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Relationship Between Particulate Matter (PM2.5μg/m³) and Some Lower Atmospheric Parameters in North-Central Nigeria, During Dip Minimum Solar Activity

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ABSTRACT

This paper investigated the relationship between particulate matter (PM 2.5 μg/m³) concentrations and some lower atmospheric parameters in Niger State (Minna) during the year of minimum solar activity 2008. Lower atmospheric parameters, such as temperature and pressure, were used in the study. The particulate matter and the monthly average atmospheric parameters were converted to daily averages and normalised to a standard scale. The result shows seasonally enhanced PM 2.5 μg/m³ with temperature, with the least amplitude in autumn and the least difference in winter, and rarely any noticeable difference in spring and summer. The seasonal correlation between PM 2.5 μg/m³ and temperature shows a low indirect relationship, with a magnitude of -0.12235 in winter relative to spring -0.01050. In contrast, the PM2.5 μg/m³ maintained a higher direct relationship in autumn compared to summer, with magnitudes of 0.083316 and 0.003048, respectively. The correlation between PM2.5 μg/m³ and pressure in autumn, winter, and spring shows a positive correlation of 0.048192, 0.014496, and 0.006861, respectively. However, an indirect relationship in summer with a magnitude of -0.05282 was observed. The correlation coefficient of PM2.5 μg/m³ is higher during autumn, 0.048192, and has a lower value during summer, -0.05282, due to the scavenging process. Generally, a higher direct correlation exists between PM 2.5 μg/m³ and atmospheric parameters, particularly in autumn, with a correlation coefficient of 0.083316 across all seasons. This is due to the transport of dust particles by dry continental air masses, which is similar to the correlation observed in 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, which are dominant during these periods.

Keywords: Air temperature (0^c), Minna, pressure (hpa), PM2.5 μg/m³.

INTRODUCTION

The term Particulate Matter (PM 2.5 µg/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 µg/m^3 denotes particles with diameters that are equal to or less than 2.5 µg/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 µg/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 µg/m^3 and various meteorological variables, encompassing temperature and atmospheric pressure. (Shi et al., 2012). 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 leading to a negative impact on the environment and the health of living things. The restriction of movement and vehicles, and the closure of industries in the world during COVID-19, have positively impacted air pollutants because artificial air pollutants 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 µg/m^3), persist in presenting noteworthy perils to global health, particularly in emerging nations (Kliengchuay et al., 2022). However, Fine Particulate Matter (PM2.5 µg/m^3) has been recognised as a significant threat to public health; numerous investigations have documented the correlation between PM2.5 µg/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 µg/m^3) on human well-being. Their primary objectives are to offer comprehensive spatial and temporal observations of atmospheric parameters and air pollution studies on the overall well-being of humans and health research. As such, the utilization of satellite remote sensing for the monitoring of fine particulate matter is becoming increasingly vital in the field of environmental surveillance (Zhang & Li, 2015). According to Tran et al. (2020), once air pollutants are emitted, 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 µg/m^3. The influence of meteorological parameters has been acknowledged as significant in the escalation or reduction of PM2.5 µg/m^3. Meanwhile, climate change is expected to modulate ambient PM2.5 µg/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. Surface pressure is commonly observed during calm and cloudless weather conditions when the mixing of air masses is sluggish. In contrast, low pressure usually prevails during convective and stormy conditions, characterised by strong winds. These 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 PM2.5µg/m^3 concentration and pressure exhibits a 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, it exhibits a positive magnitude (0.03). They further observed that the correlation coefficient has a stronger magnitude in summer (0.14) with temperature. At the same time, winter exhibits a positive and low value (0.27). However, the coefficient of correlation between PM2.5ug/m³ and temperature has a 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 southwest China. The cities with the positive value are larger in spring and winter due to the presence of sulfate content, which makes the Correlation positively stronger. The correlation differs greatly with different seasons. However, the most influencing factor within the eight seasons where temperature in summer (R^2=0.14), the cities with positive correlation value is larger in spring and winter due to coal combustion which lead to increase in PM2.5ug/m³ concentration and other air pollutant in this region, due to present of sulfate content that make the correlation positively stronger, the correlation between PM2.5μg/m³ and temperature differ greatly with different seasons. However, the seasonal variation of the coefficient of correlation in the two regions shows a negative correlation in each season. 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 diffuse and are diluted vertically. Meanwhile, a direct correlation between annual PM2.5μg/m³ with temperature was observed (R^2=0.37, $P<0.017$), which is statistically significant. However, the relative humidity was (R^2=0.39, $P<0.05$) at a significant level. At the same time, the atmospheric pressure has a positive correlation (R^2=0.219, $P<0.05$). This study was conducted by Kermani et al. during the year 2019-2020 at Isfahan in Iran. In a similar study conducted by Wang and Ogawa (2015) in Japan, Nagasaki, using Spearman correlation analysis, they found that there exists a seasonal variation between PM2.5μg/m³ and meteorological parameters. PM2.5μg/m has a strong positive correlation with temperature, with no significant differences among the four seasons. Because temperature can affect the formation of particles, 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 most of the pollutant to Nagasaki in all 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 were health effect can be harnessed relatively easy by using statistical analysis because a large majority of PM2.5μg/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 PM2.5μg/m³ particularly in this region.

MATERIALS AND METHOD OF ANALYSIS

This study uses lower atmospheric parameters, such as temperature, PM2.5 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 hourly PM2.5 μg/m³ (merr-2-model) data for each day were analyzed using Microsoft Excel and the Spearman correlation technique. The hourly lower atmospheric parameters, such as temperature, pressure, and PM2.5 μg/m³ from (merra-2), were used during the year of dip minimum solar activity 2008. The study covers the 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 results in an intensification of air pollution from the most important source of its formation. Moving vehicles are also a causative agent and release high amounts 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 a 95% significance level.

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

The PM2.5 μg/m³ variable is transformed using a linear regression technique and used as the dependent variable in the correlation analysis. The PM2.5 μg/m³ and the atmospheric parameters values were normalised to have a standard scale between 0 and 1, using 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).

$$X_{normlized} = \frac{X - X_{min}}{X_{max.} - X_{min}} \qquad (2)$$

RESULTS AND DISCUSSION

All the data were normalised, and their values were between 0 and 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 abundant rainfall. This is evident with the increase in pressure (hpa) as indicated in Figure 1. We assert that the presence of rainfall in those months is likely to 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 corresponds to the period when the sub-solar point is directly at the equator, resulting in higher temperatures in these months (Bardhan et al., 2014). This may likely suppress some of the effects that may arise from lower atmospheric parameters, as is evident 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 a subsequent increase in the atmospheric pressure (hPa) as shown in Figure 1.

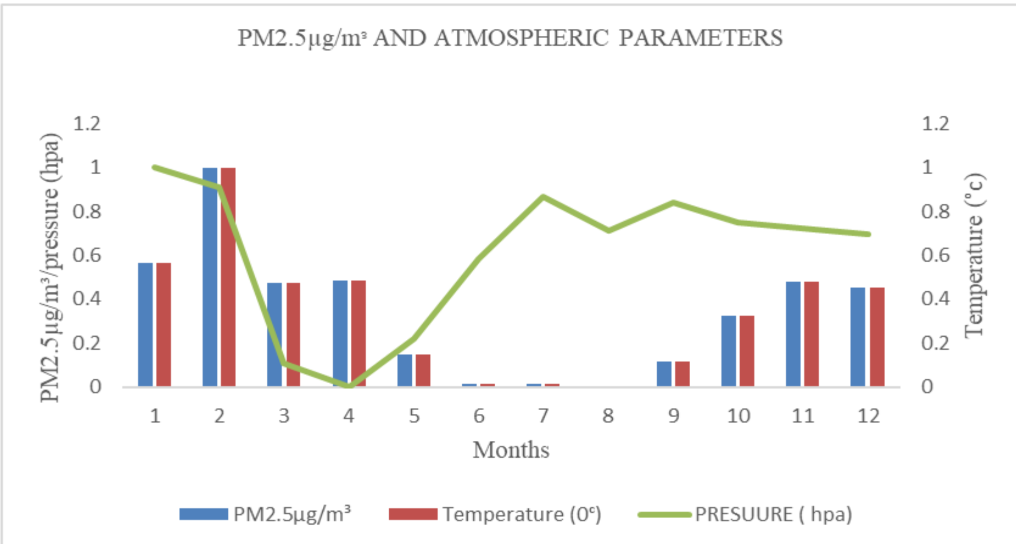

Figure 1 shows a relationship between PM2.5 μg/m³ and some lower atmospheric parameters in 2008

Generally, the result shows a linear relationship between PM2.5 µg/m^3 concentrations and atmospheric pressure (hPa) in spring, but not in autumn, which is an equinoctial month, indicating equinoctial asymmetry between the two parameters, as shown in Figure 1. The consistent minimum PM2.5 µg/m^3 concentrations in summer months could be influenced by higher concentrations of atmospheric pressure (hPa), as indicated in Figure 1.

To investigate the relationship between PM2.5µg/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 µg/m^3 and temperature shows a more indirect relationship with magnitude (-0.122354) in winter. In contrast, in summer, a direct relationship was observed with a positive value of 0.003048, indicating that PM 2.5 µg/m^3 exhibits a positive correlation with temperature in summer compared to winter. In terms of magnitude, the correlation is higher in winter than in summer, which could be due to stronger solar wind speed in winter compared to summer. While in spring (autumn), the correlation of PM 2.5 µg/m^3 displayed a similar magnitude with negative (positive) variation, having correlation values -0.010502 (0.083316) respectively. The overall correlation of PM 2.5 µg/m^3 with temperature seems to indicate an indirect relation in winter and spring, while the 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 µg/m^3 with pressure has a positive value (0.014496). In contrast, a negative correlation was obtained in summer (-0.05282), which is contrary to the observed relationship with temperature in these seasons. Generally, a strong correlation exists between PM 2.5 µg/m^3 and atmospheric parameters, particularly in the summer season. This strong relationship may be attributed to some meteorological influences. However, the correlation between PM2.5 µg/m^3 and pressure shows an indirect relationship in spring (-0.006861) while PM2.5 µg/m^3 shows a direct relationship in autumn (0.048192). These results are similar to what was observed concerning temperature. Suppose the P-value is smaller than the significance level (α =0.05). In that case, we reject the null hypothesis in favour of the alternative, concluding that the correlation is statistically significant or that there is a linear relationship between temperature/pressure and particulate matter (PM2.5 µg/m^3) in the analysis at a p-value. However, if the P-value is bigger than the significance level (α = 0.05), we fail to reject the null hypothesis. We conclude that the correlation is not statistically significant, and the p-value is derived from the ANOVA table.

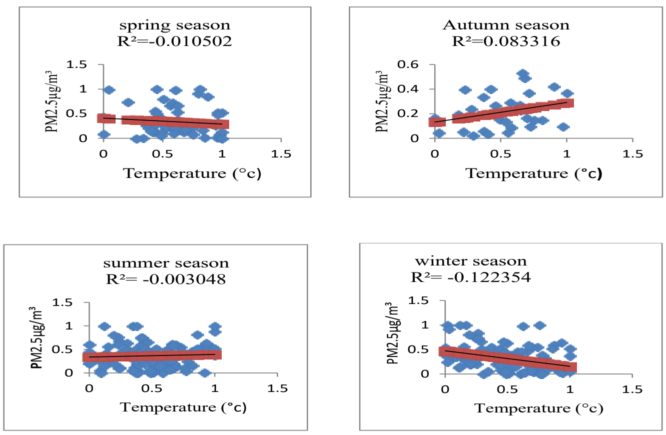

Figure 2. Seasonal correlation of PM2.5 µg/m^3 concentrations with temperature at Minna

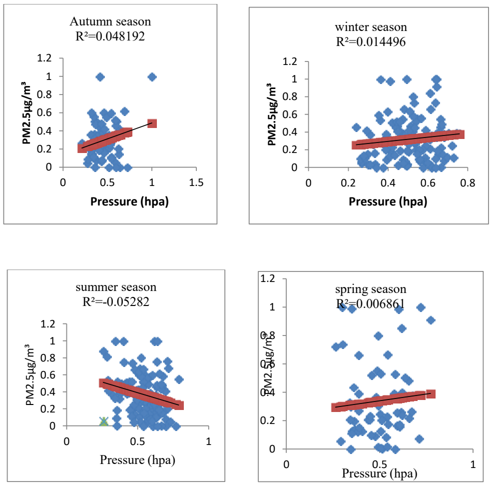

Figure 3: seasonal correlation between PM2.5 µg/m³ concentration and pressure at Minna

the correlation between PM2.5 µg/m³ and temperature indicate a high negative magnitude (-0.003048, P<1.23E-19) due to horizontal transport of dust particles from the sub-Sahara region by dry continental air masses that dominated the area as compare with winter solstice which has lowest magnitude (-0.122354, P<7E-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<7.7E-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 PM 2.5 µg/m³ 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 significant. Furthermore, the correlation between PM 2.5 µg/m³ and atmospheric pressure shows an indirect relation with the 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 µg/m³ also increases. However, in the autumn season, the correlation between PM 2.5 µg/m³ and pressure was a different indication of a weak direct relationship with a magnitude (0.048192, P>0.163777). It is consistent with the study of (Tran et al., 2020), which reached a magnitude of 0.0042. This is due to the anthropogenic emission of particulate matter and the presence of high pressure (low wind) prevailing during the period, which provides room for the accumulation of PM 2.5 µg/m³. However, the correlation between PM 2.5 µg/m³ and atmospheric pressure during the summer solstice shows a indirect magnitude (-0.05282, P<1.38E-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 µg/m³ also increases or vice-versa. During this season, the region exhibits high pressure (low temperature), which leads to the accumulation of PM 2.5 µg/m³ due to low wind speed.

CONCLUSION

The study has established a relationship between PM 2.5 µg/m³ and some lower atmospheric parameters (temperature and pressure). The main findings show that PM 2.5 µg/m³ concentration has a positive correlation with pressure during winter solstice (0.014496), Autumn (0.048192), and spring solstice (0.006861), while a negative correlation was observed during summer equinox (-0.05282). The autumn solstice indicates the highest coefficient of correlation, 0.048192, with pressure, but the lowest correlation was observed during summer (-0.05282), which indicates that pressure influences PM 2.5 µg/m³ mainly during the autumn solstice. However, temperature shows a minimum and indirect magnitude during winter (-0.122354), followed by the spring equinox (-0.010502). Furthermore, during autumn and summer, it indicates a direct magnitude of 0.083316 and 0.003048, respectively. However, generally during autumn, PM 2.5 µg/m³ indicated the highest direct correlation with temperature as compared to all seasons, and mainly influences PM 2.5 µg/m³ concentration. During the autumn solstice, PM

2.5 μg/m³ exhibits a direct magnitude of 0.048192 compared to all seasons with pressure.

SUMMARY

The lower atmospheric parameters like temperature and pressure have impacted the variation of PM2.5 μg/m³ concentration level at different seasons during the year of 2008 when the local emission is control, the correlation between PM2.5 μg/m³ 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 μg/m³ at different seasons.

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CONFLICT OF INTEREST

The author has no conflicts of interest.

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