# AIRBORNE PARTICULATE MATTER IN THE ATMOSPHERIC ENVIRONMENT OF A TOBACCO MANUFACTURING PLANT

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***ABSTRACT***

*Quarterly concentrations of ambient particulate matter mass ranges $PM_1$, $PM_{2.5}$, $PM_7$, $PM_{10}$, and Total Suspended Particles (TSP) were measured in a major cigarette manufacturing company in Ibadan, southwestern Nigeria. The samplings were carried out in both the indoor and outdoor environment of the study location. During the study, the ambient measured microclimatic parameters agreed with the weather historical data of the area. Measured and extrapolated 24-hr concentration of the $PM_{2.5}$,$PM_{10}$, and TSP were compared with the World Health Organization, Federal Ministry of Environment (FMENV), and the World Bank Standards. Particulate matter (PM) was measured with GT-331 Particle Mass Monitor while weather tracker Kestrel 4500 was used for the measurements of microclimatic parameters. It was found that some of the PM ranges measured fall within standard while some exceeded the set standards. The highest measured concentrations of the particulates were noticed in the first quarter which could be attributable to the prevailing microclimatic conditions during the quarter. $PM_{10}$ and TSP gave the highest measured and 24-hr extrapolated concentrations for all the quarters in the indoor and outdoor environments. Seasonal/quarterly variation and compliance with cleaner practice were found to be associated with $PM_{10}$ and TSP concentration.*

***Keywords:*** *particulate matter, tobacco , microclimatic parameter, indoor, outdoor*

## 1.0 INTRODUCTION

Rapid industrialization in the urban areas of Nigeria is of great threat to air quality. However, efforts are being put in place to control it (Yusuf and Sonibare, 2004). The identification and quantification of the types of pollutants emitted from industrial sources is important as it can serve as health and environmental indicator in the urban habitats. Aside the gaseous emissions, particulate matter (PM) can be regarded as the most abundant harmful air pollutant found in the ambient air of industrialised environments. Particulate matter from industrial activities have been recognised as a major pollutant that can have adverse impact on both the ambient environment, vegetation and human health (Noble, 2001; Shi *et al.*, 2009). Epidemiological studies have traced PM concentration in the ambient air to be associated with various health related problems (Brook *et al*., 2010; Delfino, 2002; *Gilmour et al., 2006;* Mutlu, 2007; Hales*, 2012)*. A large percentage of these studies specifically mentioned tobacco induced particulate matter as being responsible for respiratory, carcinogenic and mutagenic diseases in man (Brook *et al*., 2010; Delfino, 2002; Soberanes *et al*., 2012; *Scott, 2004*). The increase in consumption of tobacco has led to the expansion of the industry in the developing countries.

The process used to turn tobacco to packaged cigarette can be descibed to be energy intensive and this could impair ambient air. The process of cigarette production starts from tobacco harvesting in the farm, to curing, grading and buying, primary processing, cigarette manufacturing, and packaging (Figure 1).In the primary processing, tobacco of different types is mixed according to precise recipes with moisture added to render it supple enough for handling in processing and manufacturing. This is followed by casing where variety of ingredients is added to tobacco before being cut. The cut tobacco is dried and cooled to the final moisture required. On attaining the required moisture level, flavours are added either by spraying (*Baker et al., 2004)*. The cut tobacco is then placed in silos. After the necessary treatment and processing of tobacco, it is made into cigarettes in machine called the "Maker"; produced cigarettes are then put through quality control checks for standard

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compliance before packaging. In summary, the unit operations required generally in cigarette manufacturing include mixing, cutting, drying, cooling, spraying, and packaging.

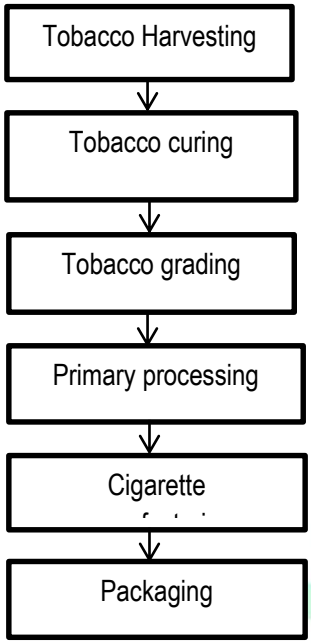


*Figure 1: Cigarettes Manufacturing Process Flow Diagram*

Cigarette manufacturing results in large quantity of airborne pollution (*Novotny and Zhao, 1999*). Previous studies have linked ill health of workers to exposure to variety of particles emitted from the processes and activities involved in cigarette manufacturing (Uitti *et al., 1998;* Reimann and Uitti*, 2000*]. Aside the core manufacturing processes, other sources of airborne particulate matter in a cigarrette company may include power generation, manual handling and transportation within the factory. This study investigates the quarterly variation of airborne particulate matter emanating from one of the world's largest tobacco processing plants in its indoor and outdoor locations of the British American Tobacco Company Plant, Ibadan, Southwestern Nigeria. It was with the purpose of determining workers' exposure levels to PM and to determine the plant's compliance level with the regulatory standards of the World Health Organization, Federal Ministry of Environment (FMENV), and the World Bank.

## 2.0 MATERIALS AND METHODS

To carry out a comprehensive study, sampling stations were set up in the indoor and outdoor environment of the study plant. The materials used and methods adapted for the study are discussed in the following subsections.

### *2.1 Sampling Locations*

The measurements were taken in the premises of one of the leading cigarettte manufacturing companies based in the city of Ibadan, southwestern, Nigeria. Quarterly samples were taken for the year 2012. The measurements took place in twenty different locations strategically located within the company premises comprising of the indoor and the outdoor locations in order to fully quantify the PM emissions (Table 1).

*Table 1: Description of Sampling Locations around the Study Area*

| Station ID | Location |
|---|---|
| **Indoor Locations** | |
| L1 | Supply Chain |
| L2 | Reception |
| L3 | Secondary Manufacturing Department (SMD) |
| L4 | Tea Room |
| L5 | Smoke Laboratory |
| L6 | Filter Rod Section |
| L7 | Cut Tobacco Store (CTS) |
| L8 | Primary Manufacturing Department (PMD) |
| L9 | SMD Dust Room |
| L10 | PMD Dust Room |
| L11 | Ware House 1 |
| L12 | Ware House 2 |
| L13 | Ware House 3 |
| **Outdoor Locations** | |
| L14 | Open Office |
| L15 | PMD end |
| L16 | Generator Exhaust Area |
| L17 | ETP/Waste Area |
| L18 | Finished Goods Store (FGS) Open Area |
| L19 | Tank Farm |
| L20 | Car Park |

### 2.2 *Sampling Strategy and Methodology*

Online monitors were used to obtain real-time measurements for the air quality and microclimatic parameters in this study.

#### *2.2.1 Microclimatic Parameters*

Weather Tracker Kestrel 4500 was used for the measurements of microclimatic parameters. This was used to measure the wind speed, wind direction, relative humidity, pressure and temperature during the study.

#### *2.2.2 Air Sampling for Particulates*

Particulate matter (PM) was measured with GT-331 Particle Mass Monitor, an equipment from Met One Instruments. It is handheld, battery operated and completely portable unit measuring five mass ranges of

TSP: $PM_1$, $PM_{2.5}$, $PM_7$, $PM_{10}$, and TSP with a concentration range of 0 – 1 mg/m$^3$ (and resolution of 0.1 µg/m$^3$), a sampling time of 2 minutes and a flow rate of 2.83 l/min. To measure, it was placed at 1 m above the ground level, switched on in the environment of interest and the measured concentration read directly on the screen after particle capturing. Measured particulates concentrations were compared with the existing standards (Table 2.).

*Table 2: Standards for Particulates*

| Particulates | Concentrations (µg/m$^3$) | | |
|---|---|---|---|
| | FMENV [16] | World Bank [17] | WHO [18] |
| $PM_{2.5}$ | - | - | 25 |
| $PM_{10}$ | - | 80 | 50 |
| TSP | 250 | 80 | - |

## 3.0 RESULTS AND DISCUSSION

### *3.1 Microclimatic Parameters*

In the first quarter, the measured microclimatic parameters (Table 3) agreed with the historical data on climate of the area. The indoor relative humidity was 49.2 – 70.5% with a mean 60.9% while the outdoor level was 51.9 – 60.8% with an average of 57.7%. The mean measured ambient temperature indoor was 30.7 °C with a range of 24.2 – 35.5 °C but outdoor, it was 33.4 – 35.1 °C with 34.2 °C as average. Outdoor, the wind speed was 1.3 – 2.1m/s with an average of 1.5 m/s and prevailing NE direction.

In the second quarter, the indoor relative humidity was 55.4 – 69.7% with a mean of 60.9% while the outdoor level was 53.4 – 61.0% with an average of 57.0%. The mean measured ambient temperature indoor was 27.6 °C with a range of 23.5 – 32.4 °C but outdoor, it was 32.2 – 35.7 °C with 34.4 °C as average. Outdoor, the wind speed was 0.7 – 2.1 m/s with an average of 1.5 m/s and prevailing NE/SW directions.

In the third quarter, the measured microclimatic parameters (Table 3) agreed with the historical data on climate of the area. The indoor relative humidity was 57.3 – 75.3% with a mean of 67.0% while the outdoor level was 66.9 – 75.0% with an average of 73.0 %. The mean measured ambient temperature indoor was 26.6 °C with a range of 22.8 – 30.2 °C but outdoor, it was 27.8 – 29.1 with 28.4 °C as average. Outdoor, the wind speed was 0.8 – 1.8 m/s with a mean of 1.5 m/s and prevailing Northeast/Southwest directions.

In the fourth quarter, the measured microclimatic parameters (Table 3) also agreed with the historical data on climate of the area. The indoor relative humidity was 52.0 – 77.5% with a mean of 61.8% while the outdoor level was 49.2 – 59.7% with an average of 55.5%. The mean measured indoor air temperature was 29.8 °C ranging between 24.8 °C and 36.2 °C but outdoor, it was 34.5 °C ranging between 33.4 and 35.7

°C. Outdoor, the wind speed was 0.4 – 1.8 m/s with a mean of 1.1 m/s and prevailing Northeast/Southwest directions.

*Table 3: Measured Meteorological Parameters during the Study*

| Location | Level | Temperature (°C) | Humidity (%) | Wind | |
|---|---|---|---|---|---|
| | | | | Speed | Direction |
| First Quarter (January – March) | | | | | |
| Indoor | Min | 24.2 | 49.2 | Indoor | |
| | Max | 35.5 | 70.5 | | |
| | Mean | 30.7 | 60.9 | | |
| Outdoor | Min | 33.4 | 51.9 | 1.3 | Southwest |
| | Max | 35.1 | 60.8 | 2.1 | Northeast |
| | Mean | 34.2 | 57.5 | 1.5 | Northeast |
| 2nd Quarter (April – June) | | | | | |
| Indoor | Min | 23.5 | 55.4 | Indoor | |
| | Max | 32.4 | 69.7 | | |
| | Mean | 27.6 | 60.9 | | |
| Outdoor | Min | 32.2 | 53.4 | 0.7 | Northeast |
| | Max | 35.7 | 61 | 2.1 | Southwest |
| | Mean | 34.4 | 57 | 1.5 | Northeast |
| 3rd Quarter (July – September) | | | | | |
| Indoor | Min | 22.8 | 57.3 | Indoor | |
| | Max | 30.2 | 75.3 | | |
| | Mean | 26.6 | 67 | | |
| Outdoor | Min | 27.8 | 66.9 | 0.8 | Northeast |
| | Max | 29.1 | 75 | 1.8 | Southwest |
| | Mean | 28.4 | 73 | 1.5 | Southwest |
| 4th Quarter (October – December) | | | | | |
| Indoor | Min | 24.8 | 52 | Indoor | |
| | Max | 36.2 | 77.5 | | |
| | Mean | 29.8 | 61.8 | | |
| Outdoor | Min | 33.4 | 49.2 | 0.4 | Northeast |
| | Max | 35.7 | 59.7 | 1.8 | Southwest |
| | Mean | 34.5 | 55.5 | 1.1 | Southwest |

### *3.2 Indoor and Outdoor Particulates Levels*

For all the four quarters considered in this study, 24 hr extrapolated concentration for $PM_{2.5}$, $PM_{10}$ and TSP were compared with World Bank, WHO and FMENV standards. The 24 – hr extrapolated concentration of the aforementioned particulates are presented in Table 4.

For the four quarters considered in this study, the 24-hr extrapolated concentrations of $PM_{2.5}$ fall below the WHO standard of 25 $\mu g/m^3$. However, WHO standard for $PM_{10}$ were exceeded in indoor location L11 and all the outdoor locations except location L14 for the first quarter. It also exceeded both the WHO and the World bank standard in L7 during the second quarter. The reduction in the $PM_{10}$ for the subsequent quarters indicates an improvement in the maintainance of air quality/cleaner practice.

In the first quarter, particulates were detected in all the sampling locations in the factory during the course of the study. In the indoor environment, these were 0.4 – 19.2 $\mu g/m^3$ with an average of 3.5 $\mu g/m^3$; 1.9 – 3.1 $\mu g/m^3$ with an average of 13.0 $\mu g/m^3$;7.7 – 182.3 $\mu g/m^3$ with an average of 64.0 $\mu g/m^3$; 9.4 – 231.8 $\mu g/m^3$ with 80.2 $\mu g/m^3$ as the average; and 16.3 – 259.8 $\mu g/m^3$ with an average of 99.2 $\mu g/m^3$ for $PM_1$, $PM_{2.5}$, $PM_7$, $PM_{10}$ and TSP respectively but in the outdoor environment, the $PM_1$, $PM_{2.5}$, $PM_7$, $PM_{10}$ and TSP were respectively 0.8 – 4.2 $\mu g/m^3$ with 3.4 $\mu g/m^3$ as average, 3.4 – 25.8 $\mu g/m^3$ with 20.1 $\mu g/m^3$ as average, 11.7 – 136.1 $\mu g/m^3$ with 108.7 $\mu g/m^3$ as average, 11.7 – 240.0 $\mu g/m^3$ with 142.7 $\mu g/m^3$ as average and 18.3 – 196.0 $\mu g/m^3$ with 177.8 $\mu g/m^3$ as average.

Indoor, the 24-hours extrapolated concentrations of $PM_{10}$ were 4.5 – 60.1% of the 80 $\mu g/m^3$ World Bank guideline with an average of 32.4% except in the Warehouse 1 where the limit was breached but outdoor, these were 5.6 – 75.6% of the limit except in the Car Park where it was also breached. Similarly, the 24-hour extrapolated TSP concentrations were 2.5 – 39.8% of the Federal Ministry of Environment's limit of 250 $\mu g/m^3$ with 15.2% as average in the indoor locations but outdoor, it was 2.8 – 45.4% with 27.3% of the limit as average.

For the second quarter, Indoor 24-hours extrapolated concentrations of $PM_{10}$ were 2.0 – 31.9% of the 80 $\mu g/m^3$ World Bank guideline with an average of 9.1% in the indoor environment except in the Cut Tobacco Store (CTS) where it was 2.2 folds of the limit. Outdoor, these were 4.0 – 9.5% of the limit with an average of 6.5%. Similarly, the 24-hour extrapolated TSP concentrations were 0.8 – 41.1% of the 250 $\mu g/m^3$ Federal Ministry of Environment's limit with 7.0% as average indoor except in the same Cut Tobacco Store (CTS) where it was just about the limit but outdoor, it was 1.8 – 3.9% of the limit with 2.9% as average.

Indoor, the 24-hours extrapolated concentrations of $PM_{10}$ were 2.0 – 31.9% of the 80 $\mu g/m^3$ World Bank guideline with an average of 9.1% in the indoor environment except in the Cut Tobacco Store (CTS) where it was 2.2 folds of the limit. Outdoor, these were 4.0 – 9.5% of the limit with an average of 6.5%. Similarly, the 24-hour extrapolated TSP concentrations were 0.8 – 41.1% of the 250 $\mu g/m^3$ Federal Ministry of Environment's limit with 7.0% as average indoor except in the same Cut Tobacco Store (CTS) where it was just about the limit but outdoor, it was 1.8 – 3.9% of the limit with 2.9% as average.

$PM_{10}$ were 1.4 – 42.7% of the 80 $\mu g/m^3$ World Bank guideline with an average of 11.0% in the indoor environment. Outdoor, these were 6.1 10.5 % of the limit with an average of7.7%. Similarly, the 24-hour extrapolated TSP concentrations were 0.8 – 19.1% of the 250 $\mu g/m^3$ Federal Ministry of Environment's limit with 4.6% as average indoor but outdoor, it was 2.3 – 4.5% with 3.5% as average.

In the third quarter,particulates were detected in all the sampling locations in the factory during the study. In the indoor environment, these were 0.2 – 23.9 $\mu g/m^3$ with an average of 2.2 $\mu g/m^3$; 0.5 – 30.7 $\mu g/m^3$ with an average of 4.0, $\mu g/m^3$1.4 – 52.9 $\mu g/m^3$ with an average of 16.6 $\mu g/m^3$; 3.0 – 89.0 $\mu g/m^3$ with 22.9 $\mu g/m^3$ as the average; and 4.9 – 124.4 $\mu g/m^3$ with an average of 30.2 $\mu g/m^3$ for $PM_1$, $PM_{2.5}$, $PM_7$, $PM_{10}$ and TSP respectively but in the outdoor environment, the $PM_1$, $PM_{2.5}$, $PM_7$, $PM_{10}$ and TSP were respectively 0.4 – 0.8 $\mu g/m^3$ with 0.7 $\mu g/m^3$ as average, 2.0 – 3.7 $\mu g/m^3$ with 2.9 $\mu g/m^3$ as average, 11.4 – 15.6 $\mu g/m^3$ with 13.3 $\mu g/m^3$ as average, 12.8 – 22.0 $\mu g/m^3$ with 16.2 $\mu g/m^3$ as average and 15.2 – 29.3 $\mu g/m^3$ with 22.7 $\mu g/m^3$ as average.

On extrapolation the measured particulates in the indoor environment became 0.1 – 9.2 $\mu g/m^3$ with an average of 0.8 $\mu g/m^3$; 0.2 – 11.8 $\mu g/m^3$ with an average of 1.5 $\mu g/m^3$; 0.5 – 20.3 $\mu g/m^3$ with an average of 6.4 $\mu g/m^3$; 1.2 – 34.1 $\mu g/m^3$ with 8.8 $\mu g/m^3$ as the average; and 1.9 – 47.7 $\mu g/m^3$ with an average of 11.6 $\mu g/m^3$ for $PM_1$, $PM_{2.5}$, $PM_7$, $PM_{10}$ and TSP respectively but in the outdoor environment, these were 0.2 – 0.3 $\mu g/m^3$ with an average of 0.3 $\mu g/m^3$; 0.8 – 1.4 $\mu g/m^3$ with an average of 1.7 $\mu g/m^3$;4.4 – 6.0 $\mu g/m^3$ with an average of 5.1 $\mu g/m^3$; 4.9 - 8.4 $\mu g/m^3$ with 6.2 $\mu g/m^3$ as the average; and 5.8 – 11.2 $\mu g/m^3$ with an average of 34.2 $\mu g/m^3$ for $PM_1$, $PM_{2.5}$, $PM_7$, $PM_{10}$ and TSP respectively.

These 24-hours extrapolated concentrations of $PM_{10}$ were 1.4 – 42.7% of the 80 μg/m³ World Bank guideline with an average of 11.0% in the indoor environment. Outdoor, these were 6.1 10.5 % of the limit with an average of7.7%. Similarly, the 24-hour extrapolated TSP concentrations were 0.8 – 19.1% of the 250 μg/m³ Federal Ministry of Environment's limit with 4.6% as average indoor but outdoor, it was 2.3 – 4.5% with 3.5% as average

For the fourth quarter, indoor environment PM readings were 0.2 – 10.1 μg/m³ with an average of 1.4 μg/m³; 0.7 – 12.5 μg/m³ with an average of 4.1, μg/m³; 2.6 – 82.7 μg/m³ with an average of 21.8 μg/m³; 3.7 – 112.3 μg/m³ with 29.5 μg/m³ as average; and 5.3 – 125.4 μg/m³ with an average of 39.7 μg/m³ for $PM_1$, $PM_{2.5}$, $PM_7$, $PM_{10}$ and TSP respectively. Outdoor, the $PM_1$, $PM_{2.5}$, $PM_7$, $PM_{10}$ and TSP were respectively 0.8 – 1.6 μg/m³ with 1.2 μg/m³ as average, 3.0 – 5.57 μg/m³ with 4.4 μg/m³ as average, 13.3 – 29.7 μg/m³ with 21.4 μg/m³ as average, 18.8 – 34.8 μg/m³ with 27.2 μg/m³ as average and 24.5 – 40.2 μg/m³ with 32.2 μg/m³ as average. On extrapolation the measured $PM_{10}$ became 1.8 – 53.8% of the 80 μg/m³ World Bank guideline with an average of 14.2% in the indoor environment but outdoor, they were 9.0 – 16.7 % of the limit with an average of 13.1%. Similarly, the measured TSP became 0.8 – 19.2% of the 250 μg/m³ Federal Ministry of Environment's limit with 6.1% as average indoor but outdoor, it was 3.8 – 6.2% with 4.9% as average.

On extrapolation the measured particulates in the indoor environment become 0.1 – 3.9 μg/m³ with an average of 0.6 μg/m³; 0.3 – 4.8 μg/m³ with an average of 1.6 μg/m³; 1.0 – 31.7 μg/m³ with an average of 8.3 μg/m³; 1.4 – 43.1 μg/m³ with 11.3 μg/m³ as the average; and 2.0 – 48.1 μg/m³ with an average of 15.2 μg/m³ for $PM_1$, $PM_{2.5}$, $PM_7$, $PM_{10}$ and TSP respectively but in the outdoor environment, these were 0.3 – 0.6 μg/m³ with an average of 0.4 μg/m³; 1.2 – 2.1 μg/m³ with an average of 1.7 μg/m³; 5.1 – 11.4 μg/m³ with an average of 8.2 μg/m³; 7.2 - 13.3 μg/m³ with 10.4 μg/m³ as the average; and 9.4 – 15.4 μg/m³ with an average of 12.3 μg/m³ for $PM_1$, $PM_{2.5}$, $PM_7$, $PM_{10}$ and TSP respectively.

These 24-hours extrapolated concentrations of $PM_{10}$ were 1.8 – 53.8% of the 80 μg/m³ World Bank guideline with an average of 14.2% in the indoor environment but outdoor, they were 9.0 – 16.7 % of the limit with an average of 13.1%. Similarly, the 24-hour extrapolated TSP concentrations were 0.8 – 19.2% of the 250 μg/m³ Federal Ministry of Environment's limit with 6.1% as average indoor but outdoor, it was 3.8 – 6.2% with 4.9% as average.

### *3.3 Comparison between Quarterly Indoor and Outdoor Particulates Concentration*

The measured quarterly indoor and outdoor concentrations of particulate matter sizes were compared. Figures 2 present the comparisons between indoor and outdoor PM measured in box and whiskers plots for all the quarters. Highest PM concentration levels were obtained in the first quarter for both indoor and outdoor environments. Average PM indoor/outdoor ratios were 1.06, 0.65, 0.59, 0.56 and 0.56 for quarter one; 2.41, 1.57, 1.36, 0.92, 1.12, and 0.42 for quarter 2; 3.17, 1.36, 1.25, 1.42, and 1.33 for quarter 3 and 1.26, 0.92, 1.02, 1.08, and 1.23 for $PM_1$, $PM_{2.5}$, $PM_7$, $PM_{10}$ and TSP, respectively. For the whole year, average I/O ratios and standard deviations of measured PM are 1.97±0.99, 1.12±0.42, 1.39±0.93, 1.70±1.40, and 1.97±1.89 for $PM_1$, $PM_{2.5}$, $PM_7$, $PM_{10}$ and TSP, respectively. I/O ratio of value greater than 1 indicates that the measured indoor concentrations were higher than the corresponding outdoor concentrations. Higher indoor cocentration levels are attributable to additional indoor PM sources, PM resuspension and inadequate ventilation. It was observed that the metereological parameters like wind speed, relative humidity and temperature have influence on the particulate concentrations. This conforms with the previous studies (*Kozawa et al., 2012;* Turahoglu *et al., 2005;* Elminir*, 2005; Gupta, 2008; Majewski et al., 2011)*. It was found that the first quarter had the highest concentations of $PM_1$, $PM_{2.5}$, $PM_7$, $PM_{10}$ and TSP measured with mean temperature of 30.7 °C and mean RH of 60.9 % for the indoor environments; mean temperature of 34.2 °C and mean RH of 67.5 % , average wind speed of 1.5 m/s due Northeast, for the outdoor environments. This was followed by quarter 4(mean temperature and RH of 29.8 °C and 61.8% respectively for the indoor environments and mean temperature and RH of 34.5°C and 55.5 % respectively for the outdoor environment), then quarter 3 (mean temperature and RH of 26.6 °C and 67.0 % respectively for the indoor environment and mean temperature and RH of 28.4 °C and 73 % for the outdoor environment).

Quarter 2 has the least concentrations of particulates with mean temperature and RH of 27.6 °C and 60.9 % for the indoor environment and mean temperature and RH of 34.4 °C and

57.0 % respectively with an average windspeed of 1.5 m/s in the Northeast direction. For the four quarters, $PM_1$ has the lowest measured concentrations of less than 5 μg/m³for both indoor and outdoor environments. This was followed by $PM_{2.5}$, $PM_7$,$PM_{10}$ and TSP for the indoor environments. However, $PM_{10}$ did not follow this trend in the outdoor environments as its concentration fell below 5 μg/m³ as obtainable for $PM_1$ for the four quarters. This may be attributable to earlier prediction that the higher diameter particles are easily deposited than the finer particles (Piazzola *et al*., 2010; Wang *et al., 2009*). Also, the concentration of $PM_1$ measured falls in line with the results of Wang *et al*. (2009) as fine particles can be transported and diffused more easily than the coarse ones.

Higher concentrations of particulate matter observed during quarters 1 and 4 were caused by the fact that relative humidity is lower, temperature is warmer and windspeeds are higher. Extent of activities in the plant are higher during quarters 1 and 4 because tobacco leaves yield are higher during this period. Wet deposition decreases the concentration of ambient particulate matter during wet season. Rain wash-out and increase in aerodynamic diameter of PM increases particulate deposition during the wet seasons. Increase in windspeed may cause more lifting of particles during the dry seasons. Lower concentration levels observed for quarters 2 and 3 are linked to humid and lower temperatures which creates deeper boundary layer heights that prevents PM from remaining airborne for longer period (Alizadeh-Choobari *et al., 2016)*. Seasonal variations affeected the concentration levels of particulate matter in the tobacco manufacturing plant. The contribution of weather conditions to particulate matter levels in the indoor and outdoor environment of the plant for the four quarters considered reflected indoor levels were greater than the outdoor levels mostly.

## 4.0 CONCLUSION

Quarterly particulate matter sizes of $PM_1$, $PM_{2.5}$, $PM_7$, $PM_{10}$, and TSP were measured in a major cigarrete manufacturing company in a town in southwestern Nigeria. Indoor and outdoor quarterly concentration profile followed same pattern for the indoor and outdoor locations. The highest concentrations were obtained during the first quarter (dry season). This was followed by quarter 4, then quarter 3 and quarter 2. Quarter 2 and Quarter 3(wet seasons) gave the lowest concentrations of the PM measured. Generally quarter 1 was characterized with lower relative humidity ranges and higher temperature while quarter 2 and 3 have higher humidity ranges and lower temperature which may likely favour particulates deposition especially $PM_{10}$ and TSP. $PM_1$ has concentrations of less than 5 μg/m³for all the four quarters in both the indoor and outdoor environment indicating that the average wind speed of about 1.5 m/s will aid smaller particulates transport and diffussion easily. Microclimatic parameters and the company's efforts towards reduction of air pollution from the manufacturing processes have influence on the ambient particulate concentration.

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*Table 4: 24-Hour Extrapolated Particulate Concentrations for $PM_{2.5}$, $PM_{10}$ and TSP*

| Station ID | QUARTER | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PM CONC. (μg/m³) | | | | | | | | | | | |
| | Quarter 1 | | | Quarter 2 | | | Quarter 3 | | | Quarter 4 | | |
| | $PM_{2.5}$ | $PM_{10}$ | TSP | $PM_{2.5}$ | $PM_{10}$ | TSP | $PM_{2.5}$ | $PM_{10}$ | TSP | $PM_{2.5}$ | $PM_{10}$ | TSP |
| **Indoor Locations** | | | | | | | | | | | | |
| L1 | 2.9 | 12.5 | 14.8 | 0.5 | 4.5 | 6.4 | 0.5 | 3.7 | 4.4 | 0.6 | 3.5 | 4.5 |
| L2 | 3.8 | 21.4 | 27.7 | 0.8 | 5.1 | 8.7 | 0.6 | 4.1 | 5.0 | 1.3 | 5.7 | 7.0 |
| L3 | 1.5 | 7.0 | 9.4 | 0.2 | 1.6 | 2.7 | 0.5 | 3.3 | 5.3 | 1.2 | 4.9 | 6.5 |
| L4 | 11.9 | 24.6 | 29.3 | 8.4 | 13.7 | 16.5 | 11.8 | 18.0 | 19.8 | 4.8 | 8.7 | 11.4 |
| L5 | 1.5 | 6.7 | 7.6 | 0.5 | 1.6 | 2.0 | 0.5 | 1.6 | 2.1 | 0.5 | 1.4 | 2.0 |
| L6 | 2.8 | 12.8 | 15.5 | 0.3 | 1.9 | 4.1 | 1.0 | 5.2 | 6.3 | 1.0 | 3.8 | 4.5 |
| L7 | 0.7 | 3.6 | 6.3 | 6.8 | 178.7 | 251.1 | 0.9 | 34.1 | 47.7 | 0.8 | 16.2 | 25.1 |
| L8 | 6.1 | 48.0 | 61.8 | 2.2 | 16.6 | 102.7 | 1.1 | 16.9 | 26.5 | 2.6 | 24.8 | 43.3 |
| L9 | 6.3 | 48.1 | 58.3 | 0.8 | 6.4 | 17.5 | 0.8 | 5.6 | 7.4 | 1.6 | 12.2 | 15.7 |
| L10 | 6.8 | 45.6 | 66.0 | 0.6 | 4.0 | 6.3 | 0.8 | 4.9 | 7.2 | 1.4 | 8.6 | 11.4 |
| L11 | 8.8 | 88.9 | 99.6 | 0.6 | 5.9 | 8.8 | 0.7 | 6.2 | 7.1 | 1.2 | 5.5 | 6.5 |
| L12 | 5.8 | 39.0 | 50.9 | 0.9 | 4.6 | 5.9 | 0.9 | 10.5 | 12.0 | 2.0 | 23.7 | 30.6 |
| L13 | 6.1 | 41.5 | 47.4 | 0.4 | 25.5 | 41.8 | 1.1 | 7.6 | 9.2 | 1.1 | 7.5 | 9.4 |
| **Outdoor Locations** | | | | | | | | | | | | |
| L14 | 1.3 | 4.5 | 7.0 | 0.8 | 3.2 | 4.5 | 0.8 | 8.4 | 9.6 | 1.2 | 8.6 | 11.0 |
| L15 | 8.2 | 56.8 | 70.2 | 0.9 | 5.0 | 6.5 | 1.0 | 4.9 | 5.8 | 2.1 | 12.7 | 13.7 |
| L16 | 8.9 | 60.5 | 73.3 | 1.1 | 3.8 | 7.2 | 1.4 | 6.1 | 11.2 | 1.2 | 7.2 | 9.4 |
| L17 | 8.2 | 51.9 | 74.4 | 1.9 | 7.6 | 8.7 | 1.0 | 6.8 | 8.4 | 1.6 | 8.1 | 10.8 |
| L18 | 8.6 | 56.7 | 65.6 | 0.9 | 5.0 | 6.5 | 1.4 | 6.1 | 11.2 | 2.1 | 12.7 | 13.7 |
| L19 | 8.9 | 60.5 | 73.3 | 0.8 | 6.9 | 9.7 | 1.0 | 4.9 | 5.8 | 2.0 | 13.3 | 15.4 |
| L20 | 9.9 | 92.0 | 113.5 | 0.8 | 3.2 | 4.5 | 0.8 | 8.4 | 9.6 | 1.2 | 8.6 | 11.0 |

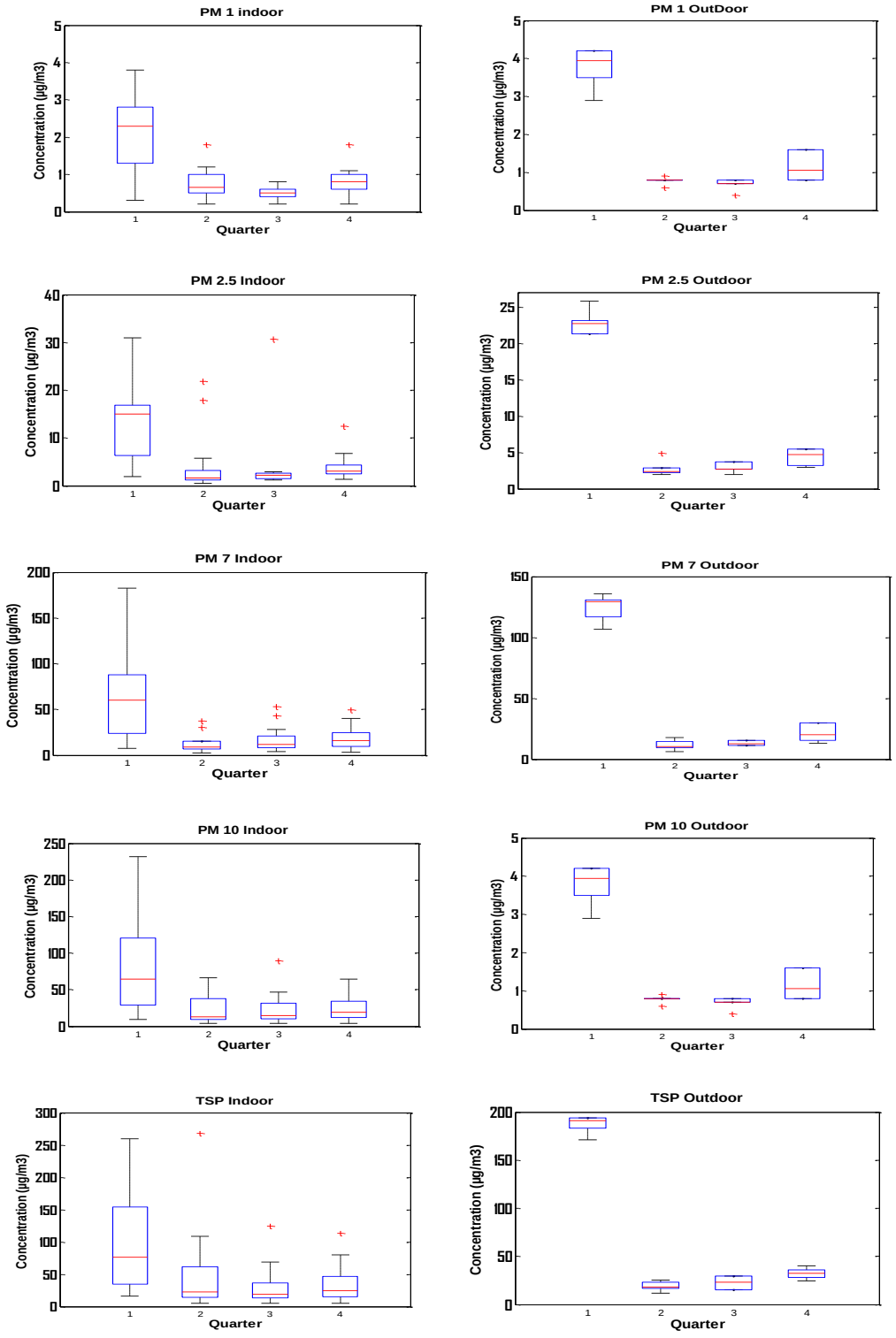


*Figure 2: Box plots for Quaterly variation between Indoor and Outdoor Concentration of Particulates*