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Clean air: an outlook for achieving sustainable development goals: the state of the indoor environment in Michika area of Adamawa state, Nigeria

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Abstract

This study assessed the health implications of air quality decline in residential, workplace, and school indoor environments and its implications on the health of the inhabitants of the Michika Area of Adamawa State. Pollutants such as PM, CO, NO_2, and SO2 were evaluated in the morning and evening hours within 10 days using an in situ gas sampler. The data were compared to WHO and NESREA limits for human exposure. Anova and student t-test statistics were adopted to hypothesize the mean differences in the diurnal and spatial conditions of indoor air pollutants. The air quality index was estimated using the US EPA equation to determine the level of indoor air quality in relation to health implications. The study found, among other things, that ambient pollutant concentrations were statistically different in the respective indoor environments for CO (P value = 0.000), SO_2 (P values of 0.02 and 0.000), NO_2 (P value = 0.000), and $PM_{2.5}$ (P = 0.001 and 0.0001). The residential indoor environment was reportedly dangerous for sensible groups due to the poor AQI rating for SO_2, NO2 and PM_{10}. In conclusion, air pollution is evident in the Michika area of Adamawa State, and the rate of exposure is particularly higher in the residential indoor space.

Keywords: *Air Quality Index; Indoor Air Quality; Pollutants; Michika.*

1. Introduction

Clean air is a basic resource that is required for healthy living in all forms of life, including plants and animals that are integral aspects of the ecosystem (Mannucci and Franchini, 2017). To support the vital role of clean air, Sustainable Development Goal 3, which targets good health and well-being, requires member states to reduce the rate of mortality attributed to household ambient air pollution (SDG-3.9.1). In 2018, the World Health Organization (WHO) also ratified the global community to prevent air pollution and its antecedent effects on human health and the environment from 2019—2023. Both ratifications stimulated the resolution on air pollution and health, and the subsequent road map for an enhanced global response set forth by the World Health Assembly in 2015, as a strategy for reducing public health risks from air pollution. The resolution also stimulates the campaign for Breathe Life and commits member states to reduce air pollution by the end of 2030, in line with WHO Air Quality Guidelines. However, achieving clean air remains a pipe dream, threatening the health of millions of people (particularly in Nigeria) (Okobia et al., 2017; Lucky et al., 2021).

Epidemiological studies have highlighted the effects of air pollution from different sources on human health (Brokamp et al., 2019; Sacks et al., 2020; Liu et al., 2022). In recent times, problems associated with outdoor air pollution have received publicized attention due to the prominence of major pollutant sources such as traffic, industries, construction, and combustion sources (Crippa et al., 2018; Harrison, 2020; Lucky et al., 2020). However, public concerns about indoor air quality (IAQ) have attracted a great deal of attention as the isolation of indoors from outdoor environments has become notable with the widespread construction of low-ventilated buildings (Kabir et al., 2012). Building and furnishings materials, combustion sources (such as burning fuels, coal, and wood; tobacco products; and candles); central heating and cooling systems; humidification devices; moisture processes; electronic equipment; household cleaning products; mosquito repellents; artificial fragrances; pets; and building occupant behavior (smoking and painting) have all been identified as sources of indoor air pollution (Apte and Salvi, 2016).

Ana et al., (2015) posit that air quality in indoor space is crucial for healthy living and people's well-being. Oddly, indoor air pollution is present in virtually all indoor spaces, with the exception of strictly controlled and sterile spaces such as medical and research facilities. The mere presence of people in a building can significantly alter indoor air quality (Ana et al., 2015). According to Martin et al., (2013), around 3 billion people cook and heat their homes using open fires and simple stoves burning biomass (wood, animal dung, and crop waste) and coal. As a result, over 4 million people die prematurely from illness attributable to household air pollution, with over 50% of premature deaths among infants below five years of age (Lim et al., 2012). In recent times, indoor air pollution has been significantly linked to airborne diseases, including the novel COVID-19 virus, with increased cases among children and the elderly (Filippini et al., 2020; Naglaa et al., 2021). Individual exposure to indoor air pollutants such as particulate matter, carbon monoxide, sulphur dioxide,

lead, nitrogen dioxide, and ozone can be regulated by an interaction between their indoor source strengths and the entrapped time in indoor environments (Yousef et al., 2013). The exposure level of humans to these pollutants is worrisome because people spend about 90% of their time in both private and public indoor environments, such as homes, gyms, schools, and work places, among others (Cincinelli and Martellini, 2017).

Hypothetical investigation revealed that the quality of the indoor environment is a strong determinant of occupants' health (Majdan et al., 2012). People living in greener buildings and a healthy environment are more likely to live in better health conditions (Chan and Liu, 2018). In contrast, housing units relying on the use of inefficient and highly polluting solid fuels are more susceptible to indoor air pollution-related illness. On average, particulate matter 2.5 ($PM_{2.5}$) concentrations in households using solid fuels have been reported to range from 133.5 $\mu g/m^3$ to 670 $\mu g/m^3$ compared to the range of 10 $\mu g/m^3$ to 38 $\mu g/m^3$ in households using cleaner fuels in Europe (Shez et al., 2017; Yun et al., 2020). This disparity has clearly shown the differences in indoor air pollution burden with remarks on its contribution to disability-adjusted life years (DALY) lost (Murray et al., 2020).

Indoor air pollution-related cases are disproportionate in developing nations, with reports indicating that 32% of the burden occurs in Sub-Saharan Africa, 37% in South Asia, and 18% in East Asia and the Pacific (Po et al., 2011; Hulin et al., 2012). Traditional fuels (mainly fuel wood and charcoal), which supply more than 70% of household energy needs in developing countries, have been recognized to be the major threat to increasing indoor air pollution (Sanbata et al., 2014). A study carried out in Nepal revealed that air pollutants in households that used kerosene stoves exceeded WHO limits (Lohani, 2011). In a replica case, indoor air pollution was reported above the WHO limit among households using both clean and fuelwood energy in South Africa (Jafta et al., 2017; Wernecke et al., 2015). In Ethiopia, indoor air pollution for households using clean energy and fuelwood exceeded WHO limits, and nearly 5% of the national burden of disease was due to the use of solid fuel (Sanbata et al., 2014).

Nigeria, like other developing countries, is faced with an increasing risk of indoor air pollution resulting from the overreliance of small-capacity fossil fuel electricity generators and fuelwood as the main energy sources. These, along with poor ventilation, influence the quality of indoor air (Okafor et al., 2008; Ana et al., 2015). The report showed that indoor air pollution is the leading cause of death in Africa and is ranked the fourth leading risk factor for mortality in Nigeria, accounting for more than 7% of deaths (114,100), as well as 150 deaths per 100,000 Nigerians (Health Effects Institute, 2019). In different parts of Nigeria, annual mean indoor pollution concentrations have been reported to exceed both the WHO and National Standards (Njoku et al., 2016; Jelili et al., 2020), leading to high records of hospitalization, disability, and early death associated with air pollution-related illnesses (Afolabi et al., 2016). According to Qian (2017), even in areas where air pollution meets federal standards, continuous exposure to air pollution can increase the mortality rate among Medicare recipients. Yet awareness of indoor air pollution is poor, particularly among suburban and rural communities in Michika. This paper aims to establish the conformity of indoor air quality in residential, school, and workplace environments in the Michika community in line with the following objectives:

1) Determine the diurnal ambient concentration of indoor pollutants within a period of 10 days across the indoor residential, workplace, and school environment.
2) Compare the results in objective 1 above with the Regulatory Limit of WHO and NESREA.
3) Determine the health implications of the concentration of these air pollutants using the air quality index model.

2. Materials and methods

2.1. Study location

Michika Local Government Area is located in Adamawa State's northeastern axis, between latitudes 10° 32'N and 10° 14'N and longitudes 13° 19'E and 13° 25'E (Obiefuna et al., 2018). It shares boundaries with Madagali Local Government Area to the north, Lassa (Borno State) to the west, the Republic of Cameroun to the east, and Mubi South Local Government Area to the South (Fig 1). Michika covers an aerial extent of about 188.5km^2. Michika is located within the semi-arid climatic zone of Nigeria, characterized by dry and wet seasons. The main rock types in the Michika area include new basalt, coarse-grained biotite granites, coarse porphyritic granites, and medium-grained granites. The parent rock has undergone complete weathering, decomposition, and lateralization, resulting in about 6 to 20 m of unconsolidated weathered overburden layer of soil consisting of coarse sands, loamy, and clayey soils (Jimoh, 2011). The study area is characterized by Sudan's savannah vegetation, which is dominated by grass and weeds with a few scattered woody plants (Peter et al., 2016). Common tree species in the area are *Ficus species, Vitex donniana, Vitellaria paradoxa, Termarendus indica, Acacia species, Parkia biglobosa, Daniella oliverii, Adansonnia digitatata, Gardenia species, Grewia molii, Perinary excelsa, Anagecious liocarpos,* and some shrubs such as *Phylostigma thonigii, Ziziphus mauritiana, Gardenia aqualla, Nuclea latifolia, Anona senegalensis and Sterculia setigera* (Amadi et al., 2018). With a projected population of 460,194, over 80% of the population of the Michika area are farmers.

2.2. Methodological design

2.2.1. Types and sources of data

The criteria pollutants, which include NO_2, SO_2, CO, and PM (PM_{10} and $PM_{2.5}$), were measured in the respective indoor environments (residential, workplace, and school) using mobile detector devices. The measurements were conducted in the morning and evening periods, respectively.

2.2.2. Sampling frame and sample size

The Michika Local Government Area of Adamawa State was selected as the sample frame for this study. The indoor air quality investigation was carried out in three different indoor spaces (residential, workplace, and school) within Michika Town for a period of 10 days. The non-probability sampling technique was adopted to select the indoor environment based on the concept of purposive sampling. This technique was adopted because the indoor environments are selected purposively. Only areas with no restricted access and with the full consent of occupants were selected for indoor air pollution monitoring.

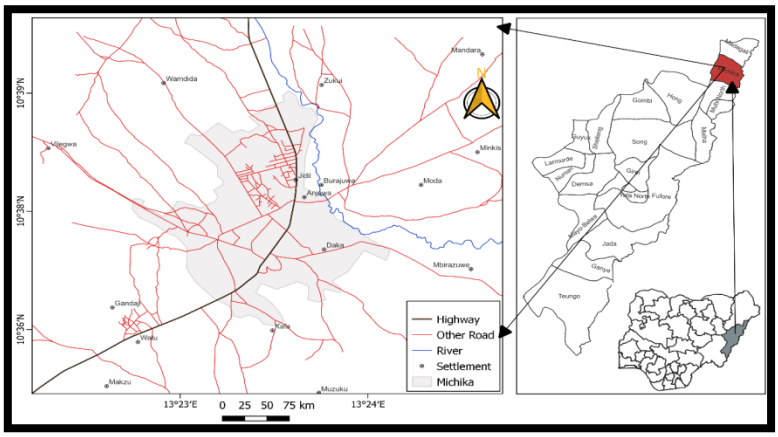


Fig. 1: Map of Michika.

2.2.3. Field experimentation

Real-time ambient monitoring of IAP in different indoor environments was carried out in the month of October 2021, lasting for 10 days with the aid of an in-situ standard tracer mobile gas sampler device (Table 1). The in-situ assessment was conducted for both the morning and evening periods across the three indoor environments (residential, school, and workplace). The in-situ assessment was conducted for both the morning and evening periods across the three indoor environments (residential, school, and workplace). The mobile gas sampler device was switched on, placed on a base of 1–1.5m in an indoor environment, and allowed to detect the indoor pollutants. The readings were collated every 20 minutes for a period of 1 hour and the average values were recorded as indoor air pollution. The exercise was repeated during the evening period to understand the temporary variations in indoor air pollution in the indoor environment. The parameters of interest include nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon monoxide (CO), and particulate matter (2.5 and 10).

Table 1: Adopted Instrument

S/No	Instrument	Model	Purpose
1	Global Positioning System	GPSmap 60Cx	Obtain sampling points.
2	Gasman Auto Sampler	GAXT-S-DL	Record NO_2, SO_2, CO
3	HAZE Dust Particulate Monitor	GAXT-D-DL	Record hourly PM concentration
4	Notepad/Pen	40 leaves/bic	Writing
5	QGIS	Qgis 3.2 Bonn	Develop imagery map
6	ArcGIS	ArcGIS 10.1	Produce a study area map

2.2.4. Data analysis

IAP profiles measured from the respective indoor environments were visualized using bar charts, while hypothetical results were presented in tabular form. The data were subjected to three null hypotheses as follows:

a. Ho_1: There is no significant difference in indoor air pollutants across the three indoor environments (residential, workplace, and schools).
b. Ho_2: There is no significant variation in the diurnal concentration of indoor pollutants in the respective indoor environments (residential, workplace, and schools).
c. Ho_3: There is no significant correlation among the average daily concentration of indoor air pollutants (PM, CO, NO_2, SO_2)

The descriptive statistic (mean) was used to present, interpret and bench mark the result of the IAP measured in the respective indoor environment compared to the WHO and NESREA limits, while the anova variance test, the student's t test, and zero-order correlation were adopted to validate the research hypothesis (see equations below).

i). Mean

$$\bar{X} = \frac{\sum X}{N} \quad (1)$$

Where: $\bar{X}$ = Mean
$\sum$ = Summation of the entire data points in the data set
N = Number of data points in the data set
The diurnal variations of the average ambient concentration of indoor pollutants in the respective indoor environments were analyzed using a student t-test, while the average concentration of pollutants across the indoor environment was determined using the single factor anova test (see equation 2 and 3 below).).

ii). Student t-test

$$t = \frac{\hat{x}_1 - \hat{x}_2}{\sqrt{(\sigma_1^2/N_1) + (\sigma_2^2/N_2)}} \quad (2)$$

$\hat{x}_1$ = mean variable one (IAP measured in the morning)
$\hat{x}_2$ = mean variable two (IAP measured in the evening)
σ_1^2 = the square of the standard deviation of variable one
σ_2^2 = the square of the standard deviation of variable two
N_1 = total number of values in variable one
N_2 = total number of values in variable two

iii). Anova

$$TSS = \Sigma i \Sigma (Xij - X{+}{+})^2 \quad (3)$$

$$BSS = \sum j \; nj \; (X{+}j - X{+}{+})^2$$

$$WSS = \Sigma j \Sigma (Xij - XXj)2 = \sum j(nj - 1) \; sj2$$

To assess indoor air quality and provide context for potential exposures, data were compared with the values of human criteria established by the WHO and NESREA (See Table 2).

Table 2: IAQ standards of WHO and NESREA

Pollutants	Concentration Level (µg/m^3)/ppm	Exposure Time	Organization
CO	100	15m	WHO
	60	30 m	
	30	1 h	
	10	8 h	
	20	1 h	NESREA
CO_2	1800	1 h	WHO
	10	1 h	NESREA
NO_2	0.4	1 h	WHO
	0.2	24 h	
	0.06	24 h	NESREA
PM	25 (2.5)	24 h	WHO
	50 (10)	24 h	
	80 (2.5)	1 h	NESREA
	250 (10)	1 h	
SO_2	0.5	10m	WHO
	0.35	1 h	
	0.10	1 h	NESREA

iv). Assessment of PM Pollution Index

The Air Quality Index (AQI) establishes daily air quality to examine the health implications relating to indoor air pollution. This AQI is divided into six categories, indicating increasing levels of health concern. The results from the AQI computation were subjected to the air quality-rating table to determine the condition of the indoor air as presented in Table 3. The pollutant index concentration is expressed as a percentage of the relevant air quality standard. The AQI was calculated by the equation given by the US EPA as follows:

$$\text{Index} = \frac{\text{Polution concentration}}{\text{Pollution standard level}} \text{ X } 100 \quad (4)$$

Table 3: Air Quality Rating

Air Quality Index (AQI) Values	Levels of Health Concern	Colors
0 to 50	Good	Green
51 to 100	Moderate	Yellow
101 to 150	Unhealthy for Sensitive Groups	Orange
151 to 200	Unhealthy	Red
201 to 300	Very Unhealthy	Purple
301 to 500	Hazardous	Maroon

v). Correlation Analysis

Pearson's product moment correlation analysis was utilized to establish the degree of relationship among the indoor air pollutants.

$$rp = \frac{\sum(x-\bar{x})(y-\bar{y})}{\sqrt{\sum(x-\bar{x})^2 \sum(y-\bar{y})^2}} \quad (5)$$

where rp = product moment correlation ratio

$\sum(x - \bar{x})(y - \bar{y})$ = summation of both variables' deviation from their mean
$\sum(x - \bar{x})^2$ = summation of the square of all deviation from the mean in the independent variable
$\sum(y - \bar{y})^2$ = summation of square of all deviations from the mean in the dependent variable

3. Result and Discussion

3.1. Episodes of indoor air pollutants

3.1.1. Ambient concentration of carbon monoxide (CO)

The concentration of CO pollutants varied across the respective indoor environments diurnally, as shown in Fig 2. The ambient concentration of CO pollutants ranged from 2.3–6.1ppm in residential units to 0.4–1.5ppm and 1.0–2.9ppm at workplace, and school buildings during the morning period. During the evening period, the indoor CO value ranged from 9.2–12.7ppm in residential units, 0.6–3.1ppm in the workplace, and 1.7–9.2 in the school building. The results showed an increasing amount of indoor CO concentration during the evening period compared to the values recorded during the morning period in the respective indoor environments. However, the presence of CO in the indoor environment of residential and school buildings is much higher than the values recorded in the workplace environment. The number of times one spends indoors, particularly in residential and school settings, on a daily basis is more than 18 hours altogether. As such, the results imply that individuals in the respective residential units and schoolchildren are vulnerable to long-term exposure to CO pollutants. According to Opasola et al. (2020), exposure to indoor pollutants is related to respiratory illness among residents relying on unclean energy sources, such as the use of fuelwood. Schoolchildren can be more vulnerable to adverse health effects, such as cardiovascular and neurobehavioral processes, unconsciousness, or death.

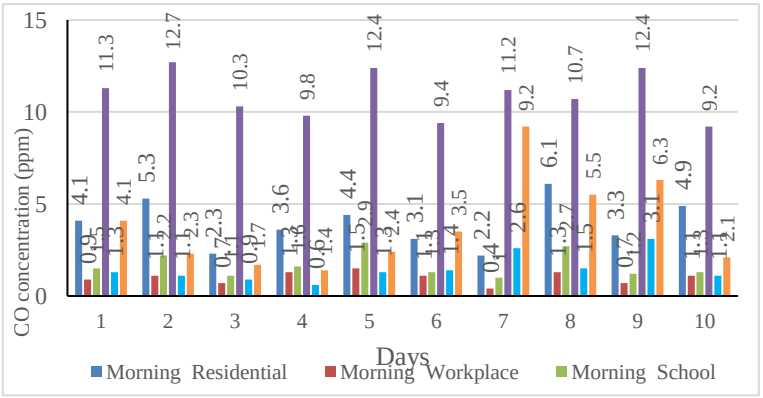


Fig. 2: Ambient Concentration of Indoor CO Pollutant.

3.1.2. Ambient Concentration of sulfur dioxide (SO_2)

During the investigation, traces of SO_2 pollutant were detected in the respective indoor environments during both morning and evening hours (Fig 3).

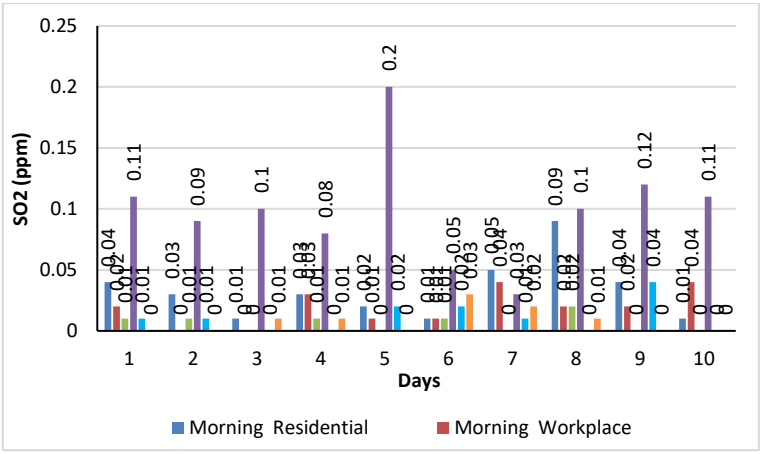


Fig. 3: Ambient concentration of indoor SO_2 pollutant.

The results presented in Fig 3 showed that SO_2 ranged from 0.01–0.09ppm in residential units to 0.01–0.04ppm and 0.01–0.02ppm in the workplace and school classroom during the morning period. On the contrary, low ambient SO_2 concentrations were recorded during the evening period in the range of 0.03–0.2ppm, 0.01–0.04ppm, and 0.01–0.03ppm in the residential, work and school classroom environments, respectively. The results revealed that the value of SO_2 in the residential building is higher than in other indoor environments (workplace and school classroom). This can be attributed in part to the use of fuelwood, candlesticks, and kerosene as cooking, heating and lighting sources among residents of Michika. However, the presence of SO_2 in the indoor environment of residential buildings may also be due to outdoor sources. The result is favorable compared to the indoor SO2 concentration (0.650 $\mu g/m^3 \pm 0.454$ $\mu g/m^3$) observed by Rantetampang et al. (2013), in the Wamena district of Papua Province, Indonesia. Similarly, high amount of SO_2 have been observed in indoor residential environments in Nigeria where SO_2 varied from 0.6 to 25ppm in Nsukka (Agbo et al., 2021) and 0.00–14 $\mu g/m^3$ in Kano metropolis (Ayodele and Abubakar, 2010).

3.1.3. Ambient concentration of nitrogen oxide (NO_2)

The ambient concentration of NO_2 across the respective indoor environments (residential, workplace, and school environment) is presented in Fig 4. The results showed that in the morning hours, the values of NO_2 in residential building ranged from 0.07–0.3ppm, whereas at workplace and school classroom, ambient NO_2 ranged from 0.0–0.06 and 0.0–0.04ppm, respectively. On the contrary, the NO2 ambient indoor concentrations recorded during the evening hours throughout the study period stood at 0.1–0.36, 0.02–0.07ppm, and

0.0–0.06ppm in the residential, workplace, and school classroom respectively. The result showed that the ambient episode of NO_2 is higher during the evening period than in the morning period. Likewise, higher values were recorded in the residential unit.

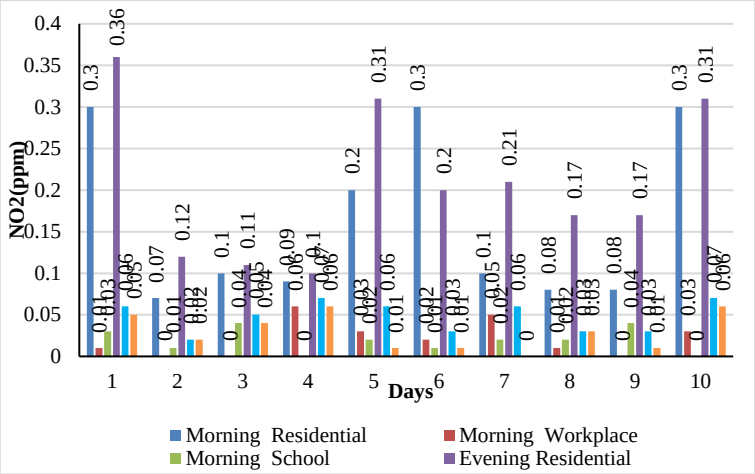


Fig. 4: Ambient concentration of indoor NO_2 pollutant.

The increasing rate of NO_2 in the residential unit may be attributed to outdoor source emissions, as well as the use of fuelwood by most residents of the area. Poor ventilation may also have contributed to the high amount of NO_2 within the residential building as opposed to the workplace and school classroom, respectively. However, the result recorded in this study is lower than the observation of Emuren and Ordinioha (2017) in the indoor environment of a tertiary hospital in Port Harcourt, where NO_2 was observed in the range of 133 µg/m3, 151 µg/m3 and 141 µg/m3. Taking into account the presence of NO_2 in indoor environments (residential, workplace, and school buildings) in the study area, the large population in the Michika area may be predisposed to NO_2 related illness. This is in relation to epidemiological findings that exposure to NO_2 may lead to allergic diseases, including asthma and lung disorders (Bowatte et al., 2014; Deng et al., 2016; Baoting et al., 2019).

3.1.4. Ambient concentration of Particulate Matter (PM)

Indoor particulate matter investigation was conducted for both $PM_{2.5}$ and PM10, as shown in Fig 5 and 6 respectively. The indoor ambient PM2.5 concentration in residential units ranged from 54.1–93.1 µg/m^3 and 66.3–97.3 µg/m^3 in both the morning and evening periods. In the workplace environment, $PM_{2.5}$ ranged from 29.1–72.1 µg/m^3 and 30.7–67.9 µg/m^3 in the morning and evening periods of investigation, respectively. The ambient concentration of $PM_{2.5}$ in the indoor school classroom environment was in the range of 36.1–64.9 µg/m^3 and 69.3–98.2 µg/m^3. The results show that the residential indoor environment recorded a high amount of $PM_{2.5}$ followed by the school indoor environment, respectively. The implication of this result is that people in residential and school classrooms will be highly exposed to $PM_{2.5}$, which is of great concern due to its effects on human health (Hamanaka and Mutlu, 2018).

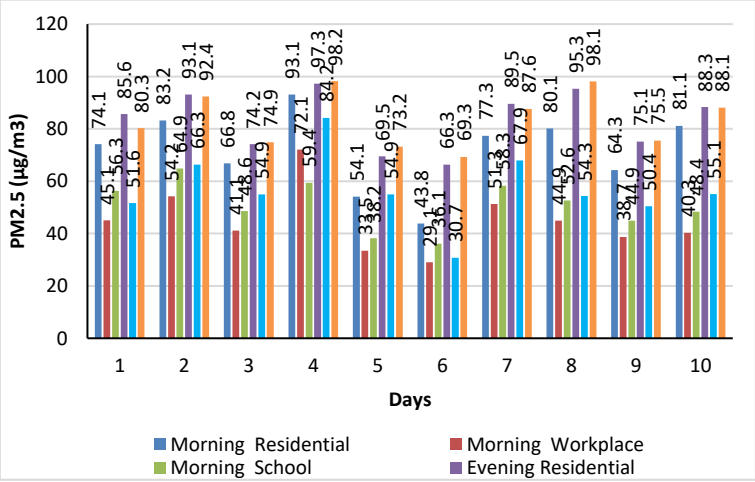


Fig. 5: Ambient concentration of the indoor $PM_{2.5}$ pollutant.

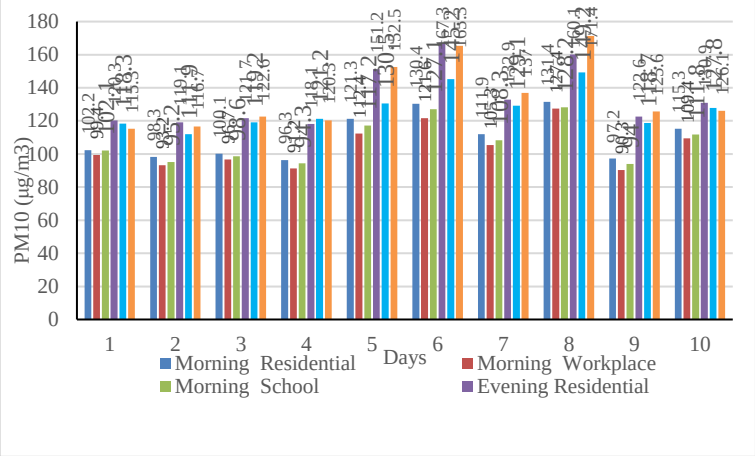


Fig. 6: Ambient Concentration of Indoor PM_{10} Pollutant.

The ambient concentration of indoor PM_{10} during the morning hours ranged from 96.3–131.4 µg/m^3 in the residential environment, whereas in the workplace and school classroom, PM_{10} ranged from 90.3–121.6 µg/m^3 and 94–128 µg/m^3 (Fig 6). During the evening period, indoor concentrations of PM_{10} ranged from 118.1–167.3 µg/m^3, 111.9–149.2 µg/m^3, and 115.3–171.4µg/m^3 at the residential, workplace, and school classroom, respectively. The results show high indoor PM_{10} in the residential and school environments, respectively. This may be attributed to cooking energy sources, building materials, poor ventilation, as well as household habits such as smoking (Yu et al., 2015; Kim et al., 2018; Tran et al., 2020). Onabowale and Owoade (2015) reported similar results in Ibadan. They found that the average mass concentrations of PM loadings obtained for firewood, kerosene, and cooking gas environments were 50.0, 22.2, and 22.7 µg/m^3 for $PM_{2.5}$ and 20.1, 24.3, and 9.0 g/m^3 for PM_{10}, respectively. The results of this study suggest that household individuals in Michika Town are highly vulnerable to particulate matter exposure. Most worrisome is the exposure of children both at home and in their school environment.

3.2. Deviation of average indoor air pollutants from established limit

The ambient average concentration of CO in the respective indoor environments was moderately below the WHO limit (25ppm) for daily exposure to CO pollutants. The result showed that the average CO in the residential indoor environment stood at 3.9 ±1.2ppm and 10.9 ±1.2ppm at the morning and evening hours. The average concentration of CO in the workplace and school indoor environment was 1 ±0.3 and 1.7 ±0.6 ppm during the morning hours, while 1.5 ±0.7ppm and 3.9 ±3.4ppm were recorded in the evening hours, respectively (Fig 7a). The results showed that the average CO in the residential indoor space during the evening hours was above the NESREA limit (10ppm). This may be strongly linked to the use of fuelwood as cooking energy—particularly during the evening periods in which residents are actively preparing food for dinner. The result agreed with the findings of Oguntoke et al., (2010) in which CO (82.5 ±1.98ppm) from households using biomass stoves was higher than the NESREA permissible limit. The implication of the result is that individual occupants in the residential unit in Michika will be exposed to indoor CO pollutants.

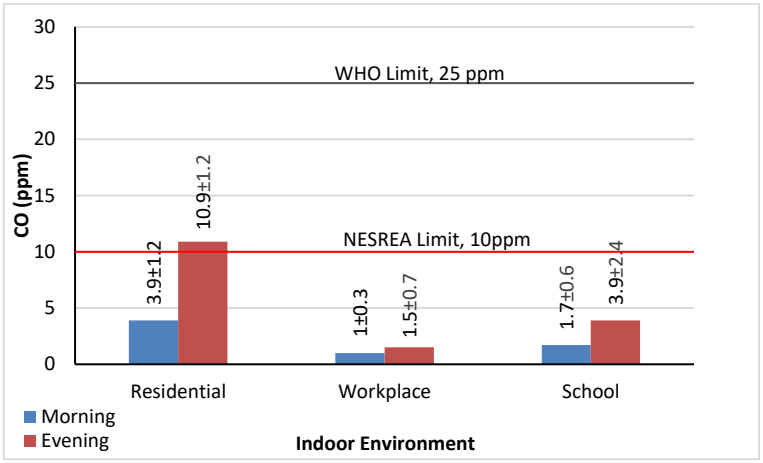
The average values of SO_2 in the respective indoor environments (residential, workplace, and school) are inconsistent (Fig 7b). The average concentration of SO_2 recorded in the morning and evening hours were 0.03 ± 0.02ppm and 0.1 ±0.04ppm in the residential indoor environment. The results are within the WHO limit (0.17pp) but exceed the NESREA limit (0.01ppm) for hourly exposure. Similarly, the average concentration of SO_2 recorded during the morning (0.02 ±0.01ppm) period is above the NESREA limit, as against the average value recorded during the evening (0.01 ±0.01ppm) hour in the workplace indoor environment. Contrarily, the observed average SO_2 recorded in the school classroom in the morning and evening hours is 0.01 ±0.01ppm. These values are all within the WHO limit for hourly SO_2 exposure. The result indicates the presence of SO_2 above the NESREA limit in the residential indoor environment irrespective of diurnal differences. The attributed source of SO_2 in the residential indoor space is connected to the use of fuelwood as a domestic energy source. The result corresponds to the findings of Agbo et al., (2021) in Nsukka.

The average concentration of NO_2 in the workplace indoor environment was 0.02 ±0.02ppm and 0.05 ±0.02ppm for the morning and evening hours, respectively. Similarly, the average ambient concentration of NO_2 stood at 0.02 ±0.01ppm during the morning period and 0.03 ±0.02ppm during the evening period in the school indoor space. The results demonstrate a moderate hourly concentration of NO_2 within the WHO and NESREA limits in both the workplace and school environment in Michika. On the contrary, the average NO_2 levels measured in the indoor residential space were 0.16 ±0.1ppm in the morning and 0.21±0.1 in the evening, which are both above the NESREA limit as well as the WHO limits during the evening hour. Thus, occupants in the residential units will be highly exposed to NO2 pollutants. However, this finding is better than the global cohort study by Salonen et al., (2018) in which the values of NO2 reported for offices (6.00 to 68.5 µg/m3) and schools (3.40 to 56.5 µg/m3) were outrageous.

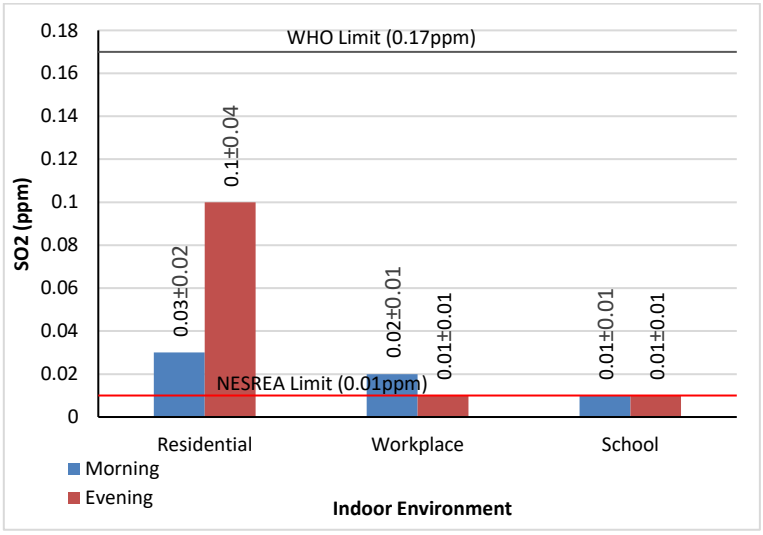
In the residential space, average values of $PM_{2.5}$ varied from 71.8 ±14µg/m^3 to 83.4 ±10.6µg/m^3 in both the morning and evening hours. Similarly, the average values of $PM_{2.5}$ in the workplace (45±11.5µg/m^3 and 57 ±13.2µg/m^3) and school classroom (50.8 ±8.8µg/m^3 and 83.8 ±10µg/m^3) also increased in the evening period compared to the morning hour. The result showed that the diurnal average concentration of $PM_{2.5}$ in the respective indoor environment were above the WHO exposure limit (25 µg/m^3), but were within the NESREA limit (80 µg/m^3) except for the values recorded during the evening period at the residential (83.4 ±10.6µg/m3) and school (83.8 ±10µg/m^3) indoor spaces. The diurnal average values of PM_{10} varied from 110.4 ±143µg/m^3 to 134.4 ±17.4µg/m^3 for both the morning and evening hours in the residential indoor space. These values are higher than the observed diurnal average PM_{10} recorded at the workplace (104.7 ±12.2µg/m^3 and 127.1±11.4µg/m^3) and school (10.7 ±12.4µg/m^3 and 135.3 ±19.5µg/m^3) indoor environments in both the morning and evening hours, respectively (Fig 7d). The result showed that the diurnal concentrations of PM_{10} in the respective indoor environments were higher than the WHO limit (50 µg/m^3) but well below the NESREA limit (250 µg/m^3). The maximum values of $PM_{2.5}$ and PM_{10} were recorded during the evening hours, particularly in residential and school indoor spaces. The result is at par with the work of Ana et. al., (2013) in which the mean indoor PM10 readings for the wet season (73.4 ± 54.4µg/m³) and dry season (296.3 ± 61.6µg/m³) in selected daycare centers in Ibadan significantly exceeded the WHO guideline limit of 50µg/m³. This implied that school pupils would

be highly exposed to this deadly pollutant both at school and in their respective homes. Traces of harmful pollutants such as CO, NO2 and PM in the indoor space are dangerous to community health and wellbeing, considering that people spend most of their time indoors either at work or school during the morning and noontime and at home during the evening period after their engagement from workplaces, schools and trade centers. A cross-sectional study conducted in Ile-Ife showed that women and children are more vulnerable to biomass-related CO exposure with an increased odds of reporting respiratory symptoms such as cough and airway obstruction (Awopeju et. al., 2017).

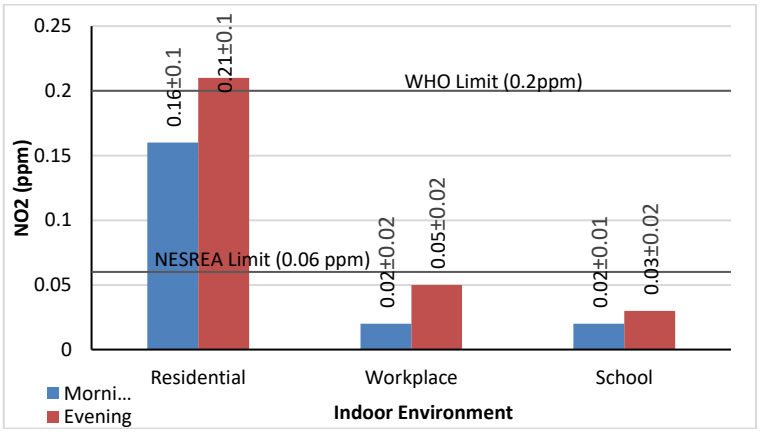
[A] CO



[B] SO_2



[C] NO_2



[D] $PM_{2.5}$ and PM_{10}

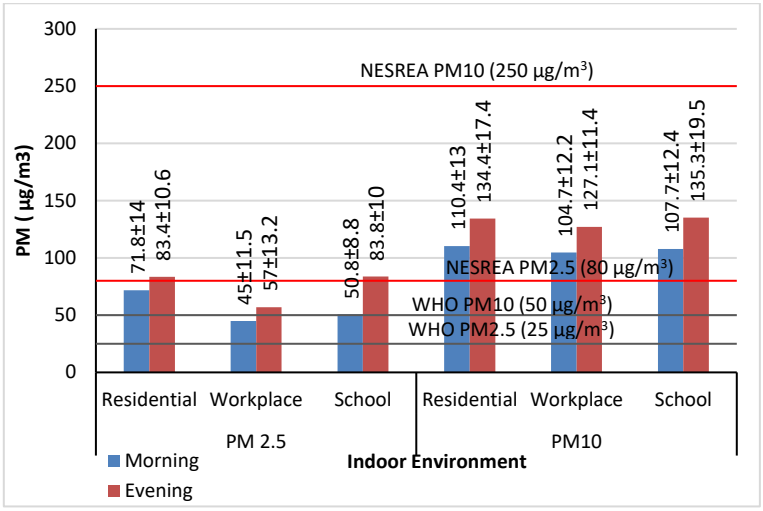


Fig. 7: Average Concentration of Criteria Pollutants in Indoor Environment against the WHO and NESREA Limit.

3.3. Statistical test

3.3.1. Test of variance

Episodes of indoor air pollutants were subjected to anova test for variation to determine the existing differences in the occurrence of pollutants in the respective indoor spaces, while the student t-test was adopted to test for diurnal differences. Both statistical tests were adopted to provide hypothetical reasoning as stated in HO_1 and HO_2. (Table 3 and 4).

The anova test result (Table 3) showed that ambient concentrations of indoor pollutants are statistically different in the respective indoor environments. This is reflected in the result for CO (P value =0.000), SO_2 (P value 0.02 and 0.000), NO_2 (P value = 0.000), $PM_{2.5}$ (P = 0.001 and 0.0001) at both morning and evening period respectively. With the exception of PM_{10}, the result implied that Ho_1 (There is no significant difference in the indoor air pollutant across the three indoor environments 'residential, workplace and school) do not stand. The implication of these results is that the rate of indoor pollutants varied across the respective indoor environments (residential, workplace and school), with residential and school indoor spaces recording the highest concentration of indoor pollutants. Must worrisome is the cultural lifestyle of the people of Michika, which is a true reflection of Northern Nigeria where women are not permitted to leave their home premises, thus, are more vulnerable to exposure of indoor pollutants since they spend almost all day indoors. Their vulnerability may also increase resulting from the over-reliance on fuelwood as a major cooking and heating energy source. According to Agwu and Ozeh (2013), exposure to harmful pollutants such as particulates and CO can cause of respiratory illness particularly asthma, bronchitis, lung cancer, cardiovascular disease, birth defects, and premature death. The risk factor is particularly high among susceptible populations including the elderly, children, women, and people with pre-existing health conditions.

The diurnal variation of ambient pollutants in the respective indoor environment depicts that the diurnal (morning and evening) concentration of CO is statistically significant only at the residential and school indoor environment with P values of 0.000 and 0.03 (see Table 4). Similarly, the diurnal variation of SO_2 is statistically significant at the residential indoor environment (P-value = 0.000), while, NO_2 pollutant showed diurnal significance with P-value of 0.02 in workplace indoor environment. The diurnal concentration of $PM_{2.5}$ is statistically significant in the school classroom environment given by the P-value of 0.00. Similarly, the t-test showed that ambient concentrations of PM_{10} recorded in the morning and evening periods at the respective indoor environments were statistically different as given by the P-values (0.006, 0.002 and 0.003).

Given by the result in Table 5, the study hypothesis (2) does not apply to CO (0.000 and 0.03) at the residential and school indoor environment, SO_2 (0.002) at the residential indoor environment and NO_2 (0.02) at the workplace environment. Similarly, the result of $PM_{2.5}$ (0.00) at the school indoor space and PM_{10} (0.006, 0.002 and 0.003) across all the indoor environment do not apply to the postulated null hypothesis 2 since the P-values were all below 0.05, indicating significant variation in the concentration of these pollutants in the morning and evening hours in Michika Area. The results are similar to the findings of indoor pollutants in various sectional units of Mahatma Gandhi Central Library (MGCL) of Indian Institute of Technology (IIT) Roorkee, reported by Sahu and Gurjar (2019). They found that the diurnal concentration of $PM_{2.5}$, PM_{10}, PM_1 and TVOC were statistically significant.

Table 3: Significant Differences of Pollutants across Residential, Workplace and School Indoor Environments (HO_1)

Morning								Evening					
	Source of Variation	SS	df	MS	F	P-value	F crit	SS	df	MS	F	P-value	F crit
	Between Groups	41.1	2	20.5	25.0	0.000*	3.4	430.8	2	215.4	68.4	0.000*	3.4
CO	Within Groups	19.7	24	0.8				75.5	24	3.1			
	Total	60.8	26	60. 8				506.3	26	506.3			
	Between Groups	0.0032	2	0.0016	5.0087	0.02*	3.40	0.046	2	0.023	26.77	0.000*	3.40
SO_2	Within Groups	0.008	24	0.0003				0.021	24	0.001			
	Total	0.011	26					0.067	26				
	Between Groups	0.096	2	0.048	14.84	0.000*	3.40	0.141	2	0.07	29.92	0.000*	3.40
NO_2	Within Groups	0.078	24	0.003				0.056	24	0.002			
	Total	0.17	26					0.197	26				
	Between Groups	3558.6	2	1779.3	10.6	0.001*	3.40	4068.9	2	2034.4	12.8	0.0001*	3.40
$PM_{2.5}$	Within Groups	4016.8	24	167.4				3813.7	24	158.9			
	Total	7575.4	26					7882.6	26				
	Between Groups	166.2	2	83.1	0.44	0.65	3.40	459.8	2	229.9	0.74	0.486	3.40
PM_{10}	Within Groups	4575.9	24	190.7				7408.7	24	308.8			
	Total	4742.2	26										

*Significant at 95% (0.05).

Table 4: Significant Variation of Diurnal Concentration of Pollutants (HO_2)

Pollutants	Indoor environment	df	t-cal	P-value
CO	Residential	16	-10.98	0.000*
	Workplace	16	-1.65	2.12
	School Building	16	-2.33	0.03*
SO_2	Residential	16	-3.61	0.002*
	Workplace	16	1.15	0.272
	School Building	16	-0.78	0.446
NO_2	Residential	16	-1.03	0.32
	Workplace	16	-2.89	0.02*
	School Building	16	-0.99	0.33
$PM_{2.5}$	Residential	16	-1.78	0.09
	Workplace	16	-1.95	0.06
	School Building	16	-6.92	0.00*
PM_{10}	Residential	16	-3.14	0.006*
	Workplace	16	-3.73	0.002*
	School Building	16	-3.55	0.003*

*Significant at 95%.

3.3.2. Correlation analysis

The concentration of ambient pollutants (PM, CO, NO_2, SO_2) in the respective indoor environments were subjected to the zero-order Pearson Product Moment Correlation Matrix to hypothesize the relationship among each of the pollutants (see Table 5).

Table 5: Zero Order Matrix Correlation of Indoor Pollutant

	M-CO	E-CO	M-SO_2	E-SO_2	M-NO_2	E-NO_2	M-$PM_{2.5}$	E-$PM_{2.5}$	M-PM_{10}	E-PM10
M-CO	1									
E-CO	0.999 (0.01)*	1								
M-SO_2	0.727 (0.48)	0.717 (0.50)	1							
E-SO_2	0.973 (0.15)	0.969 (0.16)	0.866 (0.33)	1						
M-NO_2	0.973 (0.15)	0.969 (0.16)	0.866 (0.33)	1.000 (0.00)*	1					
E-NO_2	0.944 (0.21)	0.939 (0.22)	0.912 (0.27)	0.995 (0.07)	0.995 (0.07)	1				
M-$PM_{2.5}$	0.999 (0.02)*	0.999 (0.03)*	0.745 (0.47)	0.979 (0.13)	0.979 (0.13)	0.953 (0.20)	1			
E-$PM_{2.5}$	0.677 (0.53)	0.688 (0.51)	-0.013 (0.10)	0.489 (0.68)	0.489 (0.68)	0.398 (0.74)	0.658 (0.54)	1		
M-PM_{10}	0.949 (0.20)	0.954 (0.19)	0.473 (0.69)	0.850 (0.35)	0.850 (0.35)	0.793 (0.42)	0.940 (0.22)	0.875 (0.32)	1	
E-PM_{10}	0.611 (0.58)	0.622 (0.57)	-0.100 (0.94)	0.411 (0.73)	0.411 (0.73)	0.316 (0.79)	0.590 (0.59)	0.996 (0.05)	0.829 (0.38)	1

*Significant at 95%.

The correlation coefficients range between -1 and +1 and measure the strength of the linear relationship that exists among the pollutants. Also shown in parentheses is the P-value, which tests the statistical significance of the estimated correlations. The following pairs of variables have P-values below 0.05, which indicates statistical correlation: morning and evening concentration of CO (P-value '0.01', r = 0.999); morning and evening concentration of CO and $PM_{2.5}$ (P-value '0.02', r = 0.999); concentration of SO_2 and NO_2 in the evening and morning period (P-value '0.00', r = 1.00). The established relationship showed that the presence of one pollutant is associated with the other, thus increasing the rate of exposure at composite levels among the inhabitants of Michika.

3.4. Health impact matrix of the concentration of indoor air pollution in Michika

The health impacts of the recorded indoor ambient pollutants in the respective indoor environments are discussed based on the air quality index rating presented in Table 6. The indoor air quality (IAQ) was estimated using the WHO and NESREA threshold limits for human exposure.

Table 6: Air Quality Index in the Respective Indoor Environment

	Residential Environment				Workplace Environment				Classroom Environment			
	NESREA		WHO		NESREA		WHO		NESREA		WHO	
	M	E	M	E	M	E	M	E	M	E	M	E
CO	39	109	15.6	43.6	10	15	4	6	17	39	6.8	15.6
SO_2	300	1000	17.6	58.8	200	100	11.8	5.9	100	100	5.9	5.9
NO_2	266.7	350	80	105	33.3	83.3	10	25	33.3	50	10	15
$PM_{2.5}$	89.8	104.3	287.2	333.6	56.3	71.3	180	228	63.5	104.8	203.2	335.2
PM_{10}	44.2	53.8	220.8	268.8	41.9	50.8	209.4	254.2	43.1	54.1	215.4	270.6

The result showed that the ambient concentration of CO is rated good across the entire indoor environment, with the exception of the residential unit, where the AQI of CO was rated unhealthy for sensitive groups during the evening period. This implies that residents with existing health challenges—particularly those related to respiration—are at risk of worsening pulmonary diseases. This is particularly so because CO contains dangerous black carbon substances, which are very dangerous to human health (Janssen et. al., 2011). The AQI rating of ambient SO_2 at the indoor residential unit varied from very unhealthy to hazardous in the morning and evening periods

using the NESREA permissible limits, while the WHO limits rated the AQI as good and moderate for both the morning and evening periods, respectively. Similarly, the AQI was rated based on the NESREA limit as unhealthy and moderate in the morning and evening hours in the workplace indoor environment, while for the school environment it was rated moderate. In contrast, the AQI was rated good at the workplace and school indoor spaces based on the WHO limit. The results implied that the residential and workplace environments in Michika are not safe for 24 hours based on the Nigeria Country System. In the indoor residential area, NO_2 was rated very unhealthy and hazardous based on the NESREA limit and moderate to unhealthy for sensitive groups based on the WHO limit in the morning and evening. At the workplace, indoor AQI was rated good both in the morning and evening based on the WHO and NESREA limits, except for the evening period in which NO_2 was rated moderate based on the NEREA limit. In the school's indoor space, NO_2 was rated good irrespective of the regulatory limit in the morning and evening periods.

The AQI of $PM_{2.5}$ was rate moderate at the residential indoor environment during the morning and evening period based on NESREA limit, but was rated very unhealthy and hazardous during the morning and evening period based on the WHO limit. In the workplace indoor space, $PM_{2.5}$ was rated moderate for both morning and evening period based on NESREA limit, while the rating based on WHO limit was unhealthy and very unhealthy in the morning and evening period respectively. At the indoor school environment, $PM_{2.5}$ was rated moderate to unhealthy for sensible groups based on the NESREA limit and unhealthy to very unhealthy based on the WHO limit at both morning and evening period respective. The result indicates poor indoor air quality –particularly in the evening period, which is detrimental to individual's health. The AQI of PM_{10} was rated good at morning and moderate at evening period across the respective indoor environments based on the NESREA limit. On the other hand, AQI of PM_{10} was rate very unhealthy based on the WHO limit for both morning and evening concentration levels across the respective indoor environment. The result is similar to the reported case of AQI rating in Lecture halls of Nigeria University Campuses by Osimobi et. al., (2019). However, the result is in contrast to the report of Abulude et. al., (2011) where indoor AQI was rated good and toxicity potential (TP) were below unity.

4. Conclusions and recommendations

This study has scientifically proven, beyond doubt, the increasing rate of indoor air pollution in the Michika area of Adamawa State. Residential, school, and workplace indoor environments were observed to be threatened by high concentrations of criteria pollutants such as NO_2, PM, SO_2, and CO that are harmful to community health. The AQI of the pollutants were rated from good to hazardous across the study period in the respective indoor environment. However, the residential indoor environment was reportedly dangerous for sensible groups due to the poor AQI rating for SO_2, NO_2, and PM_{10}. This is of the utmost concern as people spend roughly up to 18 hours in residential indoor space on a daily basis. The implication of these findings is the increasing rate of air-related illness among the populace of Michika, particularly the vulnerable groups which include women, children, and the elderly. It is therefore important to establish the relationship between these pollutants and the prevalence of airborne disease and the life expectancy of these vulnerable groups through comprehensive sponsored research. Similarly, an alternative clean energy source such as biogas should be provided for the people of Michika to offset their reliance on fuelwood. This can be achieved through state government interventions in renewable energy construction. The availability of clean energy sources in residential areas of Michika will reduce the use of fuelwood energy, which is a major contributor to indoor air pollution.

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