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Meteorology and Air Quality Interactions: A Study of Selected Locations in Nigeria

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ABSTRACT

Nigeria faces significant challenges in managing air quality due to rapid urbanization, industrial growth, and increasing vehicular emissions. Meteorological parameters such as temperature, humidity, wind speed, atmospheric pressure, and rainfall influence pollutant concentrations and transport patterns. Understanding the impact of meteorological conditions on air quality is essential for designing effective pollution control strategies and forecasting air quality trends in Nigeria. This research was carried out to determine the impact of meteorology on particulate matter concentration in certain locations in Nigeria. The cities considered for the study include Anyingba, Kogi state, Ibadan, Oyo state, Benin, Edo state, Lekki, Lagos state and Kebi, Kebi state. The data covered a period of one year (April 2021 to April 2022). Results show that, for Oyo state, there was a poor negative correlation between temperature and $PM_{2.5}$. For humidity, the correlation coefficient was high, though negative. This shows that temperature had very little impact on the concentration of particulate matter in ambient air of Oyo state while humidity had a strong negative impact on the concentration of particulate matter in ambient air of Oyo. For Kogi state, there was a poor positive correlation between temperature and particulate matter ($PM_{2.5}$ and PM_{10}). For humidity, the correlation coefficient was high, though negative. This shows that temperature had very little impact on the concentration of particulate matter in ambient air of Kogi state while humidity had a strong negative impact on the concentration of particulate matter in ambient air of Kogi. For Edo state, there was a poor positive correlation between temperature and particulate matter ($PM_{2.5}$ and PM_{10}). For humidity, the correlation coefficient was also low and positive. This shows that temperature and humidity had very little impact on the concentration of particulate matter in ambient air of Edo state. For Lagos state, there was a poor positive correlation between temperature and particulate matter ($PM_{2.5}$ and PM_{10}). For humidity, the correlation coefficient was also low and positive. For Kebbi state, there was a poor positive correlation between temperature and particulate matter ($PM_{2.5}$ and PM_{10}). For humidity, the correlation coefficient was also low and positive.

Keywords:
Particulate matter,
Temperature,
Humidity,
Correlation,
Positive.

INTRODUCTION

Among the most important environmental issues facing the modern world is atmospheric pollution. Because of its detrimental effects, which include a decline in life quality and changes to the biosphere's characteristics, governments and international organizations are compelled to commit financial and human resources to improving air quality in order to safeguard the biosphere. (Karagiannidis et al., 2015). The brisk pace of urban construction and the consequent acceleration of urbanization have placed significant strain on the atmosphere. Air pollution is one outcome of the process that has raised concerns about people's health, particularly with regard to the fine specific matter ($PM_{2.5}$)(Li et al., 2017). $PM_{2.5}$ is the Particulate matter that has an aerodynamic diameter of smaller than 2.5 μm and is harmful to human health. In addition, $PM_{2.5}$ reduces air visibility. More people are affected by fine particulate matter ($PM_{2.5}$) than by any other pollutant, and it has been repeatedly linked to death and morbidity from respiratory and cardiovascular diseases. In the past ten years, epidemiological data have linked $PM_{2.5}$ to numerous other health outcomes, including neurological disorders (stroke, dementia, Alzheimer's disease, autism, Parkinson's disease), perinatal outcomes (premature birth and low birth weight), and cardio-metabolic diseases (diabetes, hypertension, metabolic syndrome). (Gutiérrez-Avila et al., 2022).

One of the major challenges in addressing air pollution and its impacts on air quality is the lack of sufficient monitoring stations, particularly in developing countries. In many developed nations, comprehensive air quality monitoring networks are in place to measure and report pollutant concentrations accurately. However, this is not the case in numerous developing countries where the infrastructure and resources for monitoring are limited (Milivojević et al., 2023). Air pollution levels are strongly dependent of the emission sources and meteorological conditions. If the regional atmospheric emissions are fairly stable in a particular period, meteorological circumstances may be the decisive factor for the occurrence of air pollution (Beringui et al., 2023). The local and synoptic weather conditions that are in effect at the moment are crucial. Determining the relationships between air quality and meteorology is essential and can assist policymakers in creating environmental policies that will enhance people's quality of life. (Karagiannidis et al., 2015). Several authors have researched on the impact of meteorology on particulate matter. Allabakash et al., (2022) demonstrated in the findings of their study conducted in South Korea that the generation, movement, and deposition of air pollutants were significantly influenced by meteorological factors. While PM10 levels peaked in April, PM2.5 levels peaked in January. Both were at their lowest levels in July. Further, PM2.5 was the highest during winter, followed by spring, autumn, and summer, whereas PM10 was the highest in spring followed by winter, autumn, and summer. PM concentrations were negatively linked with temperature, relative humidity, and precipitation. Air quality was inversely connected with wind speed, while PM was favorably and negatively correlated with the zonal and vertical wind components, respectively.

Tasci et al., (2018) carried out a research in Ankara, Turkey. Result shows that climatic (temperature, humidity, pressure levels, rain, etc.) and environmental factors (airborne particles, CO, NO, and NO_X) were found to be effective in the number of patients admitted to the hospital due to pneumonia.

Islam et al. (2015) carried out a research in Dhaka city on the impact of meteorology on air quality. The published results showed that there is a slight but positive connection between Particulate matter (PM) and wind speed from the northwest, signifying minimal dilution of PM with increased wind speed; The correlation between the coarse fraction of PM and incident solar radiation implies an increase in the formation of coarse nitrate particles due to enhanced photochemical activity; A strong negative correlation exists between PM and relative humidity, indicating that particulate matter may absorb moisture, aiding in settling and removal from suspension; There is a notable negative correlation between PM and temperature, suggesting that higher PM levels have the potential to lower atmospheric temperature due to its net negative radiative forcing.

In a study conducted by (Shihab, 2022), various climatic factors were examined, such as temperature, precipitation, relative humidity, wind speed and direction, as well as air pollutants like Particulate Matter with diameter less than or equal to 10µm (PM_{10}), Ozone (O_3), Nitrogen Oxide (NO), Nitrogen dioxide (NO_2), Sulfur dioxide (SO_2), Carbon Monoxide (CO), and Methane (CH_4). The research took place in Mosul, a city in northern Iraq. The results of the canonical correlation analysis indicated that temperature exhibited the strongest explanatory power when compared to other meteorological indicators.

In a study by Karagiannidis et al. (2014), the impact of Patras, Greece's weather on air pollution was assessed. This assessment relied on the analysis of pollution levels and meteorological factors, which were derived from the WRF numerical weather prediction model. The results suggest that on days with a deeper boundary layer, pollution from external sources affects summertime PM10 and CO levels. Enhanced local horizontal ventilation leads to decreased PM10 concentration. Finally, reduced local stagnation during summer days results in elevated O3 levels.

Using 4-year (2013-2016) monitoring data of air quality metrics from the Department of Environment (DoE)-led CASE project, (Islam et al., 2021) investigated the influence of meteorological circumstances on seasonal variation of particulate matter (PM) (both PM2.5 and PM10). The Continuous Air Monitoring Station (CAMS) at Darus-Salam, Dhaka, provides monthly data for a cross-correlation research between PM and meteorological factors. There are found to be inverse connections between PM and relative humidity, temperature, and rainfall. Seasonal cross-correlation research shows a lower relationship between PM10 and PM2.5 in the winter (December-February) and monsoon (June-September) seasons.

(Ganguly et al., 2020) assessed the impact of Kolkata, India's weather on air quality. Due to the low temperatures brought on by winter as well as the arrival of dry, cold winds from the Himalayas, which reduced mixing height by reducing vertical mixing, the findings showed a consistent positive relationship between temperature and pollutant concentrations in February. June shows weak positive associations, coinciding with the sudden arrival of humid air from the Bay of Bengal. Coagulation and deposition are the reasons behind this precipitation-induced decrease in particulate matter concentration. The somewhat positive correlation for humidity in February suggests that little emission is occurring. This research aims to analyze the interplay between meteorological variables and air pollutant levels for selected locations in Nigeria, focusing on how climatic variations impact pollutant concentration.

MATERIALS AND METHODS

Materials

The data used for this study was obtained from the purple air website using python programming language. The cities considered for the study include Anyingba, Kogi state with latitude 7º 15'N and longitude 7º 11'E. Ibadan, Oyo state with latitude 7º 24'47''N and longitude 3º 55'0''E. Benin, Edo state with latitude 6º 19' 3.6''N and longitude 5º 36' 52.20''E. Lekki, Lagos state with latitude 6º 29'36''N and longitude 3º 43'14''E and Kebi, Kebi state with latitude 11º 30'47''N and longitude 4º 00'E. The data covered a period of one year (April 2021 to April 2022). The data was analyzed using the statistical package for the social sciences (SPSS) software while the visualizations was done using tableau software.

Method

The data was from the purple air website using python programming language. The data was then cleaned and stored as a comma separated (CSV) file format. The data was then pre-processed. It was then loaded into SPSS software for analysis. Regression analysis was then carried out on the data. The regression coefficients, correlation coefficient (R) and coefficient of determination (R^2) was then extracted and tabulated for each of the locations under consideration.

Locations of study

The cities considered for the study include: Anyingba, Kogi state is located at latitude 7º 15'N and longitude 7º 11'E. The city has an area of 420km^2 with a population of 189, 976 inhabitants. Ibadan, Oyo state with latitude 7º 24'47''N and longitude 3º 55'0''E. The city has an area of 6800km^2 with a population of 3,649,000 inhabitants. Auchi, Edo state with latitude 7º 04'N and longitude 6º 16'E. The city has an area of 755km^2 with a population of 500,000 inhabitants. Lekki, Lagos state with latitude 6º 29'36''N and longitude 3º 43'14''E. The city has an area of 755km^2 with a population of 401,270 inhabitants. and Kebbi, Kebbi state with latitude 11º 30'47''N and longitude 4º 00'E. The city has an area of 36,800km^2 with a population of 3,256,541 inhabitants.

Figure 1: Map of Nigeria showing locations of study

RESULTS AND DISCUSSION

The research carried out on the impact of meteorology on particulate matter ($PM_{2.5}$ and PM_{10}) concentration in certain locations in Nigeria gave very useful results. The concentration of $PM_{2.5}$ as measured for Kogi state was 36.44µg/m^3, for Oyo state, 4.29 µg/m^3, for Edo state, 64.61 µg/m^3, for Lagos state 12.76µg/m^3, and for Kebbi state, 96.41 µg/m^3. The $PM_{2.5}$ concentration for Lagos was in the same range with Taiwo et al. (2015) who measured $PM_{2.5}$ concentration to be within the range of 10 - 426 µg/m^3. In 2021, Abulude et al. (2021) found the $PM_{2.5}$ concentration for Ikeja, Lagos to be in the range of 20 - 123 µg/m^3, while Maryland was found to be 22 - 120 µg/m^3. The concentration of PM_{10} as measured for Kogi state was 39.32µg/m^3, for Oyo state, 10.23 µg/m^3, for Edo state, 70.70 µg/m^3, for Lagos state 20.74µg/m^3, and for Kebbi state, 107.60µg/m^3. These mean concentration is represented in the map in fig 2 and fig 3. The PM_{10} concentration for Lagos was not actually in the same range with Taiwo et al. (2015) who measured PM_{10} concentration to be within the range of 86 - 8765 µg/m^3. In 2021, Abulude et al. (2021) found the PM_{10} concentration for Ikeja, Lagos to be in the range of 30 - 176 µg/m^3, while Maryland was found to be 33 - 173 µg/m^3. Osimodi et al. (2019) recorded the concentration of $PM_{2.5}$ in Port Harcourt to be 29.5

μg/m^3 while that of PM_{10} was found to be 132.88 μg/m^3. Audu-Vincent et al. (2018) measured $PM_{2.5}$ concentration for Kaduna State to be 65.2 μg/m^3. Abuja's $PM_{2.5}$ concentration was measured by Shehu et al. (2019) to be in the range 3.623-4.49 μg/m^3.

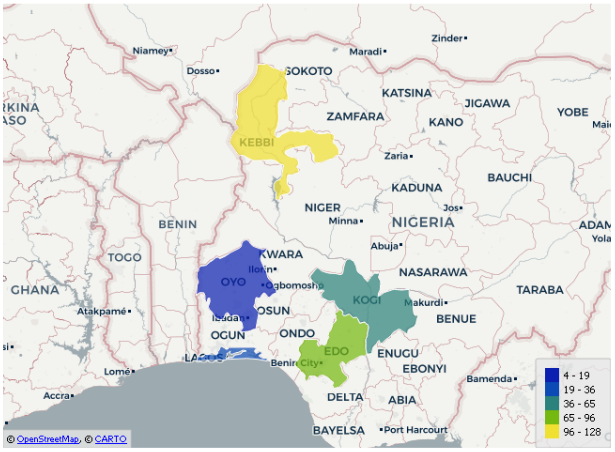

Figure 2: Map of $PM_{2.5}$ concentration

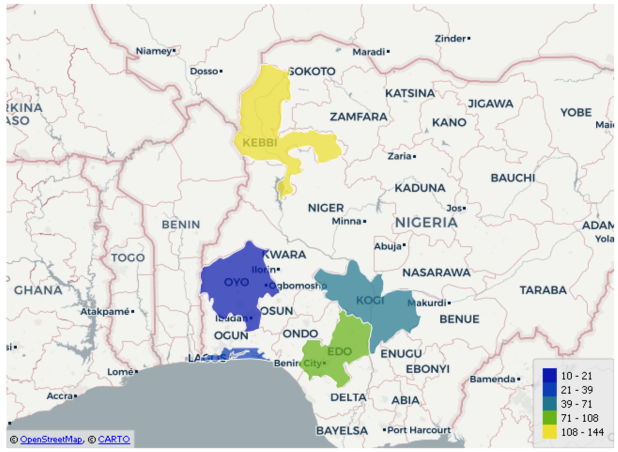

Figure 3: Map of PM_{10} concentration

This can be compared to the map of $PM_{2.5}$ published by the Health Effect Institute as State of Global Air report in 2024. The map is shown in fig 4.

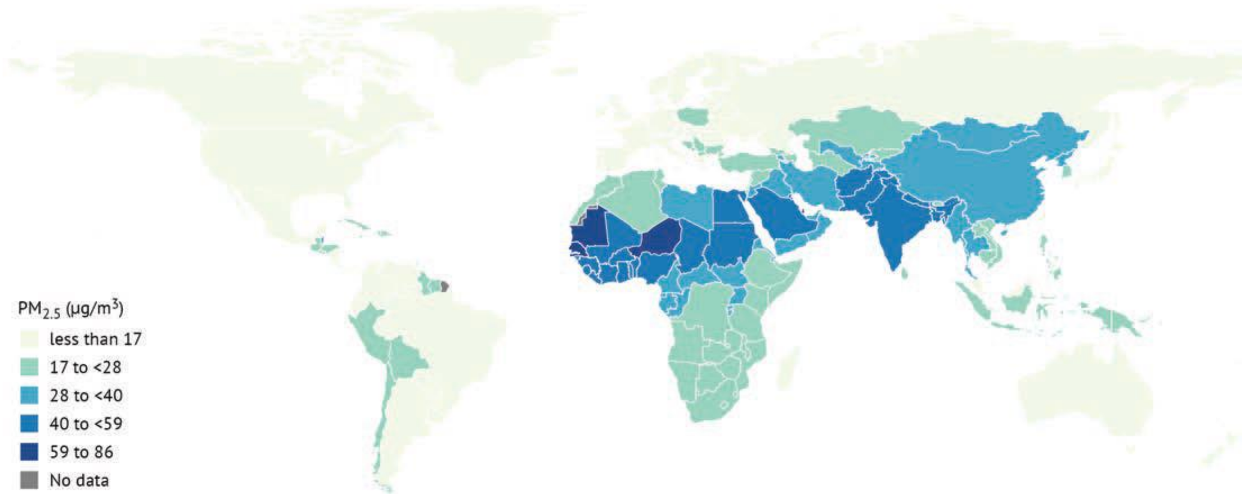

Figure 4: Map of $PM_{2.5}$ as shown in the state of global air report 2024

This is in agreement with the $PM_{2.5}$ concentration of approximately 40 μg/m^3. Fig5 shows a time series plot of $PM_{2.5}$ concentration over a period of thirty (30) years. This was published by the Health Effect Institute (HEI) in 2024. The graph shows that there was a sharp increase in the concentration of $PM_{2.5}$ in 2015. The average concentration of $PM_{2.5}$ was about 80μg/m^3. There was a slight drop afterwards up to 2020 then increased again till 2023.

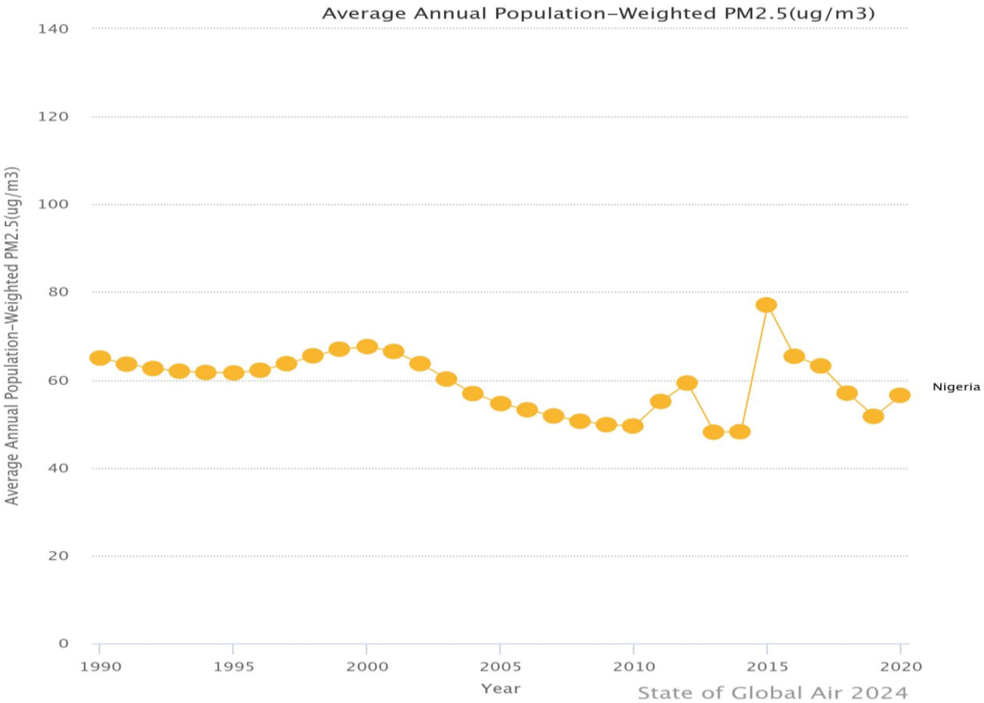

Figure 5: Time series plot of PM2.5 over the past 30 years source (HEI, 2024)

Effect of Meteorology of Particulate Matter

Nigerian climate is dominated by the influence of three major atmospheric phenomena, namely: the maritime tropical (mT) air mass, the continental tropical (cT) air mass and the equatorial easterlies. The mT air mass originates from the southern high-pressure belt located off the coast of Namibia, and in its trajectory it picks up moisture from over the Atlantic Ocean, crosses the equator and enters Nigeria. The cT air mass originates from the high-pressure belt north of the Tropic of Cancer. It picks up little moisture along its path, and thus is dry. The two air masses (mT and cT) meet along a slanting surface called the intertropical discontinuity (ITD). The equatorial easterlies are rather erratic, cool air masses that come from the east and flow in the upper atmosphere along the ITD. Occasionally, however, the air mass dives down, undercuts the mT or cT air mass and gives rise to a line of squalls or dust devils (Odekunle, 2004). Linear regression analysis was performed for the different locations under consideration. The regression analysis was carried out to establish the relationship between particulate matter and meteorological parameters (temperature and humidity). Table 1 shows the model equation and parameters for Oyo, State. The table shows that for Oyo state, there was a poor negative correlation between temperature and $PM_{2.5}$. For humidity, the correlation coefficient was high, though negative. This shows that temperature had very little impact on the concentration of particulate matter in ambient air of Oyo state while humidity had a strong negative impact on the concentration of particulate matter in ambient air of Oyo. Greater percentage of particulate matter are taken out of the atmosphere through wet deposition since there is increase in humidity. The coefficient of determination R^2 for humidity and $PM_{2.5}$ = 0.5617 shows that 56.17% of change in the concentration of $PM_{2.5}$ in the atmosphere is linked with how humid the air is. For PM_{10}, it is 60.91%. This correlation is shown in fig 6 and fig 7. Fig6 shows correlation of $PM_{2.5}$ with temperature and humidity while fig 7 shows correlation of PM_{10} with temperature and humidity.

Table 1: Model equation and parameters for Oyo state

State	Model equation	R	R^2	p-value
OYO	$PM_{2.5}$ = -0.726848*Tem + 27.94	-0.326	0.1061	0.0001
	PM_{10} = -1.50935*Tem + 59.34	-0.349	0.1218	0.0001
	$PM_{2.5}$ = -0.201093*Humidity + 18.15	-0.749	0.5617	0.0001
	PM_{10} = -0.405802*Humidity + 38.19	-0.779	0.6091	0.0001

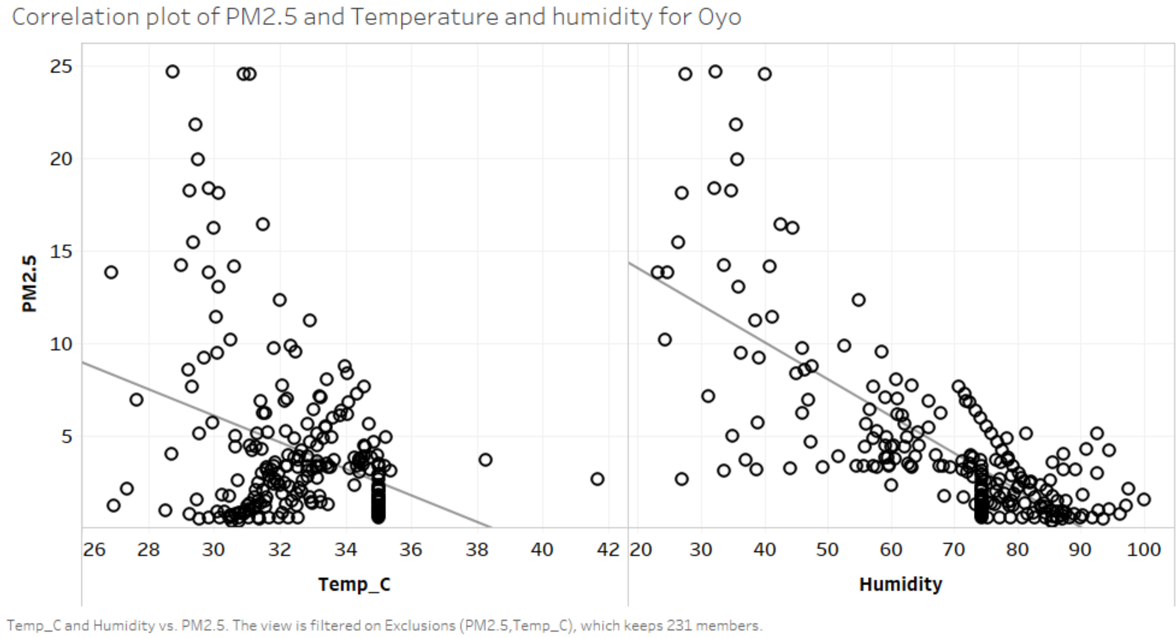

Figure 6: Correlation plot between $PM_{2.5}$ with Temperature and Humidity for Oyo

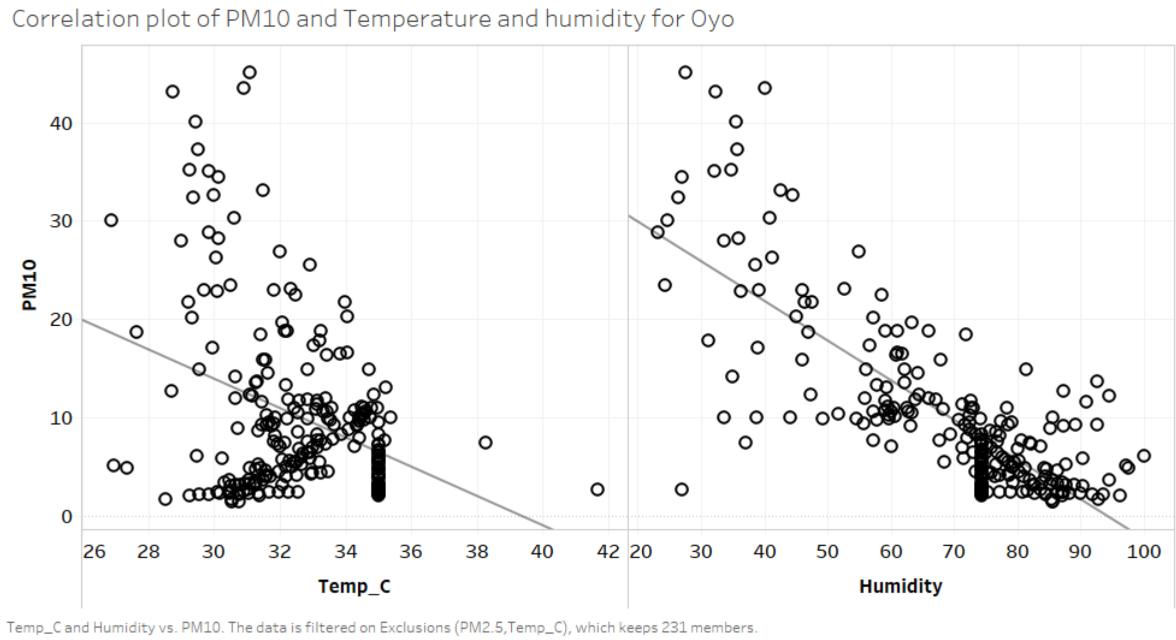

Figure 7: Correlation plot between PM_{10} with Temperature and Humidity for Oyo

Table 2 shows the model equation and parameters for Kogi, State. The table shows that for Kogi state, there was a poor positive correlation between temperature and particulate matter ($PM_{2.5}$ and PM_{10}). For humidity, the correlation coefficient was high, though negative. This shows that temperature had very little impact on the concentration of particulate matter in ambient air of Kogi state while humidity had a strong negative impact on the concentration of particulate matter in ambient air of Kogi. Greater percentage of particulate matter are taken out of the atmosphere through wet deposition since there is increase in humidity. The coefficient of determination R^2 for humidity and $PM_{2.5}$ = 0.5038 shows that 50.38% of change in the concentration of $PM_{2.5}$ in the atmosphere is linked with how humid the air is. For PM_{10}, it is 60.91%. This correlation is shown in fig 8 and fig 9. Fig8 shows correlation of $PM_{2.5}$ with temperature and humidity while fig 9 shows correlation of PM_{10} with temperature and humidity.

Table 2: Model equation and parameters for Kogi state

State	Model equation	R	R^2	p-value
KOGI	$PM_{2.5} = 2.24498*Tem - 33.81$	0.239	0.0571	0.0001
	$PM_{10} = 2.3799*Tem - 35.16$	0.233	0.0541	0.0001
	$PM_{2.5} = -1.53037*Humidity + 110.77$	-0.710	0.5038	0.0001
	$PM_{10} = -1.67595*Humidity + 120.72$	-0714	0.6091	0.0001

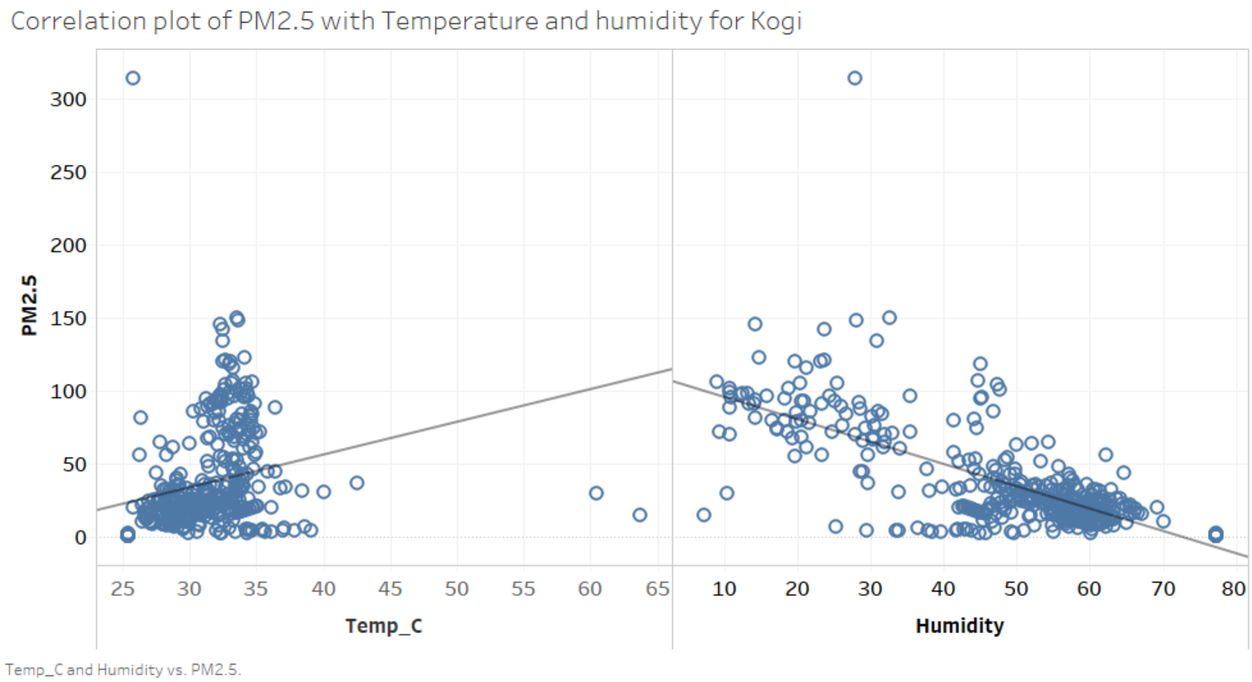

Figure 8: Correlation plot between $PM_{2.5}$ with Temperature and Humidity for Kogi

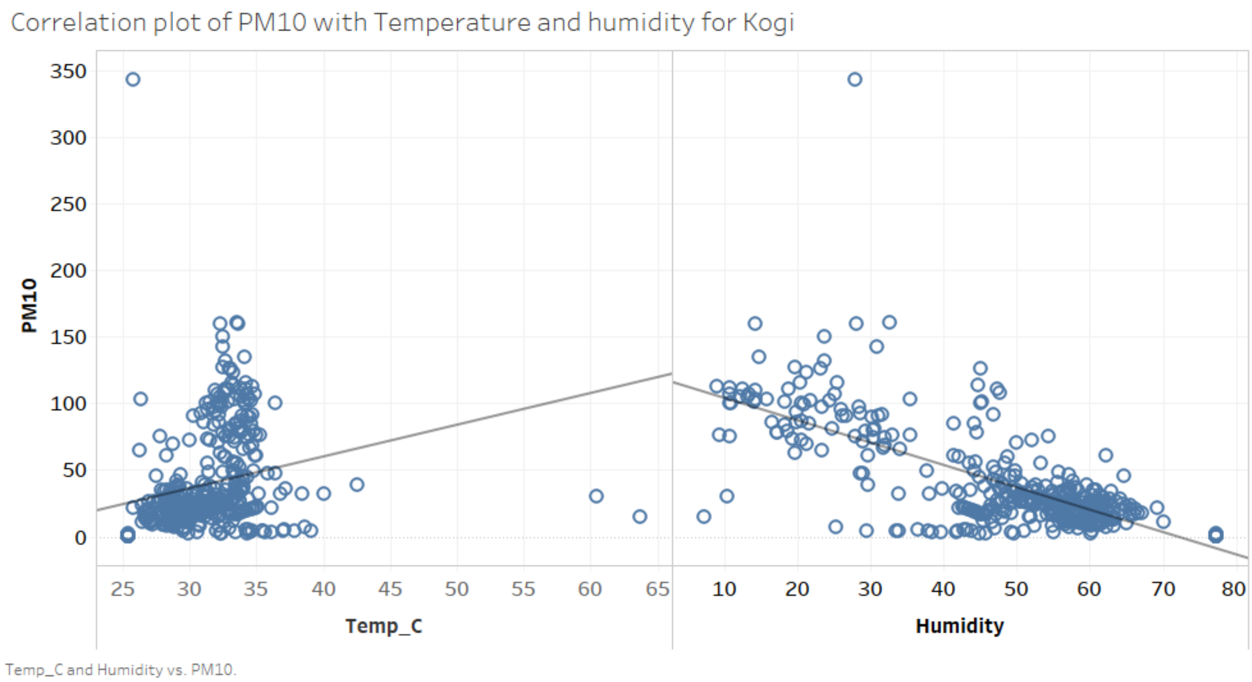

Figure 9: Correlation plot between PM_{10} with Temperature and Humidity for Kogi

Table 3 shows the model equation and parameters for Edo, State. The table shows that for Edo state, there was a poor positive correlation between temperature and particulate matter ($PM_{2.5}$ and PM_{10}). For humidity, the correlation coefficient was also low and positive. This shows that temperature and humidity had very little impact on the concentration of particulate matter in ambient air of Edo state. However, in 2023, (Popoola et al., 2023) correlated meteorology and Particulate Matter in Benin City, Edo State. Their results showed that temperature correlated with Particulate matter with value R = 0.575 and relative humidity correlated with value R = -0.563. This showed high positive correlation with temperature and high negative correlation with Relative humidity. The coefficient of determination R^2 for humidity and $PM_{2.5}$ = 0.355 shows that 35.5% of change in the concentration of $PM_{2.5}$ in the atmosphere is linked with how humid the air is. For PM_{10}, it is 7.38%. This correlation is shown in fig 10 and fig 11. Fig10 shows correlation of $PM_{2.5}$ with temperature and humidity while fig 11 shows correlation of PM_{10} with temperature and humidity.

Table 3: Model equation and parameters for Edo state

State	Model equation	R	R^2	p-value
Edo	$PM_{2.5}$ = 6.10844*Tem – 122.94	0.355	0.12577	0.0001
	PM_{10} = 6.2939*Tem – 122.53	0.336	0.11331	0.0001
	$PM_{2.5}$ = -1.48385*Humidity + 134.084	0.355	0.12577	0.0001
	PM_{10} = -0.730759*Humidity + 75.2599	0.272	0.07381	0.0001

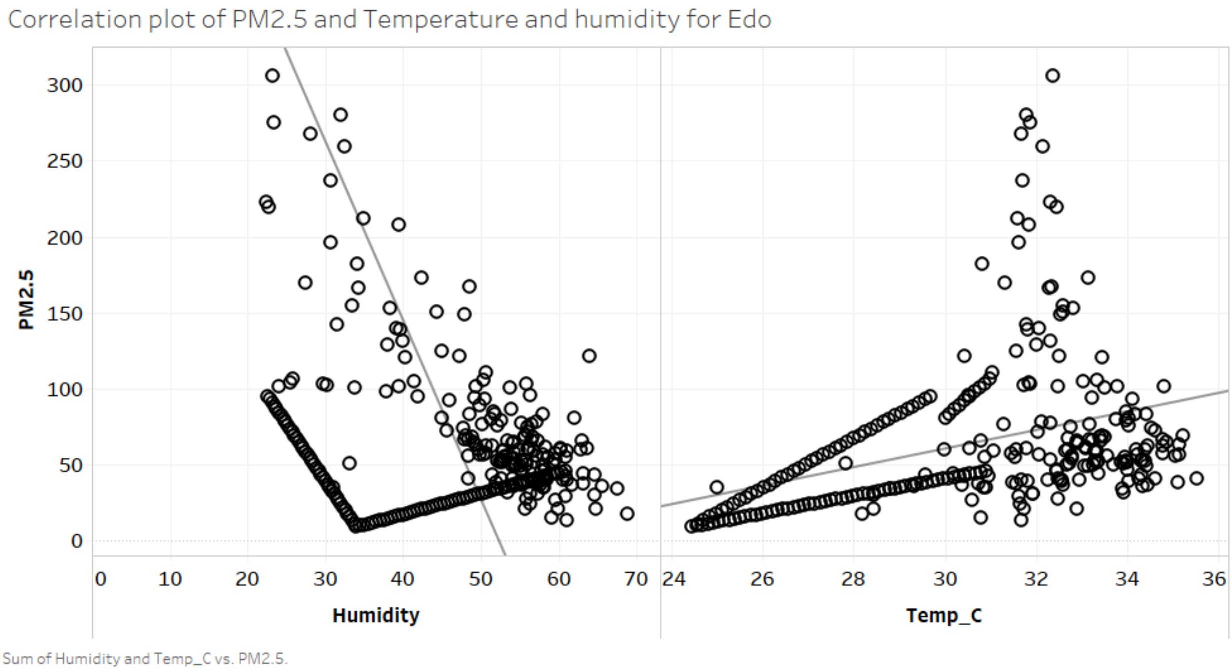

Figure 10: Correlation plot between $PM_{2.5}$ with Temperature and Humidity for Edo

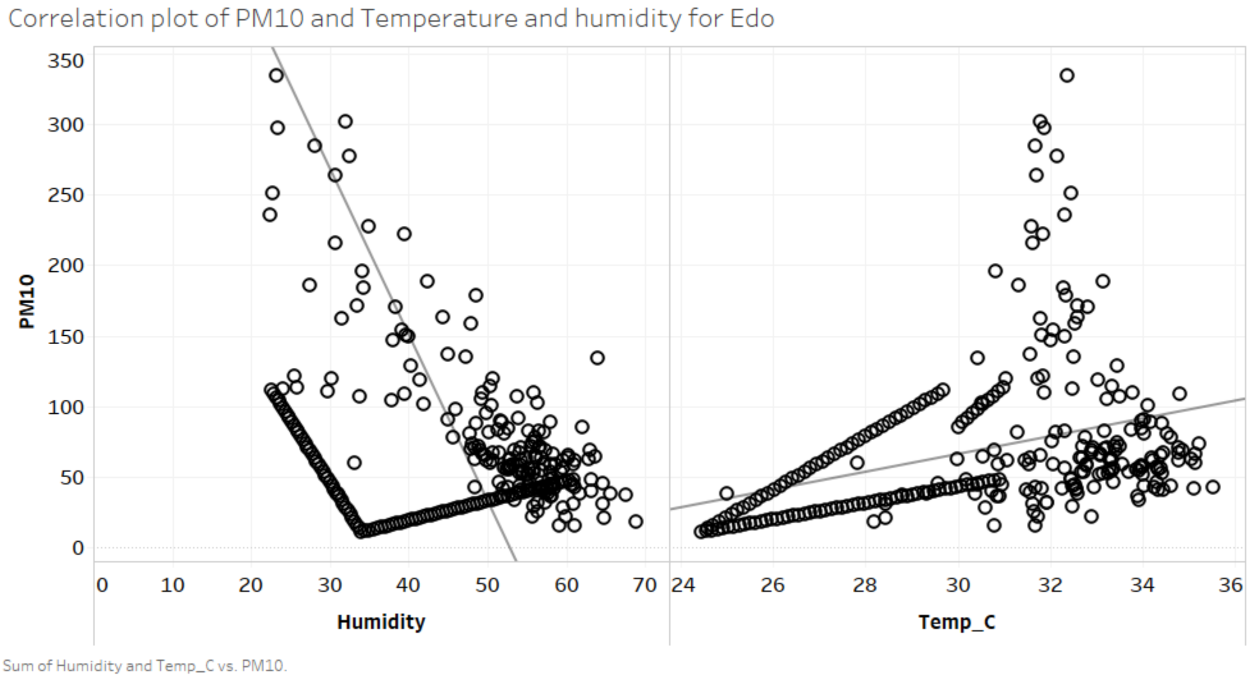

Figure 11: Correlation plot between PM_{10} with Temperature and Humidity for Edo

Table 4 shows the model equation and parameters for Lagos, State. The table shows that for Lagos state, there was a poor positive correlation between temperature and particulate matter ($PM_{2.5}$ and PM_{10}). For humidity, the correlation coefficient was also low and positive. This shows that temperature and humidity had very little impact on the concentration of particulate matter in ambient air of Lagos state. This result confirmed what (Emekwuru, 2023) did in 2023 in Lagos. His result showed that correlation of $PM_{2.5}$ with temperature had value R = -0.24 while Humidity and $PM_{2.5}$ had value R = 0.26. This showed that temperature had a low negative impact while humidity had low positive impact. For PM_{10}, temperature correlation had value R = -0.37 while humidity had value R = 0.37. This shows that both temperature and humidity had low impact on PM_{10}. The coefficient of determination R^2 for humidity and $PM_{2.5}$ = 0.005 shows that 0.5% of change in the concentration of $PM_{2.5}$ in the atmosphere is linked with how humid the air is. For PM_{10}, it is 0.3%. This correlation is shown in fig 12 and fig 13. Fig12 shows correlation of $PM_{2.5}$ with temperature and humidity while fig 13 shows correlation of PM_{10} with temperature and humidity.

Table 4: Model equation and parameters for Lagos state

State	Model equation	R	R^2	p-value
Lagos	$PM_{2.5}$ = 0.392905*Tem + 6.8403	0.047	0.00223	0.0001
	PM_{10} = 0.477755*Tem + 5.812	0.051	0.00259	0.3151
	$PM_{2.5}$ = 0.145545*Humidity + 10.9875	0.071	0.00490	0.1662
	PM_{10} = 0.128375*Humidity + 13.5692	0.055	0.00299	0.2795

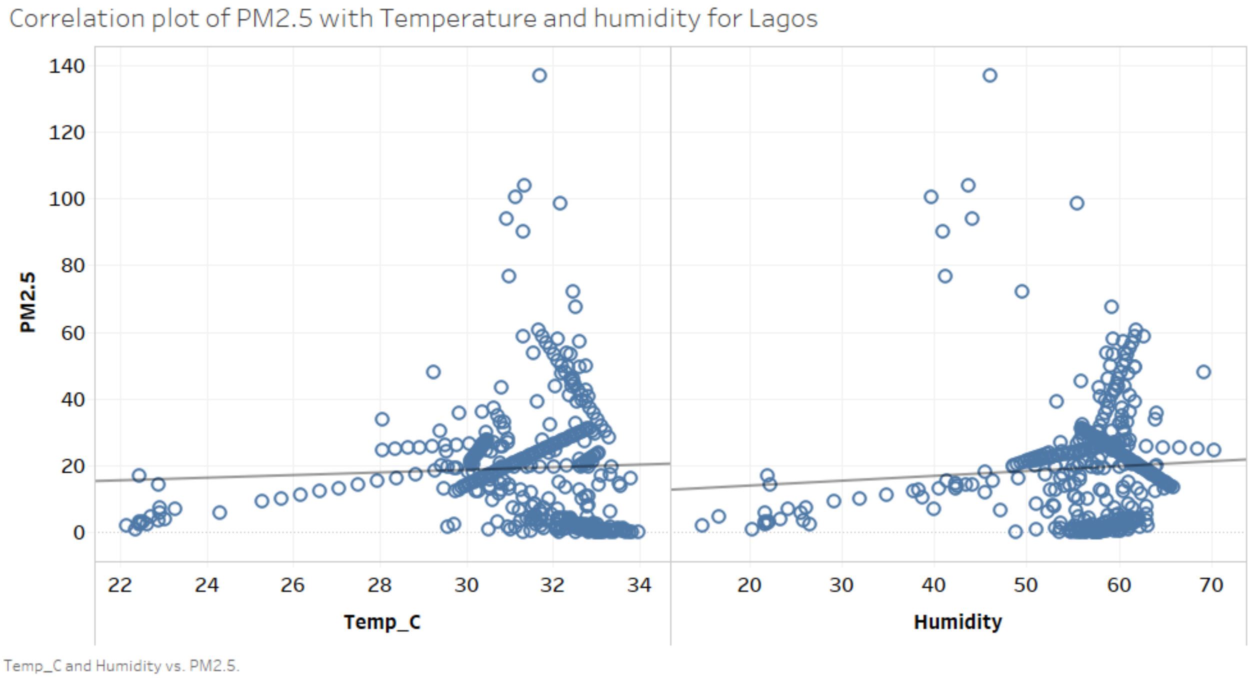

Figure 12: Correlation plot between $PM_{2.5}$ with Temperature and Humidity for Lagos

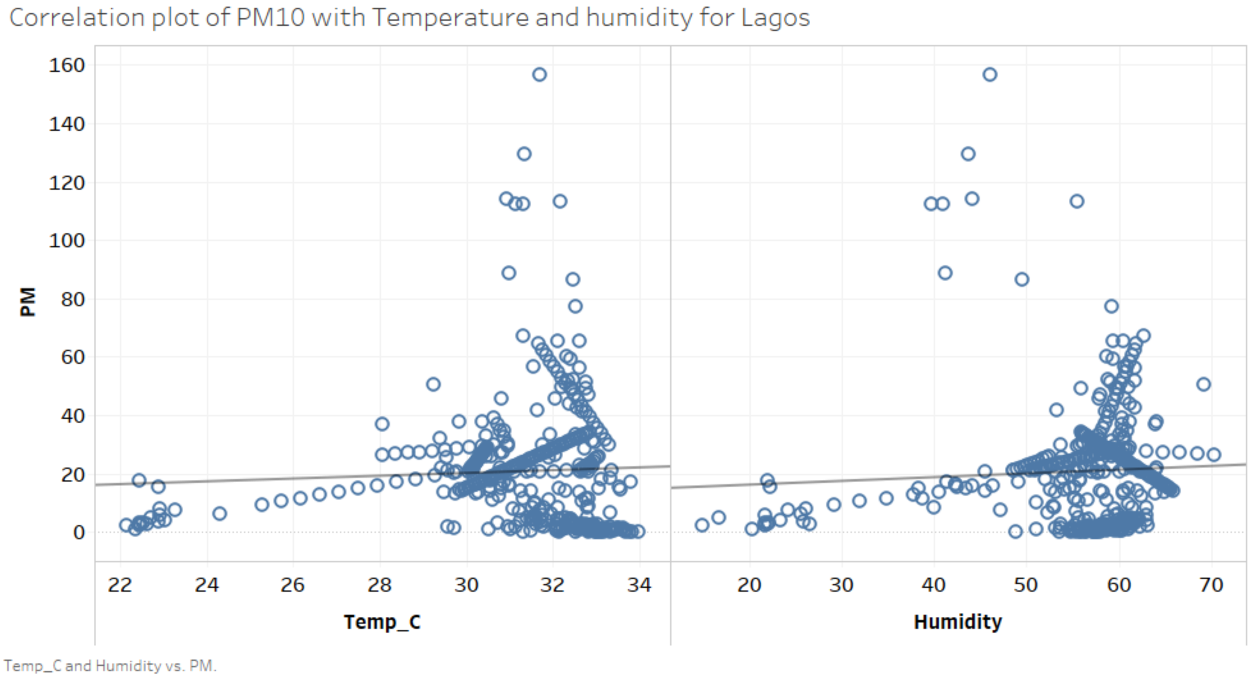

Figure 13: Correlation plot between PM_{10} with Temperature and Humidity for Lagos

Table 5 shows the model equation and parameters for Kebbi, State. The table shows that for Kebbi state, there was a poor positive correlation between temperature and particulate matter ($PM_{2.5}$ and PM_{10}). For humidity, the correlation coefficient was also low and positive. This shows that temperature and humidity had very little impact on the concentration of particulate matter in ambient air of Kebbi state. The coefficient of determination R^2 for humidity and $PM_{2.5}$ = 0.00093 shows that 0.09% of change in the concentration of $PM_{2.5}$ in the atmosphere is linked with how humid the air is. For PM_{10}, it is 0.08%. This correlation is shown in fig 14 and fig 15. Fig14 shows correlation of $PM_{2.5}$ with temperature and humidity while fig 15 shows correlation of PM_{10} with temperature and humidity.

Table 5: Model equation and parameters for Kebbi state

State	Model equation	R	R^2	p-value
Kebbi	$PM_{2.5} = 11.5641*Tem - 315.20$	0.063	0.00400	0.2911
	$PM_{10} = 10.1783*Tem - 254.676$	0.056	0.00311	0.3522
	$PM_{2.5} = -1.62715*Humidity + 123.194$	0.031	0.00093	0.6106
	$PM_{10} = -1.54338*Humidity + 133.01$	0.029	0.00084	0.6287

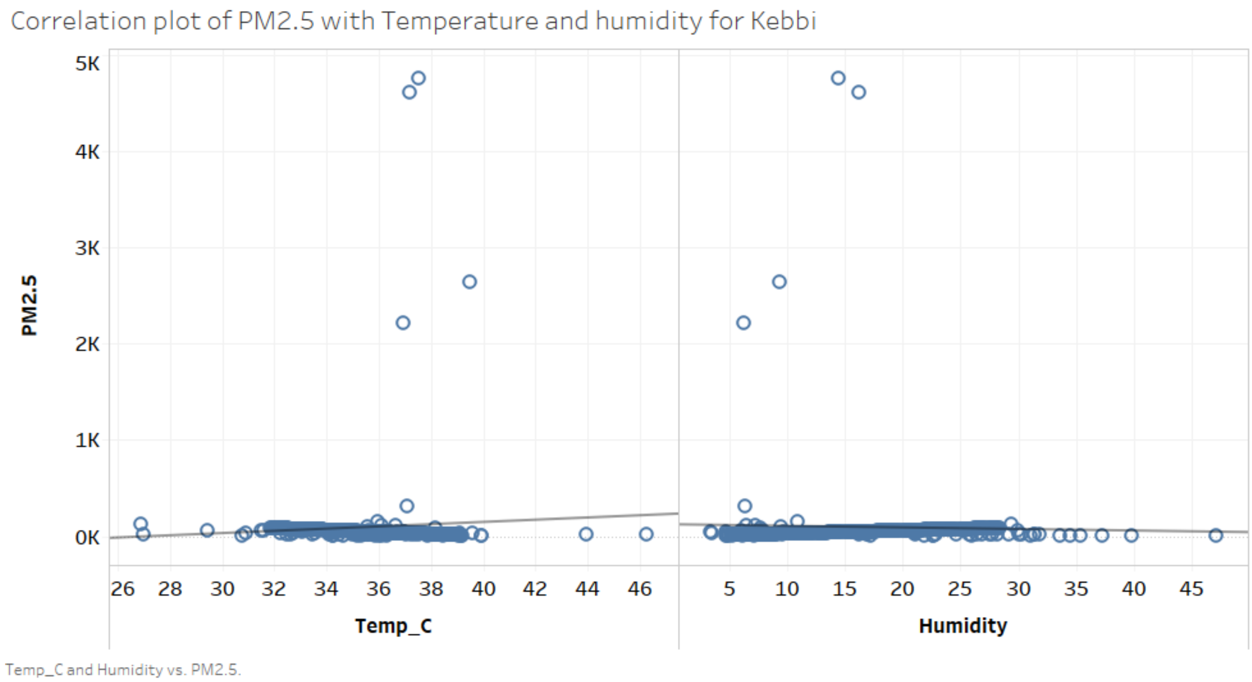

Figure 14: Correlation plot between $PM_{2.5}$ with Temperature and Humidity for Kebbi

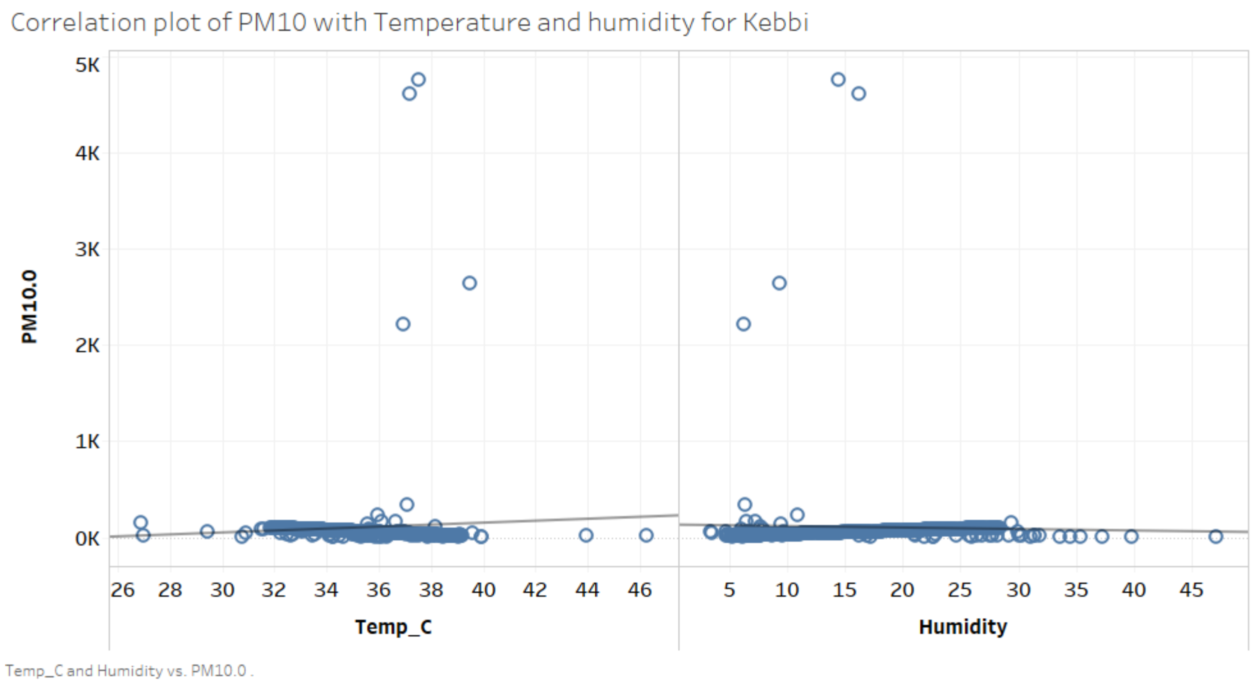

Figure 15: Correlation plot between PM_{10} with Temperature and Humidity for Kebbi

CONCLUSION

A research was carried out to determine the impact of meteorology on particulate matter concentration in certain locations in Nigeria. The following conclusions were arrived at. For Oyo state, there was a poor negative correlation between temperature and $PM_{2.5}$. For humidity, the correlation coefficient was high, though negative. This shows that temperature had very little impact on the concentration of particulate matter in ambient air of Oyo state while humidity had a strong negative impact on the concentration of particulate matter in ambient air of Oyo. For Kogi state, there was a poor positive correlation between temperature and particulate matter ($PM_{2.5}$ and PM_{10}). For humidity, the correlation coefficient was high, though negative. This shows that temperature had very little impact on the concentration of particulate matter in ambient air of Kogi state while humidity had a strong negative impact on the concentration of particulate matter in ambient air of Kogi. For Edo state, there was a poor positive correlation between temperature and particulate matter ($PM_{2.5}$ and PM_{10}). For humidity, the correlation coefficient was also low and positive. This shows that temperature and humidity had very little impact on the concentration of particulate matter in ambient air of Edo state. For Lagos state, there was a poor positive correlation between temperature and particulate matter ($PM_{2.5}$ and PM_{10}). For humidity, the correlation coefficient was also low and positive. This shows that temperature and humidity had very little impact on the concentration of particulate matter in ambient air of Lagos state. For Kebbi state, there was a poor positive correlation between temperature and particulate matter ($PM_{2.5}$ and PM_{10}). For humidity, the correlation coefficient was also low and positive. This shows that temperature and humidity had very little impact on the concentration of particulate matter in ambient air of Kebbi state.

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