Journal of Basics and Applied Sciences Research (JOBASR)
ISSN (print): 3026-9091, ISSN (online): 1597-9962
Volume 1(1) IPSCFUDMA 2025 Special Issue
DOI: https://dx.doi.org/10.4314/jobasr.v1i1.7s

Establishing Variation of some Ambient Air Pollutant Concentrations, Temperature and Solar Radiation in Sokoto metropolis

Sharafa S. B.[1,2*], Akpootu D. O.[2], Aliyu R.[3], Bello S. A.[1], Yusuf K. A.[1], Saidu I. G.[2], Alaiyemola S. R.[2] & Aweda F. O.[4]
[1]Department of Physics, University of Ilorin, Ilorin, Nigeria.
[2]Department of Physics, Usmanu Danfodiyo University Sokoto, Sokoto, Nigeria.
[3]Department of Physics, Aliko Dangote University of Science and Technology Wudil. Nigeria.
[4]Department of Physics, Bowen University, Iwo, Nigeria.
*Corresponding Author Email: sharafa.sb@unilorin.edu.ng

ABSTRACT
Short-term assessment of air quality variation of key air pollutants and meteorological parameters in Sokoto metropolis, Nigeria, was carried out. Key air pollutants and meteorological parameters considered are particulate matter (PM_{10} and $PM_{2.5}$), carbon dioxide (CO_2), carbon monoxide (CO), temperature and solar radiation data. Their high-frequency field measurements were done for three months (August to October, 2024) in three different air quality hotspots(i) the entrance to Sokoto State main Motor Park, a hotspot for high vehicular emissions; (ii) Hajiya Halima phone mart complex, ahotspot for high electricity generating sets emissions; and (iii)Mahuta abattoir, a hotspot for biomass burning. Results showed that the highest value of PM_{10} exceeds WHO guidelines by over sixteen folds in all stations; highest value of $PM_{2.}$ exceeds WHO guidelines by over forty-five folds in all stations; highest value of CO_2 exceeds WHO guidelines by over two folds in all stations; highest value of CO exceeds WHO guidelines by over four folds in all stations. In general, the motor park is the most polluted station.The highest value of temperature was recorded at Mahuta station (49.68 ^oC) followed by Hajiya Halima station (32.65 ^oC). It was also observed that the temperatures measured in each site has a direct relationship with CO_2. This finding supports global warming warnings as a result of its increasing emission. Findings highlight urgent need for air quality management strategies to mitigate vehicular, biomass and electricity generator emissions in the rapidly urbanizing northern Nigeria and by extension, the whole country.

Keywords:
Variation
Ambient,
Air Pollutant,
Concentrations,
Temperature,
Solar Radiation.

INTRODUCTION

Quality of air extensively affects human health, induced by both natural and human actions (Kabir et al., 2023). This has increased recognition of quality of air's health effects and also inspired the review of the World Health Organization (WHO) guidelines, backing stringent pollution standards, in 2021. However, research on quality of air has majorly concentrated on high-income nations and heavily populated cities, leaving out low- and middle-income nations (Hilly et al., 2024).The challenges of quality of air faced in developing nations are complicated by low environmental policy implementation, rapidly increasing population and little or no air quality monitoring networks (Akanji, Francis, & Akintola, 2024). Studies have identified vehicular emissions, industrial pollutants, and waste burning as the majorsources of the high PM concentrations observed in most countries (Odubanjo et al., 2024).

Quality of air and global warming are strongly linked because some air pollutants influence climate change. For example, gases like ozone, with its precursors, are both regular air pollutants and greenhouse gases that warm the atmosphere (IPCC, 2024). Air quality has a vital effect on health as it can cause health challenges linked to heart or lung diseases (Vargas-Cuentas, Ramos-Cosi, & Roman-Gonzalez, 2021).

Development of our society, agriculture, engineering and industrial works and greenhouse effects are the main drivers of changes observed in climate around the world. These changes are the drivers of the yearly variation in Carbon dioxide (CO_2) and temperature (Kabir et al., 2023). Increase in atmospheric CO_2-concentration has been widely believed to be the major driver of global warming and a key driver for biological activities (Florides & Christodoulides, 2017). Studies could not establish any clear-cut relationship between CO_2 and temperature (Soon et al., 1999; Nelson & Nelson, 2024). Air pollution increase pose a huge threat to public health while atmospheric stagnation entraps pollutants, thereby aggravating their health impacts. Global warming is expected to affect stagnation patterns in the future, affecting the efficiency of air quality policies (Zhou *et al.*, 2024). Studies have emphasized the significance of adding knowledge of the local people in each community to climate change planning for better acceptability (Gambo et al., 2025).

Climate change has the tendency to disturb meteorological parameters and influence quality of air, human wellbeing, reduction in crop yield, changes in planting days and the economy. (Tsai et al., 2024; Dachung, Ndor, & Ekhuemelo, 2025). Air quality in Nigeria has shifted dynamically because of the influence of increased vehicular traffic, industrialization and urbanization. These changes have caused variation of pollutants emission and the composition of the atmosphere. WHO stated that "unwholesome quality of air has brought about over 5 million sudden deaths annually from the rising cases of protracted (to severe) respiratory health issues such as asthma, heart diseases, lung cancer, neurological health issues, stroke, because few observatories and appraisal exercises are carried out to alleviate the release of pollutants in specific places in Nigeria by adopting workable green practices. The burden of health issues related to poor quality of air in Nigeria is increasing, a developing nation that has experienced major modification in its atmospheric composition over some time now like acid rain, increasing temperature, desertification, etc (Omokpariola, Nduka, & Omokpariola, 2024). In addition, particulate matters (PMs) i.e., particles with aerodynamic diameters of 10 or 2.5 nm (PM10 and $PM_{2.5}$) are associated with a short-term excess mortality of 0.39% and 0.43%, respectively, with levels above the current WHO air quality guidelines (AQGs) limit values (Madaniyazi et al., 2024). PM_{10} is from activities like construction works and dust resuspension by vehicular movements, mechanical processes, etc, whereas $PM_{2.5}$ usually comes from combustion sources.Climate change has been found to worsen concentrations of major air pollutants, particularly fine particulate matter ($PM_{2.5}$). Elevated temperatures, decreased rainfall, and fluctuations in atmospheric circulation patterns are important drivers of these increases (Alexander & Ajiboye, 2024). Dryness and heat can cause an increase in air pollution in general by raising the rates of photochemical production. Increased heatwaves occasioned by climate change will cause more wildfires that will increase harmful emissions like greenhouse gases (GHGs) and PM (Pinho-Gomes et al., 2023). Ground observed PM_{10} in certain seasons is subject to meteorological conditions (Zha, Gao & Jiang, 2010). The new limits recommended by WHO for mean annual concentrations of PM_{10} and $PM_{2.5}$ is 15 μg/m^3 (PM_{10}) and 5 μg/m^3 ($PM_{2.5}$) (WHO, 2021; Leão, Zhang, & Junior, 2023). They can be influenced by boundary layer height, wind, and rainfall (Tsai et al., 2024). Results have shown that the concentration of $PM_{2.5}$ have exceeded the permissible limits in Jordan (Odat & Alodat, 2017). Same trend has also been observed for PM_{10} in Iran (Masoudi & Gerami, 2018).Both PM2.5 and PM10 concentration has been found to exceed WHO AQGs in some cities in Nigeria (Odubanjo et al., 2024).

Seasonal and diurnal changes of global solar radiation over Anyigba in Nigeria shows that global solar radiation have dissimilar pattern of diurnal variation in different seasons, just as has been recorded in other parts of the country. Also, the quantity of solar activity, local meteorology and air pollution plays an important role in the value of solar radiation received at any time and location. The temperature has also been seen as a function of solar radiation heating of the atmosphere (Adedoja, & Ayantunji, 2015). It has also been established that the solar radiation received on earth is always highest during the dry season in Nigeria (Akpootu et al., 2022).

Sokoto has different physiographical features and varying level of urbanization and development. Because of this, quality of the ambient air differs greatly across the town but the lack of air quality monitoring stations in this town makes it difficult to monitor all air quality criteria, i.e., carbon dioxide (CO_2), carbon monoxide (CO), and PMs, at different air quality hotspots. Our interest is to use hand-held sensors establish the need to have many air quality stations in all state of the federation because of the numerous pollution hotspots that may located within the same state and to also evaluate the spatiotemporal relationships between the parameters. In Sokoto metropolis, there are only three known sources of air pollution i.e., vehicular emission, biomass burning and exhaust from electricity generating sets. The aim of this study is to establish the variation of ambient air pollutants concentration and temperature in the best representative station each for the three hotspots for three months. The three months field campaign is a representative data collection period that cuts through the two major seasons. In particular, we would 1) quantify the ambient air pollutants concentration and temperature in each station, 2) compare these pollutants concentration with temperature, 3) compare the WHO AQGs per station, and 4) determine the station with the highest pollution issues.

MATERIALS AND METHODS

Air Quality Monitoring Sites

Sokoto state is located in the extreme north western part of Nigeria under latitude 13.060092^{0}N longitude 5.2390213^{0}E and Altitude 513m. The ecological zone of the area is Sudan savannah agro ecological zone of Nigeria. There are two major seasons in the area, namely wet and dry seasons. Sokoto state is boarded with Zamfara state to the east and south by Kebbi state and boarded with Niger republic in the north(Abdullahi & Sharafa, 2017).

The air quality was monitored at three (3) stations spread over Sokoto urban center, The three air quality monitoring points are(i) Sokoto State Main Motor Park, (ii) Hajiya Halima phone mart section and (iii) Mahuta Abattoir (Kasuwan daji area)and they are shown in Figure 1 while their locations can be seen in Table 1. These places represent automobile pollution hotspot, electricity generating set pollution hotspot and hyde and skin (biomass) burning hotspot, respectively. At each of these points, PM_{10}, $PM_{2.5}$, CO, CO_2, temperature and solar radiation will be monitored and the data obtained from these points will be collected over time and stored in a database.

Figure 1. Map showing the three selected hotspots (https://mapcarta.com)

Table 1: The three stations and their location

S/No	Station	Longitude	Latitude	altitude
1	Sokoto State Main Motor Park	5.24751° E	13.00625° N	279 m
2	Hajiya Halima Phone Mart	5.22489° E	13.05834° N	279 m
3	Mahuta Abattoir	5.22704° E	13.07287 N	279 m

Sokoto State main Motor Park is located near the Alhaji Shehu Shagari market, the biggest market in the Sokoto metropolis. It is an open space park. Between 10.00 am and 7.00 pm (both local times), there use to be high population density of both human and automobiles which add to the CO_2, CO and PM loads around the place. The major air pollution source here are pollutants released from moving vehicles.

Hajiya Halima phone mart is the biggest complex spanning an area of about 600 m^2 where those trading in, and repairing phones and computers are housed in Sokoto. The ventilation here is poor as the buildings are close to each other and the use of both diesel and petrol-powered electricity are commonly used. There are some places in this complex where the sky can be seen. The major source of air pollution here are pollutants released from working electricity generating set and human.

Mahuta abattoir is a government recognized abattoir located close to Kasuwan Daji (market for fruits and vegetables). It is an open space abattoir where over a hundred farm animals (like Bull, Carmel, Cow, Goats, Rams and sheep) are killed daily. The animals'hyde are mostly removed for use in industries that specialize in leather works. The heads and legs are mostly processed (having the hair on their skin burnt to make it edible) at the abattoir for domestic consumption (feed) by humans and other animals. Also, about 50 m away from the abattoir is a small refuse dump where light burning of dry straws.The major source of air pollution here are pollutants released from animal's hyde and skin burning.

According to World Health Organization (WHO, 2021) and National Environmental Standards and Regulations Enforcement Agency (NESREA, 2020), the mean concentration of pollutants that must not be exceeded for health and environmental sustainability are shown in Table 2. The two standards are on a slightly different scale average.

Table 2: Pollutants and their threshold

Parameter	WHO standard	NESREA standard
CO	100 µg m^{-3} (87.29 ppm) (mean 24-hour concentration)	5,000 µg m^{-3} (4365.5 ppm) (mean 8-hour concentration) 10.000 µg m^{-3} (8729.0 ppm) (mean 1-hour concentration)
CO_2	1800 µg m^{-3} (1000.02 ppm) (mean 24-hour concentration)	-
$PM_{2.5}$	5 µg m^{-3} (mean annual concentration) 15 µg m^{-3}(mean 24-hour concentration)	-
PM_{10}	15 µg m^{-3}(mean annual concentration) 45 µg m^{-3}(mean 24-hour concentration)	60 µg m^{-3} (mean annual concentration) 150 µg m^{-3} (mean 24-hour concentration)

Quality Assurance/Quality Control (QA/QC) Details of Instrument 9-in-1 Multifunctional air quality detector WP6932:
Ensure high precision sensors such as Non-dispersive infrared (NDIR) for CO_2 and laser diffusion technology (LDT) PM_{10} and $PM_{2.5}$ particle detection. Both NDIR and LDT are precise and stable and provides accurate and stable real-time readings on the device's screen. Key quality control aspects include sensor sensitivity, fast data refresh rates (1 – 2 seconds), error free monitoring through advanced algorithms, easy to read display and calibration functions. Built-in calibration functions allow users to easily reset and re-calibrate sensors, thereby maintaining accuracy over time.

Solar power meter SM206: A precision instrument for measuring light intensity. It is used in solar radiation measurement, solar research and meteorology. It has a selectable two units (W/m^2 and Btu). Measures directly without adjustment and steadily measures for a long period. It has an accuracy of ±5 %.

PG03 Mini compass handheld GPS: This provides direction and distance to the destination. It provides longitude, latitude and altitude information. It can automatically save the date and time on the screen. It can also return the target position.

Figure 2: PG03 Mini Compass Handheld GPS

Figure 3: Solar Power Meter SM206

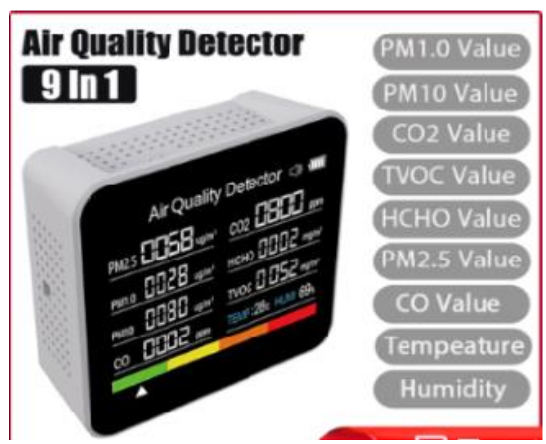


Figure 4: 9-in-1 Multifunctional Air Quality Detector WP6932

Air Quality and Meteorological Data Collection
Data collection period is short (August - November) as this is a pilot research in Sokoto. The period falls within the end of rainy season and the onset of dry season. The concentrations of four pollutants (CO_2, CO, $PM_{2.5}$ and PM_{10}) and two meteorological parameters (solar radiation and temperature) were monitored every ten (10) minutes daily, from 12 hours

(local time) to 15 hours (local time),across the three stations in Sokoto metropolis from August to October 2024 using the handheld metres in Table 3 below.

Table 3: Equipment and the parameters measured

Equipment	Manufacturer	Quantity	Parameter to be measured	Range (Unit)
9-in-1 Multifunctional Air Quality Detector	VSON Technology Co., Ltd,, Guangdong, China	3	CO CO_2 $PM_{2.5}$ PM_{10} Temperature	0 – 999 (ppm) 0 – 5,000 (ppm) 0 – 999 (μg/m^3) 0 – 999 (μg/m^3) 0 – 50 (^{o}C)
Solar Power Meter SM206	Shenzhen Sanpo Instrument Co., Ltd., Shenzhen, China	1	Solar Radiation	0.1– 3999 (W/m^2)
PG03 Mini Compass Handheld GPS	Shenzhen Kingbek Electronic Technology Co., Ltd., Guangdong, China	1	Position (Long/Lat)	Not Applicable

DATA ANALYSIS

Daily mean of the data collected were calculated using Statistical Package for the Social Sciences (SPSS) softwareand it was used to run the other analysis.Statistical (p-value of 0.05) and data analysis such as creating a model equation combining the parameters, correlation and trend analysis was employed to analyze the trends of each parameter and then compare same with the trend of temperature. Regression coefficient (R) is specific to the units of the variables and the context of the model, holding other independent variables constant. Coefficient of determination (R^2) this shows the proportion of the variance in the dependent variables that is explained by the independent variables in a regression model. It is a value between 0 and 1 (or 0 % and 100 %) where a higher value shows a better fit of the model to the data, meaning the model accounts for more of the outcome's variability. Standard error of the estimate quantifies the variability of sample means and can be used to construct confidence intervals to provide a range of likely values for the true population mean. Low SE means the sample mean are closely clustered around the population mean, suggesting that the specific sample mean is a reliable estimate. High SE shows that the sample mean are widely spread, making it less likely that the sample mean is close to the population mean.

Spearman Correlation Equation was used to rank the relationship of each parameter using the formula

$$r_s = 1 - \frac{6(\sum d_i^2)}{n(n^2-1)} \qquad (1)$$

Where *n* is the number of cases and *d* is the difference between the rankings of the two variables. If there are no rank ties, this equation can also be used to calculate the Spearman correlation. If we have a coefficient between -1 and less than 0, there is a negative correlation, that is, a negative relationship between the variables. If we have a coefficient greater than 0 and less than 1, there is a positive correlation, that is, a positive relationship between the two variables. If the result is 0, there is no correlation.

Also, the relationship between temperature and other parameters will also be explored.

RESULTS AND DISCUSSION

Relationship of the Air Pollutants and Temperature in each Site

Table 4: Spearman's correlation (r_s) matrix table for temperature and air pollutants

Parameter	Temperature	$PM_{2.5}$	PM_{10}	CO	CO_2
	Mahuta Abattoir				
Temperature	1.000	0.132	-0.119	0.270**	-0.219*
$PM_{2.5}$	0.132	1.000	0.628**	0.361**	-0.089
PM_{10}	-0.119	0.628**	1.000	0.353**	0.057
CO	0.270**	0.361**	0.353**	1.000	-0.004
CO_2	-0.219*	-0.089	0.057	-0.004	1.000

	Hajiya Halima Phone Service Complex				
Temperature	1.000	0.100	-0.202	0.136	0.347**
$PM_{2.5}$	0.100	1.000	0.227*	0.137	0.092
PM_{10}	-0.202	0.227*	1.000	0.153	-0.066
CO	0.136	0.137	0.153	1.000	0.099
CO_2	0.347**	0.092	-0.066	0.099	1.000
	Sokoto Main Motor Park				
Temperature	1.000	0.207*	-0.099	0.137	0.626**
$PM_{2.5}$	0.207*	1.000	0.545**	0.345**	0.260*
PM_{10}	-0.099	0.545**	1.000	0.320**	-0.046
CO	0.137	0.345**	0.320**	1.000	0.207*
CO_2	0.626**	0.260*	-0.046	0.207*	1.000

** Correlation is significant at the 0.01 level (2-tailed)
* Correlation is significant at the 0.05 level (2-tailed)

Figure 4 shows the Spearman's correlation matrix for temperature and air pollutants in the three stations under consideration. At Mahuta abattoir, negative correlation can be seen between the following pairs of variables: temperature and PM_{10}, temperature and CO_2, $PM_{2.5}$ and CO_2, CO and CO_2. All these individual pairs have inverse relationships. The other pairs have direct relationships. The most positively correlated pair in this station has 62.8 % ($PM_{2.5}$– PM_{10} pair) correlation.

At Hajiya Halima and Main Park, negative correlation can be seen in the following pairs: temperature and PM_{10} and PM_{10} and CO_2. Other pairs are related by direct proportionality. The most positively correlated pair in these stations has 34.7 % and 62.6 % (temperature– CO_2 pair) correlation, respectively. This statement suggests that these two stations have similar source(s) of pollution. It also supports the widely reported link between CO_2 and global warming.

Monthly Mean Values of the Air Pollutants and Meteorological Parameters in each Site

Table 5: Meteorological parameters and pollutants average monthly data

Monthly mean	**Sample size (n)**	**August**	**September**	**October**	**Average value**
		Mahuta Abattoir			
Temperature (°C)	92	35.69	41.78	41.13	39.53
Solar radiation (Wm^{-2})	92	515.53	621.67	950.95	696.06
$PM_{2.5}$ ($\mu g\ m^{-3}$)	92	461.96	460.04	529.63	483.88
PM_{10} ($\mu g\ m^{-3}$)	92	549.73	513.74	530.01	531.16
CO (ppm)	92	213.29	251.49	253.84	239.54
CO_2 (ppm)	92	1405.62	1343.28	1283.66	1344.19
		Hajiya Halima Phone Service Complex			
Temperature (°C)	92	35.45	41.30	40.81	39.19
Solar radiation (Wm^{-2})	92	515.54	621.68	950.95	696.06
$PM_{2.5}$ ($\mu g\ m^{-3}$)	92	473.03	505.31	485.02	487.79
PM_{10} ($\mu g\ m^{-3}$)	92	595.91	588.80	544.01	576.24
CO (ppm)	92	232.92	266.42	257.91	252.42
CO_2 (ppm)	92	1761.70	1950.49	1895.65	1869.28
		Sokoto Main Motor Park			
Temperature (°C)	92	36.15	41.33	40.88	39.45
Solar radiation (Wm^{-2})	92	515.54	621.68	950.95	696.06
$PM_{2.5}$ ($\mu g\ m^{-3}$)	92	446.46	484.15	538.33	489.65
PM_{10} ($\mu g\ m^{-3}$)	92	542.42	544.43	554.99	547.28
CO (ppm)	92	241.27	274.31	288.65	268.08
CO_2 (ppm)	92	1152.61	1945.37	2124.15	1740.71

Table 5 shows the average monthly values of each meteorological parameters and pollutants over the study areas. At all the sites under consideration, the lowest average temperature was recorded in August while the highest was recorded in September. August is the month with the highest rainfall in Sokoto, lower temperatures may be expected. From September, the rain reduces drastically. Solar radiation data varies from low (during the rainy months) to high during the transition month of October.

The result from Table 4 shows that the monthly average $PM_{2.5}$ and PM_{10} concentrations for the study period is in excess of the WHO 24-hour guideline by approximately 30 and 11 folds, respectively. The average PM_{10} concentrations for the study period is in excess of the NESREA 24-hour guideline by approximately three (3) folds.This may be connected tothe dry dusty north-easterly trade wind that comes with harmattan (dusty and cold period). It can also be seen that the average $PM_{2.5}$ values are less than those of PM_{10} in all the three stations.

Also, the Table shows that the monthly3-hour average COand CO_2 concentration for the study period exceedsthe WHO 24-hour guideline by 3 and 1.3 folds, respectively.This may not be unconnected to the increasingpopulation density as well as the increasing vehicular traffic observed in the three stations. The NESREA 8-hour guidelineis greater than the average COconcentrations for the study period by approximately 18 folds.This shows that the CO pollution is within a safe limit with regards to the national guidelines.

Furthermore, the Table displayed the monthly average values of solar radiation and temperature for the study period. It can be observed that both meteorological parameters has a direct relationship (i.e., as solar radiation increases, the temperature also increases). Changes in ambient temperature influences convection in the atmosphere, which also influences concentration of air pollutants. The ambient temperature recorded at thestudy areas varies from 32.54°C (low) to 49.68°C (high) with a cumulative average value of 39.39°C. September had the highest mean temperature of 41.49ºC while the lowest was recorded in August (35.76°C) for the study period.

At Mahuta abattoir, the concentration of the averaged $PM_{2.5}$ and PM_{10} has the highest value in August (461.96 μg m^{-3} and 549.73 μg m^{-3}, respectively) and the lowest in October (460.04 μg m^{-3} and 513.74 μg m^{-3}, respectively). The increase in the value of PM during rainy months may be as a result of more aerosols (including water vapour) in the atmosphere. CO increases from August (213.29 ppm) to October (253.84 ppm) while CO_2 decreases from August (1405.62 ppm) to October (1343.28 ppm). The observed behavior of both CO and CO_2 may be because only CO_2 can be washed off the atmosphere by rain and the hygroscopicity of CO.

At Hajiya Halima phone service complex, the concentration of the average $PM_{2.5}$ have its lowest value in August (473.03 μg m^{-3}) and highest in September (505.31 μg m^{-3}). PM_{10} has the highest value in August (595.91 μg m^{-3}) and the lowest in October (544.01 μg m^{-3}). CO and CO_2 increases from August (232.92 ppm and 1761.70 ppm, respectively) to its highest value in September (266.42 ppm and 1950.49 ppm, respectively). The observed behavior of both CO and CO_2 may be because this site is covered with canopies and roofing sheets.

At Sokoto main motor park, the concentration of the averaged $PM_{2.5}$ and PM_{10} has the highest value in August (446.46 μg m^{-3} and 542.42 μg m^{-3}, respectively) and the lowest in October (538.33 μg m^{-3} and 554.99 μg m^{-3}, respectively). CO and CO_2 increases from August (241.27 ppm and 1152.61 ppm, respectively) to its highest value in September (288.65 ppm and 2124.15 ppm, respectively). The observed behavior of both CO and CO_2 may be because this site is an open space with expected rapid changes in the concentration of air pollutants as a result of rapid air movement.

Table 5 also shows that the highest mean temperature value was recorded at Mahuta abattoir (39.53 ºC) and lowest was observed at Hajiya Halima phone service complex (39.19 ºC). The high values of mean temperature observed in the abattoir may be as a result of the heat being generated by the burning activities going on around the area whereas that for the main motor park may be as a result of the heat being generated when shortwave radiation is converted to longwave radiation.

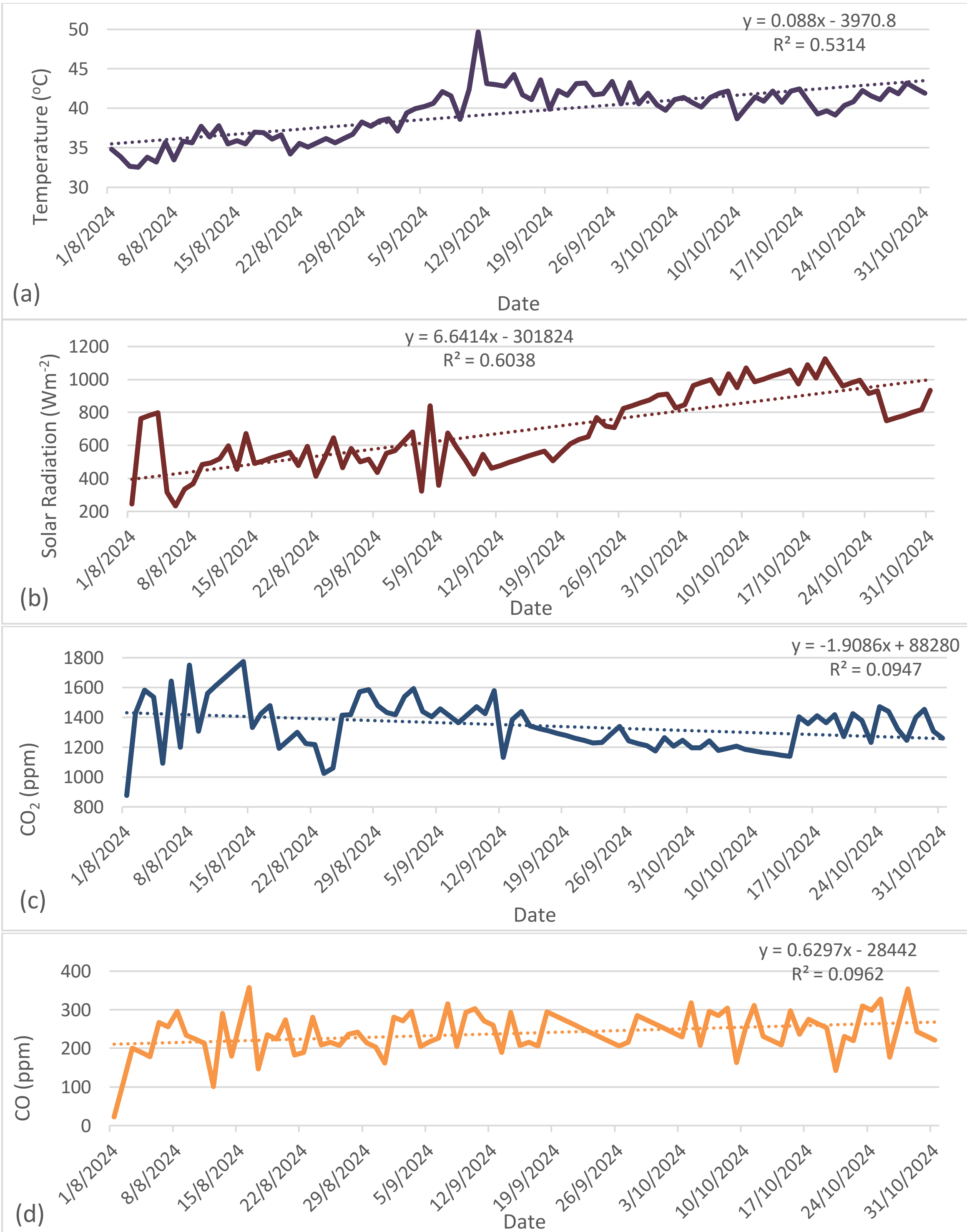
It can also be seen in Table 5 that the lowest mean $PM_{2.5}$ value was recorded at Mahuta abattoir (483.88 μg m^{-3}) and highest was observed at Sokoto main motor park (489.65 μg m^{-3}). This high values of mean $PM_{2.5}$ observed in the main park may be as a result of the fine mode aerosols being generated from the exhaust of moving automobiles around the area whereas that for the phone service complex may be as a result of the wide use of electricity generating sets when there is no power from the national grid.

The mean PM_{10} value was shown in Table 5 to have the highest value at the phone service complex (576.24 μg m^{-3}) and the lowest at the abattoir (531.16 μg m^{-3}). These observations may be as a result of the presence of more number of coarse mode aerosols at the phone service complex.

Table 5 also contains information the mean concentration of CO. Its lowest mean value was recorded at Mahuta (239.54 ppm) and the highest was in the Main motor park (268.08 ppm). Explanation here is that there should be more CO wherever there are more number of fine mode aerosols i.e., exhaust from automobile.

Also, the mean value of CO_2 has the lowest value at Mahuta (1344.19 ppm) and the highest at the Phone service complex (1869.28 ppm). The observed value at the phone service complex is expected because the site is an enclosure and crowded, too.

Variation of Air Pollutants Concentrations and Meteorological Parameters Mahuta Abattoir



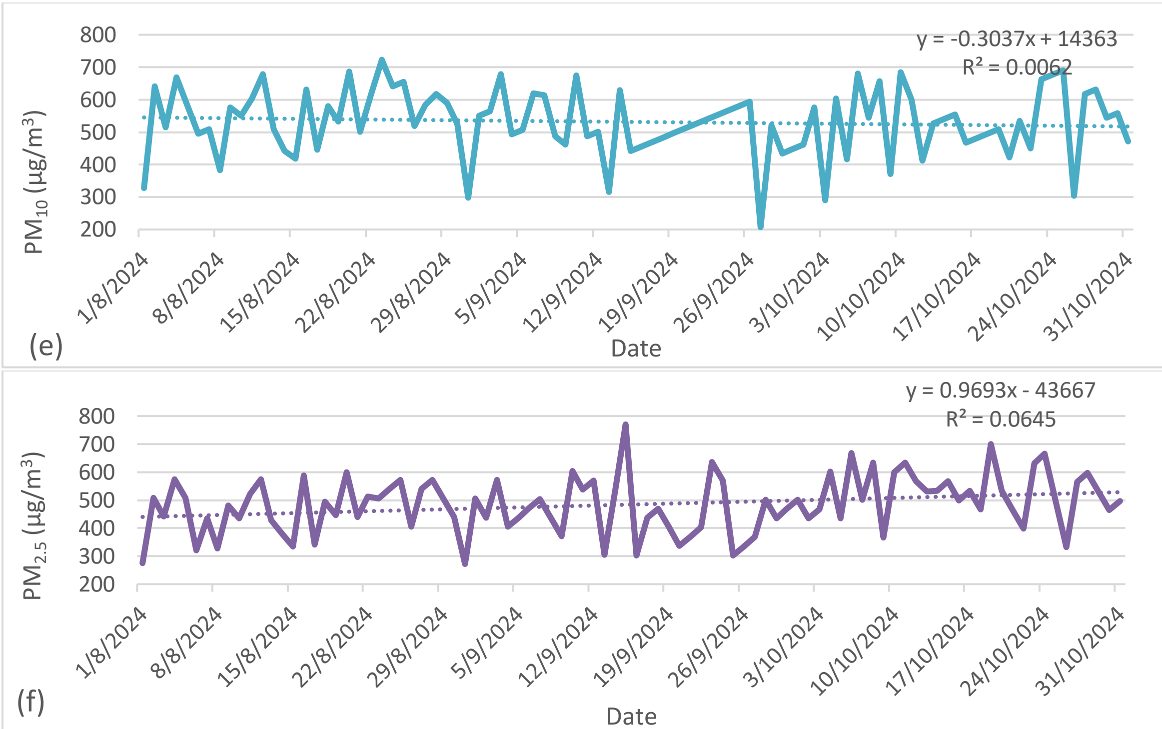


Figure 5: *The variation, at Mahuta abattoir, of the (a) average ambient temperature over the period of study; (b) average Solar radiation over the period of study; (c) average CO_2 concentration over the period of study; (d) average CO concentration over the period of study; (e) average PM_{10} concentration over the period of study; (f) average $PM_{2.5}$ concentration over the period of study.*

Figure 5(a) shows the variation of the average ambient temperature over the period of study around the vicinity where hyde is being burnt. It can be seen that the highest and lowest temperature in this place over this period of study is 49.68ºC (11th September, 2024) and 32.55ºC (4th August, 2024) respectively. The temperature is lower in august than other months because August is the peak of rainy season in Sokoto town. It can also be seen that the temperature here has an increasing trend (0.088ºC day^{-1}).

Figure 5(b) shows the variation of the average solar radiation over the period of study around the vicinity where hyde is being burnt. It can be seen that the highest and lowest solar radiation in this place over this period of study is 1125.94 Wm^{-2} (19th October, 2024) and 233.27 Wm^{-2} (6th August, 2024) respectively. The Solar radiation is lower in august and early September than other months because August is the peak of rainy season in Sokoto town and there will be more cloud cover and by extension upward reflection during this period. It can also be seen that the solar radiation has an increasing trend (6.641 Wm^{-2} day^{-1}).

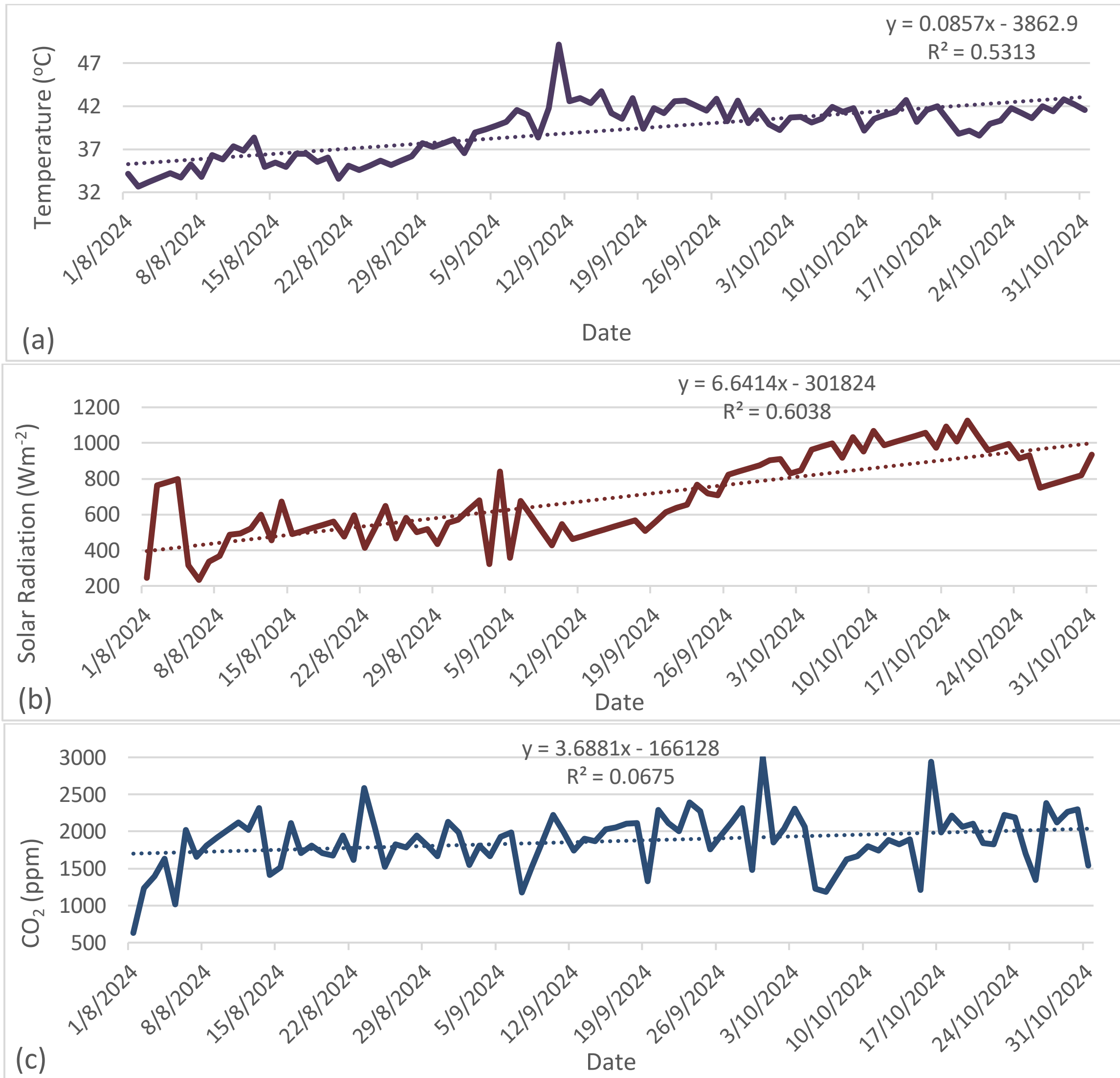
Figure 5(c) shows the variation of the average CO_2 concentration over the period of study around the vicinity where hyde is being burnt. It can be seen that the highest and lowest CO_2 concentration recorded in this place over this period of study is 1774.42 ppm (14th August, 2024) and 876.53 ppm (1st August, 2024) respectively. The CO_2 is higher in August and early September than other months because August is the peak of rainy season in Sokoto town. It can also be seen that the CO_2concentration has a decreasing trend (-1.909 ppm day^{-1}).

Figure 5(d) shows the variation of the average CO concentration over the period of study around the vicinity where hyde is being burnt. It is bimodal in nature. It can be seen that the highest and lowest CO concentration recorded in this place over this period of study is 357.42 ppm (16th August, 2024) and 22.42 ppm (1st August, 2024) respectively. The CO is lower in August and early September than other months because of the wet deposition during the peak of rainy season. It can also be seen that the CO concentration has an increasing trend (0.630 ppm day^{-1}).

Figure 5(e) shows the variation of the average PM_{10} concentration over the period of study around Mahuta abattoir. It can be seen that the highest and lowest PM_{10} concentration recorded in this place over this period of study is 722.82 µg/m^3 (23rd August, 2024) and 207.11 µg/m^3 (27th September, 2024) respectively. The PM_{10} is higher in August and early September than other months because fine mode aerosols are predominant during rainy season. It can also be seen that the PM_{10} has a decreasing trend (-0.304 µg/m^3 day^{-1}). The negative trend in the concentration of PM_{10} at Mahuta abattoir could be due to the low amount of desert dust during this period.

Figure 5(f) shows the variation of the average $PM_{2.5}$ concentration over the period of study around Mahuta abattoir. It can be seen that the highest and lowest $PM_{2.5}$ concentration recorded in this place over this period of study is 770.11 μg/m^3 (15th September, 2024) and 271.95 μg/m^3 (31st August, 2024) respectively. The $PM_{2.5}$ is lower in August and early September than other months because of wet deposition. It can also be seen that the $PM_{2.5}$ has an increasing trend (0.969 μg/m^3 day^{-1}). The positive trend in the concentration of $PM_{2.5}$ at this site may be attributed to burning of biomass, which are a major source of soot that inevitably result in high concentrations of $PM_{2.5}$ in the atmosphere.

Hajiya Halima Phone Service Complex



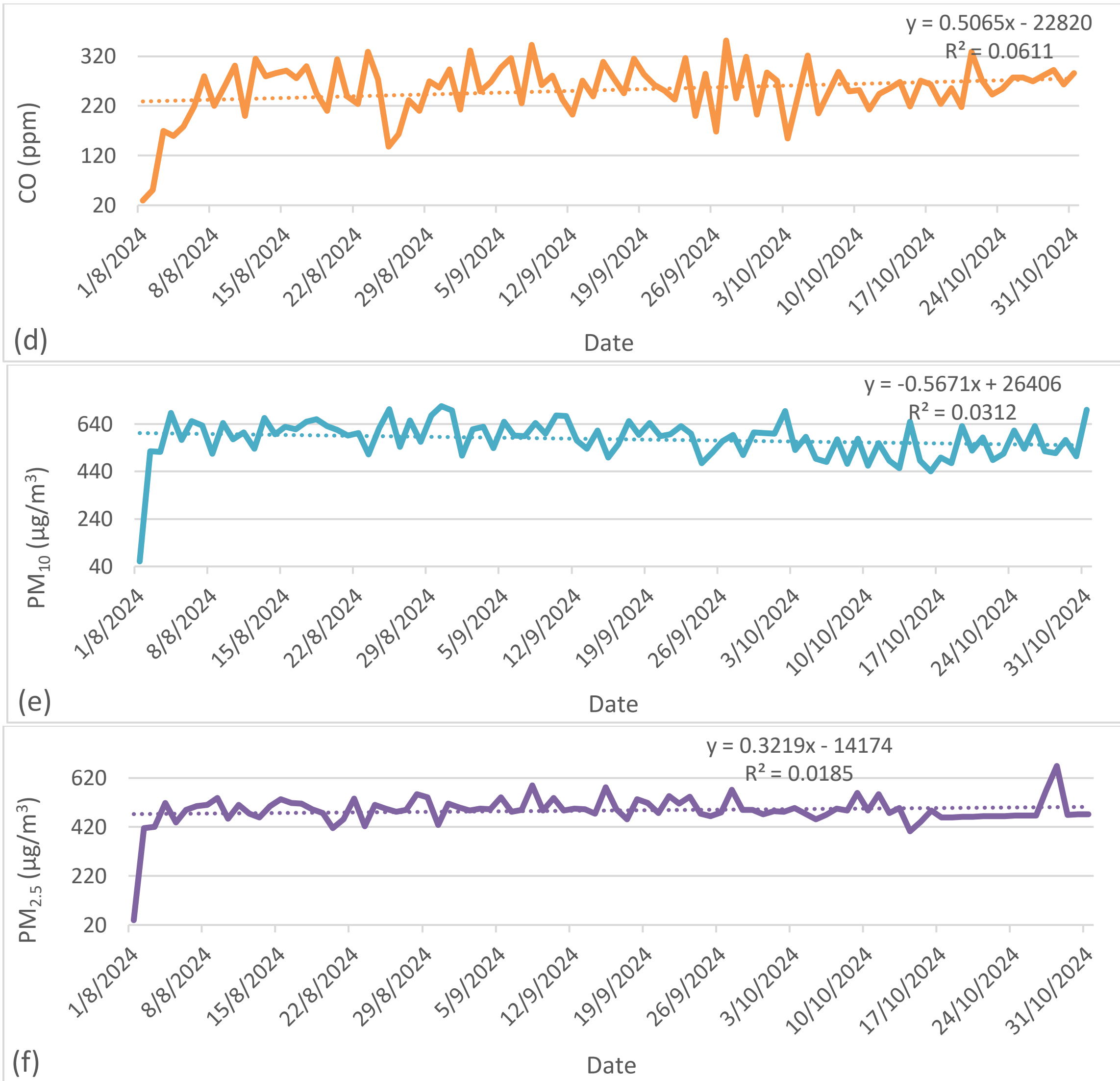


Figure 6: *The variation, at Hajiya Halima Phone Service Complex, of the (a) average ambient temperature over the period of study; (b) average Solar radiation over the period of study; (c) average CO_2 concentration over the period of study; (d) average CO concentration over the period of study; (e) average PM_{10} concentration over the period of study; (f) average $PM_{2.5}$ concentration over the period of study.*

Figure 6(a) shows the variation of the average ambient temperature over the period of study around the vicinity where electricity generating set is being used. It can be seen that the highest and lowest temperature in this place over the period of study is 49.15°C (11th September, 2024) and 32.65°C (2nd August, 2024) respectively. The temperature is lower in august than other months because August is the peak of rainy season in Sokoto town. It can also be seen that the temperature here has an increasing trend (0.086°C day^{-1}).

Figure 6(b) shows the variation of the average solar radiation over the period of study around this vicinity. It can be seen that the highest and lowest solar radiation in this place over this period of study is 1125.94 Wm^{-2} (19th October, 2024) and 233.27 Wm^{-2} (6th August, 2024) respectively. The Solar radiation is lower in august and early September than other months because August is the peak of rainy season in Sokoto town and there will be more cloud cover and by extension upward reflection during this period. It can also be seen that the solar radiation has an increasing trend (6.641 Wm^{-2} day^{-1}).

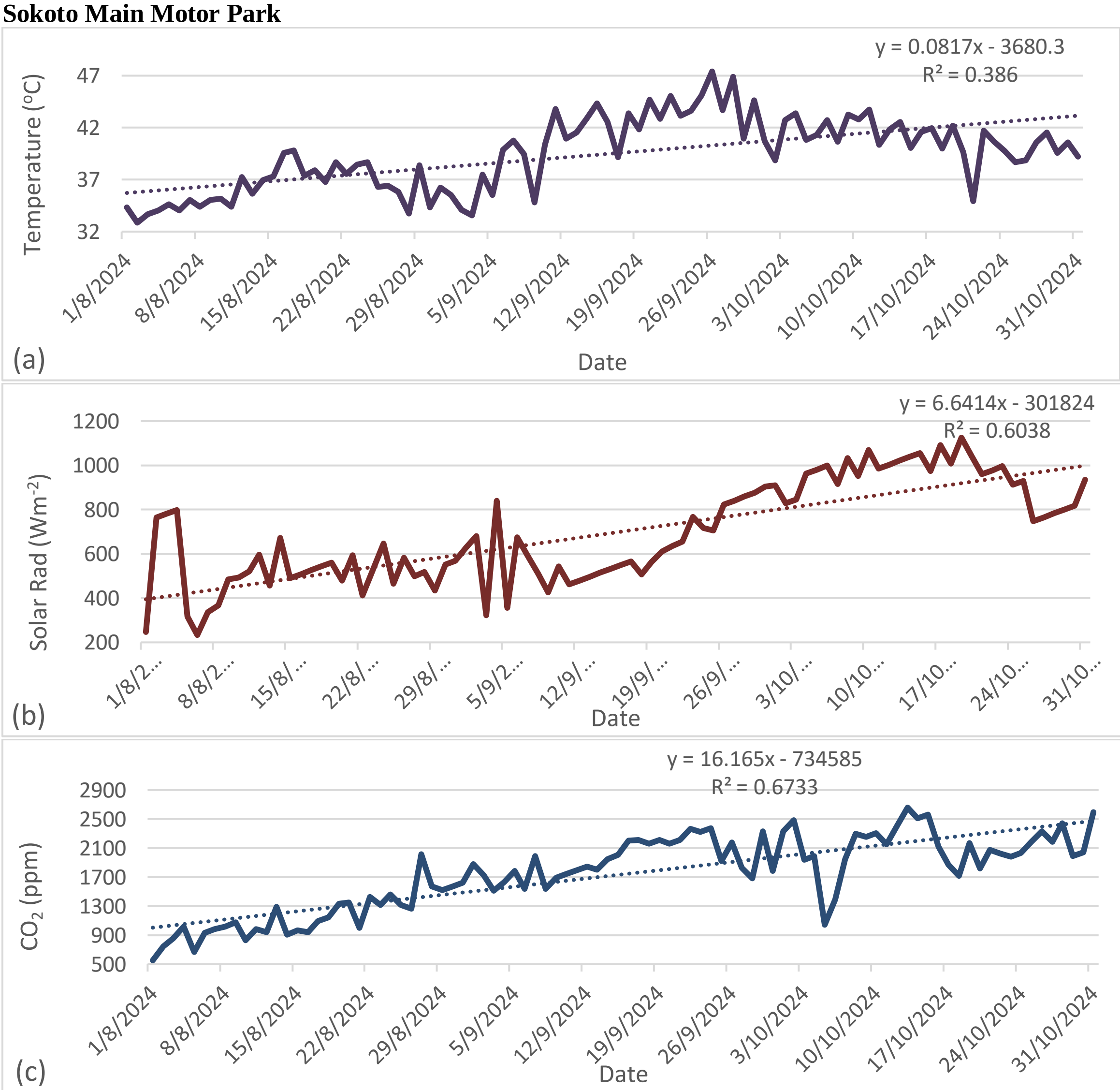
Figure 6(c) shows the variation of the average CO_2 concentration over the period of study around this vicinity. It is bimodal in nature. It can be seen that the highest and lowest CO_2 concentration recorded in this place over this period of study is 3002.21 ppm (30th September, 2024) and 630.63 ppm (1st August, 2024) respectively. The CO_2 is lower in August and early September than other months because wet deposition. It can also be seen that the CO_2concentration has an increasing trend (3.688 ppm day^{-1}).

Figure 6(d) shows the variation of the average CO concentration over the period of study around this vicinity. It can be seen that the highest and lowest CO concentration recorded in this place over this period of study is 351.97 ppm (27th September, 2024) and 29.58 ppm (1st August, 2024) respectively. The CO is lower in August and early September than other months because of the wet deposition during the peak of rainy season. It can also be seen that the CO concentration has an increasing trend (0.507 ppm day^{-1}).

Figure 6(e) shows the variation of the average PM_{10} concentration over the period of study around this vicinity. It can be seen that the highest and lowest PM_{10} concentration recorded in this place over this period of study is 715.57 μg/m^3 (30th August, 2024) and 61.11 μg/m^3 (1st August, 2024) respectively. The PM_{10} is higher in August and early September than other months because fine mode aerosols are predominant during rainy season. It can also be seen that the PM_{10}concentration has a decreasing trend (-0.567 μg/m^3 day^{-1}).

Figure 6(f) shows the variation of the average $PM_{2.5}$ concentration over the period of study around this vicinity. It can be seen that the highest and lowest $PM_{2.5}$ concentration recorded in this place over this period of study is 669.46 μg/m^3 (28th October, 2024) and 39.53 μg/m^3 (1st August, 2024) respectively. The $PM_{2.5}$ is lower in August and early September than other months because of wet deposition. It can also be seen that the $PM_{2.5}$concentration has an increasing trend (0.322 μg/m^3 day^{-1}).

Sokoto Main Motor Park



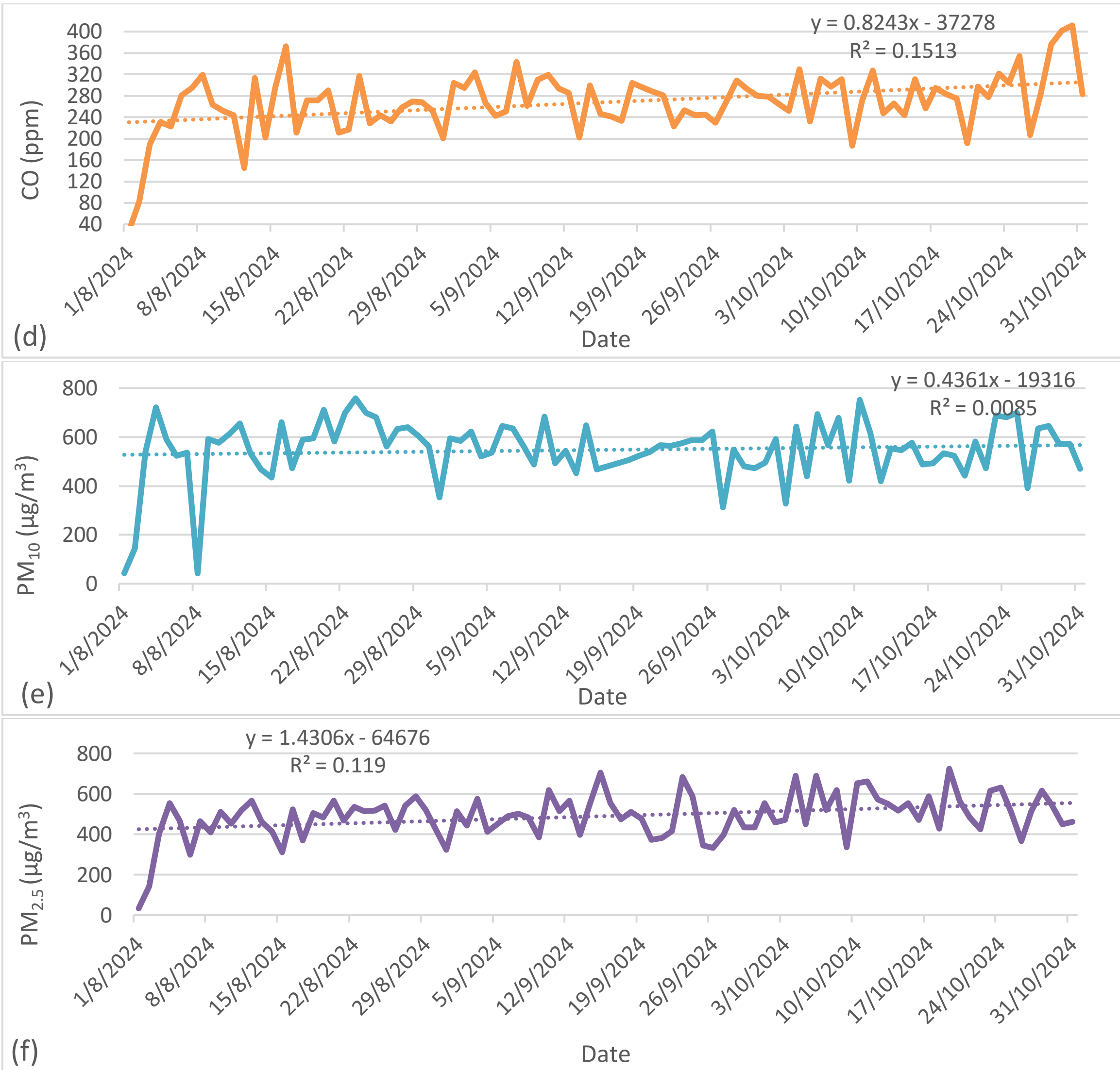


Figure 7: *The variation, at Sokoto Main Motor Park, of the (a) average ambient temperature over the period of study; (b) average Solar radiation over the period of study; (c) average CO_2 concentration over the period of study; (d) average CO concentration over the period of study; (e) average PM_{10} concentration over the period of study; (f) average $PM_{2.5}$ concentration over the period of study.*

Figure 7(a) shows the variation of the average ambient temperature over the period of study around the vicinity where there is heavy traffic. It can be seen that the highest and lowest temperature in this place over the period of study is 47.41°C (26th September, 2024) and 32.86°C (2nd August, 2024) respectively. The temperature is lower in August than other months because August is the peak of rainy season in Sokoto town. It can also be seen that the temperature here has an increasing trend (0.082°C day^{-1}).

Figure 7(b) shows the variation of the average solar radiation over the period of study around this vicinity. It can be seen that the highest and lowest solar radiation in this place over this period of study is 1125.94 Wm^{-2} (19th October, 2024) and 233.27 Wm^{-2} (6th August, 2024) respectively. The Solar radiation is lower in august and early September than other months because August is the peak of rainy season in Sokoto town and there will be more cloud cover and by extension upward reflection during this period. It can also be seen that the solar radiation has an increasing trend (6.641 Wm^{-2} day^{-1}).

Figure 7(c) shows the variation of the average CO_2 concentration over the period of study around this vicinity. It is bimodal in nature. It can be seen that the highest and lowest CO_2 concentration recorded in this place over this period of study is 3658.72 ppm (13th September, 2024) and 552.90 ppm (1st August, 2024) respectively. The CO_2 is lower in August and early September than other months because wet deposition. It can also be seen that the CO_2concentration has an increasing trend (16.165 ppm day^{-1}).

Figure 7(d) shows the variation of the average CO concentration over the period of study around this vicinity. It can be seen that the highest and lowest CO concentration recorded in this place over this period of study is 411.53 ppm (30th October, 2024) and 27.63 ppm (1st August, 2024) respectively. The CO is lower in August and early September than other months because of the wet deposition during the peak of rainy season. It can also be seen that the CO concentration has an increasing trend (0.824 ppm day^{-1}).

Figure 7(e) shows the variation of the average PM_{10} concentration over the period of study around this vicinity. It has a bimodal feature. It can be seen that the highest and lowest PM_{10} concentration recorded in this place over this period of study is 758.78 $\mu g/m^3$ (23rd August, 2024) and 41.79 $\mu g/m^3$ (8th August, 2024) respectively. The PM_{10} is higher in August and early September than other months because fine mode aerosols are predominant during rainy season. It can also be seen that the PM_{10} has an increasing trend (0.436 $\mu g/m^3$ day^{-1}). The positive trend of the concentration of PM_{10} at this site can be attributed to the presence of desert dust in this area thereby elevating the concentrations of PM_{10} in the atmosphere.

Figure 7(f) shows the variation of the average $PM_{2.5}$ concentration over the period of study around this vicinity. It can be seen that the highest and lowest $PM_{2.5}$ concentration recorded in this place over this period of study is 723.98 $\mu g/m^3$ (19th October, 2024) and 33.42 $\mu g/m^3$ (1st August, 2024) respectively. The $PM_{2.5}$ is lower in August and early September than other months because of wet deposition. It can also be seen that the $PM_{2.5}$concentration has an increasing trend (1.431 $\mu g/m^3$ day^{-1}).

Modeling of the Air Pollutants and Meteorological Parameters in each Site

Table 6: Meteorological parameters and pollutants multiple regression model equation

Description	Regression coefficient (R)	Coefficient of determination (R^2)	Standard error (SE) of the estimate	Model Equation
Mahuta Abattoir	0.559	0.313	2.750	$T = 39.186 + 0.005PM_{2.5} - 0.011PM_{10} + 0.021CO - 0.003CO_2 + 0.004Solar\_Rad$
Hajiya Halima Complex	0.512	0.263	2.941	$T = 29.558 + 0.011PM_{2.5} - 0.008PM_{10} + 0.008CO + 0.002CO_2 + 0.004Solar\_Rad$
Sokoto Main Motor Park	0.709	0.503	2.777	$T = 29.603 - 0.001PM_{2.5} - 0.001PM_{10} + 0.004CO + 0.004CO_2 + 0.005Solar\_Rad$

Table 6 shows the multiple linear regression details of the model equation of each station for the period under review.

The R-value for Mahuta is 0.559 and it indicates that the change in temperature due to a single unit change in a specific independent variable when other independent variables in the model are held constant. Those for Hajiya Halima and the motor park are 0.512 and 0.709, respectively. This indicates the changes in temperature due to a single unit change in a specific independent variable when other independent variables in the model are held constant in the two stations respectively.

The R^2 value of 0.313 at Mahuta shows that 31.3 % of the variation in temperature is explained by the independent variables in the model. The remaining 68.7 % is due to factors not accounted for by the model. Those for Hajiya Halima and the motor park are 0.263 and 0.503, respectively. This indicate that 26.3 % and 50.3 %of the variations in temperature in the two stationscan only be explained by the independent variables in the model for the two station, respectively.

The low SE (2.750, 2.941 and 2.777, respectively) in the three stations show that the sample means of each station is closely clustered around the respective population mean, which suggest that each specific sample mean is a reliable estimate.

It can be deduced that all the model equations are good. Ranking-wise, the model equation for the motor park is the best, and is closely followed by that of Mahuta abattoir.

CONCLUSION

During August–October 2024 at three urban sites in Sokoto (Motor Park, Hajiya Halima phone complex, Mahuta abattoir) we observed monthly mean $PM_{2.5}$, PM_{10}, CO and CO_2 that exceed WHO guideline values by a significant order of magnitude at the sampled locations, with the motor-park($PM_{2.5}$ 538.33 $\mu g/m^3$ (489.65$\mu g/m^3$); PM_{10} 595.91 $\mu g/m^3$ (547.28$\mu g/m^3$), CO 288.65 ppm (268.08 ppm), CO_2 2124.15 ppm (1740.71 ppm)) and phone-complex($PM_{2.5}$ 505.31 $\mu g/m^3$ (487.79 $\mu g/m^3$); PM_{10} 595.91 $\mu g/m^3$ (571.24 $\mu g/m^3$), CO 266.42 ppm (252.42 ppm), $CO_2$1950.49 ppm (1869.28 ppm)) areas having the largest concentrations(monthly mean). Complete field data collection for the period under review was achieved as there are no missing or data values exceeding the ranges of our data collection instruments.It was also noted that all the parametershave an increasing trend, the highest trend of temperature (slope = 0.088 ^{o}C/day, r_s = positive) was noted at Mahuta abattoir; the highest trend of CO_2(slope =16.165 ppm/day, r_s = positive) was noted at Sokoto motor park; the highest trend of CO (slope =0.8243 ppm/day, r_s = positive) was noted at Sokoto motor park; the highest trend of PM_{10} (slope =0.4361μg/m^3/day, r_s = positive) was noted at Sokoto motor park; the highest rend of $PM_{2.5}$ (slope =1.4306 μg/m^3/day, r_s = positive) was noted at Sokoto motor park.These result shows that the most polluted station is the Sokoto motor park. Results reflects late-rainy to early-dry season findings (August - October): all year-round monitoring is required for annual exposure estimates.Werecommend the immediate enforcement of electricity generator and vehicular emissions control and prohibition of open burning near crowded places. Medium-term deployment of low-cost reference monitors at different air pollution hotspots and a seasonal monitoring campaign coupled with PM chemical speciation to enable source-specific mitigation.The future studies should include the characterization of air pollutants over major parts of Sokoto to further understand the origins of aerosols and their impact so that the efforts on its mitigation can be focused on the sources.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

ACKNOWLEDGEMENT

This study was funded by the Institutional Based Research (IBR) of the Tertiary Education Trust Fund (TETFund) and supported by the Directorate of Research, Development and Innovation (DRD&I), Usmanu Danfodiyo University Sokoto, Sokoto, Nigeria. We are indebted to everyone at TETFund and DRD & I for the conceptualization and success of this research. The researchers acknowledge the contributions of the Atmospheric Physics Research group at Bayero University, Kano, under the leadership of Prof. B. I. Tijjani.

REFERENCES

Abdullahi, M. B., & Sharafa, S. B. (2017). Multivariable empirical equation for estimation of global Solar radiation in Sokoto Nigeria. *ATBU, Journal of Science, Technology & Education (JOSTE)*, *5*(3), 187–192.

Adedoja, O. S., Ayantunji, B. G., U.A., S., & S.S, J. (2015). Diurnal and seasonal variation of global Solar radiation at Anyigba, North-Central Nigeria. *International Journal of Engineering Science and Innovative Technology*, *4*(4), 140–145.

Akanji, A. R., Francis, M. O., & Akintola, A. F. (2024). Air Quality Trends and Pollution Analysis in Nigerian Cities Using Time Series Methods. *International Journal of Advanced Statistics and Probability*, *11*(2), 108–123.

Akpootu, D. O., Iliyasu, M. I., Olomiyesan, B. M., Fagbemi, S. A., Sharafa, S. B., Idris, M., … Meseke, N. O. (2022). Multivariate models for predicting global Solar radiation in Jos, Nigeria. *Matrix Science Mathematic (MSMK)*, *6*(1), 5–12. https://doi.org/10.26480/msmk.01.2022.05.12

Alexander, C. B., & Ajiboye, S. A. (2024). The impact of climate change on air pollution: A review of current evidence. *Pollution and Effects on Community Health*, *3*(1), 1–14. https://doi.org/10.58489/2836-3590/022

Dachung, G., Ndor, I. J., & Ekhuemelo, D. O. (2025). Climate change awareness, impacts, and adaptation measures among rural agroforestry farmers in Guma LGA, Benue State, Nigeria. *Journal of Basic and Applied Sciences Research (JOBASR)*, *3*(3), 294–307. https://doi.org/https://dx.doi.org/10.4314/jobasr.v3i3.31

Florides, G. A., & Christodoulides, P. (2017). Global warming and carbon dioxide through sciences. *Environment International*, *35*(2), 390–401. https://doi.org/10.1016/j.envint.2008.07.007

Gambo, J., Ahmed, A., Madaka, U. A., Abubakar, A., Yusuf, Y. A., Babura, B. S., & Muhammad, S. M. (2025). Community perceptions of climate change and its impact on the Baturiya Wetlands in Hadejia national park, Nigeria. *Journal of Basic and Applied Sciences Research (JOBASR)*, *3*(3), 331–341. https://doi.org/https://dx.doi.org/10.4314/jobasr.v3i3.34

Hilly, J. . J., Singh, K. R., Jagals, P., Mani, F. S., Turagabeci, A., Ashworth, M., … Dansie, A. P. (2024). Review of scientific research on air quality and environmental health risk and impact for PICTS. *Science of the Total Environment*, *942*, 1–14. https://doi.org/10.1016/j.scitotenv.2024.173628

IPCC. (2024). WMO air quality and climate bulletin. *Number 4*, 1–12.

Kabir, M., Habiba, U. E., Khan, W., Shah, A., Rahim, S., Rios-escalante, P. R. D. L., … Shafiq, M. (2023). Climate change due to increasing concentration of carbon dioxide and its impacts on environment in 21st century; a mini review. *Journal of King Saud University - Science*, *35*(5), 102693. https://doi.org/10.1016/j.jksus.2023.102693

Leão, M. L. P., Zhang, L., & Junior, F. M. R. da S. (2023). Effect of particulate matter (PM2.5 and PM10) on health indicators: climate change scenarios in a Brazilian metropolis. *Environmental Geochemistry and Health*, *45*(5), 2229–2240. https://doi.org/10.1007/s10653-022-01331-8

Madaniyazi, L., Alpízar, J., Cifuentes, L. A., Riojas-Rodríguez, H., Hurtado Díaz, M., de Sousa Zanotti Stagliorio Coelho, M., … Tobías, A. (2024). Health and economic benefits of complying with the World Health Organization air quality guidelines for particulate matter in nine major Latin American cities. *International Journal of Public Health*, *69*(May), 1–7. https://doi.org/10.3389/ijph.2024.1606909

Masoudi, M., & Gerami, S. (2018). Assessment of PM10 concentration and its prediction using meteorological parameters in the air of Isfahan, Iran. *Jordan Journal of Earth and Environmental Sciences*, *9*(2), 75–80.

Nelson, M., & Nelson, D. B. (2024). Decoupling CO2 from climate change. *International Journal of Geosciences*, *15*, 246–269. https://doi.org/10.4236/ijg.2024.153015

NESREA. National environmental (air quality control) regulations. , Regulation National Environmental Standards and Regulations Enforcement Agency § (2020).

Odat, S., & Alodat, M. T. (2017). The impact of weather parameters on atmospheric PM2.5. *Jordan Journal of Earth and Environmental Sciences*, *8*(1), 17–25.

Odubanjo, O. F., Falaiye, O. A., Orosun, M. M., & Sanni, M. (2024). Investigation of particulate matter Air Quality Index (AQI) and risk assessment in some locations in Nigeria. *Journal of the Nigerian Society of Physical Sciences*, *6*, 1–11. https://doi.org/DOI:10.46481/jnsps.2024.2120

Omokpariola, D. O., Nduka, J. N., & Omokpariola, P. L. (2024). Short-term trends of air quality and pollutant concentrations in Nigeria from 2018–2022 using tropospheric sentinel-5P and 3A/B satellite data. *Discover Applied Sciences*, *6*(4). https://doi.org/10.1007/s42452-024-05856-8

Pinho-Gomes, A. C., Roaf, E., Fuller, G., Fowler, D., Lewis, A., ApSimon, H., … Holgate, S. (2023). Air pollution and climate change. *The Lancet Planetary Health*, *7*(9), e727–e728. https://doi.org/10.1016/S2542-5196(23)00189-4

Soon, W., Baliunas, S. L., Robinson, A. B., & Robinson, Z. W. (1999). Environmental effects of increased atmospheric carbon dioxide. *Climate Research*, *13*, 149–164.

Tsai, I., Hsieh, P., Hsu, H., Tung, Y., Chen, Y., & Cheng, C. (2024). Climate change-induced impacts on PM 2 . 5 in Taiwan under 2 and 4 ◦C global warming. *Atmospheric Pollution Research*, *15*(6), 102106. https://doi.org/10.1016/j.apr.2024.102106

Vargas-Cuentas, N. I., Ramos-Cosi, S. J., & Roman-Gonzalez, A. (2021). Air quality analysis in Pasco Peru using remote sensing. *International Journal of Engineering Trends and Technology*, *69*(12), 30–38. https://doi.org/10.14445/22315381/IJETT-V69I12P205

WHO. (2021). *WHO global air quality guidelines*.

Yong Zha, Jay Gao, Jianjun Jiang, H. L. and J. H. (2010). Monitoring of urban air pollution from MODIS aerosol data: effect of meteorological parameters. *Series B Chemical and Physical Meteorology*, *62B*, 109–116. https://doi.org/10.1111/j.1600-0889.2010.00451.x

Zhou, M., Xie, Y., Wang, C., Shen, L., & Mauzerall, D. L. (2024). Impacts of current and climate induced changes in atmospheric stagnation on Indian. *Nature Communications*, *15*, 1–12. https://doi.org/10.1038/s41467-024-51462-y