INTRA-URBAN PATTERN AND DETERMINANTS OF INDOOR AIR QUALITY IN OGBOMOSO, NIGERIA

***JELILI, M.O.; *ALABI, T. A. and *ODUNOLA, O.O.**
**Department of Urban and Regional Planning,
Ladoke Akintola University of Technology,
Ogbomoso, Nigeria*

ABSTRACT
Given the rising concern on the pernicious effects of indoor air pollution, this paper evaluates the extent, spatial variation and causes of declining indoor air quality in Ogbomoso, a medium-sized traditional urban settlement in Nigeria. Data for the study were obtained from 385 buildings sampled across 27 selected precincts within the identified residential zones in the study area. This was achieved by measuring with gas samplers, the concentrations of four Particulate Matter analytes (PM_1, $PM_{2.5}$, PM_{10} and TSP) within the buildings and administering questionnaire to 441 occupants. Analysis of Variance was used to explain the inter-zonal variations in indoor air quality. Findings from the study revealed a relatively poor air quality in Ogbomoso with the mean indoor $PM_{2.5}$ (41.6μg/m³) and PM_{10}(175.5μg/m³) and TSP (257.2μg/m³) higher than the WHO and FEPA limits. The inter-zonal variations of air quality, using "Indoor PM Aggregate" as a surrogate measure, shows that indoor air quality varied significantly with residential zone (p = 0.0005) but not with building type (p = 0.007). Causes of the observed variations were found to be residents' adopted fuels/ energy contrivances as firewood, and charcoal, among other fuels, linked with increased concentrations of particulate matters within residential zones. The paper finally recommended, among others, the need for a shift from the preponderant biomass burning (firewood and charcoal) and generator use to cleaner (environmental friendly) fuels in order to enhance air quality within residential buildings.
Keywords: Air quality, ambient environment, particulate matters,

INTRODUCTION
Human activities, especially following the dawn of the industrial revolution, have always had the propensity of instigating a variety of environmental pathologies. Notable among such is air pollution- a global environmental problem which has induced widespread concern all around the world owing to its pervasive nature and pernicious effects. Pollutants like Carbon [II] oxide (CO), Sulphur [IV] oxide (SO_2) and Particulate Matters (PM) from a multiplicity of transportation, domestic, industrial and other sources now pervade the contemporary urban scene, permeating the ambient air, with detrimental implications on environmental sustainability and ultimately, human health. It has been revealed by the World Health Organization (2014) that an estimated 6.5 million deaths (11.6% of all global deaths) are associated with both indoor and outdoor air pollution.
Although both developed and developing countries are at risk with regards to air pollution, the situation is critical in developing countries like Nigeria where pollutant-emitting activities like biogas combustion, bush burning and refuse burning are endemic. It is thus not surprising that the biggest air-pollution and its related burden to health occur in the developing countries (Carter, 1998, Mac, 2009; Bency *et al.* 2003).Yet, efforts made at improving the body of knowledge on the phenomenon are rather inadequate in developing countries compared to the developed ones where studies are numerous and data is abundant. Research efforts often do not quantify the extent of air pollution, what is common is generalized assertion on the extent of air pollution predicated on the intensity of economic and domestic activities in an area.
In Nigeria, the instances where empirical studies measuring pollutants' concentrations are carried out, such are often fixated on outdoor air pollution in urbanized and industrialized settlements. For example, extensive enquiries have been made into air pollution in the Niger Delta region of Nigeria by Oluwole *et al.* (1996) which reveal that the levels of volatile oxides of Carbon, Nitrogen and Sulphur and Total Suspended

Particulates (TSP) exceed existing Federal Environmental Protection Agency (FEPA) standards. Similar studies have been carried out in other prominent cities like Lagos, Ibadan and Ado-Ekiti. As documented by Koku and Osuntogun (1999), Lagos has the highest concentrations of SO_2 and NO_2 and Ado-Ekiti, the highest concentration of CO followed by Ibadan. Still, other studies that measure indoor pollutant concentrations focus mainly on undeveloped rural areas as exemplified in Oguntoke *et al.* (2010) in Ogun state Nigeria.

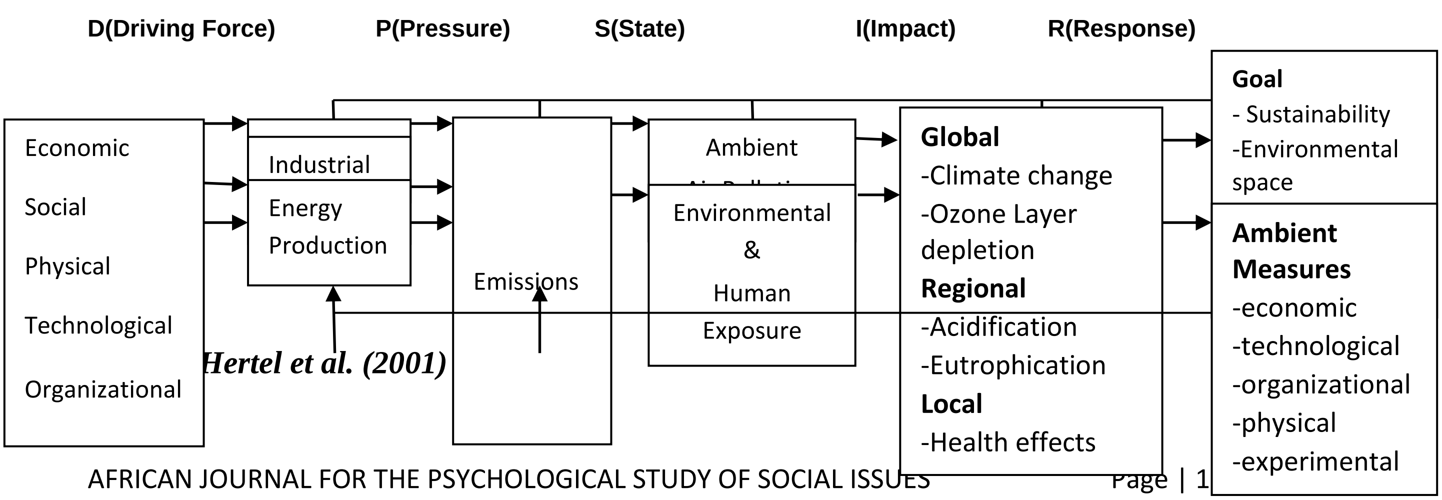
However, there is need for increased research efforts on air quality especially on air pollution in indoor environments as it is more harmful inside homes and buildings where people spend most of their time. A review by the World Health Organization (2007) establishes causal relationships between indoor air pollution and Acute Lower Respiratory Infections (ALRI) among children, Chronic Obstructive Pulmonary Disease (COPD) and lung cancer among adults. Poor indoor air quality has claimed over 1.6 million lives and has left 38.5 million disabled around the world at the dawn of the twenty first century (Smith et. al., 2003). The situation is so critical that reduction of indoor air pollution is a component of the United Nations' Millennium Development Goals, (United Nations, 2005).

Given these facts, a critical enquiry into indoor air pollution configuration in urbanizing traditional cities is imperative. It was against this background that this study appraised the extent of indoor air pollution in Ogbomoso, explicated the spatial pattern of air quality across residential zones and probed into the peculiar causes of declining air quality.

Conceptual Framework

Hertel, De Leeuw, Raaschou-Nielsen, Jensen, Gee, Herbarth, Pryor, Palmgren and Olsen, (2001) present a model of air pollution impact assessment by applying the DPSIR (Drivers, Pressures, State, Impact, Response) model of intervention developed in the 1980s by the National Institute of Public Health and the Environment. The DPSIR is a casual framework for describing the interactions between society and the environment. The model developed by Hertel *et al.* (2001) is a schematic illustration of the chain in air pollution impact assessment (Fig. 2). Succinctly, driving forces (D) such as transport and industry lead to environmental pressures (P) that degrade the state (S) of the environment that has an impact (I) on human health or the environment, which makes the society carry out a response (R) through various actions. This frame work simplifies the collection of information on the relevant elements in the DPSIR chain as well as the possible connections between the different aspects.

Figure 1: Pathway of Air Pollution



Particulate Matters (PM) was used as a surrogate measure of air quality in this study. Particulate matters are pollutants formed by a complex mixture of organic and inorganic substances. They are released during certain operations, such as transport (movement of automobiles) and open storage of solid materials. They also come from combustion of wood and other biomass fuels. Other sources include exposed soil surfaces, including unpaved roads, dust, aerosols, environmental tobacco smoke (ETS) and building materials. All these are common features obtainable in the study area.

Particulate matters represent a wide variety of substances ranging from 0.005 to 100 μm (microns) in aerodynamic diameter like asbestos, dust, mould, pollen, and dander (Lee, 1996). Particulate matters have been classified using particles' aerodynamic diameter in microns (WHO, 2006). These are;

- ✓ $PM_{0.1}$- particles with a diameter less than 0.1μm (ultrafine particulates).
- ✓ $PM_{2.5}$ - particles with a diameter less than 2.5μm (fine particulates)
- ✓ PM_{10}- particles with a diameter less than 10 μm (coarse particles)
- ✓ TSP -particles with diameter between 30 and 100 μm (Total Suspended Particles)

There is however more concern about PM_{10} and $PM_{2.5}$ because of the potential health risks that they pose, given that such fine particles are able to be deposited in, and cause damage to, the lower airways and gas-exchanging portions of the lungs. According to WHO (2005), $PM_{2.5}$ represents respirable particulates while PM_{10} represents inhalable particulates. The later which are the larger particles are deposited on the hairs in the nose or at the bends of the nasal passages while the former which are smaller particles pass through the nasal region and are deposited in the windpipe and lung (tracheobronchial and pulmonary) regions. Both are known to cause respiratory and cardiovascular morbidity and mortality from acute lower respiratory infections (ALRI) and chronic obstructive pulmonary disease (COPD). $PM_{2.5}$ is however a stronger risk factor for mortality than the coarse part of PM_{10} (WHO, 2013).

THE SETTING AND METHODOLOGY

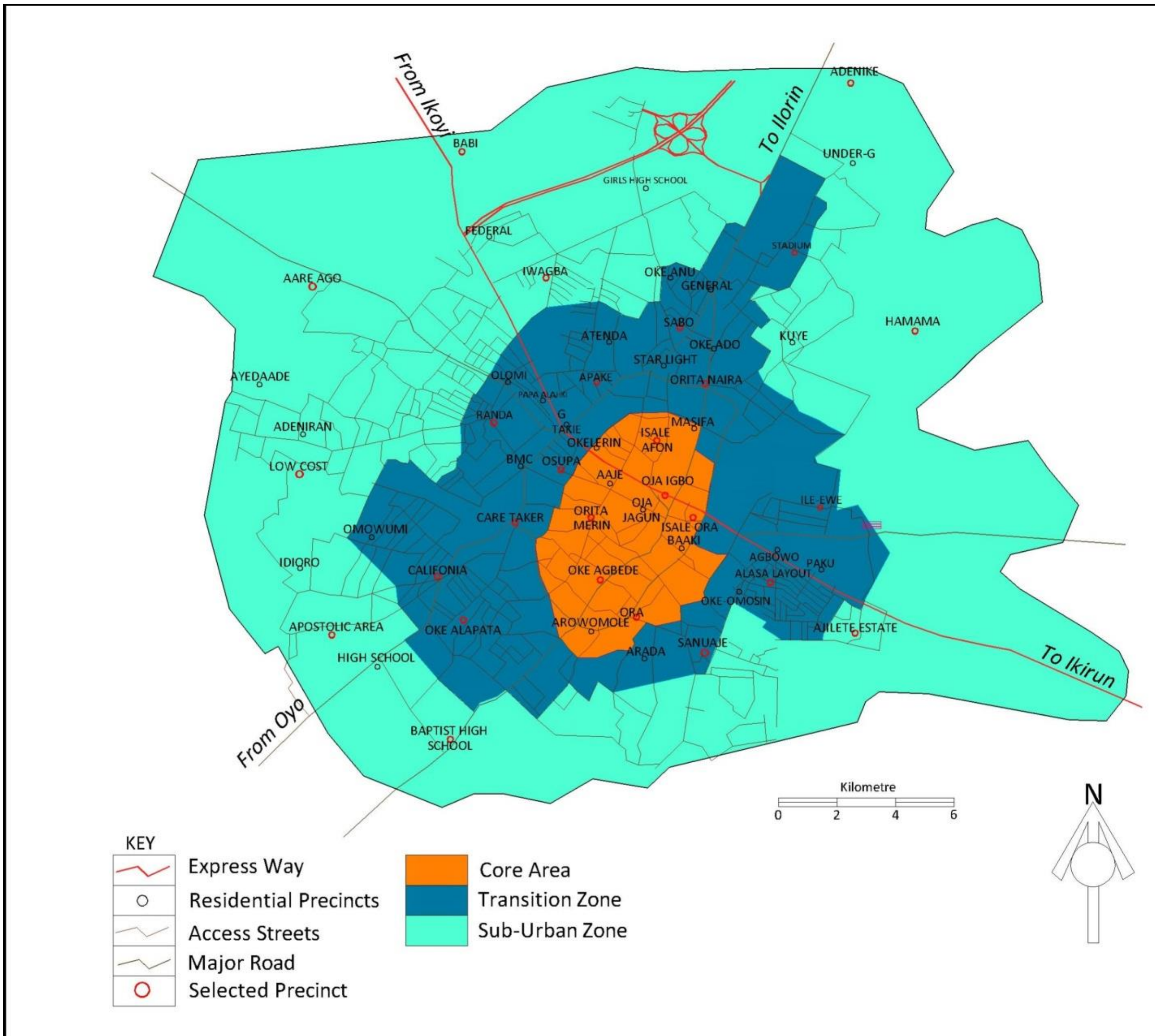
The setting for this study is Ogbomoso, a rapidly urbanizing settlement in Oyo State, south western Nigeria. The town, the second largest after Ibadan, is located around latitude $8^{o}07^{1}$N and longitude $4^{o}14^{1}$E. Ogbomoso lies in the derived savannah vegetation zone and is considered to be a low land rain forest area with its larger part at about 300m-600m above sea level. It experiences wet season between March and October and its dry season between November and February with a mean annual temperature of about 26.2°C, a mean annual rainfall of about 1200mm and average relative humidity of 60%. The study covers Ogbomoso Township comprising Ogbomoso North and South Local Government Areas – the two urbanized local government areas - having a combined estimated population of 354, 617 (National Bureau of Statistics, 2012). Within the study area, fifty-four (54) residential precincts virtually covering the entire township were identified and mapped.

Like other predominantly residential traditional cities in south-western Nigeria, it is possible to delineate Ogbomoso into three ecological zones produced from the pre-colonial, colonial and post-independence historical epochs. Each zone is homogenous in terms of physical layout, socioeconomic status and environmental amenities (Afon, 2009) and they are the core, transition and suburban zones (Figure. 1). The core area is the central zone that dates from the pre-colonial era and constitutes the oldest part of the town. It consists of the king's palace, important cultural landmarks like traditional monuments, market and closely built (high density) residential areas connected by footpaths, narrow access roads, and in some cases by motorable roads. The transition zone surrounds the core and is an area of wholesales and light manufacturing mixed with medium density housing units submerged in a considerable level of built environment deterioration. The last zone is often beyond the city limit in suburban areas and is a zone of spotty development of high class residences along lines of rapid transit. It is commonly referred to as commuter's zone. This morphology simplifies the analysis of various urban issues including that of air pollution and this informed the decision to use the approach in this study.

The survey research method was adopted for the study using questionnaire, direct observation and gas sampler as instruments of data collection. First, half the total number of precincts within each residential zone, evenly spread enough to prevent clusters and maximize coverage, was selected. Hence a total of twenty seven (27) precincts were selected having 6,12 and 9 precincts in the core, transition and suburban zones respectively (giving a ratio of 2:4:3) based on their respective human and housing population sizes. Because of the need to collect environmental and air quality data alongside residents' socioeconomic data, buildings were used as a basis for data collection. With the aid of Google Earth, the buildings in each selected precinct were enumerated and physical survey used to update the situations. Next, 10% of the buildings in a selected precinct were sampled. Random systematic sampling technique was used to select buildings along the already identified roads within each precinct using an interval of eight. On the whole, a total of 441buildings were covered in the study.

Data was collected over a period of four weeks. Basically, in each residential building sampled:

- A resident of above 18 years was chosen for questionnaire administration
- Ambient environmental characteristics were observed and recorded
- MetOne GT-531S Mass/Laser particle counter were used to measure the concentration of pollutants (Particulate Matters) within sampled buildings.



STUDY AREA (Sampled Precincts and Residential Zones)

Source: Author's cartography from Google Earth (2015); Afon (2002) & field survey (2016).

Figure 2: Ogbomoso Township

Of the 441 copies of questionnaire administered, 385 were returned; this was augmented with observed indoor pollutant concentrations representing a recovery rate of 87.3%. PM mass concentrations for all four analytes were measured across the 385 sampling points in the 27 residential precincts within the three residential zones. Mean indoor PM levels for the sampled buildings within each precinct were computed (Table 1) but particular attention was given to respirable particles ($PM_{2.5}$) and inhalable particles (PM_{10}).

Data on residents' socio-economic variables obtained were analyzed using frequencies and percentages, cross tabulation and chi-square to provide insight into the divers of air quality. One Sample t-test was used to compare the observed pollutant concentration with the set WHO to make necessary inferences. Moreover, one-way Analysis of variance (ANOVA) was used to test the variation of indoor air quality across residential zones using the recorded pollutant concentration levels in selected buildings. However, data transformation was conducted via log transformation prior to using the ANOVA in order to ensure normal distribution of the collected data. Base-10 log transformation was adopted because it is possible to look at them and still see the magnitude of the original number.

RESULTS AND DISCUSSION

Indoor PM Concentrations within Residential Areas

The lowest mean $PM_{2.5}$ concentration recorded was 27.8μg/m³ in Ajilete Estate, while the highest was 51.4μg/m³ in Alasa Layout. Similarly, the lowest mean PM_{10}concentration was 142.7μg/m³ in Low Cost Area, while the highest was 230.8μg/m³ in Alasa Layout. The cumulative mean PM values of $PM_{2.5}$ and $PM_{10}$for the study area were compared to the WHO standards for daily average concentration. The results revealed that the mean indoor $PM_{2.5}$ (41.6μg/m³) was lower than the WHO IT-1 limit (75μg/m³), while the mean for indoor PM_{10} (175.5μg/m³) was higher than WHO IT-1 limit (150μg/m³) in the study area. It is noteworthy that the rationale for the WHO Interim Target (IT) limits is to promote a shift from high air pollutant concentrations, which have serious health consequences, to lower concentrations in order to promote steady progress towards meeting the air quality objectives in developing countries.

Given the situation in the study area, indoor air pollution with respect to particulate matters was discernible. Even though the concentration of $PM_{2.5}$ was within the acceptable limits, the quality of indoor air in buildings within the study area was low given the high concentration of inhalable particulates (PM_{10}) which exceeded the prescribed limit.

Table 1: Indoor PM Concentrations within Residential Precincts *(μg/m³)*

Sampling Point (s/n)	Residential Precincts	PM_1	$PM_{2.5}$	PM_{10}	TSP
Core 1	Oja Igbo	26.6	45.3	168.1	219.4
C2	IsaleOra	24.3	44.8	178.0	216.9
C3	IsaleAfon	25.8	41.7	177.3	278.4
C4	OritaMerin	26.3	45.4	200.8	400.8
C5	OkeAgbede	24.1	41.8	154.5	270.5
C6	Ora	24.2	47.6	186.3	279.4
Transition 7	Ileewe	24.2	41.3	154.9	214.7
T8	Alasa layout	32.3	51.4	230.8	330.2
T9	Sanuaje	25.6	48.8	189.4	253.6
T10	OkeAlapata	22.9	40.3	159.6	280.3
T11	California	22.2	36.2	172.3	247.5
T12	Care Taker	26.6	41.7	184.9	285.8
T13	Osupa	25.1	49.6	218.9	250.2
T14	Randa	22.6	46.3	220.8	243.7
T15	Apake	22.9	40.9	189.2	276.3
T16	Sabo	23.2	36.1	194.7	288.2
T17	Stadium	25.1	40.3	195.8	280.3
T18	Orita Naira	22.9	48.9	221.5	235.5
Suburban 19	Ajilete Estate	17.9	28.7	168.7	312.9
S20	Iwagba	20.0	37.6	170.5	287.5
S21	Bapt. High Schl.	20.6	36.9	148.8	213.1
S22	Babi	19.8	32.3	144.8	195.4
S23	Hamama	22.3	45.1	157.3	238.1

S24	Adenike	20.9	37.5	154.7	227.3
S25	Aare Ago	21.1	48.1	145.8	225.5
S26	Low Cost	18.8	30.3	142.7	250.8
S27	Apostolic	23.7	40.4	145.7	221.1
Daily Average		***23.6***	***41.6***	***175.5***	***257.2***

Source: Source: Field survey (2016) ****Sampling Time Range: 45 min. – I hour***

Furthermore, One Sampled t-test was used to compare the mean indoor PM values with the WHO standards to see any significant differences in the computed mean for each residential zone and the set standards. Table 2 shows that the mean indoor $PM_{2.5}$ concentrations for the three residential zones (43.7, 42.8 and 38.4) were lower than the WHO standard. Moreover, given the p-value (0.0005< 0.05) of the one sampled T-Test**,** the differences in the set standard and the observed means for the three residential zones were statistically significant. This implies a decent indoor air quality with regards to $PM_{2.5}$ as its concentrations was not up to the level deemed inimical to healthy living in the study area.

For PM_{10}, the mean concentrations for each of the residential zones were higher than the WHO standard. In the core and transition zones, the mean indoor PM_{10} concentrations were significantly higher than the set standard (p-value 0.0005 < 0.05). However, in the suburban zone, the mean PM_{10} value was higher than the set standard, but the difference was not statistically significant with p = 0.3210 (> 0.05). The implication of this is that indoor air pollution with regards to PM_{10} was discernible only in the core and transition zones where the PM levels were significantly beyond the standards for healthy living

Table 2: One Sample t-test for $PM_{2.5}$ and PM_{10}

Pollutant	**Zone**	**Mean**	**WHO IT-1 Limits**	**Df**	**t-value**	**p-value**
$PM_{2.5}$	Core	43.773	75µg/m³	72	-34.125	0.0005
	Transition	42.839	75µg/m³	186	-39.272	0.0005
	Sub-urban	38.384	75µg/m³	124	-46.187	0.0005
PM_{10}	Core	174.323	150µg/m³	72	5.345	0.0005
	Transition	190.585	150µg/m³	186	9.066	0.0005
	Sub-urban	153.770	150µg/m³	124	0.997	0.3210

Source: Source: Field survey (2016)

Variation in Indoor Air Quality across Residential Zones

The two vital indoor air quality indicators $PM_{2.5}$ and PM_{10}were aggregated into a single composite variable labelled "Indoor PM aggregate" (obtained by standardizing the two variables and taking their average), measured across the 385 sampling points to crystallize the intra-urban variation in air quality.

The results on mean indoor PM aggregate are shown in Table 3, with the transition zone having the highest score (112.59µg/m³). This was followed by the core area (107µg/m³), while the suburban zone had the least (93.33µg/m³). Hence, indoor air pollution was highest within the transition zone. A look at Table 1 lends credence to this as Alasa Layout in the transition zone recorded the highest level of indoor $PM_{2.5}$ (51.4µg/m³) and indoor PM_{10} (230.8µg/m³).

Table 3: Indoor PM with Residential Zones (Indoor PM ($PM_{2.5}$& PM_{10} Aggregate)

Residential Zone	N	Mean (Log trans.)	Mean (µg/m³)	Std. Deviation	Std. Error	95% Confidence Interval for Mean	
						Lower Bound	Upper Bound
Core Area	73	2.0296	107.05	1.22	1.023	102.28	112.07
Transition Zone	187	2.0515	112.59	1.30	1.019	108.37	117.00
Suburban Zone	125	1.9700	93.33	1.28	1.022	97.52	97.52
Total	385	2.0209	104.93	1.29	1.013	107.72	102.24

Table 4: Tukey HSD Post Hoc Test(Indoor PM ($PM_{2.5}$& PM_{10}) Aggregate)

(I) Residential Density	(J) Residential Density	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Core Area	Transition Zone	-.02190	.1485	.304	-.0568	.0130
	Suburban Zone	.05959*	.1585	.001	.0223	.0969
Transition Zone	Core Area	.02190	.1485	.304	-.0130	.0568
	Suburban Zone	.08149*	.1243	.000	.0522	.1107
Suburban Zone	Core Area	-.0.5959*	.1585	.001	-.0969	-.0223
	Transition Zone	-.08149*	.1243	.000	-.1107	-.0522

*. The mean difference is significant at the 0.05 level.

ANOVA results revealed a statistically significant difference at alpha level of 0.05 in the mean indoor PM aggregate for the three residential zones ($F_{2,\ 382}$) = 21.784 and p = 0.0005 (p value < 0.05). The Null hypothesis (H_O) was thus rejected and the alternative hypothesis accepted. Hence, indoor air quality varies significantly with residential zones. Post Hoc test using the Tukey HSD (Table 4) revealed that the mean indoor PM aggregates of the core area and transition zones had no statistically significant difference with significant value of 0.304 (> 0.05). Both however differed significantly from that of the suburban zone. Since the mean indoor PM aggregate of the suburban zone was lower, it can be inferred that the air quality of the suburban zone was significantly better than that of the other residential zones.

Comparison of total suspended particles (TSP) levels across the 27 sampling points in the study area revealed the same trend. The average indoor TSP concentration in the study area (257.2µg/m³) was higher than the 250µg/m³maximum daily average TSP limits set by the Federal Environmental Protection Agency (FEPA), the only precincts with buildings having indoor TSP levels lower than the FEPA limits were found in the suburban zone.

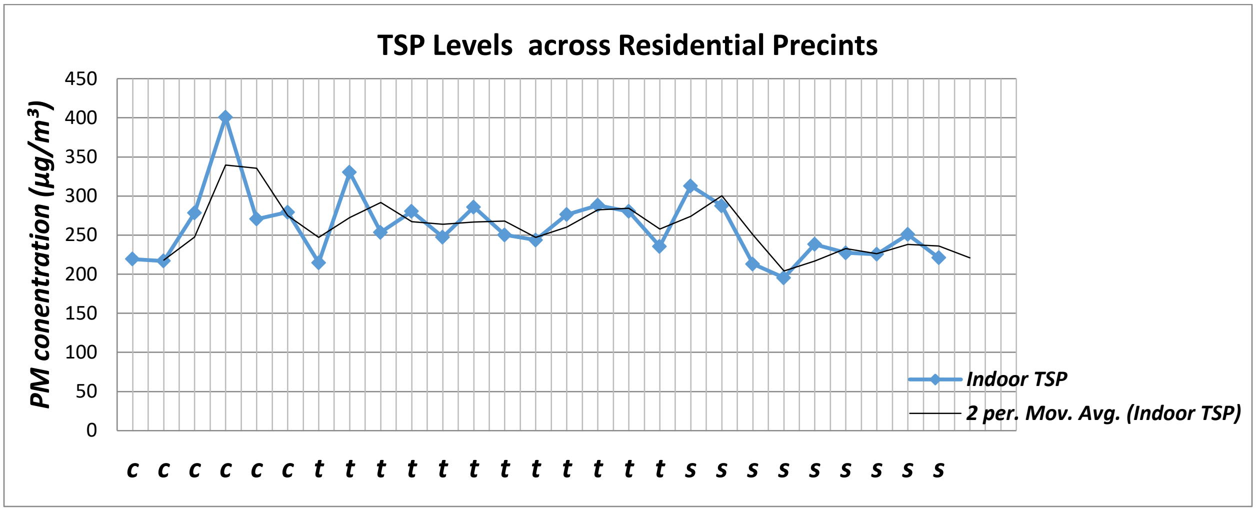


***Figure 3: Indoor and Outdoor PM $_{2.5}$ Levels**
Source: Field survey (2016)

Variation of Indoor Air Quality with Building Types

Indoor air pollution occurs in the confines of a building and four major building types exist in the study area. Within the residential zones, the core area had the highest proportion of impluviums (42.5%); the transition zone had the highest proportion of rooming buildings (66.8%) while the suburban zone had the highest proportion of flats and duplexes (47.2%; 21.6%).

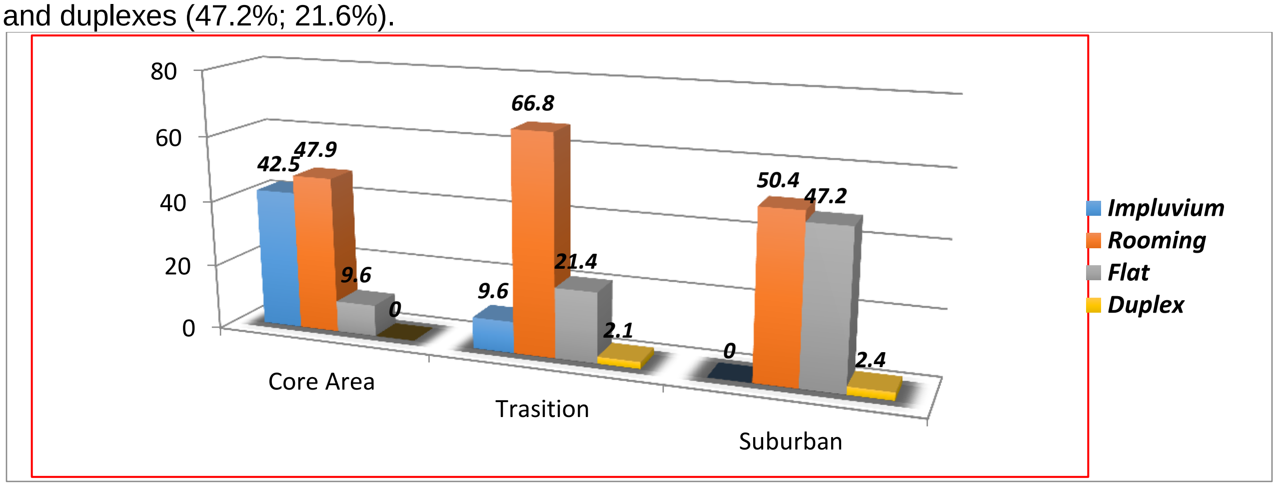


Figure 4: Building Types within Residential Zones
Source: Field survey (2016)

Given the disparity in the spread of building types across residential zones, ANOVA was also used to compare the indoor air quality among the four building types using the composite variable of Indoor PM aggregate. The result revealed no statistically significant difference at alpha level of 0.05 in the mean indoor PM concentrations for the four building types; F (2, 381) = 4.145 and p = 0.007 (P value > 0.05). The H_O was thus accepted, asserting that the indoor air quality does not vary significantly with building type. In other words, the difference in the mean indoor PM aggregate among building types (Table 4), decreasing from impluviums (110.92µg/m³) to duplexes (90.93µg/m³) was not statistically significant.

Table 4: Indoor PM with Building Types (Descriptives)

Indoor PM ($PM_{2.5}$& PM_{10} Aggregate)

Building Type	N	Mean (Log trans.)	Mean (µg/m³)	Std. Deviation	Std. Error	95% Confidence Interval for Mean	
						Lower Bound	Upper Bound
Impluvium	50	2.0450	110.92	1.28	1.424	103.30	119.07
Rooming	222	2.0305	107.28	1.28	1.017	103.80	110.87
Flat	106	1.9936	98.54	1.32	1.306	93.45	103.89
Duplex	7	1.9587	90.93	1.37	1.125	68.14	121.31
Total	385	2.0209	104.93	1.30	1.013	102.24	107.72

Consequently, though indoor air quality varies significantly across residential zones, the building types within those residential areas are not the cause of the observed variation. For instance, the transition zone has the highest proportion of “rooming buildings” but this is not the cause of its having the highest mean indoor PM aggregate neither is the highest proportion of flats and duplexes in the suburban zone responsible for the sub-urban zone having the lowest mean indoor PM aggregate. In a nut shell, building type is not a significant factor influencing indoor air pollution configuration in the study area. Hence other factors appear to be responsible for the observed intra-urban variation in indoor air quality.

Observed Drivers of Indoor Air Quality

Resident’s income and cooking fuels are important drivers of indoor air quality and since building type is not a significant driving factor, analysing them becomes imperative. Within the study area, the highest proportion of residents (42.9%) earned below the minimum monthly wage of ₦18,000 and the lowest proportion (3.4%) earned high between ₦100,000 and ₦200,000. The population was however mainly made up of low income earners (39.0%) earning between ₦19,000 and ₦50,000. Furthermore, the Chi-square test revealed a variation in income level across residential zones (X^2 value = 15.693; Asp. Sig. = 0.015) with the suburban zone having the highest proportion of high income earners while the core area had the highest proportion of low income earners (49.3%).

However, the transition zone had the highest proportion (49.1%) of those earning below minimum wage. These are the residents with a greater propensity to adopt less efficient (unclean) fuels like sawdust, firewood or charcoal that can increase the concentration of pollutants in the indoor environment.

Table 4: Domestic Fuel/Energy Contrivances across Residential Zones

Cooking Fuel		**Residential Zone**			**Chi-Square Analysis**		
		Core	Transition	Suburban	X^2 Value	Asp. Sig.	Remarks
Firewood	Yes	26 (32.9%)	34 (43.0%)	19 (24.1%)	12.997	0.02	Significant
	No	47 (15.4%)	153 (50.3%)	106 (34.6%)			
Charcoal	Yes	65 (25.6%)	116 (45.7%)	73 (28.7%)	21.792	0.0005	Significant
	No	8 (6.1%)	71 (54.2%)	52 (39.7%)			
Kerosene Stove	Yes	68 (19.1%)	176 (49.4%)	112 (31.5%)	2.256	0.324	Not Significant
	No	5 (17.2%)	11 (37.9%)	13 (44.8%)			
Gas Cooker	Yes	4 (3.0%)	68 (51.5%)	60 (45.5%)	37.679	0.0005	Significant
	No	69 (27.3%)	119 (47.0%)	65 (25.7%)			
Electric Cooker	Yes	18 (14.6%)	52 (42.3%)	53 (43.1%)	9.540	0.008	Not Significant
	No	55 (21.0%)	135 (51.5%)	72 (27.5%)			
Saw Dust	Yes	0 (0.0%)	1 (0.0%)	0 (0.0%)	1.062	0.588	Not Significant
	No	73 (19.0%)	186 (48.4%)	125 (32.6%)			
	Yes	35	97	82			

Generator		(16.4%)	(45.3%)	(38.3%)	7.849	0.020	Significant
	No	38 (22.2%)	90 (52.6%)	43 (25.1%)			

Degree of Freedom = 2
Source: Field survey (2016)

Seven (7) fuel/energy contrivances were identified in the study area and Chi-square test indicated that only four varied across residential zones (Table 5). The frequencies of usage of kerosene stove, electric cooker and saw dust appeared to be relatively the same across residential densities, while those of firewood, charcoal and gas cooker and generator exhibited significant differences. Of the four, firewood, charcoal and generator are capable of generating high levels of Carbon [II] oxide and particulate matters. Yet the transition zone had the highest proportion of all the three with 43.0%, 49.9% and 45.3% respectively. All these can explain why the transition zone had the highest levels of particulate matters concentration, giving it the worst indoor air quality. The suburban zone on the other hand had the highest proportion of clean cooking fuels like gas cooker (45.5%) and electric cooker (43.1%) and lowest proportion of residents using unclean ones like firewood (24.1%), which could explain why this zone had the lowest concentration of particulate matter pollutants in the study area.

Conclusion

The inter-zonal analysis of indoor air quality using data on particulate matters in Ogbomoso has provided the much needed insight into the air quality situation in the town. Indoor air quality in residential buildings was generally low as the mean $PM_{2.5}$; PM_{10} and TSP concentrations exceeded the prescribed limits. Moreover, the indoor air quality was not spatially homogeneous but exhibited significant variations, with the transition zone having the worst. The study also showed that building type had no significant effect on indoor air compared to domestic fuel/energy utilities. Considering the negative consequences of indoor air pollution, mitigating measures to improve air quality are imperative in the study area.

There is need for a shift from the preponderant biomass burning (firewood and charcoal) and generator use to cleaner (environmental friendly) energy burning such as liquefied petroleum gas, solar power and electricity. The government needs to improve people's accessibility to these environmental friendly energy sources especially gas and stable hydro-electricity, as this will reduce residents' exposure to the pollutants. Furthermore, environmental education is a necessary course of action. There is the need to continuously enlighten the residents on the extent, causes and effects of indoor air pollution. The responsibility lies on the Public Health and Town Planning departments of Local Governments to create awareness on indoor air pollution so that residents can realize the dangers and health hazards therein and learn how to forestall it. Any such efforts, given the observed spatial variation of air quality, are better focused first on the transition zones to ensure effectiveness. These actions when taken can help foster cleaner indoor air in the interest of residents.

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