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Assesement Of Atmospheric Particulate Matter 2.5 ($Pm_{2.5}$) Air Pollution Levels At Abakaliki Rice Processing Sites

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Abstract
At regular intervals, the atmospheric air that supports life on Earth is often polluted through several sources. In our contemporary society, there are great concerns about the high levels of atmospheric air pollution due to the $PM_{2.5}$ generated, particularly at various rice processing sites, and are circulated in the lower atmosphere (troposphere), where life is supported. After being harvested, Abakaliki rice normally undergoes numerous processing cycles to make it viable for human consumption. The aim of this study was to assess the levels of $PM_{2.5}$ generated at Abakaliki rice processing sites. The dataset used in this study was obtained via direct monitoring and measurement of $PM_{2.5}$ levels at various rice processing sites in the areas of study. The results revealed high $PM_{2.5}$ concentrations at the husk removing, parboiling, final heating and de-stoning sites with values of 72 $\mu g/m^3$, 69 $\mu g/m^3$, 66 $\mu g/m^3$ and 70 $\mu g/m^3$, respectively, and annual mean concentrations of 58.75, 55.50, 55.75, and 58.08 $\mu g/m^{3,}$ respectively. Similarly, high levels of air quality indices (AQIs) were obtained for all the sites, which are far above the World Health Organization 2021 updated guidelines recommended for safe and healthy air. Thus, there is a potential trait for the health of people at those processing sites and an urgent need for the replacement of the traditional methods of processing rice with the modern methods with a moderated emission of $PM_{2.5}$ capacity.

Keywords: *Atmosphere, $PM_{2.5}$, air pollution, Abakaliki rice, processing sites.*

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I. Introduction

The atmosphere is generally regarded as part of the universe that is composed of gaseous mixtures surrounding the Earth. It provides many functions that support and protect life on Earth, such as providing shields from direct ultraviolet rays emanating from the sun and providing breathing air. Additionally, by means of insolation, the atmosphere can keep the planet warm and therefore regulate extreme temperature variations between day and night. At regular intervals, the atmospheric air that supports life is often polluted by natural and artificial activities on Earth through several sources.

Atmospheric air pollution due to $PM_{2.5,}$ particularly in the lower atmosphere (troposphere), where life is supported and controlled by numerous artificial and natural interactions, is highly important in contemporary society. This is because human breathing levels through the nostril lie within this region, and hence, any little air pollution has grave consequences for humans, as they consistently inhale air at all times.

Particulate matter 2.5 ($PM_{2.5}$), also called fine particulate matter, is an atmospheric air pollutant that is essentially made up of tiny solid particles and liquid aerosols that have diameters less than 2.5 microns. Air pollution refers to contamination of the indoor or outdoor environment by any chemical, physical or biological agent that modifies the natural characteristics of the atmosphere (WHO, 2023).

Combustion devices found in different households, smoke from motor vehicles, emissions from industrial facilities and forest fires constitute common sources of air pollution in our environment. According to the WHO (2023), the major health concerns in our environment are ozone, nitrogen dioxide, carbon monoxide, PM, and sulphur dioxide. Respiratory and other chronic diseases caused by outdoor and indoor environmental air pollution from PM and other sources are associated with high morbidity and mortality (WHO, 2023).

Atmospheric air pollution resulting from $PM_{2.5}$ will be of great concern if the level in a given ambient air exceeds the World Health Organization (WHO) (2021) updated guideline recommended for healthy air quality. Inhaling $PM_{2.5}$ that its level in the atmosphere exceeds the WHO recommended standard level for healthy air quality can trigger numerous health-related complications, such as cough, catarrh and other health-related issues. According to Philip *et al.* (1992), PM is formed from vehicular fuel burning, wood burning, stoves and power plants. $PM_{2.5}$ can be emitted from various sources, such as automobile emissions in the air, industrial emissions from combustion engines, and forest fires, and since it is so minute in size, it may continue to remain suspended in the atmosphere for several years and hence is capable of travelling very long distances.

According to the IEC (2022), $PM_{2.5}$ is capable of penetrating deep into the lungs and entering the bloodstream, therefore posing risks of health issues such as cardiovascular, respiratory, and neurological diseases. $PM_{2.5,}$ known as fine PM with a diameter less than 2.5 µm, is capable of penetrating the alveolar region of the respiratory system (Utell and Frampton, 2000). In 2012, the WHO reported that more than 3.3 million deaths worldwide were attributed directly to particulate matter pollution (WHO, 2012). A study conducted by Brown (2009), Global Sources of Local Pollution (2009), and Martuzzi *et al.* (2006) reported that the health consequences of exposing the general population to particulate matter air pollution may include respiratory and heart diseases, increases in complications for people with chronic diseases, and increases in the number of hospitalization cases. The increase in the death rate due to heart and respiratory disease as well as lung-related diseases is equally prominent (WHO, 2013; Takashi *et al.*, 2015).

Rice is a cereal crop and a staple food that is widely cherished and consumed by wider populations. Rice is considered one of the most common cereal crops consumed by more than half of the world's population (Khush, 1997; Dogara and Jumare, 2014).

Abakaliki rice, often referred to as local rice, is cultivated and harvested within and outside Abakaliki, the capital city of Ebonyi State, primarily by local farmers. After it is harvested, it must subsequently undergo vigorous processing cycles to make it viable for human consumption. These processing cycles involve numerous strenuous techniques that are carried out mostly by farmers for personal usage or by individuals who engage with them for commercial purposes. To process Abakaliki rice, it must pass through various processing stages that may involve the use of different equipment and methods that are capable of generating fine particulate matter and other air pollutants that are emitted into the atmosphere during operation. These emissions may consequently lead to atmospheric air pollution and therefore may pose grave health problems for farmers who process rice and for society at large. Other researchers have focused on rice processing methods, but little attention has been given to the atmospheric air pollution generated at processing sites and its negative impact on the farmers who are most vulnerable to direct exposure to $PM_{2.5}$ emissions from rice processing equipment and methods. Therefore, the objective of this paper is to investigate the level of $PM_{2.5}$ distribution at Abakaliki rice processing sites and the possible impacts of atmospheric air pollution on farmers to sustain rice production and boost agricultural sustainability and development.

II. Abakaliki Rice Processing Stage

Chaff removal: This is the first stage in the Abakaliki rice processing stage, which involves the processor pouring and soaking the harvested rice paddy, which is composed of normal rice, chaffs and dust particles, into a drum containing water. As rice paddies are poured, dust particles escape into the atmosphere, and normal rice sinks into the bottom of the drum for further processing while the chaffs are hand sieved out by the farmer.

Parboiling (initial heating): This involves heating or boiling a normal rice paddy to a certain temperature using firewood for a given period of time, which is determined by the farmer, who regularly monitors and controls the fire until the parboiling time is reached.

The final heating process involves the heating of the parboiled rice paddy in a drum to enable the rice husk to break open from the paddy. During this process, the parboiled rice that has been left overnight to cool is first removed from the remaining water in the drum, and the water is poured out. After that, the rice is returned back into the drum, a small quantity of water is poured into the drum, and then, the farmer begins heating using firewood.

Sun drying: This involves removing rice paddies from the drum after final heating and spreading them on mats, cemented floors or any other platform to drain the water content out.

Husk removal/milling: Remove the husk from the Cain. Rice milling is usually carried out by rice farmer or rice mill engine operators via a rice milling engine as well as by manual sieving method to separate rice from Cain and some quantities of rice that are mixed with husk chaff during milling.

De-stoning: De-stoning is used further to remove the remaining chaff and stones from the milled rice prior to packaging for consumption.

Table 1: Design of rice processing sites in area A

Rice processing site	Nature	No. of doors	No. of windows
Chaff removing	Open space	Nile	Nile
Parboiling	Open space	Nile	Nile

Final heating & spraying	Open space	Nile	Nile
Sun drying	Open space	Nile	Nile
Husk removing/milling	In-house	1	2
De-stoning	In-house	1	2

Table 2: Design of rice processing sites in area B

Rice processing site	Nature	No. of doors	No. of windows
Chaff removing	Open space	Nile	Nile
Parboiling	Open space	Nile	Nile
Final heating	Open space	Nile	Nile
Sun drying	Open space	Nile	Nile
Husk removing/milling	In-house	1	2
De-stoning	In-house	1	2

Fig. 1: (a) Chaff removing site (b) Parboiling site (c) Final heating site (d) Sun drying site (e) Husk removing/milling site (f) De-stoning site

III. Materials And Methods

Study Area

This research was carried out in Abakaliki, the capital city of Ebonyi State, which is located at longitudes and latitudes of 6.316°N and 8.127°E, respectively. This study was carried out at various rice processing sites within the Abakaliki metropolis. The data used covered a period of one year (2023).

Data collection

The particulate matter 2.5 ($PM_{2.5}$) concentrations data in the ambient air at the rice processing sites were monitored and collected using a digital readout photometric-laser particle counter equipment, with the specifications Aerocet Model 531--9800 Rev. C (Metone Inc. USA). This equipment was designed with an inbuilt particle data count for particle sizes of up to eight (8) different ranges, which include $PM_{2.5}$, PM_{10}, etc.

Data Analysis

After data collection, the monthly and annual means of the $PM_{2.5}$ concentration levels were calculated using Minitab 19. The annual mean values obtained were then used to calculate the air quality indices (AQIs) of $PM_{2.5}$ at all the processing sites (Wambebe and Duan (2020); USEPA, (2018; Lala *et al.*, (2023)). That is,

$$AQI_{PM} = \frac{PM\ Concentration}{WHO\ Standard} \times 100 \qquad 1$$

According to Lala *et al.* (2023), the guideline recommended standard values of $PM_{2.5}$ levels of 5 µg/m^3 and 15 µg/m^3 for annual and 24-hour averaging times for healthy air, respectively.

The annual AQIs of $PM_{2.5}$ obtained from the computed data were compared with the updated WHO (2021) global air quality standard guidelines for healthy air, as shown in Table 3 below.

Table 3: WHO (2021) global air quality standard guidelines

Air pollutant level	AQI	Health concern level	AQI daily colour code
Level 1	0 – 50	Good	Green
Level 2	51 – 100	Moderate	Yellow
Level 3	101 – 150	Unhealthy for sensitive group	Orange
Level 4	151 – 200	Unhealthy	Red
Level 5	201 – 300	Very unhealthy	Purple
Level 6	301 and above	Hazardous	Maroon

IV. Results And Discussion

Monthly mean concentration of atmospheric $PM_{2.5}$ at the processing sites

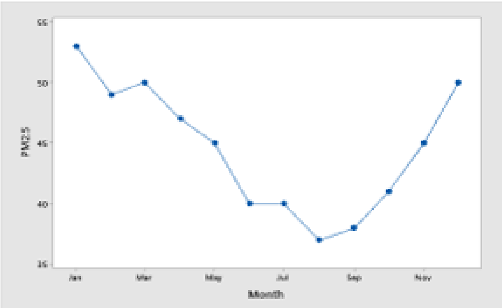

Fig. 2: Monthly mean concentration of $PM_{2.5}$ levels at the chaff removing site in area A

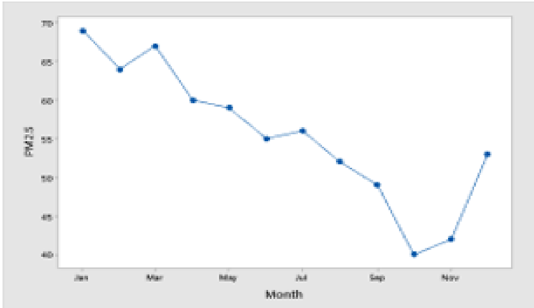

Fig. 3: Monthly mean concentration of $PM_{2.5}$ levels at the parboiling site in area A

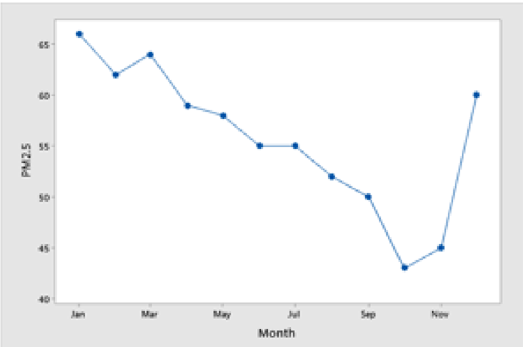

Fig. 4: Monthly mean concentration of $PM_{2.5}$ levels at the final heating site in area A

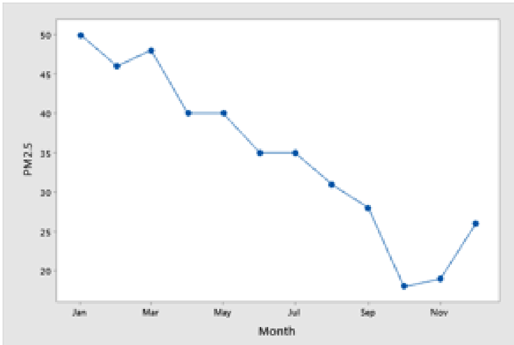

Fig. 5: Monthly mean concentration of $PM_{2.5}$ levels at the sun drying site in area A

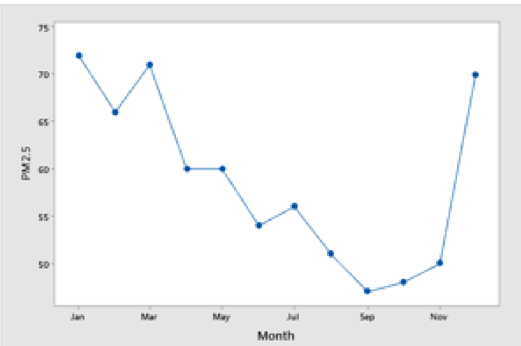

Fig. 6: Monthly mean concentration of $PM_{2.5}$ Levels at the husk removing/ milling site in area A

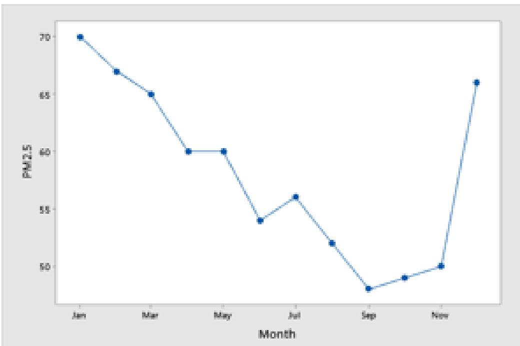

Fig. 7: Monthly mean concentration of $PM_{2.5}$ levels at the De-stoning site in area A

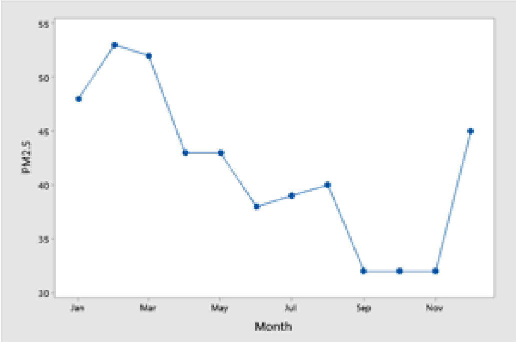

Fig. 8: Monthly mean concentration of $PM_{2.5}$ levels at the chaff removing site in area B

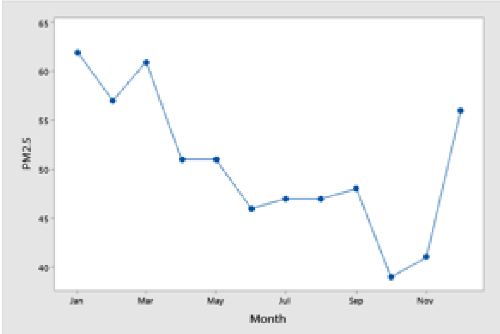

Fig. 9: Monthly mean concentration of $PM_{2.5}$ levels at the parboiling site in area B

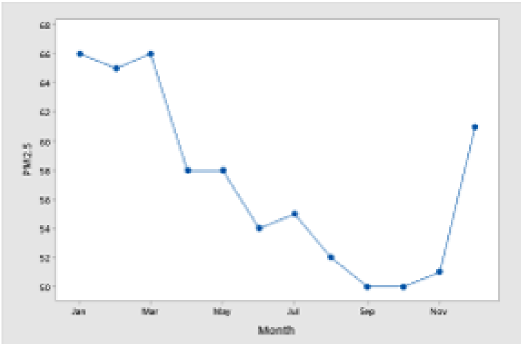

Fig. 10: Monthly mean concentration of $PM_{2.5}$ levels at the final heating site in area B

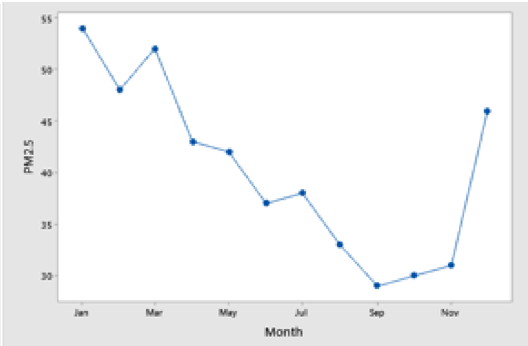

Fig. 11: Monthly mean concentration of $PM_{2.5}$ levels at the sun drying site in area B

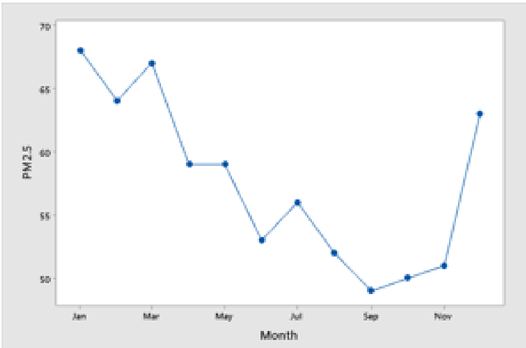

Fig. 12: Monthly mean concentration of $PM_{2.5}$ levels at the husk removing/ milling site in area B

Fig. 13: Monthly mean concentration of $PM_{2.5}$ levels at the de-stoning site in area B

Figs. 1-6 (area A) and Figs. 7-12 (area B) clearly show that the atmospheric particulate matter 2.5 ($PM_{2.5}$) levels recorded at the Abakaliki rice processing sites varied significantly during different months in the two areas of study. The 24-hour monthly mean concentrations of $PM_{2.5}$ obtained in the two areas ranged between 19 µg/m^3 and 72 µg/m^3 and between 31 µg/m^3 and 68 µg/m^{3,} respectively. The results are in accordance with the results of the monthly mean concentrations of between 17.41 µg/m^3 and 53.94 µg/m^3 for $PM_{2.5}$ obtained by Okoro and Ojobeagu (2024) in their previous work on $PM_{2.5}$ at Primary School Ogoja Road, Abakaliki. Furthermore, the findings of Ogbonna, Ukpai and Ubuoh (2020) in a related work at Ngwogwo in Ivo LGA, Ebonyi State, Nigeria are also in agreement with the results of this present study.

These concentrations are far greater than the concentration of 15 µg/m^3 recommended by the WHO (2021) air quality guideline (AQG) for healthy air 24-hour average exposures and may pose grave health effects on people within and outside the processing sites**,** especially those that are exposed to it 8 hours a day, 48 hours a week and 192 hours a month. However, it was shown that the $PM_{2.5}$ levels obtained at all the processing sites in the study areas were greater in the months of January–May and December, which are often referred to as the dry season and marked with intense sunshine, and the peak of harmattan usually characterized by high levels of dust in the ambient air due to the south-eastern trade wind laden, emanating from the Sahara Desert into Nigeria, which prevails within the period compared with the months of June–November, which are mostly referred to as the rainy season.

This may be related to the nature of the processing sites, whether they are in-house, which does not permit adequate movement of the $PM_{2.5}$ generated during processing, which tends to re-circulate within the house for a long time due to a compacted environment and thus increases the level of $PM_{2.5}$ pollution within the area or open space which depends on the method used during processing that permits the free flow of $PM_{2.5}$ generated during processing, which helps to decongest the environment of the emitted $PM_{2.5}$ and therefore reduces the level in the areas. Additionally, the methods adopted during the processing stages, which involve the use of various equipment and mechanisms such as milling machines, de-stoning machines and firewood heating, which are capable of generating $PM_{2.5}$ to a very large extent, as well as the season involved, are believed to contribute greatly to the variable increase in the concentration levels of $PM_{2.5}$ emission into the atmosphere within the areas of study. According to Ibe *et al*. (2016), fluctuations in the time of year or season could cause variations in $PM_{2.5}$ levels at any given location. In related research, Kim *et al*. (2015) reported that location differences may affect the concentrations of atmospheric pollutants across seasons. The results therefore suggest that there was a noticeable increase in the amount of $PM_{2.5}$ emitted into the atmosphere at the processing site, which is located in-house, compared with the processing sites, which are located in an open space. These findings suggest that the levels of $PM_{2.5}$ emission at all the processing sites within the study areas are greater during the dry season (January – may and December) than during the rainy season and may increase air pollution and contamination of the environment, thus indicating a very high risk to the healthy life of people within and outside the environment.

Annual mean concentration of atmospheric $PM_{2.5}$ at the processing sites

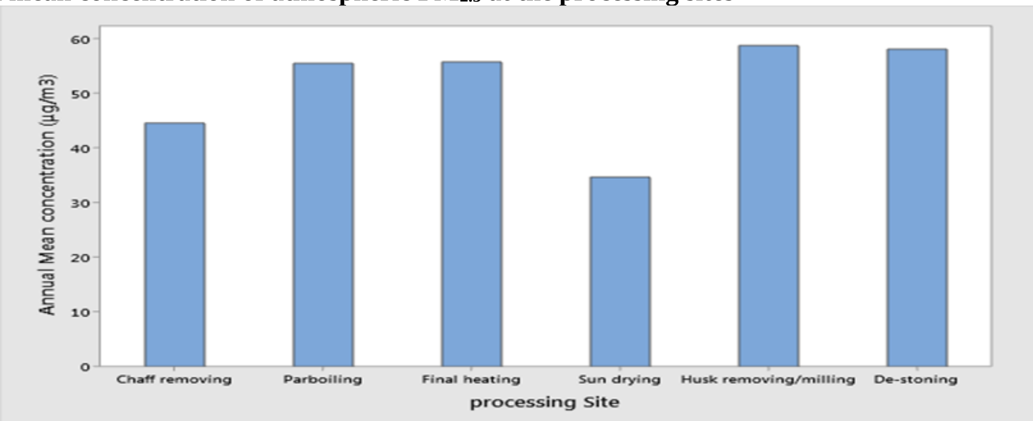

Fig. 14: Annual mean concentration of $PM_{2.5}$ at the processing sites in area A

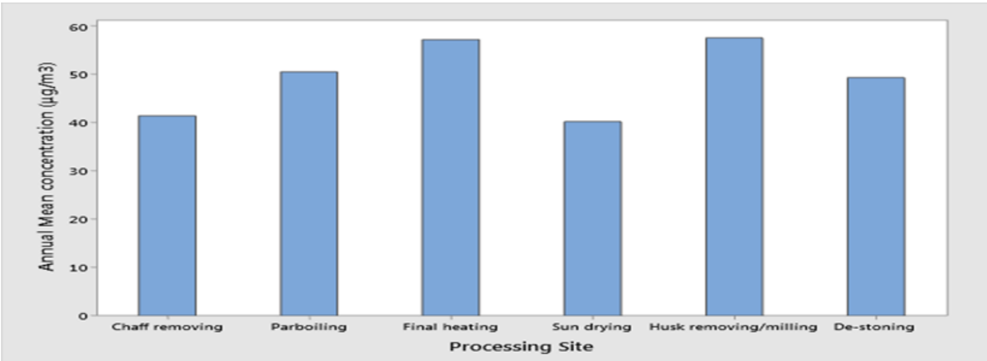

Fig. 15: Annual mean concentration of $PM_{2.5}$ at the processing sites in area B

The monitoring results in Fig. 14 generally show that the annual mean concentrations of atmospheric particulate matter 2.5 ($PM_{2.5}$) air pollution obtained at the parboiling, final heating, husk removing/milling and de-stoning rice processing sites are 55.50 µg/m^3, 55.75 µg/m^3, 58.75 µg/m^3 and 58.08 µg/m^3, respectively. The annual mean concentrations of $PM_{2.5}$ obtained at the sites are much greater than the annual mean concentrations obtained at the chaff removing and sun drying rice processing sites, with values of 44.58 µg/m^3 and 34.67 µg/m^{3,} respectively, in area A. Similarly, in area B (Fig. 15), the annual mean concentrations of atmospheric $PM_{2.5}$ air pollution of 50.50 µg/m^3, 57.17 µg/m^3, 57.58 µg/m^3 and 49.33 µg/m^{3,} respectively, were recorded at the parboiling, final heating, husk removing/milling and de-stoning rice processing sites and were higher than the annual mean concentrations of atmospheric $PM_{2.5}$ air pollution of 41.42 µg/m^3 and 40.25 µg/m^3 obtained at the chaff removing and sun drying rice processing sites.

The results revealed that high levels of annual mean concentrations of atmospheric $PM_{2.5}$ emissions were obtained at the husk removing/milling processing site, final heating processing site and de-stoning processing site in both areas of study; therefore, their contributions to high levels of atmospheric air pollution and the associated risks posed to people within that vicinity, especially those working closely with the equipment used at these sites, are emphasized. This heightens the increased level (concentration) of $PM_{2.5}$ air pollution at the processing sites and the need for immediate action towards reducing the surge to protect people within and outside the environment. This increase in the mean concentration of $PM_{2.5}$ in the two areas may be attributed to the type of equipment, methods used and environmental setting (such as the size and nature of the house where the equipment is located, the ventilation system, etc.) at the processing sites, which may be a precursor to such an increase during rice processing.

Air quality indices (AQIs)

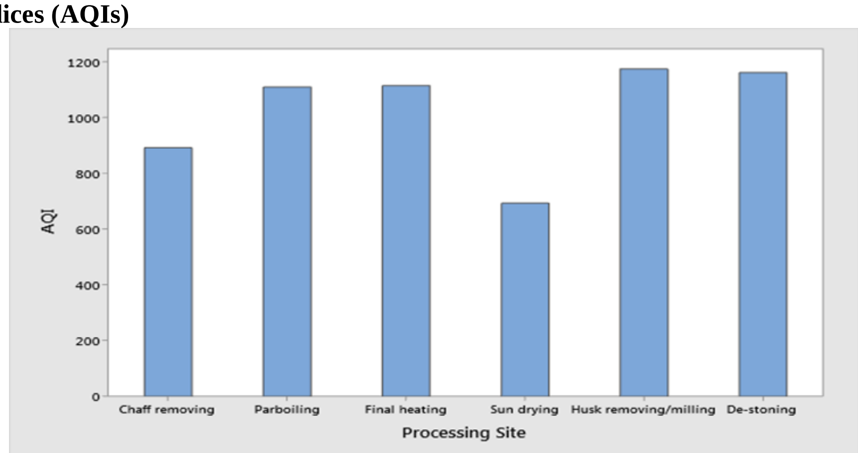

Fig. 16: Plot of air quality indices (AQIs) of $PM_{2.5}$ against processing sites in area A

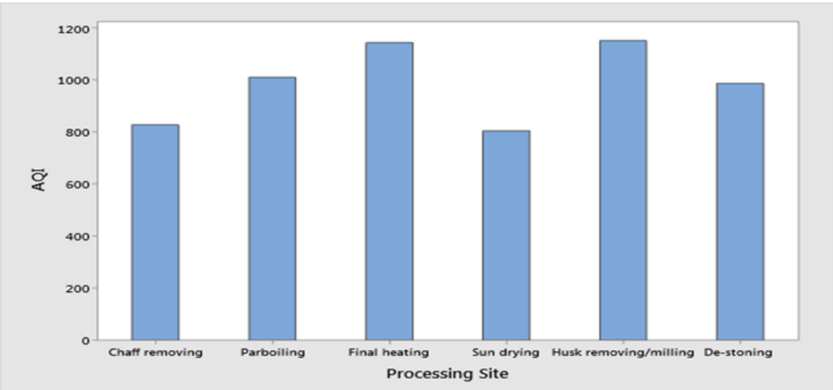

Fig. 17: Plot of the air quality indices (AQIs) of $PM_{2.5}$ against processing sites in area B

Fig. 16 shows that the chaff removing site has an AQI of 892, the parboiling site has an AQI of 1110, the final heating site has an AQI of 1115, the sun drying site has an AQI of 693.4, the husk removing/milling site has an AQI of 1175, and de-stoning the site has an AQI of 1175 in area A. Based on the AQI in area A, the husk removing/milling site has the highest value, whereas the chaff removing site has the lowest value, which signifies that the levels of air pollution generated by $PM_{2.5}$ during rice processing at different sites are not the same in the areas of study. Similarly, in area B (Fig. 17), AQIs of 828.4, 1010, 1143.4, 805 and 1151.6 were obtained at the chaff removing, parboiling, final heating, sun drying, husk removing/milling and de-stoning rice processing sites, with the husk removing/milling site having the highest value. Notably, the AQI of $PM_{2.5}$ at various rice processing sites varied differently in area B, indicating the potential hazard level of the particle. The difference in AQI at the processing sites may be associated with the nature of the sites, type of equipment used and methods adopted during rice processing.

The AQIs of $PM_{2.5}$ obtained at different processing sites in the two areas of study revealed that they are far above the WHO (2021) standard value recommended for healthy air that can be inhaled by humans. These findings suggest that $PM_{2.5}$ emissions at these sites may be potential contributors to atmospheric air pollution in the areas of study and can have severe and adverse health effects on people working at these sites. The AQI recorded at all the processing sites in both areas A and B falls within level 6 (AQI ≥ 301) and is described as hazardous by the WHO (2021) air quality standard guidelines for healthy air that can be inhaled by humans.

V. Conclusion

Atmospheric $PM_{2.5}$ concentration levels at rice processing sites in Abakaliki, Ebonyi State capital, are quite alarming. There is an explicit monthly and annual variation in the $PM_{2.5}$ concentrations at different rice processing sites in the areas of study. Higher levels were recorded within the month that was perceived to fall within the dry season, whereas the months within the rainy season presented lower levels of $PM_{2.5}$ concentration distribution at the processing sites. Similarly, the annual concentration levels were greater during the dry season than during the rainy season. The nature, methods and type of equipment used in rice processing contribute greatly to the variation in the $PM_{2.5}$ concentration at the processing sites, with the sites located in-house having heavy equipment with higher $PM_{2.5}$ levels generation compared to the sites in an open space. The 24-hour monthly mean concentration, the annual mean concentration and the air quality index obtained at all the rice processing sites in the areas of study were far greater than the values recommended by the WHO (2021) air quality standard guidelines for healthy air. Therefore, such a scenario may trigger health concerns at those sites, especially those working directly in these areas. Replacing the traditional method of rice processing with modern methods in the areas of study could strongly increase the reduction in high levels of atmospheric $PM_{2.5}$ air pollution generation and emission to minimal levels.

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