

## PAPER 40 – SEASONAL VARIATION AND HEALTH RISK ASSESSMENT OF GASEOUS AND PARTICULATE POLLUTANTS AROUND TRAFFIC HOTSPOTS OF A DENSELY POPULATED AFRICAN CITY

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### ABSTRACT

Episodes of urban air pollution in Africa have received less attention than in the rest of the world. This study investigated the concentration variations of gaseous pollutants (CO, NO<sub>2</sub>, SO<sub>2</sub>, NH<sub>3</sub>, TVOCs, and ground level O<sub>3</sub>) and Particulate Matter (PM<sub>1</sub>, PM<sub>2.5</sub>, PM<sub>10</sub> & TSP) during the rainy and dry seasons at 25 traffic intersections (TIs) within Ibadan. The daily rush and non-rush hour concentrations of pollutants were monitored. Cancer risks (CR<sub>inh</sub>) and epidemiology-based mortality estimates using Relative Risk (RR) and Attributable Fractions (AF) linked with PM<sub>2.5</sub> and PM<sub>10</sub> exposure were evaluated. The non-cancer risks via inhalation for CO, NO<sub>2</sub>, SO<sub>2</sub> and ground level O<sub>3</sub> were assessed using Hazard Quotient (HQ). The mean concentrations of PM<sub>1</sub>, PM<sub>2.5</sub>, PM<sub>10</sub> & TSP in the dry season were higher than in the rainy season by 53.24%, 132.20%, 360.49% and 365.83%, respectively. The dry season had the highest ER and AF mortality estimates from PM<sub>2.5</sub> and PM<sub>10</sub> exposures compared to estimates during the rainy season. Health risk assessment over the study period showed that CR<sub>inh</sub> of PM<sub>2.5</sub> was tolerable while HQ<sub>inh</sub> of SO<sub>2</sub> was above 1 indicating significant non-cancer risks at TIs in Ibadan.

**KEYWORDS:** Gaseous Pollutants, Particulates, Traffic Intersection, Seasons, Rush and Non-rush hour, Health Risk.

### 1. INTRODUCTION

Air quality degradation in different cities in Africa impacts poor citizens more negatively due to urbanization, surge in population, industrialization and increased vehicular emissions (Anwar *et al.*, 2021; Das *et al.*, 2015; Delkash and Mir, 2016). Hence, this study investigated the variations in seasonal concentration levels and health risks associated with gaseous pollutants (CO, NO<sub>2</sub>, SO<sub>2</sub>, NH<sub>3</sub>, TVOCs, and ground level O<sub>3</sub>) and particulates (PM<sub>1</sub>, PM<sub>2.5</sub>, PM<sub>10</sub> & TSP) in and around major traffic pollution hotspots of Ibadan metropolis.

### 2. MATERIALS AND METHODS

#### 2.1 Study area

Ibadan city was chosen as the study area for this research because it is one of the biggest cities in Africa with rapid urbanization and industrialization. Ibadan is the third most populous city and the largest by geographical area in Nigeria. It is a major commercial and transportation hub with its strategic location on the country's railway line, an airport and expressways connecting it to many other major cities. Industrial, commercial, agricultural and residential activities were predominant in the study area. Ibadan is a prominent transit point between the coastal and hinterland regions of Nigeria. Gaseous pollutants and particulate matter (PM) were sampled in twenty-five major traffic Intersections (TIs) in Ibadan during rainy (wet) and dry seasons. The selected TIs (sampling sites) TIs are the major traffic hotspots, evenly and spatially distributed within the Ibadan metropolis. A Map of Ibadan with wind roses of rainy and dry seasons is presented as Figure S1 in the supplementary document.

#### 2.2 Sampling protocol for PM and gaseous pollutants

Variations in rush and non-rush hour ambient concentrations of gaseous pollutants (CO, NO<sub>2</sub>, SO<sub>2</sub>, NH<sub>3</sub>, TVOCs, and ground level O<sub>3</sub>) and particulate matter (PM<sub>1</sub>, PM<sub>2.5</sub>, PM<sub>10</sub> & TSP) were investigated simultaneously at 25 major TIs during rainy and dry seasons. Ambient concentration levels (in ppm) of six pollutant gases were monitored at TIs with Aeroqual S500 devices having 6 sensor heads while ambient PM concentrations of PM<sub>1</sub>, PM<sub>2.5</sub>, PM<sub>10</sub> & TSP were monitored using Aerocet 531S.

#### 2.3 Human exposure risks

In this study, the health risk assessment of PM<sub>2.5</sub>, PM<sub>10</sub>, CO, NO<sub>2</sub>, SO<sub>2</sub> and ground level O<sub>3</sub> was investigated by applying the United States Environmental Protection Agency (USEPA) standard methods (Ostro, 2004; USEPA, 2011) which have been subsequently used in related studies (Chalvatzaki *et al.*, 2019; Feuyit *et al.*, 2019; Kim *et al.*, 2018; Kitwattanavong *et al.*, 2013; Morakinyo *et al.*, 2020). According to Ostro (2004) and Chalvatzaki *et al.* (2019), the relative risk (RR) for cardiopulmonary and lung cancer mortality connected with PM<sub>2.5</sub> exposure was estimated by:

$$RR = \left[ \frac{(X+1)}{(X_0+1)} \right]^\beta \quad (1)$$

RR associated with all-cause mortality was calculated by:

$$RR = \exp[\beta(X - X_0)] \quad (2)$$

The Attributable Fractions (AF) for cardiopulmonary and lung cancer mortality connected with PM<sub>2.5</sub> and PM<sub>10</sub> exposure were estimated using the:

$$AF = \frac{RR-1}{RR} \quad (3)$$

According to (USEPA, 2011), the non-cancer risks (hazard quotient-HQ) via inhalation of CO, NO<sub>2</sub>, SO<sub>2</sub> and ground-level O<sub>3</sub> were examined using equations 4 and 5 (Morakinyo *et al.*, 2020).

$$ADD_{inh} = \frac{C \times IR \times EF \times ED}{BW \times AT} \quad (4)$$

$$HQ_{inh} = \frac{ADD_{inh}}{RfC} \quad (5)$$

Cancer Risk (CR) for PM<sub>2.5</sub> through inhalation route (CR<sub>inh</sub>) was calculated by using equation 6 (USEPA, 2011). The cancer Slope Factor (SF) of PM<sub>2.5</sub> were estimated using equation 7, respectively (Kim *et al.*, 2018; USEPA, 2011). Parameters for health risk assessment of particulates and gaseous pollutants are presented in supplementary Table S1. The definitions and values of parameters in equations 1 to 7 are detailed in the supplementary document.

$$CR_{inh} = ADD \times SF \quad (6)$$

$$SF = \frac{UR}{BW \times IR} \quad (7)$$

### 3. RESULTS AND DISCUSSION

Seasonal concentration levels of gaseous pollutants at 25 selected TIs are presented in Figures 1 and 2, respectively. Mean concentrations of CO, NO<sub>2</sub>, SO<sub>2</sub>, NH<sub>3</sub>, TVOCs, and ground-level O<sub>3</sub> were higher in the dry season than rainy season by 28.76%, 33.33%, 20%, 136.31%, 126.08% and 66.67%, respectively (see supplementary Table S2). The seasonal variation in concentrations of gaseous pollutants at TIs in this study is attributed to changes in associated convective turbulence and atmospheric boundary layer dynamics, which to a higher vertical extent redistribute and mix pollutants expansively in the atmosphere during the different seasons (Adeniran *et al.*, 2017).

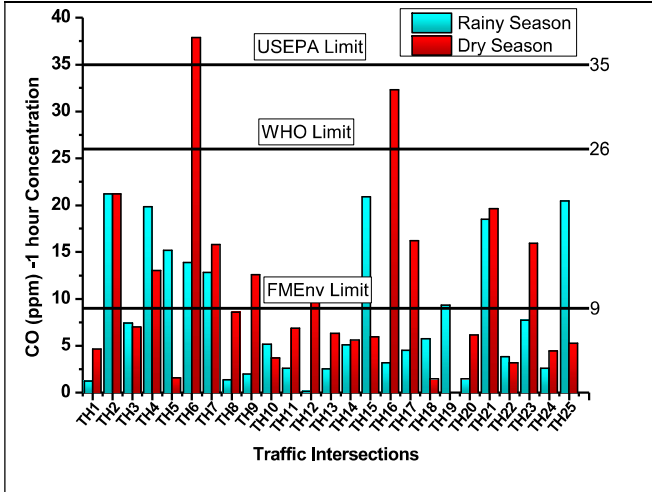
Similar to the Gaseous pollutant trends, the mean concentrations of PM<sub>1</sub>, PM<sub>2.5</sub>, PM<sub>10</sub> & TSP in the dry season were higher than rainy season by 53.24%, 132.20%, 360.49% and 365.83%, respectively (see supplementary Table S2). Chowdhury *et al.* (2019) reported that seasonal variation effects usually influence outdoor PM concentration. Re-suspended particles have varied impacts at different times of the year, due to many factors including relative humidity, wind speed, rainfall, solar radiation intensity, population of on-road vehicles and traffic flow type (Adeniran *et al.*, 2018; Fernandez *et al.*, 2017). However, forced deposition of particles may be accelerated during the rainy season than the dry season because of heavy rainfall, higher relative humidity, temperature drop, wind speed and lush vegetation (Chate, 2005; Jones and Harrison, 2004; Ranjan *et al.*, 2016). Descriptive statistics of studied pollutants at Ibadan traffic intersections and their recommended limits are presented in supplementary Table S3.

Pearson's correlation indicated that a positive correlation existed between relative humidity and wind speed while temperature and relative humidity had a strong negative correlation of -0.82 (see supplementary Table S4). The correlations of total vehicle on-road with PM<sub>1</sub> and PM<sub>2.5</sub> were positive while relationships of total vehicle on-road with PM<sub>10</sub> and TSP gave negative correlations. This suggests that emissions of ultrafine (PM<sub>1</sub>) and fine (PM<sub>2.5</sub>) particles from vehicle exhausts increase as vehicles spend more time in traffic congestion (rush hours) whereas coarse (PM<sub>10</sub>) particles rise more from road dust resuspension caused by faster vehicular movement during free-flow traffic (non-rush hours).

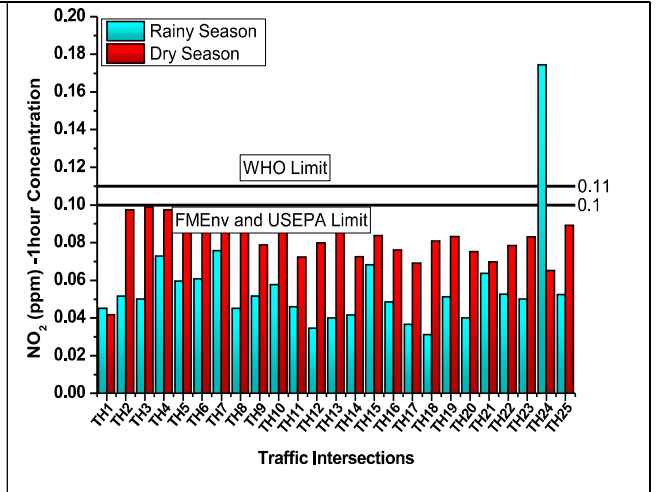
A study of air masses backward trajectories using HYSPLIT (Hybrid Single-Particle Lagrangian Integrated Trajectory Model) suggested that prevailing air masses during the rainy season came from the south-west direction (supplementary Figure S2a) though the major air masses during the dry season in Ibadan were predominantly from both northeast and southwest paths (supplementary Figure S2b). HYSPLIT results were consistent with wind roses plotted with meteorological data of the twenty-five TIs.

#### 3.1 Seasonal variation in concentration of gaseous pollutants at Tis

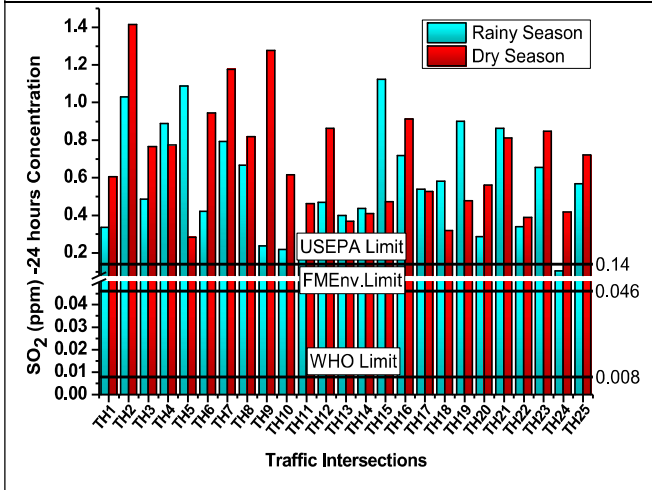
Figures 1(a) CO, (b) NO<sub>2</sub>, (c) SO<sub>2</sub>, (d) NH<sub>3</sub>, (e) TVOCs and (f) O<sub>3</sub> show the seasonal concentration levels of gaseous pollutants at 25 traffic Intersections



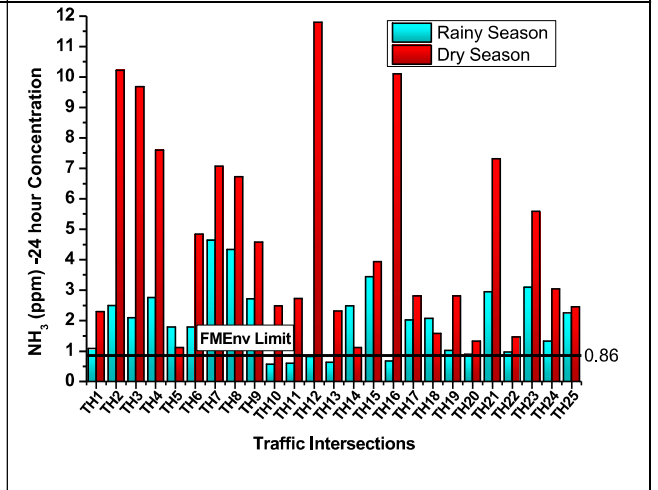
(a)



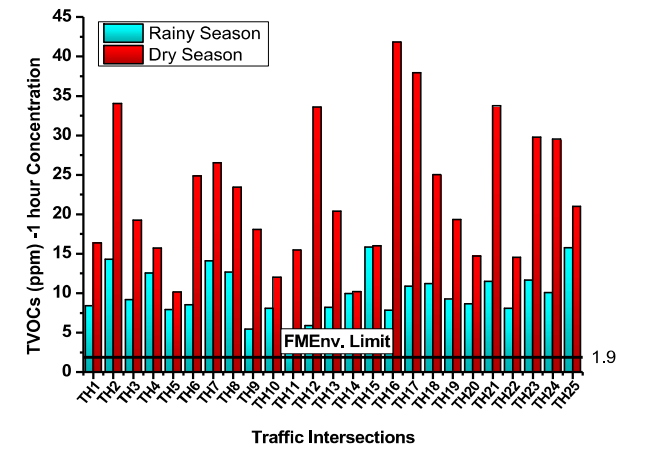
(b)



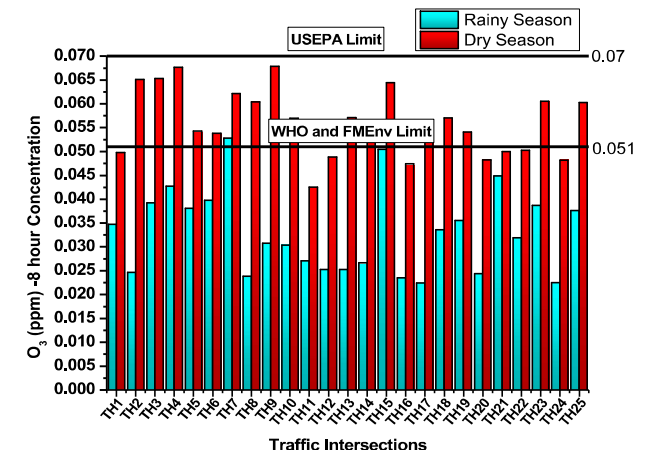
(c)



(d)



(e)

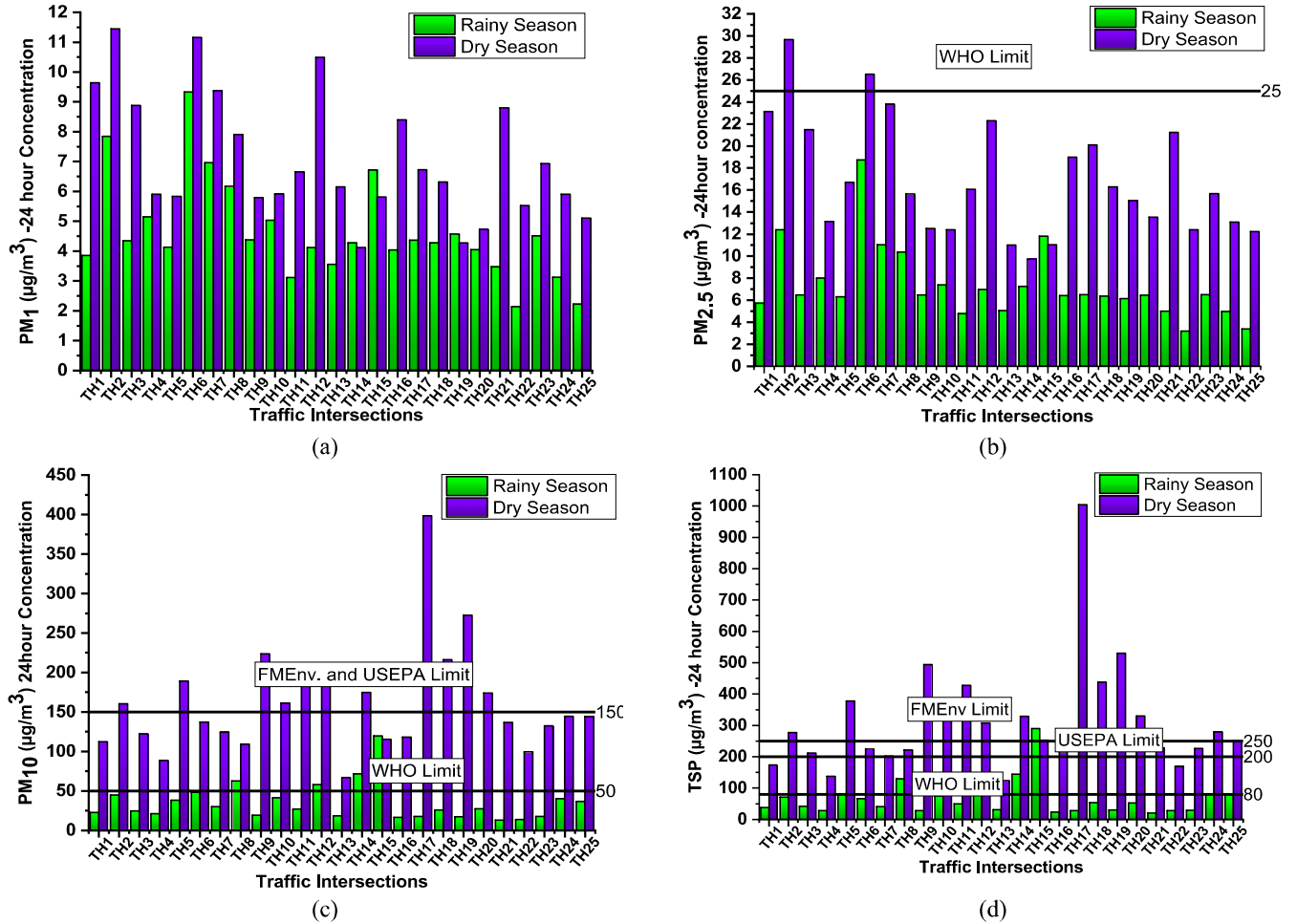


(f)

**Figure 1.** Seasonal concentration levels of gaseous pollutants at 25 traffic Intersections (a) CO (b) NO<sub>2</sub> (c) SO<sub>2</sub> (d) NH<sub>3</sub> (e) TVOCs (f) O<sub>3</sub>

**3.2 Seasonal variation in concentration of particulates at Tis**

Figure 2(a) PM<sub>1</sub> (b) PM<sub>2.5</sub> and (c) PM<sub>10</sub> shows seasonal concentration levels of particulate matter at 25 traffic Intersections.



**Figure 2.** Seasonal concentration levels of particulate matter at 25 traffic Intersections (a) PM<sub>1</sub> (b) PM<sub>2.5</sub> (c) PM<sub>10</sub> (d)TSP

**3.3 Pollutants, recommended limits and effects on air quality**

Employing the AQI ratings, Table 1 indicated that ambient air quality for PM<sub>2.5</sub>, PM<sub>10</sub>, CO and NO<sub>2</sub> were moderate, SO<sub>2</sub> was hazardous while ground-level ozone was good. This signifies that apart from SO<sub>2</sub>, all other pollutants were within the acceptable range.

**Table 1.** AQI standards for atmospheric pollutants

Index Values	AQI Categories	PM <sub>2.5</sub> (µg/m <sup>3</sup> )	PM <sub>10</sub> (µg/m <sup>3</sup> )	CO (ppm)	NO <sub>2</sub> (ppm)	SO <sub>2</sub> (ppm)	O <sub>3</sub> (ppm)
		24-hour	24-hour	8-hour	1-hour	1-hour	8-hour

0-51	Good	0-12	0-54	0-4.4	0-0.053	0-0.035	0-0.054
51-100	Moderate	12.1-35.4	55-154	4.5-9.4	0.054-0.100	0.036-0.075	0.055-0.070
101-150	Unhealthy for Sensitive Groups	35.5-55.4	155-254	9.5-12.4	0.101-0.360	0.076-0.185	0.071-0.085
151-200	Unhealthy	55.5-150.4	255-354	12.5-15.4	0.361-0.649	0.186-0.304	0.086-0.105
201-300	Very Unhealthy	150.5-250.4	355-424	15.5-30.4	0.605-1.249	0.305-0.604	0.106-0.200
301-500	Hazardous	250.5-500.4	425-604	30.5-100.4	1.250-2.049	0.605-1.004	>0.200
	Pollutants Mean Concentration	12.14	97.88	5.26	0.07	1.54	0.04
	<b>Ibadan Overall AQI ranking</b>	Moderate	Moderate	Moderate	Moderate	Hazardous	Good

### 3.4 Health Risk Assessment of TRAPs at Traffic Intersections

**Table 2.** Exposure Risk Assessment of Particulate and Gaseous Pollutants in Ibadan

Health Risk Parameters		Rainy Season	Dry Season	Rainy and Dry Seasons
PM <sub>2.5</sub> : Cardiopulmonary mortality (%)	ER	0.27	0.44	0.37
	AF	0.21	0.31	0.27
PM <sub>2.5</sub> : Lung cancer mortality (%)	ER	0.43	0.73	0.60
	AF	0.30	0.42	0.38
PM <sub>10</sub> : All-cause mortality (%)	ER	0.06	0.36	0.20
	AF	0.06	0.26	0.17
SF = UR/(BW x IR) = 8.02x10 <sup>-6</sup> (for PM <sub>2.5</sub> )				
LADD		3.64	8.40	6.02
ELCR		2.92 x 10 <sup>-5</sup>	6.74 x 10 <sup>-5</sup>	4.83 x 10 <sup>-5</sup>
Hazard Quotient (HQ) via Inhalation				
CO		6.45x10 <sup>-2</sup>	8.31x10 <sup>-2</sup>	7.38x10 <sup>-2</sup>
NO <sub>2</sub>		1.07x10 <sup>-1</sup>	1.56x10 <sup>-1</sup>	1.32x10 <sup>-1</sup>
SO <sub>2</sub>		2.13	2.56	2.35
Ground level O <sub>3</sub>		1.05x10 <sup>-1</sup>	1.77x10 <sup>-1</sup>	1.41x10 <sup>-1</sup>

Notably, overall AQIs of PM<sub>2.5</sub>, PM<sub>10</sub>, CO and NO<sub>2</sub> were acceptable despite recording high concentrations and breaching recommended limits at some TIs because of atmospheric dispersion and dilution of these pollutants concentration at the TIs. Pollutants dispersion is influenced by meteorological factors such as wind speed, wind direction, relative humidity, ambient temperature, rainfall and land topography (Ranjan *et al.*, 2016).

Table 2 indicated that AF for all-cause mortality due to PM<sub>10</sub> exposure could be avoided by 0.06%, 0.26% and 0.17% during the rainy season, dry season and combined two seasons, respectively if PM<sub>10</sub> were maintained at 10µg/m<sup>3</sup>. The elevated AF (0.26%) during the dry season denotes a higher risk in the study area. Arranz *et al.* (2014) reported that exposure to particulate was responsible for all-cause mortality of 2% in Valladolid city of

Spain while Chalvatzaki *et al.* (2019) and (Odekanle *et al.*, 2020) revealed that 2.2% and 0.14% of all-cause mortality were preventable from exposure to PM<sub>10</sub> in Lisbon (Spain) and Ile-Ife (Nigeria), respectively.

The CR<sub>inh</sub> from PM<sub>2.5</sub> exposures (Table 2) indicated that the tolerable risk of cancer is higher during the dry season ( $6.74 \times 10^{-5}$ ) than during the rainy season ( $2.92 \times 10^{-5}$ ). In this study, cancer risk through inhalation increased by 130.69% during the dry season in comparison with the rainy season signifying that the dispersion rate and toxicity of PM<sub>2.5</sub> are higher in the dry season. HQ<sub>inh</sub> results demonstrated that the probabilities that emissions of CO, NO<sub>2</sub> and ground level O<sub>3</sub> will pose non-cancer risks were all insignificant at TIs in Ibadan except SO<sub>2</sub> with HQ<sub>inh</sub> values of 2.13, 2.56 and 2.35 for the rainy season, dry season and combined two seasons which were all greater than 1.0. This implies SO<sub>2</sub> emission at the studied TIs could cause adverse non-cancer ailments in Ibadan.

#### 4. CONCLUSION

This study revealed the seasonal variation and health risks associated with exposure to gaseous pollutants (CO, NO<sub>2</sub>, SO<sub>2</sub>, NH<sub>3</sub>, TVOCs, and ground level O<sub>3</sub>) and particulate matter (PM<sub>1</sub>, PM<sub>2.5</sub>, PM<sub>10</sub> & TSP) at and around traffic hotspots in a typical African urban environment. The concentration levels of studied pollutants measured at 25 major TIs in Ibadan were considerably more hazardous to public health during the dry season than the rainy season. Dispersion of pollutants was bolstered by prevailing meteorological conditions, the number of on-road vehicles, local activities at and around TIs and the dominating wind flowing from the southwest direction during the rainy season and the assortment of wind blowing from north-east and south-west direction during the dry season. The average concentrations of gaseous and PM pollutants exceeded the threshold limits set by WHO, National Ambient Air Quality Standards (NAAQS) of the United States and FME<sub>env</sub> at many TIs mostly in the dry season. Mortality estimates associated with PM<sub>2.5</sub> and PM<sub>10</sub> exposures revealed that ER and AF during the dry season were above the estimates obtained during the rainy season and combined seasons. The AQI rating indicated that concentrations of PM<sub>2.5</sub>, PM<sub>10</sub>, CO and NO<sub>2</sub> were moderate, SO<sub>2</sub> was hazardous while ground-level O<sub>3</sub> concentration was good at the studied traffic hotspots. Health risk assessment of Ibadan TIs showed that CR of PM<sub>2.5</sub> was acceptable (tolerable) while the non-cancer risk of SO<sub>2</sub> was significant at the studied TIs. Pearson's correlation indicated that PM<sub>1</sub> & PM<sub>2.5</sub> emissions from vehicle exhausts increased as traffic congestion (rush hours) rose whereas PM<sub>10</sub> emission increased with road dust re-suspension during traffic free-flow (non-rush hours). The results of this study are expedient in planning, designing and developing robust pollution mitigation strategies to control traffic air pollution in a typical African city. Alternative routes for vehicle decongestion, the use of cleaner fuel from renewables and the strengthening of mandatory vehicle inspection and maintenance programs could be integrated as basic solutions to urban air pollution in Africa.

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