increased vehicular emissions, or changes in weather conditions are still higher than in previous years.

Monthly mean distribution of Aerosol concentration from 2019-2024 in Appendix 3 reveals that in 2019, the highest Aerosol concentration occurred in February (0.434), while the lowest was in October (-1.3777). The mean concentration of Aerosol for the year was –0.675.

In 2020, the peak concentration was also in February (0.606), making it the highest recorded monthly Aerosol level across all the study years. The lowest concentration remains in October (-1.568). The mean concentration of Aerosol for the year was -0.793.

In 2021, the highest concentration occurred in December (0.895), while the lowest was in May (-1.389). The mean Aerosol concentration for the year was -0.431.

In 2022, the highest concentration occurred in February (1.699), while in November, there was a low concentration of -0.05. The mean Aerosol concentration for the year was 0.236.

In 2023, the highest concentration occurred in February (1.496), while the lowest was in November (-0.005). The mean Aerosol concentration for the year was 0.137.

While in 2024, the highest concentration occurred in February (1.409), while the lowest was in November (0.008). The mean Aerosol concentration for the year was 0.173.

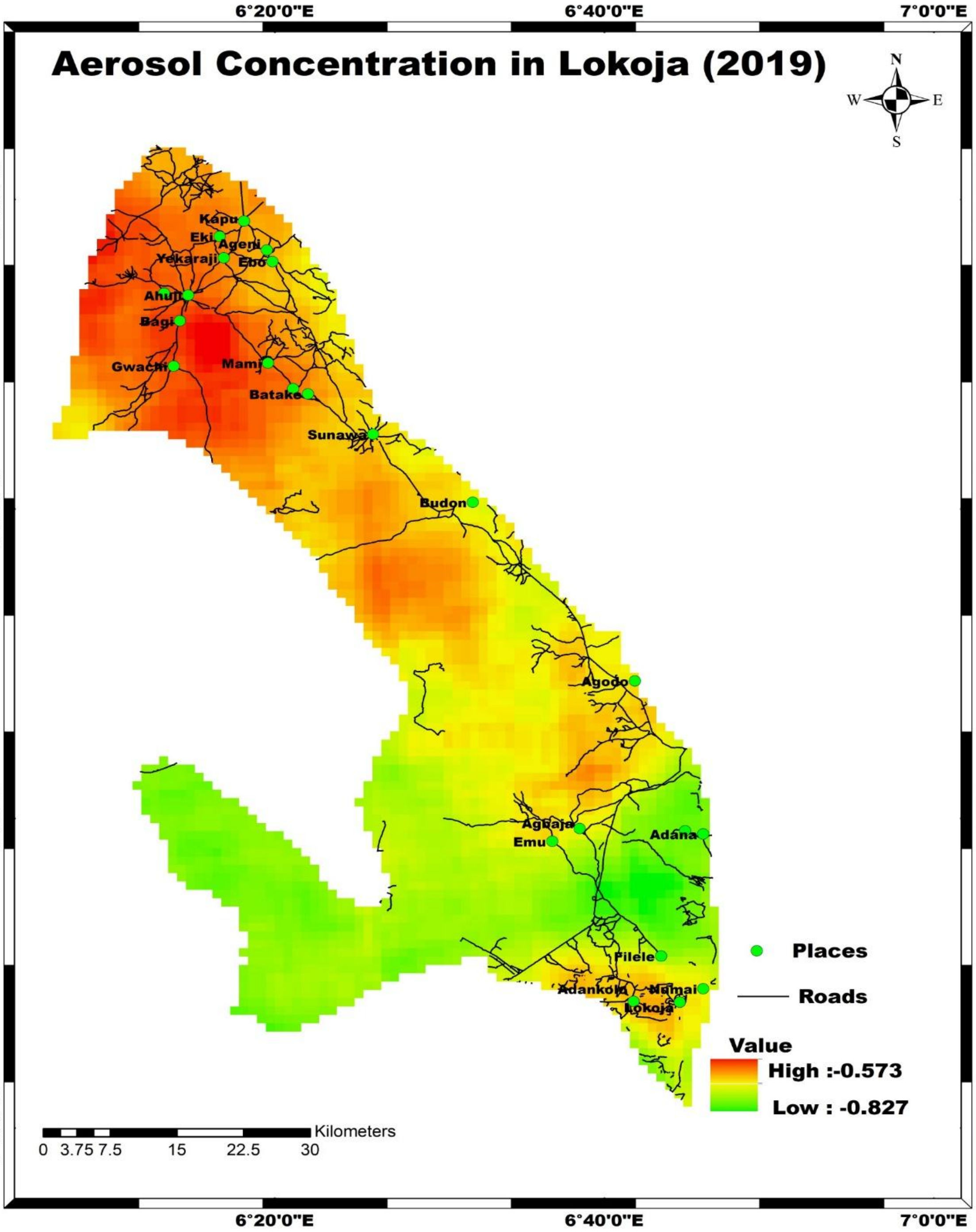

Figure 4.3.1: Aerosol concentration in Lokoja, Kogi state for the year 2019

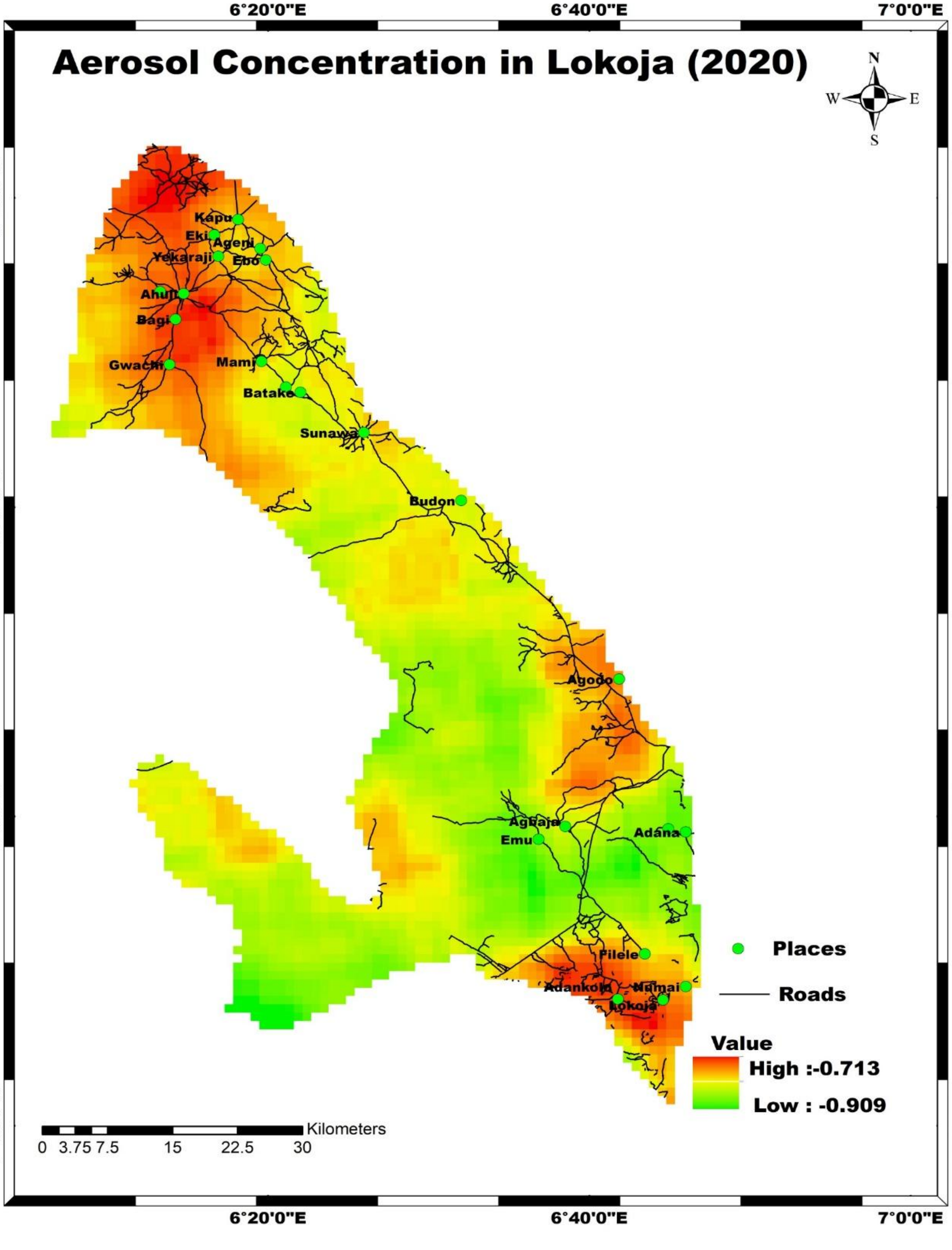

Figure 4.3.2: Aerosol concentration in Lokoja, Kogi state for the year 2020

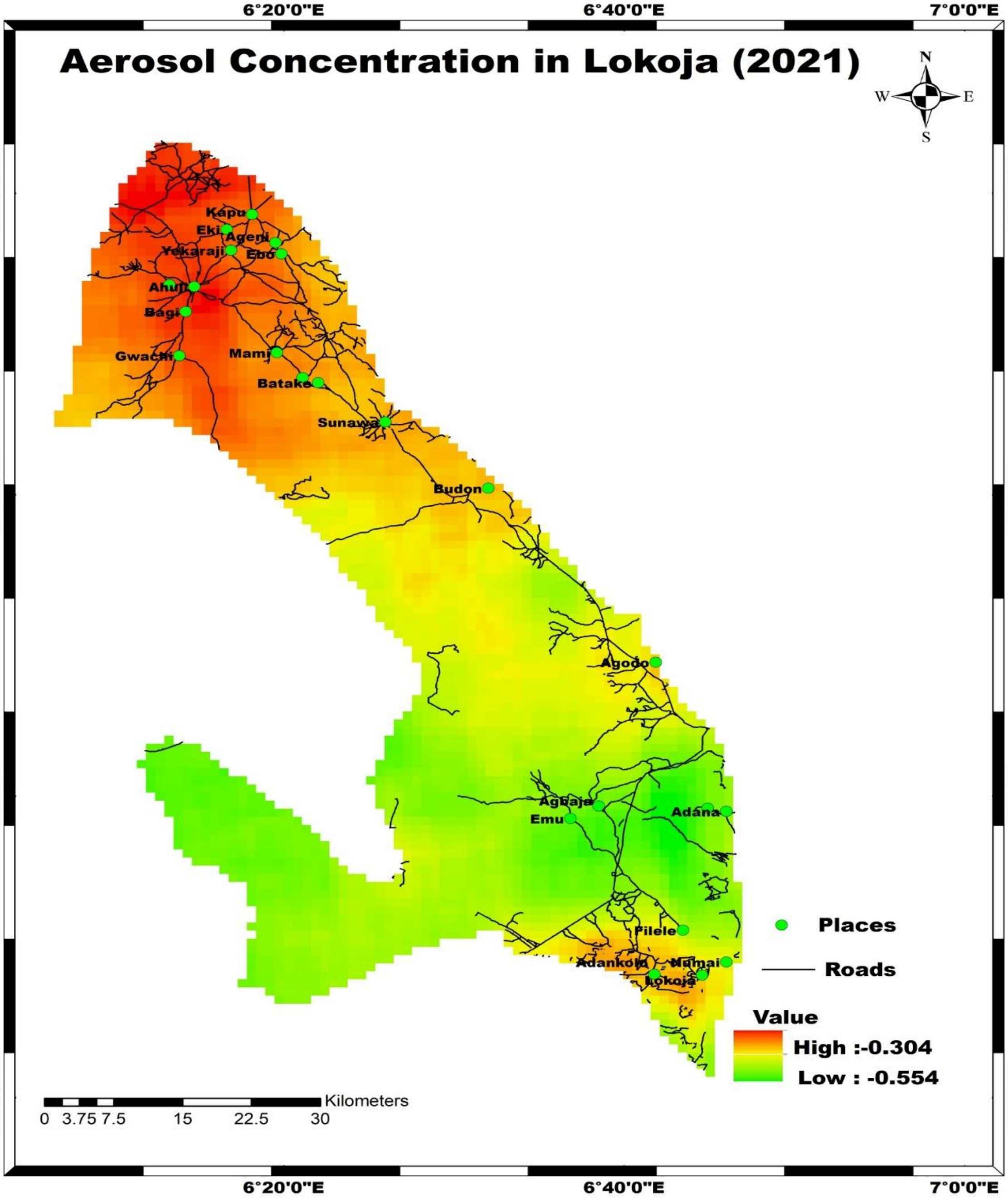

Figure 4.3.3: Aerosol concentration in Lokoja, Kogi state for the year 2021

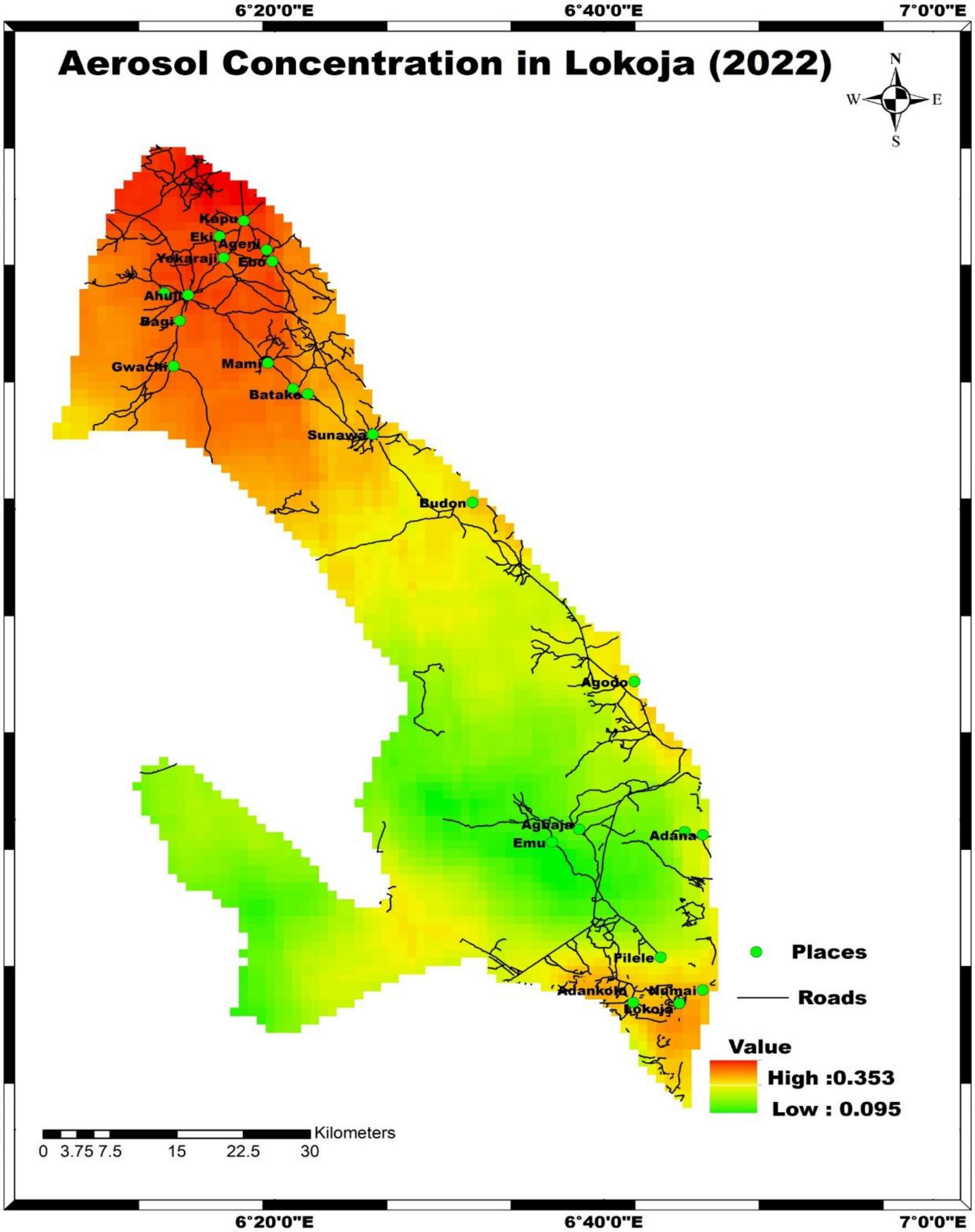

Figure 4.3.4: Aerosol concentration in Lokoja, Kogi state for the year 2022

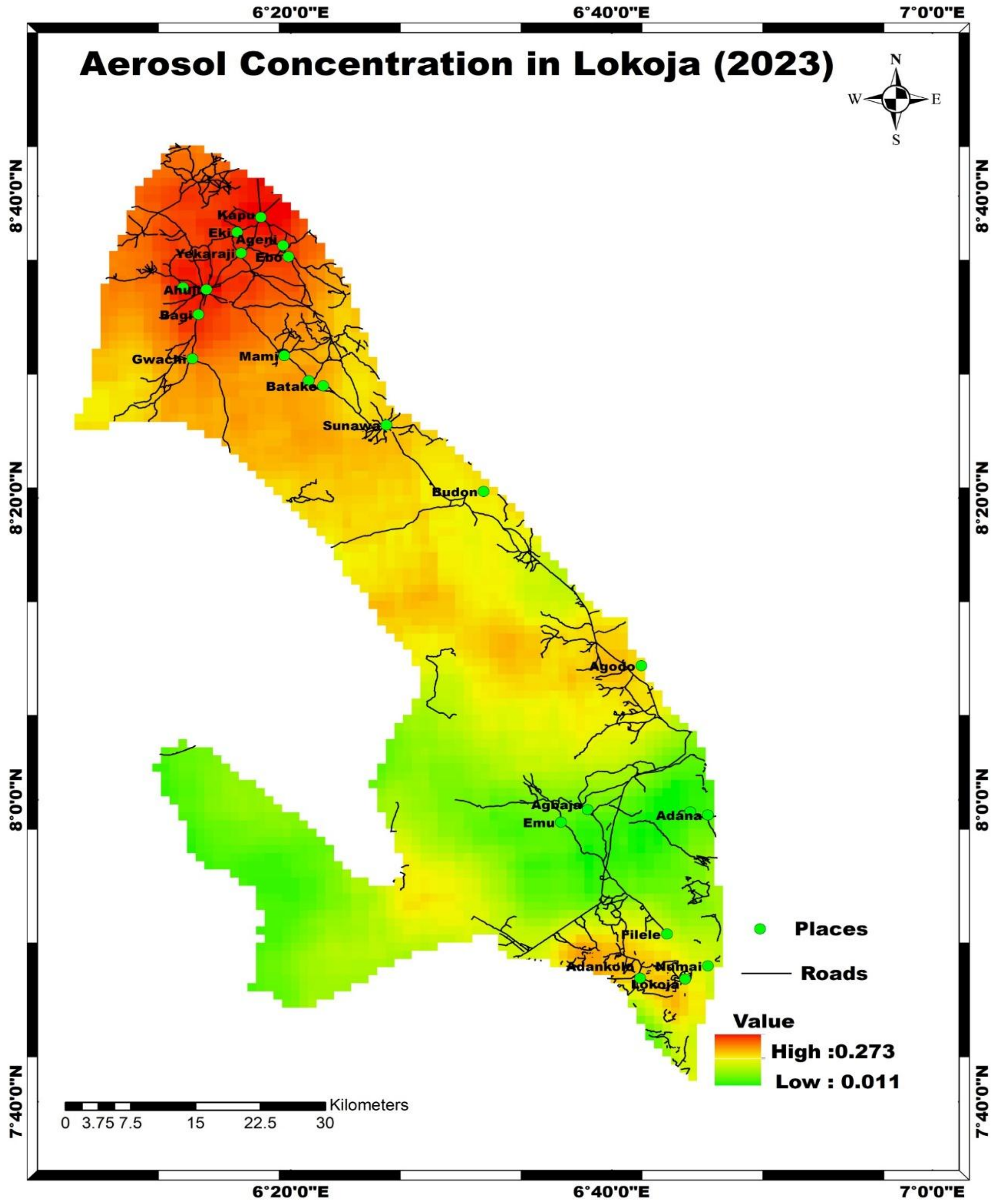

Figure 4.3.5: Aerosol concentration in Lokoja, Kogi state for the year 2023

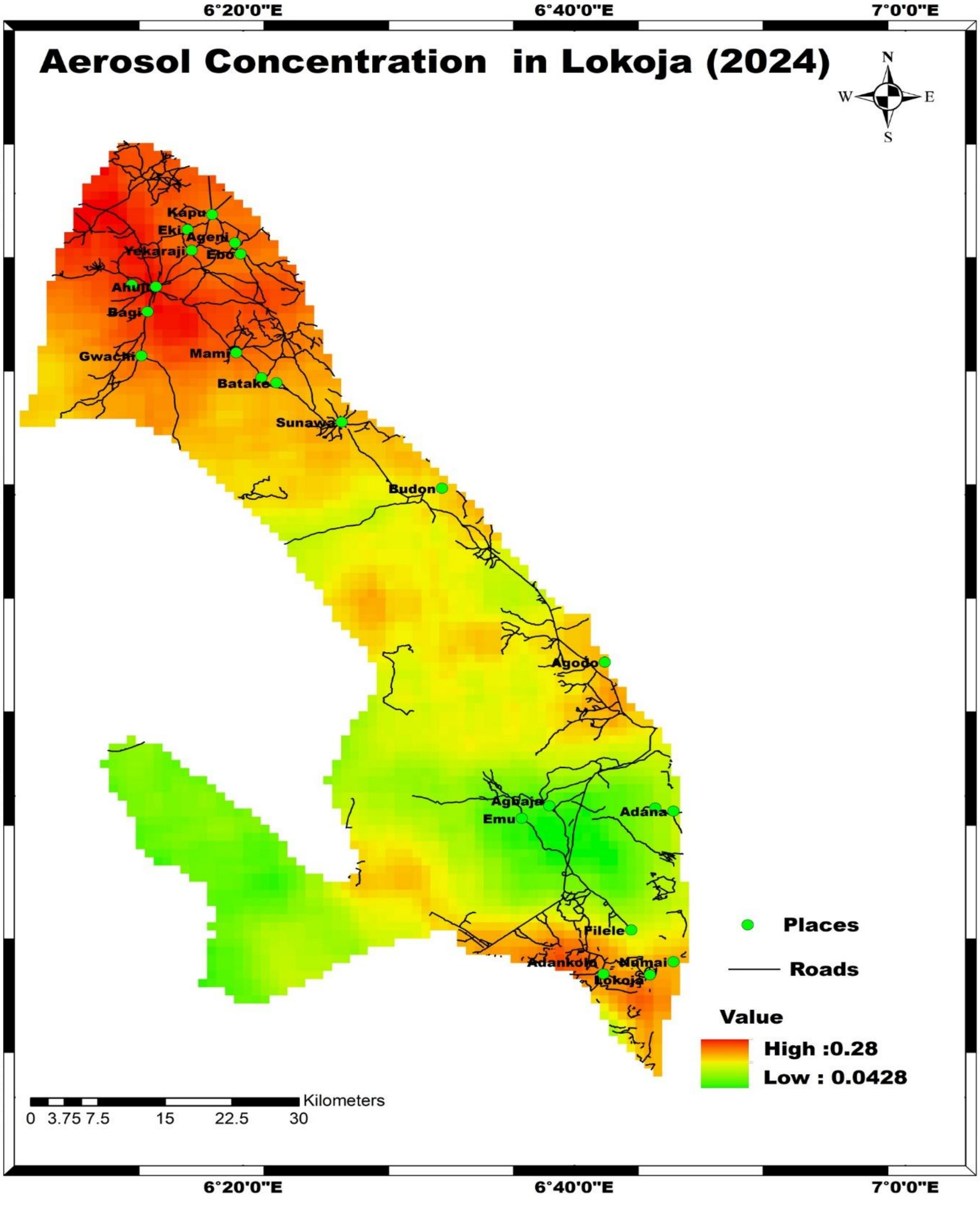

Figure 4.3.6: Aerosol concentration in Lokoja, Kogi state for the year 2024

From table (4.3.1-4.3.6), it shows the different concentration levels of aerosol in the sampling years. In 2019; areas like Gwachi, Batake, Bagi, Ahuji, Yekaraji, Eki, Kapu and Ageni had a high level of Aerosol present while the rest regions fell around moderate to low. In 2020, there was a high concentration level compared to the year 2019, areas like Gwachi, Bagi, Ahuji, Yekaraji, Eki, Kapu, Adankola, Lokoja, Numai, Agodo, Filele had high levels of the pollutants present. While areas like Mami, Bakate, Sunawa, Budon, Abaje,Emu and Adana have less aerosol concentration. In 2021; the north-west region of Lokoja has high concentration of aerosols, while every other area in the other part of the region has a low concentration level of aerosol. In 2022, the north-west region of Lokoja has a high concentration level of aerosols, given the same observation as the year 2021.

In 2023, the same observation from 2022 was also noticed and the c2oncentration level of aerosols was around the north-west region of the area. In 2024, it is evident that the whole of the north-west region and the south-west region has a high level of aerosol present while areas like Budon, Agodo, Filele has moderate level of pollutants.

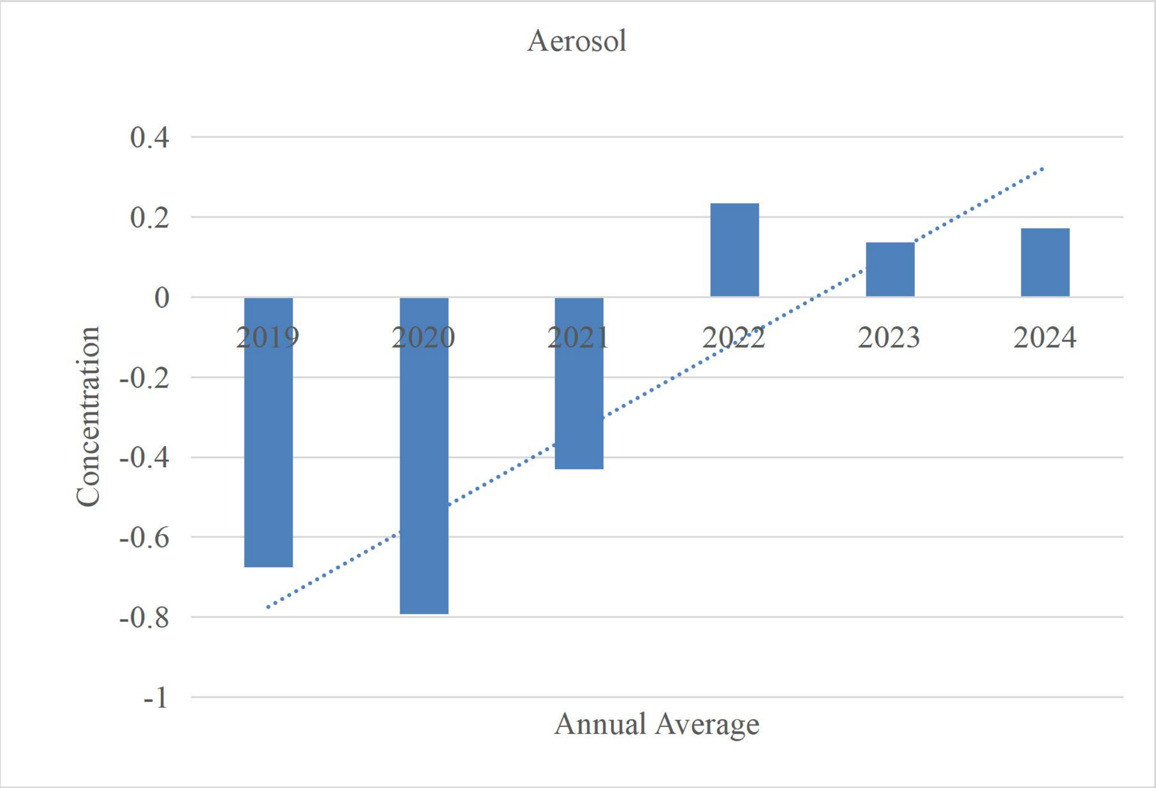

Figure 4.3.7: Trend of annual concentration of Aerosol (2019-2024)

As of 2019, there was a very low concentration of Aerosol dispersed that year. Then in 2020, the concentration decreased further and then kept increasing slowly in the year 2021 even tho the concentration of the pollutant is still low. As of 2021, there was a high increase of the concentration which then dropped a bit in 2023 and increased slightly in 2024. The trend shows a general increase in aerosol concentration observed across the study areas.

4.4. STATISTICAL DIFFERENCES ANALYSIS

For CO, a paired sample t-test revealed no significant difference between 2019 and 2020(p= 0.210). No significant difference was observed between 2020 and 2021 (p= 0.736). Between 2021 and 2022 (p= 0.084) there is a no significance difference. There was also no significant difference was observed between 2022 and 2023 (p= 0.135), and then with a no significant difference between 2023 and 2024.

For NO_2, there is no significant difference between 2019 and 2020 (p= 0.423), and then a significant difference between 2020 and 2021(p= 0.003), there was no significant difference between 2021 and 2022(p= 0.835), same thing is applicable to 2022 and 2023(p= 0.894), likewise 2023 and 2024(p= 0.289).

For Aerosol, there'no significant difference between 2019 and 2020. Also no significant difference was observed from 2020 and 2021(p= 0.149). A significant difference was observed from 2021 and 2022(p= 0.012), and from 2022 and 2023(p= 0.362), there is no significant difference noticed. Lastly from 2023 and 2024(p=0.707), there was no significant difference observed as well.

Table 4.4: Statistical Significance of Air Quality Parameter

Parameters	2019 and 2020	2020 and 2021	2021 and 2022	2022 and 2023	2023 and 2024
p-value of C0	0.210	0.736	0.084	0.135	0.54
p-value of $N0_2$	0.423	0.003	0.835	0.894	0.289
p-value of Aerosol	0.052	0.149	0.012	0.362	0.707

$P < 0.01$ = high significant difference; $p < 0.05$ = significant difference; $p > 0.05$ = no significant difference. (Source: Okoduwa and Amaechi, (2023))

CHAPTER FIVE

DISCUSSION, RECOMMENDATIONS AND CONCLUSION

5.1. DISCUSSION

This study analyzed levels of CO,NO_2, and aerosol concentration in Lokoja, Kogi state, Nigeria using sentinel 5P images in Google Earth Engine, for the study years 2019-2024.

5.1.1 CARBON MONOXIDE DISTRIBUTION IN LOKOJA ACROSS THE STUDY AREAS

The concentration levels of carbon monoxide (CO) in Lokoja have fluctuated over the years. Before 2020, CO levels were relatively low, but during the COVID-19 pandemic in 2020, there was a significant increase. This was followed by a decline in 2021-2022. However, by 2024, CO concentrations reached their highest recorded levels. The highest mean concentration was observed in 2024 at 0.544 mol/m^2, while the lowest was recorded in 2019 at 0.0459 mol/m^2.

Carbon monoxide is a colorless and odorless pollutant that results from the incomplete combustion of fuel (Barbulescu and Barbes, 2017). Its concentration in the atmosphere is influenced by various factors, including indoor and outdoor cooking, traffic congestion, and industrial activities (Ernyaish et al., 2023; Mouronte-Lopez and Subiran, 2023). The increase in CO levels in 2020, compared to 2019, can be attributed to ineffective enforcement of COVID-19 movement restrictions. While public movement decreased, industrial activities continued, contributing to higher emissions (Amaechi et al., 2023). A decline in CO levels was observed from 2021 to 2023, coinciding with the removal of fuel subsidies. This policy led to higher fuel prices, reducing the use of transportation systems and subsequently lowering emissions (Amaechi et al., 2024; Lorente *et al.,* 2019). However, in 2024, CO levels sharply increased. This rise may be attributed to increased economic activities, population growth, and a greater reliance on fossil fuels. Other contributing factors include waste burning, generator use, and construction dust, all of which negatively impact air quality and pose significant health risks, particularly for vulnerable populations (Adeoye et al., 2015).

High concentrations of CO were recorded in high-traffic and commercial areas such as Filele, Adankola, and central Lokoja. These findings suggest that CO pollution in Lokoja is closely linked to urban infrastructure, transportation patterns, and policy interventions, this findings align with the result of Macrotrends (2024). Rapid urbanization has led to a population surge, from 195,261 in 2006 to an estimated 886,000 in 2024 (Macrotrends, 2024). Economic activities driven by markets such as New Market and Kpata Market, as well as institutions like the Federal University Lokoja, have contributed to urban growth (Imam and Ojochenemi, 2024; Awodi et al., 2021). However, this expansion has also resulted in reduced agricultural activity and growing environmental concerns (Imam and Ojochenemi, 2024; Awodi et al., 2021).

The decline in CO levels from 2021 to 2023 underscores the role of economic factors in emissions reduction. However, the sharp increase in 2024 raises concerns about the long-term deterioration of air quality in Lokoja.

5.1.2. NITROGEN DIOXIDE DISTRIBUTION IN LOKOJA ACROSS THE STUDY YEARS

The concentration of nitrogen dioxide (NO_2) fluctuated over the years, with peak values occurring at different points. In 2019, NO_2 levels were relatively low. However, concentrations increased in 2020 and spiked sharply in 2021 before gradually declining from 2022 to 2024. The highest mean NO_2 concentration was recorded in 2021 at 0.0000618 mol/m², while the lowest was in 2019 at 0.0000548 mol/m².

Nitrogen dioxide primarily originates from fossil fuel combustion (Shi *et al*., 2014). The increase in NO_2 levels after 2020 can be attributed to the resumption of business and industrial activities in Lokoja following the COVID-19 lockdown, leading to higher fossil fuel combustion and energy consumption (Lorente *et al.,* 2019). A similar trend was observed globally, where NO_2 levels spiked following the COVID-19 lockdown.

The decline in NO_2 levels suggests that air quality improvements can be sustained through policy interventions and a shift to alternative energy sources instead of fossil fuels (Shi *et al*., 2014; Amaechi et al., 2023). This pattern aligns with global air pollution trends, where NO_2 levels rise during economic recovery phases before stabilizing due to regulatory efforts (Kazemi-Garajeh *et al*., 2023).

The decline in NO_2 levels from 2022 to 2024 suggests improved air quality, potentially due to stricter environmental controls and fuel pricing policies that reduced transportation emissions (Kazemi-Garajeh *et al*., 2023; Amaechi et al., 2024). These findings highlight the importance of sustainable energy policies and regulatory frameworks in mitigating air pollution and promoting long-term environmental health.

5.1.3 AEROSOL DISTRIBUTION IN LOKOJA ACROSS THE STUDY AREA

Aerosol concentrations in Lokoja exhibit significant variations throughout the year. The highest mean concentration was recorded in 2022 at 0.236, while the lowest mean concentration occurred in 2021. On a monthly scale, the highest aerosol levels were observed in February 2022, whereas the lowest levels were recorded in November 2021. Seasonal patterns, biomass burning, and dry periods contribute significantly to these fluctuations (Ezeonyejiaku et al., 2021).

In 2020, aerosol concentrations reached their lowest levels due to the COVID-19 lockdown, which led to reduced industrial activity and lower vehicular emissions. This trend aligns with the findings of Kamar et al. (2021), who highlighted a decline in aerosol levels across various cities during the same period.

Aerosol concentration patterns further indicate a sharp rise in 2022, followed by a decline in 2023, and another increase in 2024. The reduction in 2023 can be attributed to the removal of fuel subsidies, which reduced vehicular emissions due to higher fuel costs. However, the increase in 2024 suggests that the population adapted to the new fuel prices, leading to a resurgence in vehicle usage and industrial activities (Arzaghi and Squalli, 2023; Amaechi *et al*., 2024; Okorie and Wesseh, 2024).

Air quality in Lokoja remains a growing concern due to rapid urbanization, increased vehicular movement, and expanding industrial activities (Dukiya and Okhimamhe, 2013; Awodi *et al*., 2021). The Abuja-Lokoja highway, a major transport route, significantly contributes to air pollution due to emissions from heavy vehicular traffic (Awodi *et al*., 2021). Studies indicate that pollutants such as nitrogen dioxide (NO_2), carbon monoxide (CO), and particulate matter (PM) from vehicles and industries have negatively impacted air quality, affecting vegetation and public health (Awodi *et al*., 2021).

5.2. RECOMMENDATION

1. Expanding roads in high-traffic areas such as Mami, Batake, Lokoja, and Filele to reduce congestion and minimize pollutant emissions, particularly carbon monoxide (CO) and aerosols is advised.
2. Promoting the use of public transportation and reduce reliance on private cars. Encourage non-motorized transport options, such as walking and cycling, to lower vehicular emissions.
3. Given Lokoja's industrial and mining activities, strict emission control measures should be implemented in factories and mining operations to reduce pollution levels.
4. Ensuring that industries and mining camps are located away from residential areas to minimize environmental and health risks.
5. Implementing policies to reduce biomass burning, which contributes to high emissions of aerosols, CO, and NO_2, thereby improving air quality.

6. Conducting community workshops and awareness programs on proper waste management, disposal regulations, and environmental sustainability to educate residents on pollution control measures.

5.3. CONCLUSION

The concentrations of carbon monoxide (CO), aerosols, and nitrogen dioxide (NO_2) in Lokoja have fluctuated significantly between 2019 and 2024. The decline in emissions from 2022 to 2023 suggests the impact of government interventions, improved fuel quality, and seasonal factors. However, the rise in pollutant levels in 2024 may be attributed to post-pandemic economic recovery, increased urbanization, and industrial activities. Overall, air pollutant levels have shown erratic variations, influenced by seasonal patterns, fuel quality improvements, and regulatory measures. To effectively manage future fluctuations, continued efforts in emission control, environmental policies, and sustainable urban planning will be essential.

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Month	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
January	0.067	0.06	0.068	0.066	0.058	0.065
February	0.069	0.072	0.069	0.064	0.062	0.068
March	0..057	0.063	0.063	0.062	0.055	0.059

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APPENDIX

Appendix 1. Monthly mean distribution of CO concentration from 2019-2024.

April	0.05	0.051	0.053	0.052	0.048	0.051
May	0.043	0.045	0.042	0.041	0.043	0.049
June	0.038	0.04	0.039	0.039	0.037	0.041
July	0.04	0.039	0.043	0.04	0.038	0.044
August	0.041	0.046	0.041	0.044	0.045	0.049
September	0.035	0.038	0.036	0.035	0.036	0.043
October	0.036	0.036	0.037	0.035	0.038	0.089
November	0.04	0.046	0.043	0.044	0.043	0.044
December	0.046	0.052	0.05	0.049	0.049	0.051
Mean	**0.0459**	**0.0490**	**0.0487**	**0.0476**	**0.0460**	**0.0544**

Month	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
January	0.000067	0.000064	0.0000725	0.000079	0.000076	0.0000735

Appendix 2: Monthly mean concentration of NO_2 from 2019-2024

Month	2019	2020	2021	2022	2023	2024
February	0.00007	0.0000655	0.0000715	0.0000725	0.000071	0.00007
March	0.000066	0.000059	0.0000725	0.000075	0.00006	0.0000675
April	0.00006	0.000054	0.0000675	0.000063	0.0000625	0.0000655
May	0.000055	0.000051	0.0000575	0.000058	0.000066	0.0000615
June	0.000051	0.000055	0.000057	0.000056	0.000057	0.000054
July	0.000053	0.0000515	0.000055	0.0000515	0.00006	0.0000515
August	0.000043	0.0000515	0.00005	0.000054	0.000059	0.000048
September	0.000049	0.000056	0.000056	0.0000545	0.000055	0.000052
October	0.000042	0.000051	0.000058	0.000054	0.0000525	0.000052
November	0.000048	0.000057	0.000057	0.000054	0.000056	0.0000575
December	0.000053	0.00006	0.000067	0.0000675	0.000061	0.0000635
Mean	**0.0000548**	**0.0000563**	**0.0000618**	**0.0000616**	**0.0000613**	**0.0000597**

Appendix 3: Monthly mean concentration of Aerosol from 2019-2024

January	0.338	0.301	-0.287	1.182	0.9	1.114
February	0.434	0.606	0.174	1.699	1.496	1.409
March	-0.04	-0.209	-0.236	1.203	0.169	0.807
April	-0.208	-0.658	-0.758	0.353	0.292	0.524
May	-0.758	-0.971	-1.389	0.2	0.107	0.032
June	-0.988	-0.89	-1.369	-0.34	-0.45	-0.188
July	-1.064	-1.489	-0.446	-0.424	-0.658	-0.452
August	-1.162	-1.202	-0.794	-0.31	-0.364	-0.305
September	-1.317	-1.299	-0.562	-0.784	-0.514	-0.711
October	-1.377	-1.568	-0.385	-0.391	0.032	-0.633
November	-1.212	-1.318	-0.012	-0.05	-0.005	0.008
December	-0.749	-0.819	0.895	0.49	0.636	0.465
Mean	**-0.675**	**-0.793**	**-0.431**	**0.236**	**0.137**	**0.173**