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Comparative Analysis of Indoor Air Quality in Coal Mining Communities During Wet and Dry Seasons in the Coal Mining Belt of Kogi East, Nigeria

Osseini Ukwenya Enock; Muhammed Rabiu; J. A. Edicha (PhD); and S. M. Hassan (PhD)

Department of Geography and Environmental Management, University of Abuja, Nigeria.

Corresponding author: rabiu.muhammed111@gmail.com

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Abstract

This study investigates the indoor air quality in coal mining communities during wet and dry seasons in the coal mining belt of Kogi East, Kogi State, Nigeria. The research was conducted at selected coal mining sites, specifically Ika-Ogboyaga and Okaba mine sites, using a randomized sampling method. Indoor air quality data were collected from fifteen households in Ika and Odele villages within a 500-meter radius of the mining sites. Monitoring was performed using the Gasman auto sampler to measure concentrations of nitrogen dioxide (NO_2), sulphur dioxide (SO_2), carbon monoxide (CO), hydrogen sulphide (H_2S), and particulate matter (PM_2.5 and PM_{10}). Data collection spanned 7 days each for the wet season (October 2022) and the dry season (February 2023), with measurements taken thrice daily. Meteorological parameters such as temperature, wind speed, wind direction, and relative humidity were also recorded.The results indicated higher pollutant concentrations during the dry season. For instance, PM_2.5 levels in Ika during the wet season were 45.3±0.25 μg/m³ (morning), 74.6±0.49 μg/m³ (afternoon), and 56.26±0.1 μg/m³ (evening), while dry season values were 48.32±1.74 μg/m³ (morning), 74.12±0.30 μg/m³ (afternoon), and 56.9±0.75 μg/m³ (evening). Similarly, PM_{10} levels in Ika during the wet season were 73.61±1.44 μg/m³ (morning), 105.53±0.44 μg/m³ (afternoon), and 99.01±0.5 μg/m³ (evening), whereas dry season values were 75.47±0.70 μg/m³ (morning), 102.08±1.48 μg/m³ (afternoon), and 96.98±1.33 μg/m³ (evening). CO concentrations in Ika during the wet season were 4.22±0.22 ppm (morning), 6.13±0.3 ppm (afternoon), and 3.1±0.05 ppm (evening), and during the dry season, they were 5.55±1.74 ppm (morning), 8.11±1.46 ppm (afternoon), and 7.04±1.184 ppm (evening). Meteorological analysis showed that the dry season had higher wind speeds (2-4 m/s) compared to the wet season (0-2 m/s), and lower relative humidity (mean of 51.18%) compared to the wet season (mean of 77.55%). Air Quality Index (AQI) values indicated that PM_2.5 levels in both seasons were unhealthy (155.8-156.4 in the wet season and 151-200 in the dry season), while PM_{10} levels were moderate (65.5-66.9 in the wet season and 51-100 in the dry season). CO, NO_2, and SO_2 levels generally remained within permissible limits set by the World Health Organization (WHO). Statistical analysis revealed significant seasonal variations in the concentrations of the monitored pollutants, with higher levels typically recorded during the dry season.

Keywords: Indoor, Air quality, Meteorological, Coal Mining, Pollutants.

Introduction

The global mining sector plays a crucial role in generating income, employment, economic growth, development, and competitive advantage (Jerome 2003; Oelofse et al., 2008). However, mining also poses significant threats and hazards to ecosystems. Nigeria has been actively involved in solid mineral exploitation for decades, boasting over 34 solid minerals, including coal, tin, columbite, gold, lead, zinc, thorium, lignite, uranium, and tantalum, spread across more than 450 locations (Mining Journal 2006). This activity has introduced potential environmental hazards and risks (Lazareva & Pichler 2007; Othman & Al-Masri 2007; Li et al., 2014). Mining waste lands are an inevitable by-product, resulting in significant soil degradation (Liu et al., 2003; Li et al., 2014).

Coal, the most abundant fossil fuel on earth, constitutes about 75% of total fuel resources (Elliott 1981; Rashid et al., 2014). It is essential for meeting a country's energy demands, leading to frequent excavation of coal mines worldwide. However, coal mining has severe environmental, ecological, and health consequences. Improper mining can damage landscapes, soils, surface water, groundwater, and air throughout the exploration phases (Martha 2001).

Globally, coal is vital for energy production, contributing approximately 41% of total energy output (World Coal Association, 2017). In Africa, coal is crucial for economic development due to its abundance and low-cost exploitation for power and electricity generation. Despite this, coal mining can severely impact surrounding environments. It generates large amounts of spoil and waste rocks, often contaminated with inorganic elements like arsenic (As), selenium (Se), and boron (B), originating from ancient oceanic sedimentary processes (Huyen et al., 2019; Park et al., 2019). These hazardous elements are typically associated with evaporite salts, carbonates, and sulfides/organic matter (Tabelin et al., 2018).

Coal processing and cleaning produce tailings with sulfide-bearing minerals like pyrite and arsenopyrite, leading to hazardous element-polluted acidic drainage, known as acid mine drainage (AMD), when exposed to surface oxidizing conditions (Li et al., 2019). AMD is a significant environmental issue in many coal and metal-sulfide mines globally and poses one of the most severe threats to water resources (Chernaik, 2010; Younger, 1995). In surface water systems, heavy metals like Pb, Cu, and Zn may precipitate or adsorb onto suspended minerals and organic matter, eventually settling into sediments (Sultan & Shazili, 2010). While sediments act as a major sink for hazardous elements, they can also become a source of pollution due to the dynamic nature of surface water systems (Boukhalfa & Chaguer, 2012). Contaminants from coal mining can also infiltrate drinking water sources, impacting human health.

Soils are often the ultimate sink for heavy metals released into the environment due to their high metal-scavenging capacity (Banat et al., 2005; Tomiyama et al., 2020). However, excessive contaminants degrade soil quality and pose hazards to human health through direct contact or indirectly via the food chain (soil-plant-human or soil-plant-animal-human). Certain hazardous elements can bioaccumulate in food crops (Wuana & Okieimen, 2011). For example, cadmium (Cd), manganese (Mn), and arsenic (As) have been reported to accumulate in food crops like rice and vegetables (Senoro et al., 2020; Tabelin & Igarashi, 2009). As a result, contaminated soils become unsuitable for agriculture since crops grown on such soils are unsafe for consumption. Soil pollution can also cause harm through inhalation of contaminated dust, erosion into municipal waterways, and direct ingestion (geophagia) (MOE, 2010). Inhalation of contaminated dust is a known cause of lead poisoning in Kabwe, Zambia (Silwamba et al., 2020). Geophagia is common in many African and South American countries, especially among children and pregnant and breastfeeding women (Woywodt & Kiss, 2002), and is increasingly observed in Western societies (Reeuwijk et al., 2013). Consuming contaminated clay poses a significant health risk as it often exceeds safe daily exposure levels (Odongo et al., 2016).

Statement of Research Problem

The solid mineral mining landscape in Nigeria is predominantly occupied by artisanal and small-scale miners (ASMs), whose operations are largely informal and often go unregulated by the government. The widespread activities of these artisanal and small-scale miners have severely impacted the physical environment. Most mining operations in Nigeria involve open cast mining, which is particularly harmful to the ecosystem. These ecological impacts include the loss of prime agricultural land, forest cover, water resources, air quality, and biodiversity. The activities of ASMs have resulted in numerous abandoned open mines and derelict landscapes.

Mining of solid minerals such as coal can lead to significant environmental degradation. Natural forests and croplands are typically the first to be affected during coal exploration and exploitation. The open cast mining method is employed in the coal mines in Ankpa and Omala LGA of Kogi State. This strip mining process involves removing the overburden to expose the coal, which is then extracted using large cranes and trucks. It is well-documented that coal mining and its associated uses have various detrimental effects on the ecosystem, impacting the surrounding landscape, watercourses, flora and fauna, air quality, groundwater, and the social fabric of local communities (Thomas 2002).

Notably, coal mining in the current study areas has not been subjected to Environmental Impact Assessments, resulting in a lack of baseline ecological data. Several studies have highlighted the high risk of contamination by heavy metals and hazardous elements due to coal mining in Kogi State's ecosystems. For example, Ameh, Idakwo, and Ojonimi (2021) assessed the seasonal variations of toxic metal pollution in soil and sediment around the Okaba Coal Mine area, while Oloche et al. (2019) evaluated the impact of coal mining on water quality in Nigerian water sources. Additionally, Ekwule, Ugbede, and Akpen (2021) assessed heavy metal concentrations in the soil of the Odagbo area, Kogi State.

However, none of these studies have examined the implications of mining on indoor air quality in the study area, which represents a significant research gap. Thus, this study aims to address this gap.

Objectives of the Study

The specific objectives of the study are to:

i. Determine the seasonal variation of the indoor air quality in the study area.
ii. Investigate the influence of meteorological parameters, including wind speed, wind direction, temperature and relative humidity on the dispersion of pollutants originating from coal mining areas.

Research Questions

i. How does seasonal variation affect indoor air quality in the study area.
ii. What is the influence of meteorological parameters including wind speed, wind direction, temperature and relative humidity on the dispersion patterns of pollutants originating from coal mining areas.

Study Area

Ankpa LGA lies between longitude 7°36'E to 7°39' E and latitude 07°23' N to 07°26' N (Figure 2.1 and 2.2). Ankpa has an area of 1,200km^2 and a population of 267,353 at the 2006 census (Ishaka, 2012).

Ankpa falls within the Nigeria meteorological zone that is characterized by warm temperature days and moderately cool nights. Two distinct climatic divisions are demarcated as the dry and rainy seasons representing two broad periods of significant but contrasting variations of weather parameters. The area has warm Tropical Savanna Climate with clearly marked wet and dry seasons (Ali, 2010). Rainfall is well distributed and is of double maxima (Iloeje, 1972). The amount of rainfall ranges between 1,000mm to 1,750mm. Temperature is moderately high throughout the year, averaging 25oC. The maximum temperature of the area lies between 29.7oC – 35.6oC while the minimum temperature ranges between 23.3oC and 25.2oC (Ali, 2010).

The dominant vegetation communities remain the tropical savanna woodland of secondary types and mixtures of scattered tropical trees and grassland formations. Vegetation distribution in this area follows a pattern that is similar to that of rainfall distribution, Ukwedeh (2003).

The study area is known for its rich source of a variety of medicinal, cultural and edible wild plants, such as; *Abrus precatorius Linn*, *Allophyllus Africanus*, *Butyrospermum paradoxum* (Gaerrn, f.) Hepper/ vitellaria paradoxum (Gaertn,f), *Dennettia tripetala* and *Cola nitida* (Aniama et al, 2016).

Ankpa falls within the Anambra Basin whose genesis has been linked with the development of the Niger Delta Miogeosyncline and the opening of the Benue Trough, Murat (1972). The stratigraphy comprises of cyclic sedimentary sequence that started in the early Cretaceous time, Reyment (1965), Marine and fluviatile sediments comprising friable to poorly cemented sands, shales, clays and limestone were deposited, with occasional coal, peat and thin discontinuous seams of lignite. The sediments have been affected by the major

Santonian folding, and a minor Cenomanian folding and uplift, Murat (1972). The study area is typical of Ajali Formation or the false bedded sandstone and the Mamu Formation. The Ajali consists of thick friable poorly sorted sandstone, typically white in colour but sometimes iron-stained. Ajali sand is often overlain by a considerable thickness of red earthly sands, formed by the weathering and feruginization of the Formation.

The study area is drained by two major rivers, namely river Niger and river Benue. While the western flank of the study area is bounded by the river Niger, the northern part of Kogi east is bounded by the river Benue. Other moderate sized rivers and streams like Imaboro, Okura, Inachalo, Ofu, Ubele, and Omala also dots the landscape.

The drainage system in the area is that of the natural slope where water flows through the drainage channel. There is also artificial drainage channel through which water flows down slope. Its topography is that of an undulating valley surrounded by flat terrain. The area is easily eroded due to its sloppy nature. Some parts of the area like Ibaji slope downward and drain towards southeast into River Niger (Ocholi, 2020).

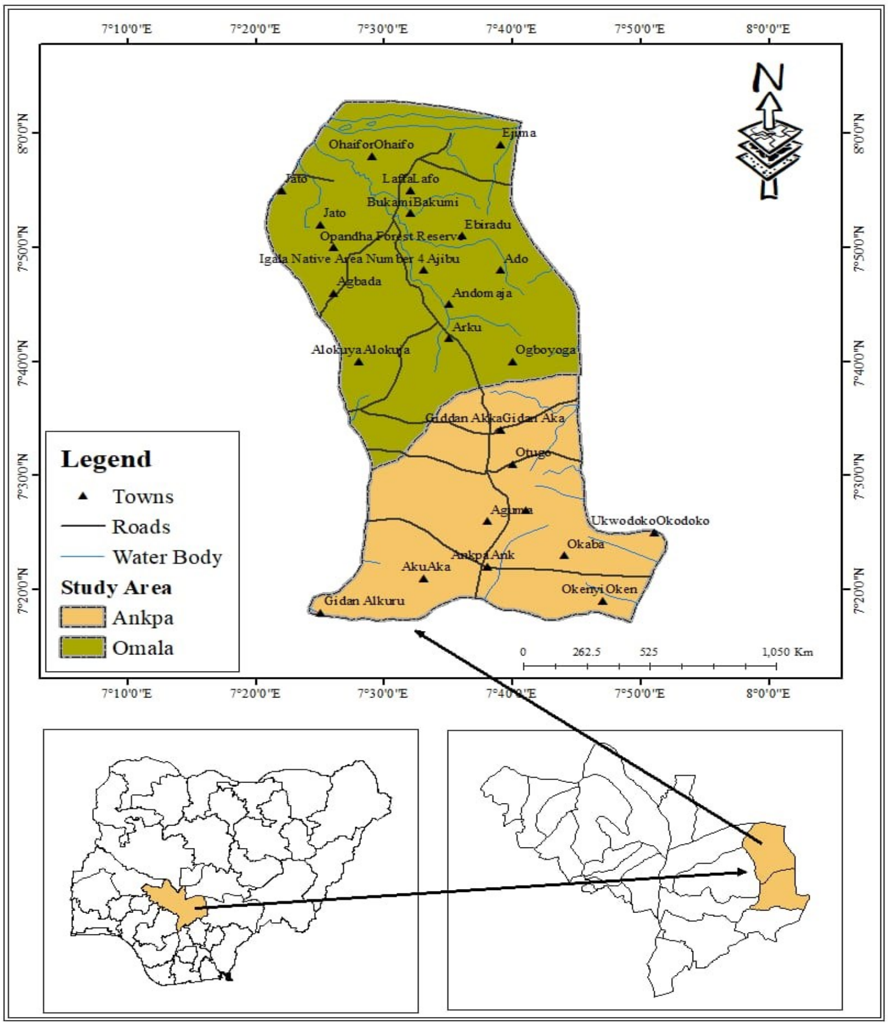

Fig 1: Map of the Study area

The prevalent land use and socioeconomic activity of the study area includes farming, mining, trading among others. Although, over time there has been a rapid change in the land-use/land cover characteristics in the study area due to development and change in land use from farmland to residential and commercial among others that are prevalent in the area and may be responsible for the considerable reduction in agrarian land use. In a study by Tokula and Ejaro, 2018, they discovered a considerable change in the land-use/land cover characteristics in Ankpa town.

Sampling Procedure

The sampling frame of this study comprises of all the Coal mining sites within the Omala/Ankpa LGA, Kogi mine district and these include; Okaba, Odagbo (Ojoku district), Ogboyaga (Ika) and Okobo (Enjema). Ika-Ogboyaga and Okaba mine sites were selected for this study. This was done with the use of the table of random numbers, this was achieved using the formula for table of Random Numbers using the Microsoft excel Software Package. The Microsoft Excel has a function to produce random numbers. The function can be set to any range; the number of communities identified in the study area is 4, therefore, the range is within 1 to 4. The function is given below

= INT (20*RAND())+1

The **INT** eliminates the digits after the decimal, the 4* creates the range to be covered, and the **+1** sets the lowest number in the range. This is presented on the table 2.

Table 1: Table of random numbers for identified communities

Communities	Random Numbers
Odagbo	3
Okaba	1
Okobo	4
Ika-Ogboyaga	2

The collection of indoor air quality for this study was carried out in the month of 4th October 2022 lasting for 7days for the wet season, while that of the dry season was carried out on the 2nd of February 2023 lasting for 7days with the aid of Gasman auto sampler. This was carried out in villages within 500-meter radius from the mining sites these include Ika and Odele Village. Fifteen households from each village was randomly selected for the indoor air monitoring. The Gasman auto sampler was used to monitor the concentration of nitrogen dioxide (NO_2), sulphur dioxide (SO_2) carbon monoxide (CO), Hydrogen sulphide (H_2S) and Particulate matter. These five gases were monitored thrice a day (morning, afternoon and evening) in replicates for a week (Table 2).

Also, data of Meteorological parameters such as Temperature, Windspeed Wind direction and Relative humidity were collected with the use of handheld thermometer (Fluke 59 MAX+ Infrared) and Peakmeter Multifunction Digital Anemometer (PM6252B).

In this study, three-hour monitoring period was carried out from early morning to late evening during the monitoring period. That is, the collection of daily indoor air quality data was from 7am to 10am in the morning; 12 noon to 3pm in the afternoon and 6pm to 9pm in the evening. During data collection, the sampling locations were geo-referenced using the Garmin Etrex 10- Handheld GPS.

Table 2: Time of day for air quality sampling in the study area

S/N	Village	Time			Coordinates	
		Morning	Afternoon	Evening	Latitude	Longitude
1	Ika-Ogboyaga	7am-9am	12pm-3pm	6pm-9pm	7.559227	7.723389
2	Odele	7am-9am	12pm-3pm	6pm-9pm	7.722559	7.654037

Method of Data Analysis

Data obtained from the indoor air quality was analyzed using descriptive and inferential statistical tools. Descriptive tools included averages, tables and charts for easy understanding of the pattern and variability in indoor air quality. Student t-test was used to determine the seasonal variation of indoor air pollutants in the study area.

Assessment of Pollution Index (PI)

The measured indoor air quality data was used to determine the pollution parameters in the study area. A pollutant's index is its concentration expressed as a percentage of the relevant air standard (Kanchan and Goyal, 2015). The index rating presented in Table 4.2 will be used to assess indoor pollution index in the study area. The information shows the numeric index and what each value stands for. In the present study, the calculation of Pollution Index was carried out using the formula given by EPA (2017) as follows:

$$Isi = \left(\frac{(Cobs - Cmin)(Imax - Imin)}{(Cmax - Cmin)}\right) + Imin$$

Where:

Isi= Sub-index value of the observed pollutant

Cobs= Observed pollutant concentration

Cmax= Maximum concentration of AQI colour category that contains ≤ Cobs

Cmin= Minimum concentration of AQI colour category that contains Cobs

Imax= Maximum AQI value corresponding to ≤ Cmax

Imin= Minimum AQI value corresponding to Cmin

Table 3: Values, index and health risks for PI

Numeric Value	Quality Indicator	Numeric Index	Health Risk
0-50	Optimum	1	No risks for people
51-75	Good	2	No risks for people
76-100	Moderate	3	No risks for people
101-125	Mediocre	4	Generally there aren't risks for people, people with asthma. Chronic bronchitis. Croniche cardiopathy may feel light respiratory symptoms only during an intense physical activity
126-150	Not much healthy	5	There risks for people with heart diseases. Olds and children
151-175	Unhealthy	6	Many people may feel light adverse symptoms, however reversible. Weak people may feel gravest symptoms.
>175	Very unhealthy	7	People may feel light adverse effects for health. There are more risks for olds, children and people with respiratory diseases

Source: Kanchan and Goyal (2015:105)

Table 4: API Pollutant-Specific Ranges

Category	API Level	$PM_{2.5}$	PM_{10}	CO	SO_2	NO_2	NH_3	H_2S
		(µg/m3) 24-hour	(µg/m3) 24-hour	(ppm) 8-hour	(ppm) 1-hour	(ppm) 1-hour	(ppm) 1-hour	(ppm) 1-hour
Good	0-50	0.0-12.0	0-54	0.0-4.4	0-0.035	0-0.053	-	-
Moderate	51-100	12.1-35.4	55-154	4.5-9.4	0.036-0.075	0.054-0.100	-	-
Unhealthy for Sensitive Groups	101-150	35.5-55.4	155-254	9.5-12.4	0.076-0.185	0.101-0.360	-	-
Unhealthy	151- 200	55.5-150.4	255-354	12.5-15.4	0.186-0.304	0.361-0.649	-	-
Very Unhealthy	201-300	150.5-250.4	355-424	15.5-30.4	0.305-0.604	0.605-1.249	-	-
Hazardous	301-500	250.5-500.4	>425	30.5-1004	0.605-1.004	1.250-2.049	-	-

Source: Kanchan and Goyal (2015:105)

Discussion of Results

Wet and Dy Season Indoor Air Quality Characteristics of the Study Area

Mean Concentration of $PM_{2.5}$ in the Study Area

$PM_{2.5}$ are tiny particles or droplets in the air that are two and one-half microns or less in width. Fine particulate matter ($PM_{2.5}$) is an air pollutant that is a concern for people's health when levels are in air are high. The concentration of $PM_{2.5}$ in the air during the wet season was investigated and the result is presented in Table 5.

Table 5 shows that during the wet season Ika community have the following mean values of $PM_{2.5}$ 45.3±0.25, 74.6±0.49 and 56.26±0.1µg/m³ for morning, afternoon and evening respectively. In the same vein, the table shows that Odele community have values of 46.42±0.33, 74.82±0.75 and 54.8±0.15 µg/m³ for morning, afternoon and evening respectively. Similarly, during the dry season the following mean values was recorded for Ika and Odele during morning, afternoon and evening; 48.32±1.74, 74.12±0.30, 56.9±0.75 and 50.14±1.196, 70.11±1.63, 54.68±1.022µg/m³ respectively. The table shows that Odele community recorded highest mean morning value in both wet and dry season, in the same vein, Ika community recorded highest mean afternoon value during the dry season, while Odele recorded the highest mean afternoon value during the wet season. Similarly, Ika community recorded the highest mean evening value in both wet and dry season. Also, the findings show no statistical significant difference in the concentration of $PM_{2.5}$ in both wet and dry season in the study area.

This finding is in tandem with the works of Adelagun *et al, (*2012) who reported that concentration of PM in mining areas is typically low in the morning and increase slightly as production activities kick off in the afternoon and evening. Similarly, Magaji and Hassan, (2015) also reported that temperature at different hours of the day affects the concentration of air quality of the area. Using the WHO 2021 Air Quality Index of 15µg/m³ for $PM_{2.5}$ as the international standard (WHO AQI, 2021), it can be seen that the mining communities and its environs were heavily polluted with the particulate matters. also, this finding is in consonance with the works of Bhanu et al (2015) who reported that the concentrations of $PM_{2.5}$ were higher than NAAQS at the Jharia Coal field (JCF) in Jharkhand, India.

These particles, when inhaled, can penetrate deeper into the respiratory system and cause respiratory ailments such as asthma, coughing, sneezing, irritation in the airways, eyes, nose, throat irritation, etc. exposure to fine particles can also affect lung function and worsen medical conditions such as asthma and heart diseases. Scientific studies have linked increases in daily $PM_{2.5}$ exposure with increased respiratory and cardiovascular hospital admissions, emergency departments visit and deaths. Studies have also shown links between PM exposure and diabetes.

Also, the dry season values are slightly above the mean values recorded during the wet season. This could be attributed to the effect of meteorological parameters during the dry season as the wind speed and temperature recorded during the dry season were above those recorded during the wet season. Hence, the values recorded showed significant variations due to season. This finding is in tandem with the findings of Ang Li et al (2021) in their study of "Environmental Investigation of Pollutants in Coal Mine Operation and Waste Dump Area Monitored in Ordos Region, China". They reported that some meteorological parameters, such as wind speed, relative humidity, temperature and rainfall were found to have significant effects on air pollutant distribution.

Mean Concentration of PM_{10} in the Study Area

PM_{10} are inhalable particles with diameters that are generally 10 micrometers and smaller. Acute or chronic exposure to particulate matter <µm in diameter (PM_{10}) is a worldwide concern.

The concentration of PM_{10} in the air during the wet season was investigated the result is presented in Table 5.

Table 5 shows that the mean wet season values during morning, afternoon and evening period for Ika and Odele community include; 73.61±1.44, 105.53±0.44, 99.01±0.5 and 74.6±0.17, 105.72±0.5, 94.46±1.22 respectively. While that of the dry season include; 75.47±0.70, 102.08±1.48, 96.98±1.33 and 77.7±0.78, 101.99±0.60, 96.89±1.32 respectively. Similarly, highest values were recorded during the day in both wet and dry seasons. Also, the dry season recorded the highest mean morning values in both communities, while the wet season recorded the highest mean afternoon values in both communities, in the same vein, the dry season recorded the highest mean evening values in the both communities.

Similarly, the findings showed no statistical significant difference in the concentration of PM_{10} in both wet and dry season in the study area.

This finding is also in consonance with the works of Adelagun *et al, (*2012), Magaji and Hassan, (2015) and Bhanu et al (2015). Also, research studies have shown that mine dumps are a major contributor to particulate matter air pollution to surrounding communities and that proximity is associated with increased asthma symptoms (Mohner et al, 2014). Also, using the WHO 2021 Air Quality Index of 45µg/m³ for PM_{10} as the international standard (WHO AQI, 2021), it can be seen that the mining communities and its environs were heavily polluted with the particulate matters. Exposure to PM_{10} is associated with the exacerbation of asthma attacks, the decline in lung function, preterm birth and an increase in hospital visits and deaths among children with pre-existing asthma conditions or respiratory disease (Pudpong et al, 2011 and Bernstein et al, 2009).

This finding also corresponds with the works of Pandey et al (2014) who reported seasonal variation in the concentration of PM_{10} in the air. The table further revealed that the values recorded in both communities were far above the permissible limits of the WHO.

Mean Concentration of CO in the Study Area

It results from incomplete combustion of carbonaceous matter in all combustion processes and can cause death at high concentrations. The mean level of CO in the mining communities is presented in table 5.

Table 5 reveals that the mean CO levels during the wet season in Ika and Odele mining communities include; 4.22±0.22, 6.13±0.3, 3.1±0.05 and 3.52±0.9, 4.88±0.62, 2.41±1.16 respectively. While the dry season values include; 5.55±1.74, 8.11±1.46, 7.04±1.184 and 5.73±1.47, 5.6±0.55, 4±0.12 respectively. The table shows that highest mean values were recorded during the dry season. Also, highest values were recorded during the afternoon period in both seasons.

The table further shows that the values recorded are within the permissible limits of the WHO.

When carbon monoxide is inhaled it displaces the oxygen in the blood, combines with hemoglobin and reduces the amount of oxygen carried to the blood tissues. It has been observed that an exposure of 10 ppm of CO for approximately 8hours may dull mental performance. At higher concentration, it causes unconsciousness and even death. It may be noted that effect of CO, in different concentrations, on human health varies. Furthermore, the study reveals a significant statistical difference in the concentration of CO in both wet and dry season in the study area.

Also, this finding is in consonance with the works of Balogun, V.S and Orimoogunje, O.O.I (2015) in their study of the assessment of seasonal variation of air pollution in Benin city, Southern Nigeria. They reported higher values of CO during the dry season and lesser value during the wet season. Although, the values recorded were slightly below the permissible limits set by the WHO (10 ppm).

Mean Concentration of NO_2 in the Study Area

Nitrogen dioxide NO_2 is a red brown gas produced from manufacture of nitric acid-nitration and combustion processes, results in severe irritation of respiratory system by 3 ppm. The mean concentration of NO_2 in the air is presented in table 5.

Table 5 shows that the mean NO_2 levels during the wet season in Ika and Odele mining communities include; 0.005±0.03, 0.02±0.01, 0.02±0.02(ppm) and 0.008±0.01, 0.01±0.05, 0.004±0.001(ppm) respectively. In the same vein, the dry season values include; 0.02±0.023, 0.04±0.026, 0.03±0.030(ppm) and 0.06±0.08, 0.05±0.06, 0.04±0.07(ppm) respectively. Also, the table shows that higher values of NO_2 was recorded during the dry season as compared to the wet season. The values recorded, were also below the permissible limits of the WHO. In the same vein, the study reveals a significant statistical difference in the concentration of NO_2 in both wet and dry season in the study area.

Also, this study contradicts the findings of Shelton et al (2022) who reported that the hourly average concentration of $PM_{2.5}$, CO and NO_2 reached their maximum during the morning and evening hours, although this current study recorded higher values during the afternoon and evening hours for these pollutants.

Nitrogen dioxide poisoning is as much as hazardous as carbon monoxide poisoning. It is when inhaled can cause serious damage to the heart, absorbed by the lungs, inflammation, and irritation of airways. Smog formation and foliage damage are some environmental impacts of nitrogen dioxide.

Mean Concentration of SO_2 in the Study Area

Sulphur dioxide is a gas with a pungent smell. It is generated in large quantity when coal, coke or certain fuel oils are burnt. The burning of coal produce about 60% of Sulphur oxides emissions. It is estimated that an average of 3 tons approximately of Sulphur dioxides are emitted from every hundred tons of coal burnt. The mean concentration of SO_2 in the air is presented in table 5.

Table 5 shows that the mean SO_2 levels during the wet season in Ika and Odele mining communities include; 0.006±0.04, 0.005±0.005, 0.05±0.03ppm and 0.003±0.005, 0.002±0.004, 0.006±0.003ppm respectively. While that of dry season include; 0.0308±0.033, 0.026±0.024, 0.022±0.026 ppm and 0.05±0.06, 0.02±0.02, 0.03±0.08 ppm respectively. The table reveals a higher mean value during the dry season as compared to the wet season. Also, the values were below the permissible limits set by the WHO as shown in the table. Similarly, the study reveals a significant statistical difference in the concentration of SO_2 in both wet and dry season in the study area.

This finding is not unconnected to the fact that coal mining activities is usually not at its peak during the wet season due to torrential rainfall that is being experienced and also the prevailing winds during this season moves at a speed of 0-2 m/s. This also influences the dispersion of pollutants in the study area. Studies have shown that meteorological variables such as wind speed, humidity and temperature influence the dispersion of pollutants such as SO_2.

This finding is in agreement with Ang Li et al (2021) in their study of "Environmental Investigation of Pollutants in Coal Mine Operation and Waste Dump Area Monitored in Ordos Region, China". They reported that some meteorological parameters, such as wind speed, relative humidity, temperature and rainfall were found to have significant effects on air pollutant distribution.

Sulfur dioxide is a major cause of haze production, acid rain, damage to foliage, monuments & buildings, reacts and forms particulate matter. In humans, it causes breathing discomfort, asthma, eyes, nose, and throat irritation, inflammation of airways, and heart diseases.

Mean Concentration of NH_3 in the Study Area

Ammonia is a compound made of nitrogen and hydrogen molecules. It is a colourless gas with a pungent odour and is reactive: it forms secondary particulates matter ($PM_{2.5}$) when combined with other pollutants in the atmosphere. This occurs through a process called nucleation, where the gaseous molecules of ammonia condense to form liquid or solid particles suspended in the atmosphere. The mean concentration of NH_3 in the air is presented in table 5.

Table 5 shows that the mean NH_3 levels during the wet season in Ika and Odele mining communities include; 0, 0.001±0.003, 0.04±0.005ppm and 0.0004±0.001, 0.001±0.004, 0ppm respectively. While that of the dry season include; 0.032±0.093, 0.021±0.023, 0.013±0.018 ppm and 0.013±0.02, 0.008±0.015, 0.007±0.015ppm respectively. These values were also higher than those recorded during the wet season. Also, the values are within the limits set by the WHO. The values recorded were far below the limit set by the WHO (0.05ppm). Also, the study reveals a significant statistical difference in the concentration of NH_3 in both wet and dry season in the study area.

Ammonia is a major reason for eutrophication in water bodies. It contributes to climate change, the formation of particulate matter, a reduction in visibility, and the atmospheric deposition of nitrogen atoms. Human beings experience immediate eyes, nose, throat, and respiratory tract burning, blindness, and lung damage upon exposure to high levels. It may cause coughing and irritation in the eyes, nose, and throat with low concentration exposure.

Mean Concentration of H_2S in the Study Area

Hydrogen sulphide is a toxic gas often present in coal seams and seriously threatens the lives and health of underground workers in coal mines. The mean concentration of H_2S in the air is presented in table 5.

Table 5 shows that the mean H_2S levels during the wet season in Ika and Odele mining communities include; 0.0004±0.005, 0.0073±0.006, 0.05±0.003 and 0, 0.0005±0.001, 0.001±0.002 respectively. While that of the dry season include; 0.012±0.018, 0.014±0.019, 0.012±0.016 and 0.006±0.010, 0.006±0.011, 0.008±0.015 respectively. In the same vein,

higher values of H_2S was recorded during the dry season when compared with the season values. Also, all values recorded are within the acceptable limits of the WHO. The study also reveals a significant statistical difference in the concentration of H_2S in both wet and dry season in the study area.
Exposure to hydrogen sulfide may cause irritation to the eyes and respiratory system. It can also cause apnea, coma, convulsions; dizziness, headache, weakness, irritability, insomnia; stomach upset and if liquid: frostbite.
Meteorological factors which influence the dispersion and dilution of pollutants include wind speed, atmospheric temperature and relative humidity. These explained seasonal differences in concentration of pollutants. This corroborates the postulation by Jacobson, that low wind speed, high temperature and low humidity reduce the rate of dispersion of air pollutants, thus increasing ground concentration of same pollutants and vice versa. Also, higher concentration of pollutants observed during the dry season could be a result of higher ambient temperatures, leading to downward movement of pollutants and consequently high ground level concentrations. If temperature of pollutants gases is higher than the surrounding air, the plumes will tend to rise. On the other hand, if temperature of ambient air is higher, pollutant gases become concentrated at ground level (Jacobson, 2005). Therefore, atmospheric temperature is thus an important factor for the dispersion of pollutant gases, as the larger the difference between cool ambient air and plumes, the higher the plume rises, so also the rate of dispersion or spread of pollutants from its source before it reaches ground level. Relative humidity is another meteorological factor that explains the concentration of pollutants at a point. Rene revealed that relative humidity is generally higher during the wet season. High relative humidity results to lower atmospheric temperature, and consequently high rate of plume ascent and vice versa (Rene, 2008).
In Nigeria, dry seasons are characterized by high temperatures and low humidity, while the reverse is the case for wet seasons. This explains why higher readings were recorded for almost all pollutants during the dry season, when compared with lower readings recorded during the wet season.

Table 5: Mean Concentration of Pollutants during Wet and Dry Season in the Study Area

Parameter	Ika				Odele			WHO Standard
	Season	Morning	Afternoon	Evening	Morning	Afternoon	Evening	
$PM_{2.5}$	Dry	48.32±1.74[a]	74.12±0.30[a]	56.9±0.75[a]	50.14±1.196[a]	70.11±1.63[a]	54.68±1.022[a]	15
	Wet	45.3±0.25[a]	74.6±0.49[a]	56.26±0.1[a]	46.42±0.33[a]	74.82±0.75[a]	54.8±0.15[a]	
PM_{10}	Dry	75.47±0.70[a]	102.08±1.48[a]	96.98±1.33[a]	77.7±0.78[a]	101.99±0.60[a]	96.89±1.32[a]	45
	Wet	73.61±1.44[a]	105.53±0.44[a]	99.01±0.5[a]	74.6±0.17[a]	105.72±0.5[a]	94.46±1.22[a]	
CO	Dry	5.55±1.74[a]	8.11±1.46[a]	7.04±1.184[a]	5.73±1.47[a]	5.6±0.55[a]	4±0.12[a]	10
	Wet	4.22±0.22[b]	6.13±0.3[b]	3.1±0.05[b]	3.52±0.9[b]	4.88±0.62[b]	2.41±1.16[b]	
No_2	Dry	0.02±0.023[a]	0.04±0.026[a]	0.03±0.030[a]	0.06±0.08[a]	0.05±0.06[a]	0.04±0.07[a]	0.1
	Wet	0.005±0.03[b]	0.02±0.01[b]	0.02±0.02[b]	0.008±0.01[b]	0.01±0.05[b]	0.004±0.001[b]	
So_2	Dry	0.0308±0.033[a]	0.026±0.024[a]	0.022±0.026[a]	0.05±0.06[a]	0.02±0.02[a]	0.03±0.08[a]	0.06
	Wet	0.006±0.04[b]	0.005±0.005[b]	0.05±0.03[b]	0.003±0.005[b]	0.002±0.004[b]	0.006±0.003[b]	
NH_3	Dry	0.032±0.093[a]	0.021±0.023[a]	0.013±0.018[a]	0.013±0.02[a]	0.008±0.015[a]	0.007±0.015[a]	0.05
	Wet	0[b]	0.001±0.003[b]	0.04±0.005[b]	0.0004±0.001[b]	0.001±0.004[b]	0[b]	
H_2S	Dry	0.012±0.018[a]	0.014±0.019[a]	0.012±0.016[a]	0.006±0.010[a]	0.006±0.011[a]	0.008±0.015[a]	0.05
	Wet	0.0004±0.005[b]	0.0073±0.006[b]	0.05±0.003[b]	0[b]	0.0005±0.001[b]	0.001±0.002[b]	

Source: Field Survey, 2022

Mean values for seasons with same letters are not significantly different

Air Pollution Index of the Study Area during the Wet and Dry Season

The Air Pollution Index (API) is a national air quality rating system based on the National Ambient Air Quality Standards (NAAQS). An index value of 100 is equal to the primary, or health-based, NAAQS for each pollutant. This allows for a comparison of each of the pollutants used in the API. These pollutants are particulate matter, carbon monoxide, sulfur dioxide, and nitrogen dioxide.

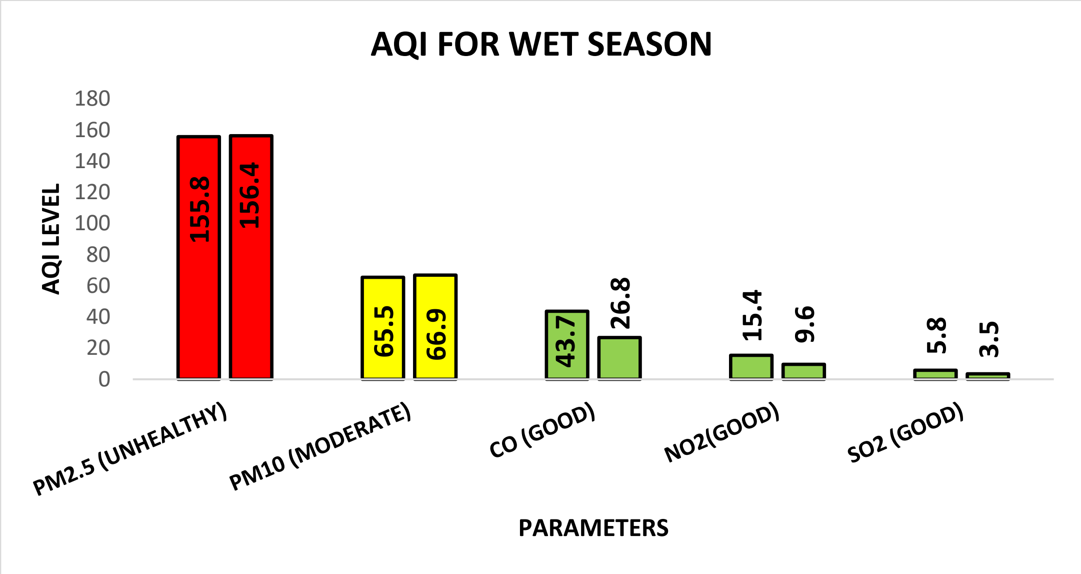

Figure 2: API Pollutant-Specific Values Recorded During the Wet Season

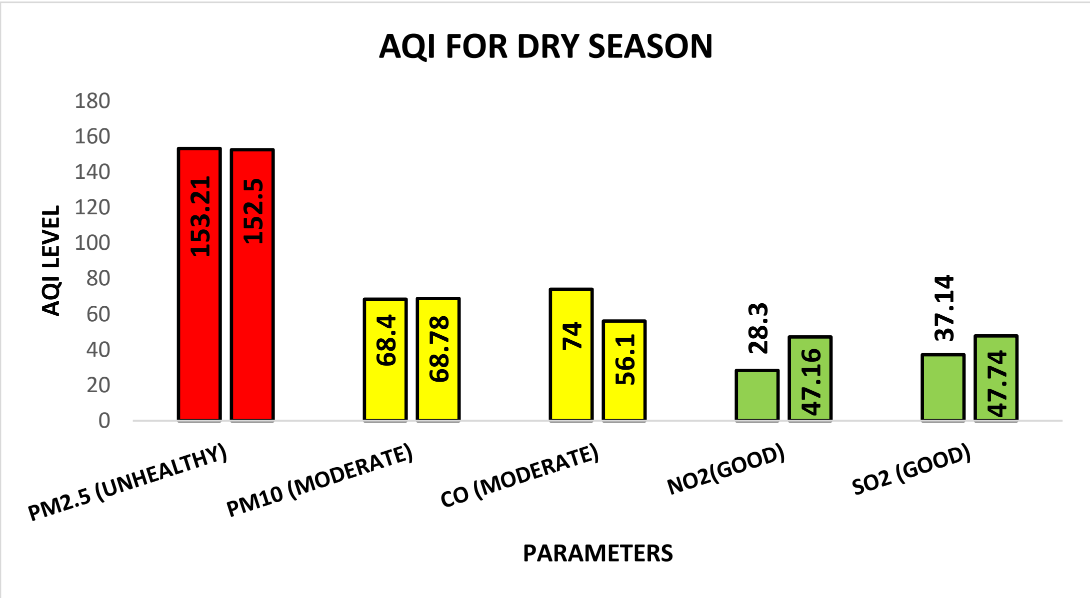

Figure 3: API Pollutant-Specific Values Recorded During the Dry Season

Figure 2 shows that the API values for $PM_{2.5}$ during the wet season in the study areas are 155.8 and 156.4 indicating that the air quality is unhealthy. In the same vein the API values for PM_{10} are 65.5 and 66.9 which indicates that the air quality is moderate which implies that Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution. Similarly, values recorded for CO and NO_2 indicates that the air quality is good.
Following the NAQI by maximum operator method the air quality in the study area during the wet season generally is Unhealthy. Which implies that Everyone may begin to

experience health effects; members of sensitive groups may experience more serious health effects.

The maximum operator method is utilized in this study due to the fact that it is free from eclipsing and ambiguity and the synergistic effects of combination of pollutants are not known hence, a health-based index cannot be combined or weighted.

This finding is also in consonance with Pandey et al (2014) who reported that the increase in API value was mainly due to increase in SPM concentration.

Similarly, figure 3 shows that the API values for $PM_{2.5}$ during the dry season in the study areas fall within the API Index of 151-200 indicating that the air quality is unhealthy. In the same vein the API values for PM_{10} and CO fall within the API Index of 51-100 indicating that the air quality is moderate. While NO_2 and SO_2 fall within the API range of 0-50 indicating that the air quality is good. These results show seasonal variations in the quality of air in the study area.

Following the NAQI by maximum operator method the air quality in the study area during the dry season generally is Unhealthy. Which implies that Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects.

Meteorological Analysis

Wind Speed/Direction

The wind pattern over an area is also essential in the determination of pollutant transport (Akinyemi, *et.al.*, 2016). In this study, the wind direction alternated between East (E) and South South East (SSE) in the wet season and between West South West (WSW), South West (SW), in the dry season.

The figure shows a seasonal variation in the windspeed pattern in the study area. During the wet season wind speed is found to be within a range of 0-2 m/s while that of the Dry season shows a higher windspeed of 2-4 m/s.

The results from this study showed lower wind speed values when compared with Oyewole and Aro (2018) in their measurement of Wind Speed pattern in Nigeria. They found the aggregate mean wind speed in Port Harcourt to be 5.51 m/s which is much higher than what was found in this study. This implies that pollutants in the study area are not widely dispersed and this can portend danger of persistence of the pollutants.

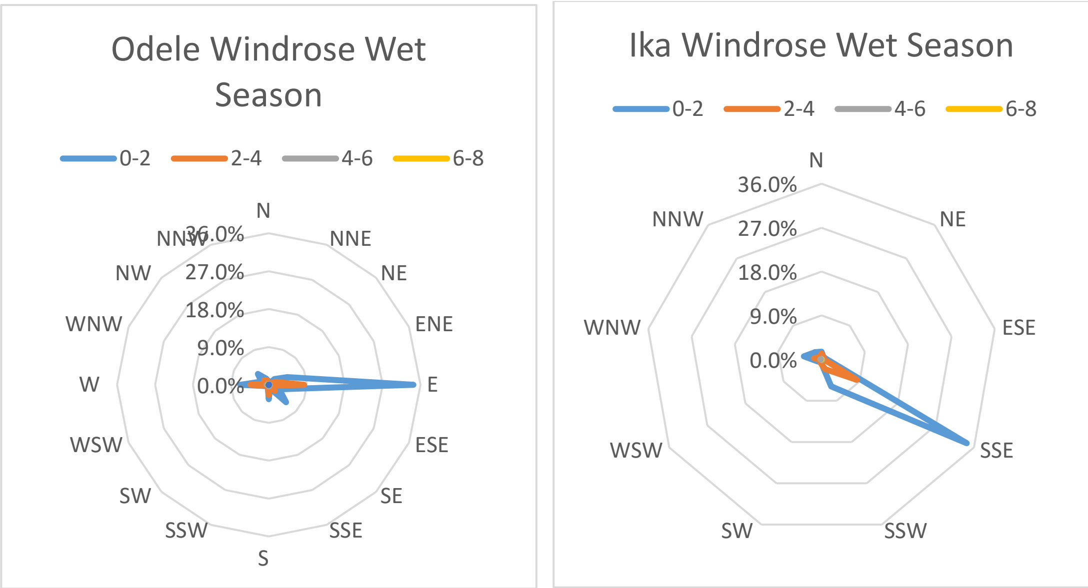

Figure 4: Wet Season Wind Direction for Ika and Odele

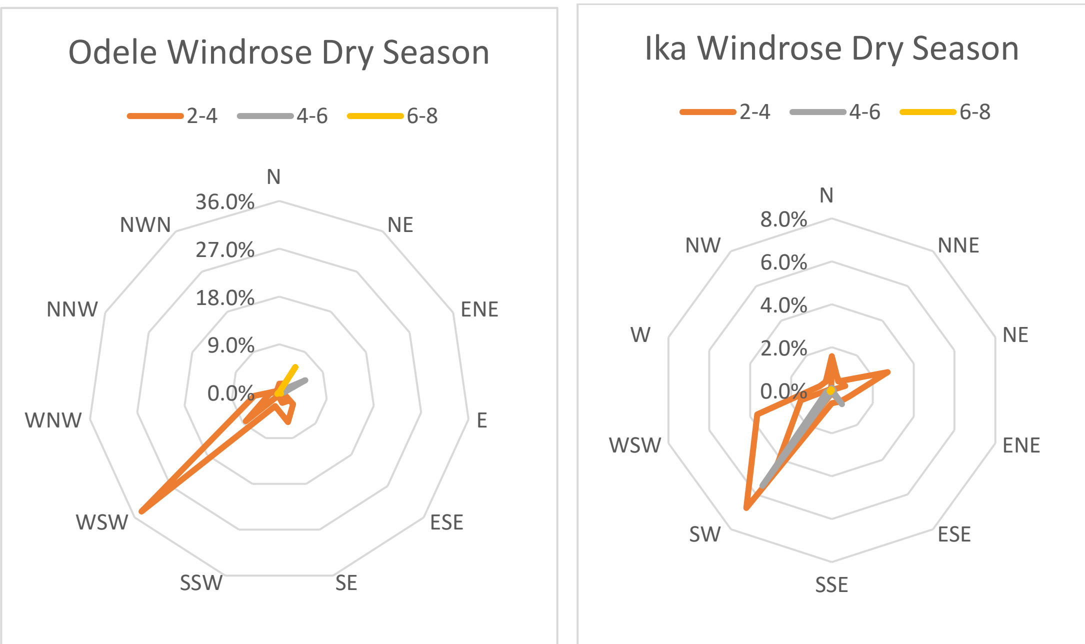

Figure 5: Dry Season Wind Direction for Ika and Odele

Relative Humidity Distribution

Relative humidity represents a percentage of water vapor in the air that changes with air temperature. Figure 6 shows that relative humidity values ranged from 35.7 to 62.2% with a mean value of 51.18% during the dry season. Similarly, the figure shows that relative humidity values ranged from 66.9 to 88.4% during the wet season with a mean value of 77.55% respectively. The observed variation in the levels of relative humidity between the wet and dry seasons can be attributed to the difference in the amount of moisture in the air as well as air temperature between the two seasons. Generally, when it rains, it can have a considerable impact on the humidity in the air (Mawonike & Mandonga, 2017). It may cause too much humidity, thus adding too much moisture into the air. On the other hand, as air temperature increases, air can hold more water molecules, and its relative humidity decreases. When temperatures drop, relative humidity increases (Mawonike & Mandonga, 2017).

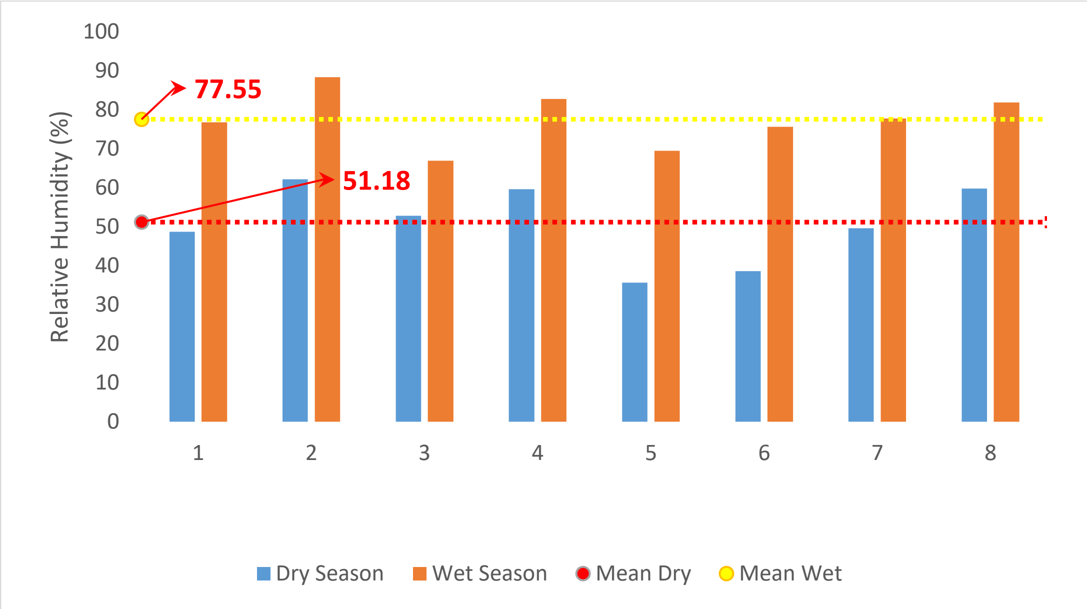

Figure 6: Seasonal Variation of Relative Humidity

Temperature

The temperature has a direct correlation with relative humidity. Higher temperature drives a lower relative humidity, while lower temperature accounts for the higher values of relative humidity. Temperature observed with the area of study is higher in dry season than in wet season and follows the same trend with Relative Humidity as shown in figure 6. Average temperature observed within the study area is 28.01°C in wet season and 30.28 °C in dry season. This is shown in figure 7.

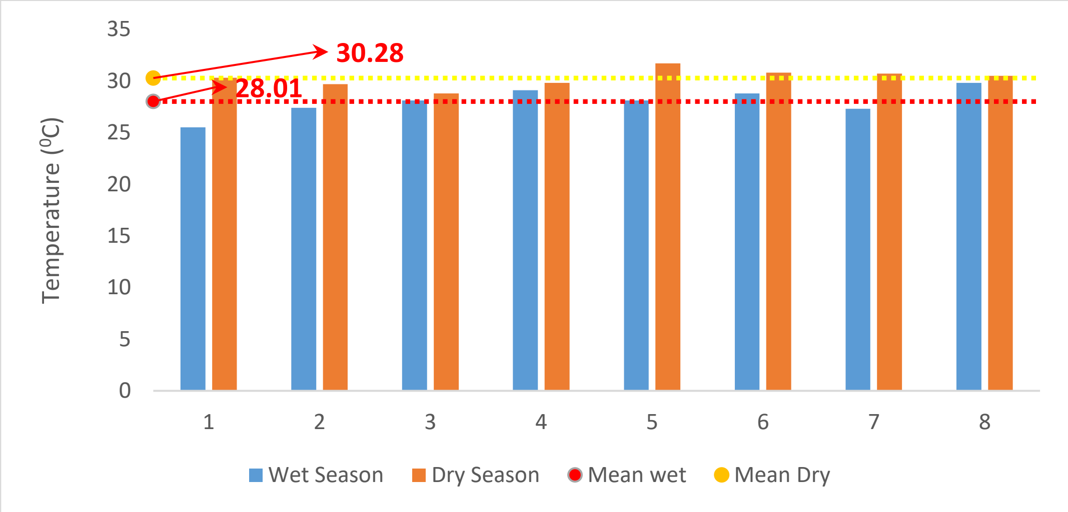

Figure 7: Seasonal Variation of Temperature

Conclusion

The study reveals that indoor air quality in coal mining communities of Kogi East is significantly impacted by seasonal variations, with higher pollutant concentrations observed during the dry season. $PM_2.5$ and PM_{10} levels were found to exceed WHO limits, posing serious health risks to residents. CO, NO_2, and SO_2 concentrations remained within acceptable limits but still exhibited seasonal fluctuations. The observed differences can be attributed to meteorological factors such as wind speed, temperature, and relative humidity, which influence pollutant dispersion.

Recommendations

Based on the findings of this study, the following recommendation are suggested:

- The Kogi State Government should pay attention to environmentally friendly mining policies which will expose the mining communities to minimum concentration of Air Pollutants.
- The State Ministry of Environment should set out enforcement policies that will require mining companies to carry out an Environmental Impact Assessment before commencing operations.
- Implement Mitigation Measures: Immediate measures should be taken to reduce indoor air pollution, such as installing air purifiers and promoting the use of clean cooking technologies.
- Seasonal Monitoring: Continuous monitoring of air quality should be maintained throughout the year to track seasonal variations and implement timely interventions.
- Community Awareness: Educate the local population on the health risks associated with indoor air pollution and promote practices to minimize exposure, especially during the dry season.

- Policy Enforcement: Strengthen the enforcement of environmental regulations to ensure mining activities adhere to air quality standards.
- Meteorological Considerations: Incorporate meteorological data in air quality management plans to predict and mitigate periods of high pollution.

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