

RELATIONSHIP BETWEEN PARTICULATE MATTER ($PM_{2.5}$ $\mu\text{g}/\text{m}^3$) AND
SOME LOWER ATMOSPHERIC PARAMETERS IN NORTH-CENTRAL
NIGERIA, DURING DIP MINIMUM SOLAR ACTIVITY

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RELATIONSHIP BETWEEN PARTICULATE MATTER ($PM_{2.5}$ $\mu\text{g}/\text{m}^3$) AND SOME LOWER ATMOSPHERIC PARAMETERS IN NORTH-CENTRAL NIGERIA, DURING DIP MINIMUM SOLAR ACTIVITY

ABSTRACT

This paper investigated the relationship between particulate matter ($PM_{2.5}$ $\mu\text{g}/\text{m}^3$) Concentrations with some lower atmospheric parameters in Niger State (Minna) during the year of dip minimum solar activity 2008. Lower atmospheric parameters like temperature, pressure were used in the study. The particulate matter and the monthly average atmospheric parameters were converted to daily average and normalized to a common scale. The result shows seasonally enhanced $PM_{2.5}$ $\mu\text{g}/\text{m}^3$ with temperature, in autumn with least amplitude in winter and rarely any noticeable difference in spring and summer. The seasonal correlation between $PM_{2.5}$ $\mu\text{g}/\text{m}^3$ and temperature shows low indirect relationship with magnitude -0.12235 in winter relative to spring -0.01050. In contrast, the $PM_{2.5}$ $\mu\text{g}/\text{m}^3$ maintained higher direct relationship in autumn as compared with summer of magnitude 0.083316 and 0.003048 respectively. The correlation between $PM_{2.5}$ $\mu\text{g}/\text{m}^3$ and pressure in autumn, winter and spring shows a positive correlation of 0.048192, 0.014496, 0.006861 respectively. However, indirect relationship in summer with a magnitude -0.05282 was observed. The correlation coefficient of $PM_{2.5}$ $\mu\text{g}/\text{m}^3$ is higher during autumn 0.048192 and has lower value during summer -0.05282 due to scavenging process. Generally, higher direct correlation exist between $PM_{2.5}$ $\mu\text{g}/\text{m}^3$ and atmospheric parameters with temperature particularly in autumn 0.083316 across all seasons due to transport of dust particles by dry continental air masses which is similar to autumn with pressure with a positive magnitude of 0.048192. This strong relationship may be explained in terms of atmospheric wind and solar zenith angle that are dominant during these periods.

Key words: Air temperature (0°), Minna, pressure (hpa), $PM_{2.5}$ $\mu\text{g}/\text{m}^3$.

Important word: winter (January, February, November, December)

Summer (May June, July, August,)

Autum (September, October)

Spring (March, April)

Atmospheric, zenith Angle.

Season, magnitude

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INTRODUCTION

The term Particulate Matter (PM 2.5 $\mu\text{g}/\text{m}^3$) is defined as fine solid or liquid particulates that are suspended in the atmosphere, demonstrating significant heterogeneity across both temporal and spatial dimensions. These particulates may manifest in detectable forms such as dust, smoke, and haze, and they originate from a diverse array of sources, including volcanic eruptions and marine aerosols. Specifically, PM2.5 $\mu\text{g}/\text{m}^3$ denotes particles with diameters that are equal to or less than 2.5 $\mu\text{g}/\text{m}^3$; the presence of aerosol particles induces the scattering and absorption of light, consequently resulting in diminished visibility. Moreover, a fraction of the PM2.5 $\mu\text{g}/\text{m}^3$ concentrations can be attributed to regional transport mechanisms and secondary transformation processes. Comprehensive research has been undertaken to evaluate the association between PM2.5 $\mu\text{g}/\text{m}^3$ and various meteorological variables, encompassing temperature and atmospheric pressure. (Shi *et al.*, 2012). A research conducted by (Kermani *et al.*, 2020) stated that air pollution is currently a major environmental issue for both developed and developing nations worldwide. It is an anthropogenic emission of hazardous chemicals that changes the chemical composition of the natural atmosphere, hence lead to a negative impact on the environment and the health of living things. The restriction of movement and vehicle, closure of industries in the world during covid 19 has impacted positively on air pollutant because man made air pollutant are seriously affecting human health (Johnson *et al.*, 2024). According to (Lin *et al.*, 2015) many epidemiological investigations have demonstrated that prolonged exposure to outdoor air pollution may augment the likelihood of acute and chronic health challenges. The principal air pollutants, namely fine particles (PM2.5 $\mu\text{g}/\text{m}^3$), persist in presenting noteworthy perils to global health, particularly in emerging nations (Kliengchuay *et al.*, 2022). However, Fine Particulate Matter (PM2.5 $\mu\text{g}/\text{m}^3$) has been recognized as a significant threat to public health, numerous investigations have documented the correlation between PM2.5 $\mu\text{g}/\text{m}^3$ and respiratory, mutagenic, and cardiorespiratory conditions, as well as mortality (Bilal *et al.*, 2017). Many investigations have highlighted the noteworthy impacts of atmospheric fine particulate matter (PM2.5 $\mu\text{g}/\text{m}^3$) on human well-being. Their primary objectives is to offer comprehensive spatial and temporal observations of atmospheric parameters and air pollution studies on the overall well-being of human and health research as such, the utilization of satellite remote sensing for the monitoring of fine particulate matters is becoming increasingly vital in the field of environmental surveillance (Zhang & Li, 2015). According to (Tran *et al.*, 2020) Once the emission of air pollutants occurs, they become either suspended or dispersed in the atmosphere. Numerous studies have discovered the existence of diurnal, and seasonal variations in the concentration levels of PM2.5 $\mu\text{g}/\text{m}^3$. The influence of meteorological parameters has been acknowledged as significant in the escalation or reduction of PM2.5 $\mu\text{g}/\text{m}^3$. Meanwhile climate change is expected to modulate ambient PM2.5 $\mu\text{g}/\text{m}^3$ exposure by perturbing ventilation rate (that depends on atmospheric boundary layer depth and wind speed), precipitation scavenging, dry deposition, anthropogenic and natural emissions (Chowdhury *et al.*, 2018). However, the atmospheric parameter like temperature is a thermodynamic state of an object, which describes the average random movement of molecules in a physical entity, the temperature of air signifies the quantification of heat content present in the atmosphere due to the combined impact of absorbed solar radiation by the surface, air convection through vertical movements of turbulent heat, and horizontal transfer of warm and cold air masses. while Surface pressure is commonly observed during calm and cloudless weather conditions when the mixing of air masses is sluggish, conversely, low pressure usually prevails during convective and stormy conditions, characterize by strong winds, the weather conditions may facilitate the rapid dispersion of airborne particles (Obisesan, 2022). A study conducted by (Yangetal.,2017), in north west china the seasonal variation between PM2.5 $\mu\text{g}/\text{m}^3$ concentration and pressure exhibit higher correlation

coefficient (0.08) in summer and closely followed by autumn with 0.07 and decreases significantly to 0.01 in spring while in summer exhibit a positive magnitude (0.03). They further observed the correlation coefficient has stronger magnitude in summer (0.14) with temperature while in winter exhibit a positive and low value (0.27) but the coefficient of correlation between PM_{2.5}µg/m³ and temperature has negative value in both spring (-0.08) and autumn (-0.21) respectively which is contrary to winter and summer (0.27) and (0.14) respectively in the south west china. The cities with the positive value is larger in spring and winter due to the present of sulfate content that make the Correlation positively stronger the correlation differ greatly with different seasons. But the most influencing factor within the eight seasons where temperature in summer (R²=0.14), the cities with positive correlation value is larger in spring and winter due to coal combustion which lead to increase in PM_{2.5}µg/m³ concentration and other air pollutant in this region, due to present of sulfate content that make the correlation positively stronger, the correlation between PM_{2.5}µg/m³ and temperature differ greatly with different seasons, but the seasonal variation of the coefficient of correlation in the two region and the negative correlation is detected in each seasons, this is due to the higher atmospheric boundary layer in summer and air convection in this region during the vertical motion is stronger due to the elevated temperature particles which mainly diffused and diluted vertically. Meanwhile a direct correlation between annual PM_{2.5}µg/m³ with temperature was observed (R²=0.37, P<0.017) which is statistically significant but the relative humidity was (R²=0.39, P<0.05) at significant level, while the atmospheric pressure has positive correlation (R²=0.219, P<0.05), this study was conducted by (Kermani *et al.*,) during the year 2019-2020 at Ishafahan in Iran. In a similar study conducted by (Wang and Ogawa, 2015) in japan Nagasaki using spearman correlation analysis were they found out that there exist a seasonal variation between PM_{2.5}µg/m³ and meteorological parameters. PM_{2.5}µg/m has a strong positive correlation with temperature with no significant differences among the four seasons. Because temperature can affect the formation of particles thus, the high temperature can promote the photochemical reaction between precursors. In winter (0.6353), summer (0.657) autumn (0.64766) spring (0.58733) and the westerly wind transport the most of the pollutant to Nagasaki in all the four seasons. This study provide government with valuable information so that early warning system can be taken to reduce negative impact of air pollutant on public health at different seasons and year, it is necessary to conduct and carry out correlation study around areas where health effect can be harnessed relatively easy by using statistical analysis because a large majority of PM_{2.5}µg/m³ might cause environmental effects, particularly in Niger state, this study will go a long way to bridge the knowledge need for atmospheric parameters, because not much has been done in assessing the relative investigation of atmospheric parameters and PM_{2.5}µg/m³ particularly in this region.

MATERIALS AND METHOD OF ANALYSIS

This study uses lower atmospheric parameters like the temperature, PM_{2.5} µg/m³ and atmospheric pressure downloaded from the automatic weather monitoring satellite that has 0.5° and 0.625° resolution. Those time series data are accessible via <http://giovanni.gsfc.nasa.gov/giovanni/>. The parameters for each particular day, the hourly PM_{2.5} µg/m³ (merr-2-model) was analyzed using Microsoft excel using spearman correlation technique for each particular day used in the study. The hourly lower atmospheric parameters such as temperature, pressure and PM_{2.5} µg/m³ from (merra-2) was used during the year of dip minimum solar activity 2008. The study covers Minna metropolis of Niger State with an estimated population of about 448,000 and 281.1m above sea level with a

surface area of approximately 76363 km². Furthermore, the latitude and longitude of the city are 09° 39'N and 06° 28' E, respectively. Because of the connection between this region and provinces of the Niger Republic, it faces daily large transport and horizontal concentration of particulate matter due to dry continental air masses from the Sahara region down to Niger (Minna) constituting a haze in the region. This result to an intensification of air pollution from the most important source of its formation. Moving vehicles are also causative agent and release high amount of PM 2.5 µg/m³ into the ambient air in this region. A linear regression technique given in equation 1 was used to examine the relationship between the PM2.5 µg/m³ and lower atmospheric parameters (temperature and pressure) and to identify factors that affect these variations using 95% significant level.

$$Y = a + bx + e \quad (1)$$

The PM2.5 µg/m³ variable is transformed using linear regression technique and used as the dependent variables in the correlation analysis. The PM2.5 µg/m³ and the atmospheric parameters values were normalized to have a common scale between 0 and 1, using the equation 1 below. The seasonal variations were classified into four; winter (November, December, January, and February), summer (May June, July and August), autumn (September and October) and spring (April and May).

$$X_{normalized} = \frac{X - X_{min}}{X_{max} - X_{min}} \quad (2)$$

RESULTS AND DISCUSSION

All the data were normalized and their values were between 0-1 with units. According to Figure 1, the seasonal average PM2.5 µg/m³ concentrations were lowest in May, June, July, and August. Those months coincide with the period of abundance rainfall. This is evident with the increase in pressure (hpa) as indicated in figure 1. We assert that the present of rainfall in those months may likely reduce the amount of particulate matter and lower the temperature of this study (Chabane *et al.*, 2020). The PM2.5 µg/m³ concentration and pressure (hpa) maintained a downward trend that started in February and extended to April. During these periods, the temperature increases monotonically as shown in Figure 1. During the summer months the consistent minimum PM2.5 µg/m³ concentrations correspond to fluctuating maximum pressure (hpa) and the downward decrease of temperature. The minimum pressure observed in spring and autumn correspond to period when the sub-solar point is directly at the equator resulting in higher temperature observed in these months (Bardhan *et al.*, 2014). This may likely suppress some of the effect that may likely arise from lower atmospheric parameters as obvious in Figure 1 of this study. The downward trend in Temperature that started in May to reach its minimum in August is a clear indication that the sub-solar point has moved away to high latitudes leading to subsequent increase in the atmospheric pressure (hpa) as shown in Figure 1.

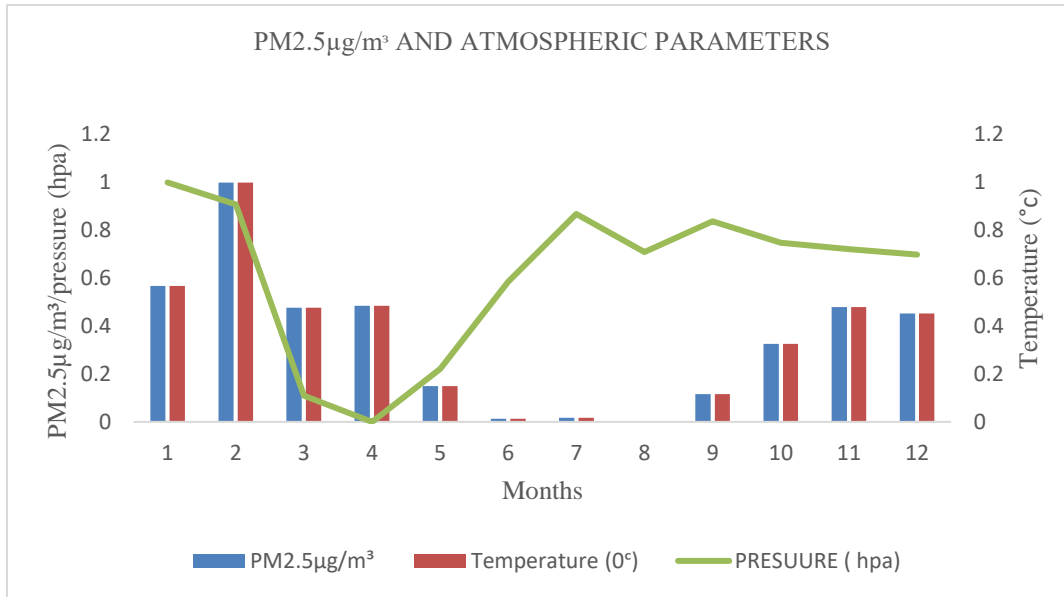


Figure 1: shows a relationship between PM2.5 $\mu\text{g}/\text{m}^3$ and some lower atmospheric parameters in 2008

Generally, the result seems to show linear relationship exist between PM2.5 $\mu\text{g}/\text{m}^3$ concentrations and atmospheric pressure (hpa) in spring and not observable in autumn which are both equinoctial months indication of equinoctial asymmetry between the two parameters as shown in Figure 1. The consistent minimum PM2.5 $\mu\text{g}/\text{m}^3$ concentrations in summer months could be influence by higher concentration of atmospheric pressure (hpa) as indicated in Figure 1.

To establish if there exist a relationship between PM2.5 $\mu\text{g}/\text{m}^3$ and some lower atmospheric parameters such as temperature and pressure, the correlation analysis was carried out and the result is displayed in Figures 2 and 3. The result shows that there exists a seasonal relationship among the atmospheric parameters in the study area. For example, From Figure 2, the seasonal correlation between the PM 2.5 $\mu\text{g}/\text{m}^3$ and temperature shows more indirect relationship with magnitude (-0.122354) in winter while in summer a direct relationship was observed with positive value 0.003048 indication that the PM 2.5 $\mu\text{g}/\text{m}^3$ exhibit positive correlation with temperature in summer compared to winter. In terms of magnitude, the correlation is higher in winter relative to the summer which could be due to stronger solar wind speed in winter compared to the summer. While in spring (autumn) the correlation of PM 2.5 $\mu\text{g}/\text{m}^3$ displayed similar magnitude with negative (positive) variation, having correlation values -0.010502 (0.083316) respectively. The overall correlation of PM 2.5 $\mu\text{g}/\text{m}^3$ with temperature seems to indicate an indirect relation winter and spring while opposite is the case in summer and autumn. This could be due to the loading and reduction during the transition of seasonal variations. In winter, the correlation of PM 2.5 $\mu\text{g}/\text{m}^3$ with pressure has positive value (0.014496) relationship while a negative correlation was obtained in summer (-0.05282) which are contrary to the observed relationship with temperature in these seasons. Generally, a strong correlation exist between PM 2.5 $\mu\text{g}/\text{m}^3$ and atmospheric parameters particularly in summer season. This strong relationship may be attributed to some meteorological influences. However, the correlation between PM2.5 $\mu\text{g}/\text{m}^3$ and pressure show an indirect relationship in spring (-0.006861) while the PM 2.5 $\mu\text{g}/\text{m}^3$ shows a direct relationship in autumn (0.048192). These results are similar

to what was observed with respect to temperature. If the P-value is smaller than the significance level ($\alpha = 0.05$), we reject the null hypothesis in favor of the alternative and then conclude that the correlation is statistically significant or we conclude that there is a linear relationship between temperature/pressure and particulate matter (PM2.5 $\mu\text{g}/\text{m}^3$) in the analysis at p-value, but if the P-value is bigger than the significance level ($\alpha = 0.05$), we fail to reject the null hypothesis then we conclude that, the correlation is not statistically significant and the p-value where drive from ANOVA table.

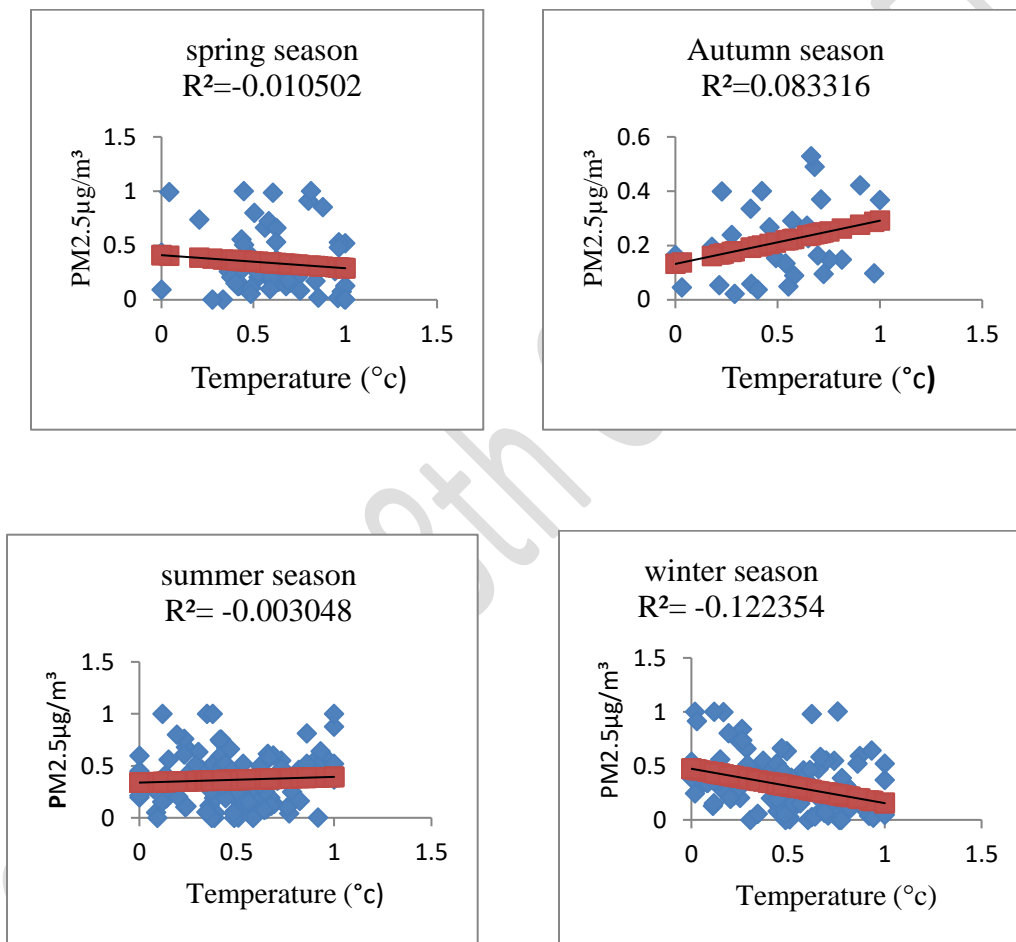


Figure 2. Seasonal correlation of PM2.5 $\mu\text{g}/\text{m}^3$ concentrations with temperature at Minna

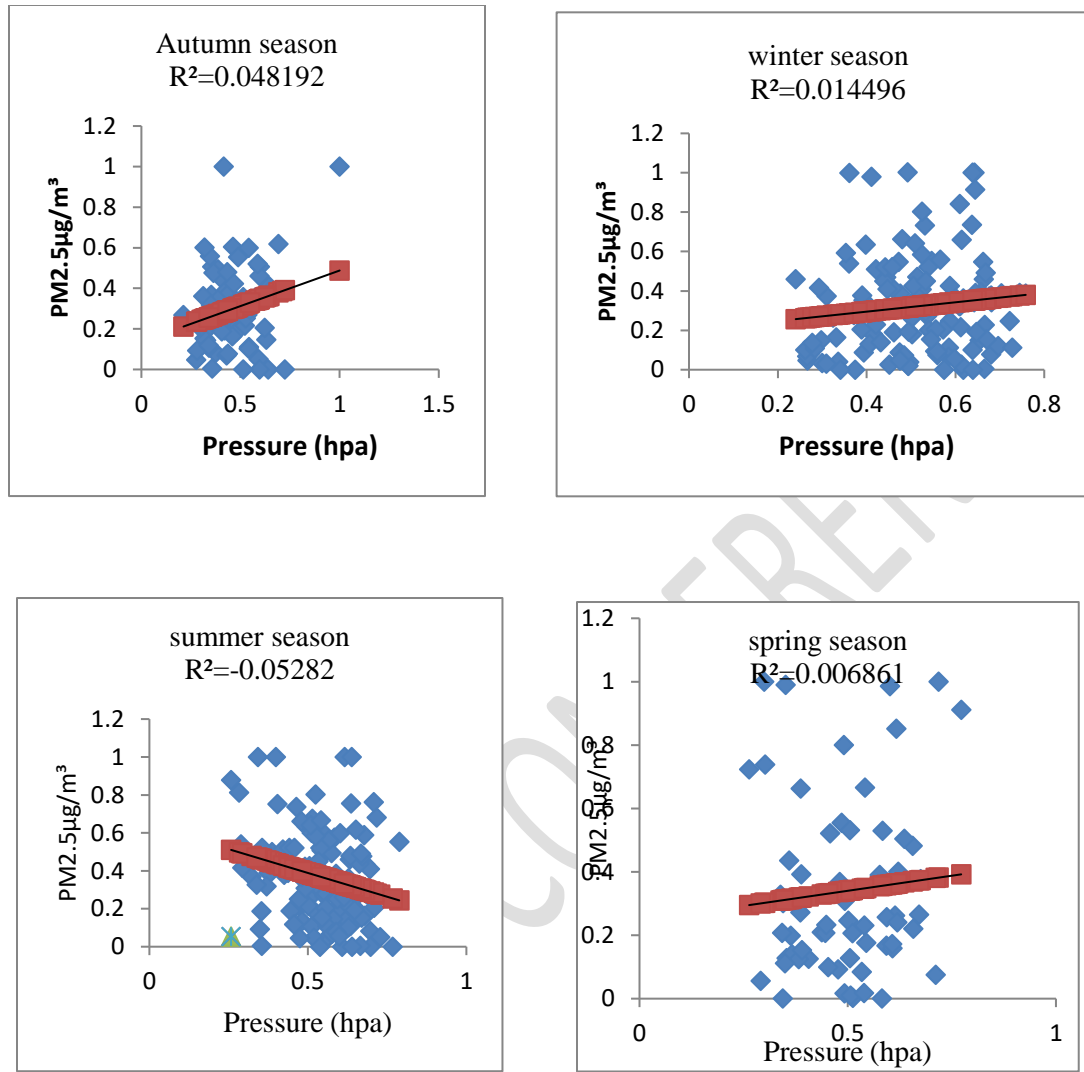


Figure 3: seasonal correlation between $\text{pm}_{2.5}\mu\text{g}/\text{m}^3$ concentration and pressure at Minna

the correlation between $\text{PM}_{2.5} \mu\text{g}/\text{m}^3$ and temperature indicate a high negative magnitude (-0.003048 , $P < 1.23\text{E}-19$) due to horizontal transport of dust particles from the sub-Saharan region by dry continental air masses that dominated the area as compare with winter solstice which has lowest magnitude (-0.122354 , $P < 7\text{E}-10$) due to scavenging process and presence of maritime air masses (south westerly wind) and inter-tropical continuity zone that brings heavy downfall from the Atlantic ocean which is in agreement with earlier work in Hong Kong by (Shi *et al.*, 2012) that found (-0.478), while during spring equinox shows an indirect correlation with lower magnitude (-0.010502 , $P < 7.7\text{E}-05$) shows similar magnitude with Autumn with positive value of (0.083316 , $P < 0.029014$) due to the transition period during which dust occur and moisture content of the atmosphere rises due to the enhancement of rainfall which reduces the loading of $\text{PM}_{2.5} \mu\text{g}/\text{m}^3$ and coincide with period where the sun move northward to equator and this result agree recent study conducted in Northeast China by (Meng *et al.*, 2020). Which is statistically at significant level. Furthermore the correlation between $\text{PM}_{2.5} \mu\text{g}/\text{m}^3$ and atmospheric pressure shows an indirect relation with lowest positive

magnitude (0.006861, $P > 0.108958$) in spring and this disagree with (Yang *et al.*, 2017) that obtained a magnitude of (0.04) indication that if atmospheric pressure increases PM 2.5 $\mu\text{g}/\text{m}^3$ also increases. But in autumn season, the correlation between PM 2.5 $\mu\text{g}/\text{m}^3$ and pressure was different indication of a weak direct relationship with a magnitude (0.048192, $P > 0.163777$) and it is in consistent with the study of (Tran *et al.*, 2020) conducted and reach out a magnitude (0.0042) this is due to the anthropogenic emission of particulate matter and presence of high pressure (low wind) which prevailing the period which provide room for accumulation of PM 2.5 $\mu\text{g}/\text{m}^3$. But the correlation between PM 2.5 $\mu\text{g}/\text{m}^3$ and atmospheric pressure during the summer solstice shows a indirect magnitude (-0.05282, $P < 1.38\text{E}-08$) and agreed with (Gao *et al.*, 2022) in Harbin with a magnitude (-0.052404), but disagree with (Poormolaie *et al.*, 2022) at Iran in Mashhad found out that (0.433, $p > 0.050$), were it is similar to winter solstice with low direct magnitude (0.014491, $P < 0.037617$), which implies that, if atmospheric pressure increases PM 2.5 $\mu\text{g}/\text{m}^3$ also increases or vice-versa. During this season the region exhibit high pressure (low temperature) which provide accumulation of PM 2.5 $\mu\text{g}/\text{m}^3$ due to low wind speed.

CONCLUSION

The study has established that there exist a relationship between PM 2.5 $\mu\text{g}/\text{m}^3$ with some lower atmospheric parameters (temperature and pressure). The main findings shows that PM 2.5 $\mu\text{g}/\text{m}^3$ concentration has positive correlation with pressure during winter solstice (0.014496), Autumn (0.048192) and spring solstice (0.006861) while negative correlation was observed during summer equinox (-0.05282). Where autumn solstice indicate highest coefficient of correlation 0.048192 with pressure, but lowest correlation was observed during summer (-0.05282) which indicate that, pressure influence PM 2.5 $\mu\text{g}/\text{m}^3$ mainly during autumn solstice, but the correlation coefficient between PM 2.5 $\mu\text{g}/\text{m}^3$. However, temperature shows a lowest and indirect magnitude during winter -0.122354 then followed by spring equinox -0.010502. Furthermore, during autumn and summer it indicate a direct magnitude with 0.083316 and 0.003048 respectively. But generally during autumn PM 2.5 $\mu\text{g}/\text{m}^3$ indicated highest direct correlation with temperature as compared to all seasons and is mainly influencing PM 2.5 $\mu\text{g}/\text{m}^3$ concentration. During autumn solstice PM 2.5 $\mu\text{g}/\text{m}^3$ exhibit similar direct magnitude 0.048192 as compare to all season with pressure.

SUMMARY

The lower atmospheric parameters like temperature and pressure have impacted the variation of PM2.5 $\mu\text{g}/\text{m}^3$ concentration level at different seasons during the year of 2008 when the local emission is control, the correlation between PM2.5 $\mu\text{g}/\text{m}^3$ concentration and other parameters can be used for prediction of air pollution concentration at different seasons and help government to make emission-control polices to prevent and reduce health effects of PM2.5 $\mu\text{g}/\text{m}^3$ at different seasons.

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CONFLICT OF INTEREST

Author have no conflicts of interest exist.

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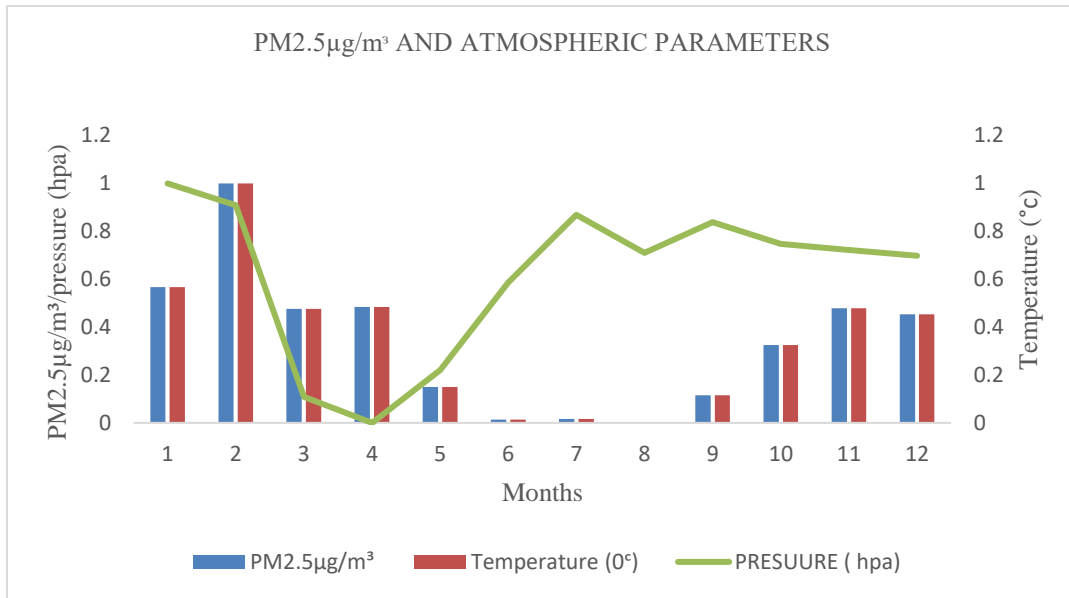


Figure 1: shows a relationship between PM2.5 $\mu\text{g}/\text{m}^3$ and some lower atmospheric parameters in 2008

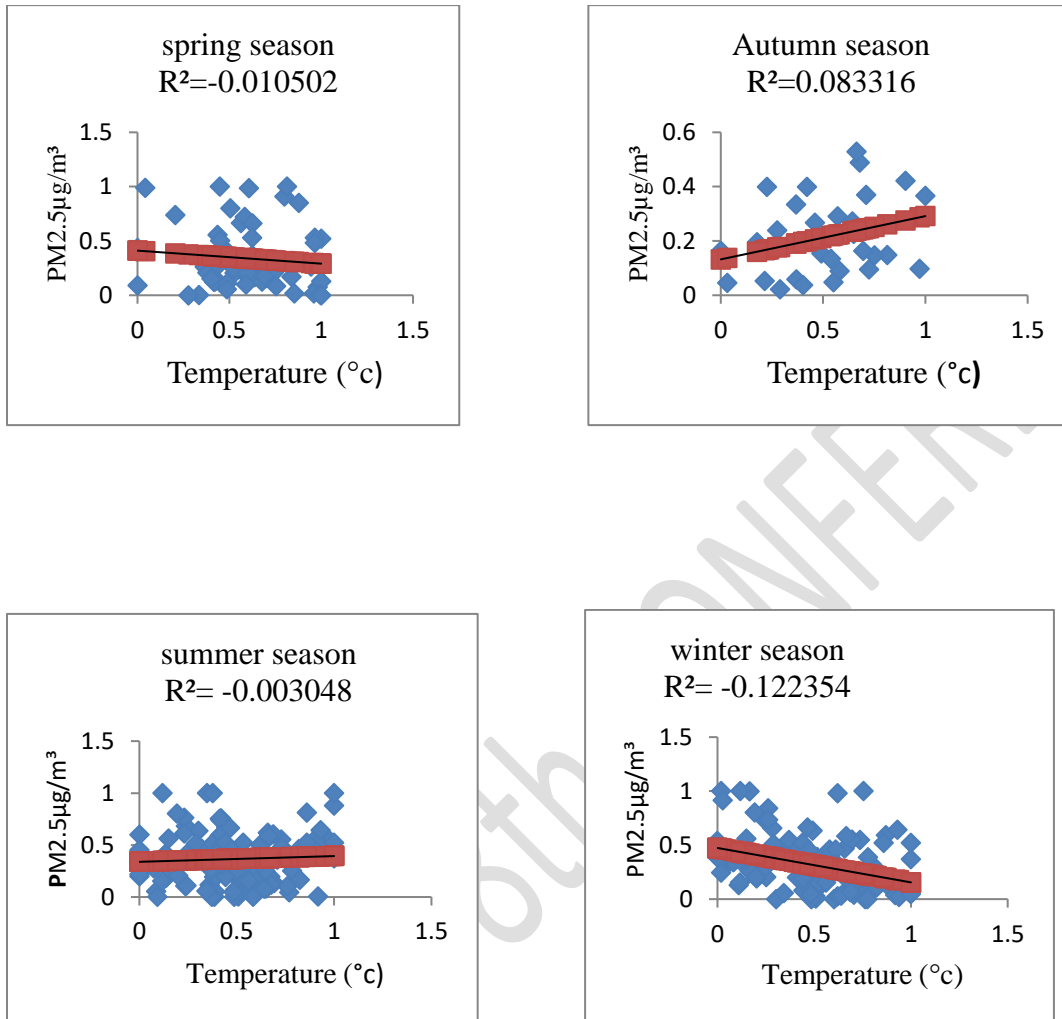


Figure 2. Seasonal correlation of PM2.5 $\mu\text{g}/\text{m}^3$ concentrations with temperature at Minna

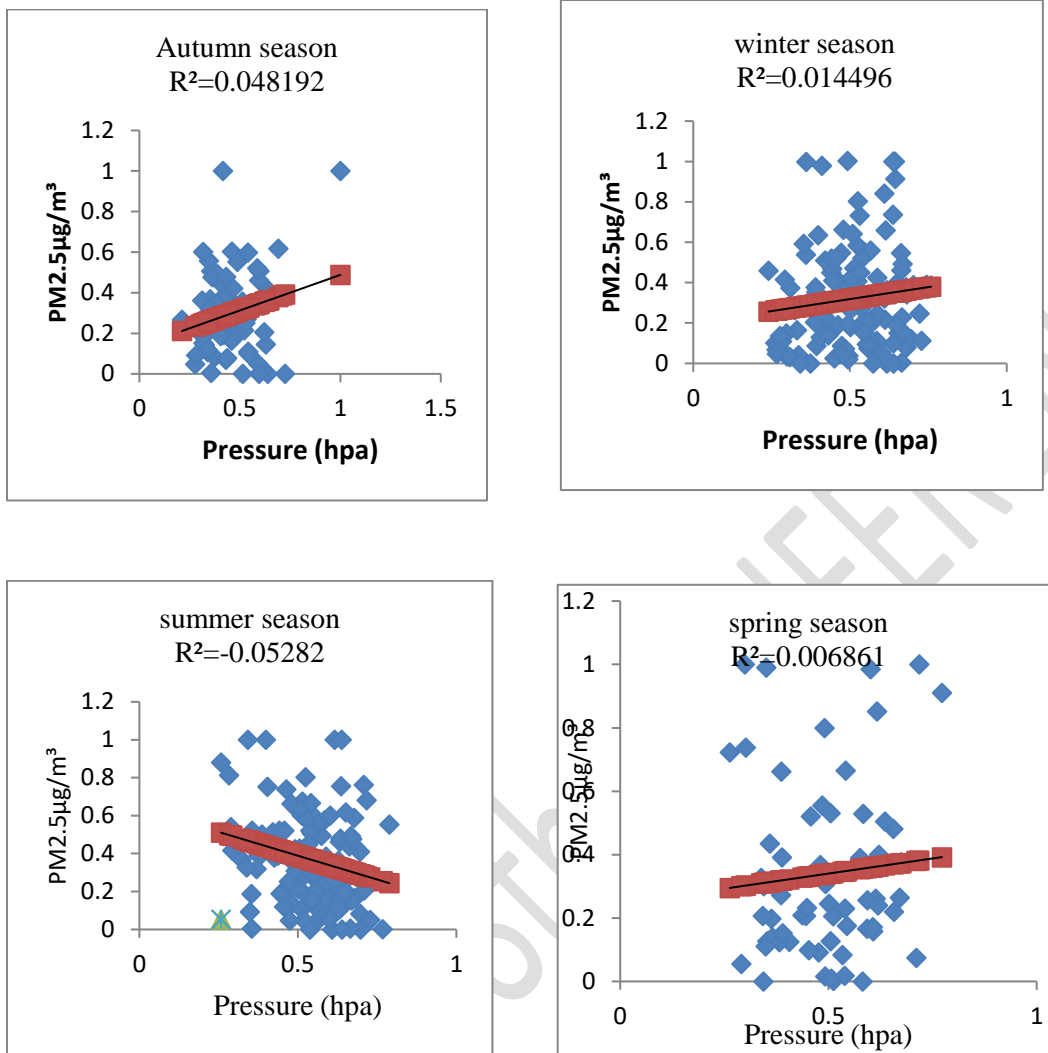


Figure 3: seasonal correlation between pm2.5 $\mu\text{g}/\text{m}^3$ concentration and pressure at Minna