World Journal of Innovation And Modern Technology E-ISSN 2756-5491 P-ISSN 2682-5910
Vol 6. No. 1 2022 www.iiardjournals.org

Covid-19 Pandemic: Year-By-Year Indoor Assessment of $PM_{2.5}$ Indices of Built Envelopes in Egbeada Housing Estate, Imo State

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DOI: 10.56201/wjimt.v6.no1.2022.pg33.56

Abstract
There has been a lot of discuss on particulate matter and its impact on human health. Of immense concern is its propensity to cause and trigger cardiac, pneumonic and bronchial ailments on occupants after long and sustained exposure. The lockdown scenario necessitated by the outbreak of the Sars-Cov-2 virus in 2019 seemed to exacerbate spike of $PM_{2.5}$ indices in livable units. This study was designed to understudy the impact of the $PM_{2.5}$ pollutant necessitated by lockdown policy directives on occupants living in Egbeada Federal Housing Estate, Owerri, Imo State, Nigeria. The study employed a year-by-year assessment of $PM_{2.5}$ readings of living units during and after the lockdown scenario. These readings, captured with particulate matter monitor PCE-RCM 05, served as major data extrapolated from living units that were selected through purposive sampling techniques. Cohort analysis was used to analyze data collated between March 2020 and December, 2021 to extract information of PM2.5 indices in all identified sections of the estate. Data visualization was also employed to show how particulate matter was distributed during and after the lockdown period while observations yielded real-time relationship between $PM_{2.5}$ indices and occupant density (OcD). Results showed that $PM_{2.5}$ indices spiked during the lockdown period and gradually assumed a flatline after the lockdown scenarios. To this end, it is advised, among other recommendations, that further research should be directed towards patenting poaceae and gramineae that have phytovolatilization capacity which can be adopted as bioremediation inclusions in planning and building regulations.

***Keywords**: Bioremediation, Cohort analysis, Data visualization, Occupant density, Phytovolatilization, $PM_{2.5}$, Poaceae, Sars-Cov-2 virus.*

INTRODCUTION

Coronavirus disease 2019 (COVID-19) is a contagious disease caused by a virus, the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). The earliest issue was noticed in Wuhan, China, in December 2019. The disease spread worldwide, leading to the COVID-19 pandemic (Wikipedia, 2022).

Symptoms of the contracted virus include high bodily temperatures, dry cough, migraine, fatigue, labored breathing, loss of smell and taste. Symptoms may begin one to fourteen days after exposure to the virus. At least a third of population that contract the virus do not develop noticeable symptoms. Of the population who develop signs noticeable enough to be classed as patients, most (81%) show mild to moderate symptoms (up to mild pneumonia), while 14% develop serious symptoms (dyspnoea, hypoxia, or more than 50% lung involvement on imaging), and 5% develop critical symptoms (respiratory failure, shock, or multiorgan dysfunction). Older people have greater risk of developing severe symptoms. Some people continue to experience a range of effects (long COVID) for months after recovery, and damage to organs has been observed.

COVID-19 in high communicable when people inhale air contaminated by minute particles containing the virus. The risk of breathing in these contaminated pockets of tainted air is highest when people are in close proximity, particularly indoors. Transmission can also occur if contact is made with contaminated fluids in the eyes, nose or mouth, and, rarely, via contaminated surfaces. People remain actively contagious for up to 20 days, and can spread the virus even if they are asymptomatic.

Several COVID-19 testing methods have been developed to diagnose the disease. The regular symptomatic method is by spotting the virus's nucleic acid by real-time reverse transcription polymerase chain reaction (rRT-PCR), transcription-mediated amplification (TMA), or by reverse transcription loop-mediated isothermal amplification (RT-LAMP) from a nasopharyngeal swab (Wikipedia, 2022).

Several COVID-19 doses have been approved and distributed in various countries which have initiated mass vaccination campaigns. Other preventive measures include physical or social distancing, quarantining, covering coughs and sneezes, hand washing, keeping unwashed hands away from the face, ventilation of indoor spaces and policy lockdown strategies.

Lockdowns provided one of many preventive measures meant to check the spread of the virus. Across the globe, many countries restricted movements to indoor spaces irrespective of the quality of such built environments. With general limitation of movements to outdoor public spaces, many people were constrained to live out their lives and daily activities within and around their living quarters. In Nigeria, the Federal Government, through the Presidential Task Force on COVID-19, implemented its Lockdown Policy on 30th March, 2020 at exactly 23:00h for an initial period of 2 weeks. Though this policy was meant for schools, organizations and businesses in FCT, Lagos and Ogun States, most other states within the country went ahead to release their own Lockdown Enforcement Policies in response and according to their own peculiarities. For the period of the lockdown, every person is confined to his or her place of

residence, unless strictly for the purpose of performing an essential service, obtaining an essential good or service, or seeking medical care (Presidential Task Force on Covid-19, 2022).
In Imo State, the government, in its Executive Order № 001, 2020 on 'Covid-19 Lockdown and Curfew' imposed restrictions which took effect from the 18th of April, 2020, 6:00pm to 6:00am daily (Vanguard Newspapers, 2020) The enforcement restricted movement of persons except for those on essential services. Just like that of the federal government, people were confined to their respective indoor environments where they are expected to carry out their daily activities with little or no contact with outdoor environment (The Guardian, 2020). According to the government, the enforcement of a total lockdown order of movement of persons was made to preserve the lives of Imo people. However, conscious studies carried out by theses authors have identified that such restrictions to indoor built envelopes might have far-reaching impact in areas of health of occupants. This is predicated on Indoor Air Quality of such environments where occupants are forced to carry out daily activities like cooking, sleeping, extracurricular hobbies, washing, etc., without option of incorporating outdoor spaces. While these lockdown policies were meant to mitigate the spread of COVID-19, they, on the other hand might be serious precursors of exacerbating particulate matter.
This scientific study looked at the relationship between spiking indices of particulate matter during and after the lockdown periods of the pandemic. This provided empirical evidence on the impact of such lockdowns on occupants of built envelopes vis-à-vis indoor particulate matter.

PROBLEM STATEMENT

The global burden of diseases associated with air pollution exposure exacts a massive toll on human health worldwide: exposure to air pollution is estimated to cause millions of deaths and lost years of healthy life annually. The burden of diseases attributable to air pollution is now estimated to be on a par with other major global health risks such as unhealthy diet and tobacco smoking, and air pollution is now recognized as the single biggest environmental threat to human health.

In Imo State, there are increasing morbidity and mortality from cardiovascular and respiratory diseases and spiking cases of lung cancer with increasing evidence of effects on other organ systems. Statistics from the office of the Commissioner of Health indicate that 3 out of 5 cases of respiratory and cardiovascular illnesses are attributable to pollution which, beyond reasonable doubt, could come from particulate matter ($PM_{2.5}$ and PM_{10}), tropospheric ozone (O_3), nitrogen oxide (NO_2), Sulphur oxide (SO_2) and carbon monoxide (CO). Apart from the diseases resulting from air pollution, this issue imposes significant economic burden on the state.

LITERATURE REVIEW

Due to the COVID-19 pandemic, a number of non-pharmaceutical interventions colloquially known as lockdowns (encompassing stay-at-home orders, curfews, quarantines, cordons and similar societal restrictions) have been implemented in numerous countries and territories around the world. These restrictions were established with the intention to reduce the spread of SARS-CoV-2, the virus that causes COVID-19. By April 2020, about half of the world's population was under some form of lockdown, with more than 3.9 billion people in more than 90 countries or territories having been told to stay at home by their governments. Although similar disease control measures have been used for hundreds of years, the scale of those implemented in the 2020s is thought to be unprecedented (Wikipedia, 2022).

Research and case studies have shown that lockdowns are generally effective at reducing the spread of COVID-19, therefore flattening the curve. The World Health Organization's advice on curfews and lockdowns is that they should be short-term checks to reorganize, regroup, rebalance resources, and protect health workers who are fagged-out. To achieve a balance between restrictions and normal life, the WHO recommends a response to the outbreak that consists of strict personal cleanliness, effective contact monitoring, and isolating when sick (Wikipedia, 2022).

Although many public health experts and economists supported lockdown measures, citing greater long-term costs for allowing the pandemic to spread uncontrollably, such restrictions have had health, social, and economic impacts, and have been met with disapprovals in some quarters.

In Nigeria, the lockdown enforcement took effect on the 30th of March, 2020 for an initial period of 14 days. During the period, citizens of the Lagos and Ogun States where confined to his or her place of residence, unless strictly for the purpose of perfuming an essential service, obtaining an essential good or service, or seeking medical care. All borders linking the two States and FCT to the rest of the country were shut during the period of the lockdown, except for the transportation of persons on essential duty, food, fuel, manufactured goods or donated relief items. Mass gatherings were prohibited, except for funeral services as guided by infection prevention and control regulations, for which social distancing rules apply and crowds were limited to not more than 20 persons. Movement between and within the affected states and FCT were restricted, except for workers involved in the delivery of authorized essential services, duties, food and goods. Retail shops and malls were closed, except where essential goods are being sold. Shops and malls that opened were mandated to enforce social distancing and hygiene measures in line with issued guidelines.

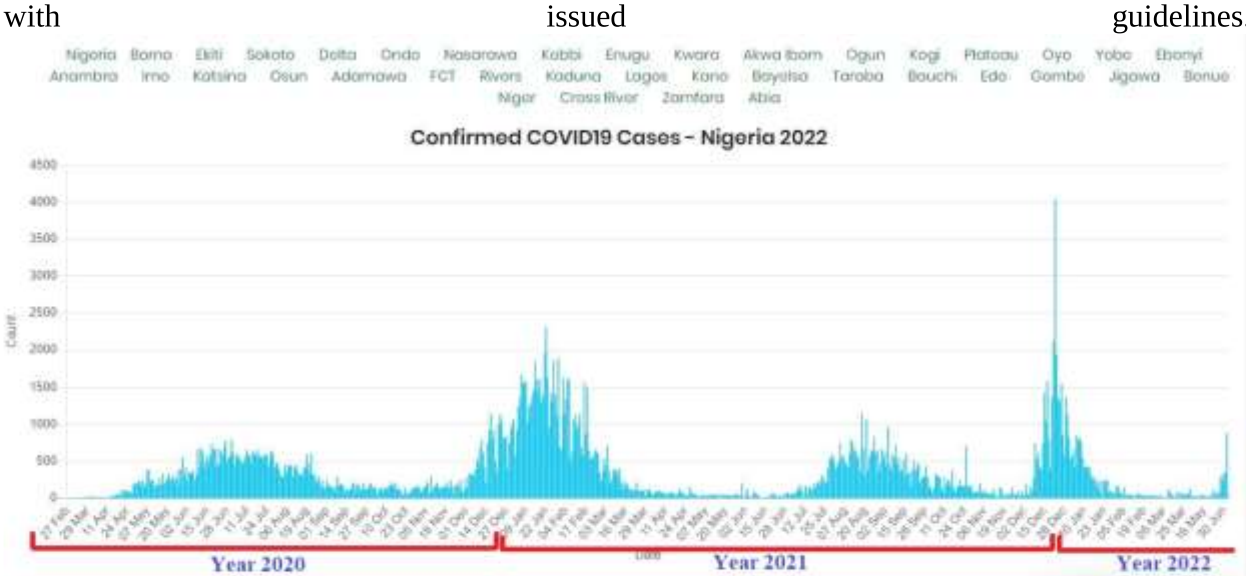

Figure 1: Confirmed COVID19 Cases from 2020 till 2022. *Source: https://covid19.ncdc.gov.ng/state/#!*

Data in figure 1 confirmed that the spread of the virus was quite minimal during the 2-week lockdown. To minimize the spike, the government maintained that industries, companies, schools, offices and government agencies should encourage their staff to work from homes thus hyper-extending the period of time individuals stayed indoors.

In Imo State, a mild drama played out when citizens misinterpreted the imposed lockdown and subsisting 6pm to 6am curfew to mean that there would be movement during the day. This made the generality of the public to still mill around during the day. However, the governor reiterated that the lockdown and curfew was total as movement of persons was completely prohibited. Consequently, all borders leading in and out of the state are shut till there was gradual easing of the lockdown. The Imo State government added another fiat which empowered it to fine violators of the order. In addition to a 7-day community service, violators

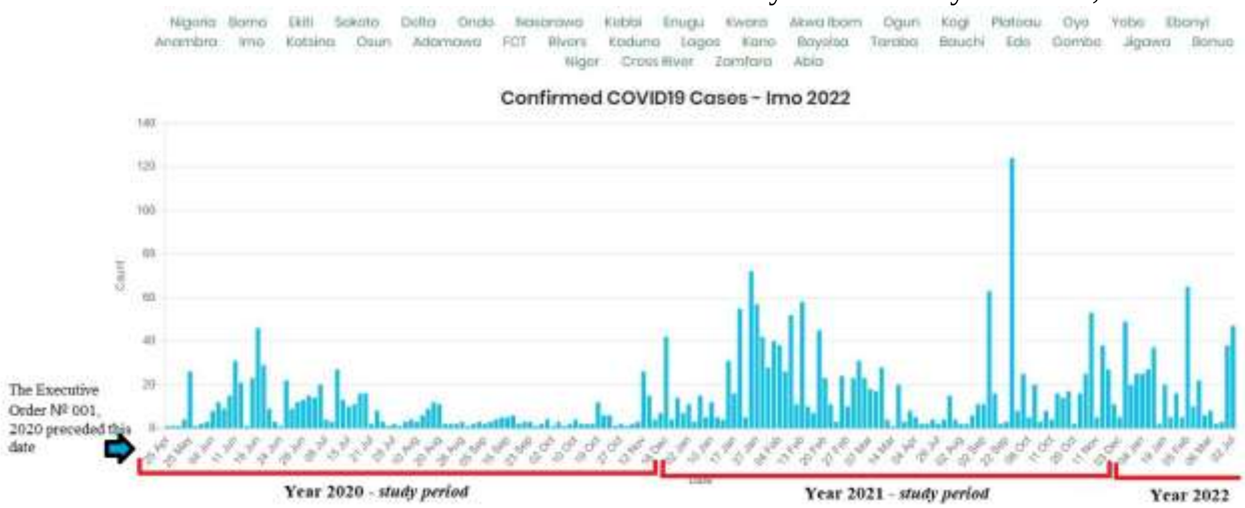

Figure 2: Confirmed COVID19 Cases in Imo State from 2020 till 2022. *Source: https://covid19.ncdc.gov.ng/state/#!*

would be forced to pay fine ranging from N7000.00 to N50,000.00 depending on the class of automobile violators ply. It is also pertinent to note that the Imo State Executive Order was not captured in the NCDC did not capture the lockdown period of the state as its records of the number of fatalities from Covid-19 started from the 25th of April, 2020 as shown in figure 2.

So far, we can agree that lockdown measures greatly slowed down the spread of the virus. However, its impact on the health of persons restricted totally to their indoor spaces is quite enormous. Many activities which should have been done outdoors, in a broader environment, are now carried out in much more restricted spaces. Chores, daily human activities, industrial itineraries, handling of chemicals and cleaning agents, etc. are done in restricted spaces, most times in non-purpose-built spaces. All these activities generate by-products which are injurious to health. Indoor Air Pollution becomes a threat which exacerbates on a daily basis.

Indoor Air Pollution (IAP) is a serious problem which compromises the health of millions of people around the world. In fact, it’s estimated that poor Indoor Air Quality (IAQ) is responsible for some 3.8 million deaths every year. As such, it’s an issue that deserves attention and concern.

There is a wide variety of different pollutants which affect IAQ, some of which are produced from natural sources, some from anthropomorphic activities and some from materials and substances found around the home. They include, but not limited to:

a. Smoking: Tobacco products contain a potent cocktail of chemicals and toxins and their links with cancer and other respiratory ailments are well-documented. It's unsurprising, then, that environmental tobacco smoke (ETS) contributes deadly pollutants to the environment, especially if it's an unventilated enclosure. Environmental Tobacco Smoke (ETS) is a serious precursor of particulate matter (PM) (EnviroTech , 2021).

b. Cooking: When oil, butter or another lubricating substance is heated on a stove or in an oven, it can produce tiny particles of pollution invisible to the naked eye, known as particulate matter (PM). Meanwhile, gas cookers can emit contaminants such as carbon monoxide if their settings are not adjusted adequately (EnviroTech , 2021).

c. Painting: Home decoration is a popular method of turning a house into a home. When carried out in restricted and unventilated spaces, these synthetic colloids emit VOCs and PMs which seriously degrade exponentially IAQ. PMs emitted are usually breathable thus affecting pulmonary and lung tissues (EnviroTech , 2021).

d. Cleaning: It's important to maintain high levels of cleanliness to prevent the spread of bacteria and germs around the home. However, many detergents, disinfectants and other cleaning agents contain tropospheric O_3 which hydrolyze to form VOCs and PMs especially when large amounts of dust clouds are released in indoor spaces (EnviroTech , 2021).

e. Washing: Certain cosmetics and other care products can release harmful pollutants like oxides of nitrogen into the atmosphere (EnviroTech , 2021).

f. Heating: Cooking activities require large amounts of heat energy from combustion of fossil fuels and wood mass. These activities are the main source of CO and PM_5 (EnviroTech , 2021).

From the foregoing, it is evident that particulate matter is a serious health concern when persons engage in chores within restricted spaces and creating pollution clouds that are injurious to health.

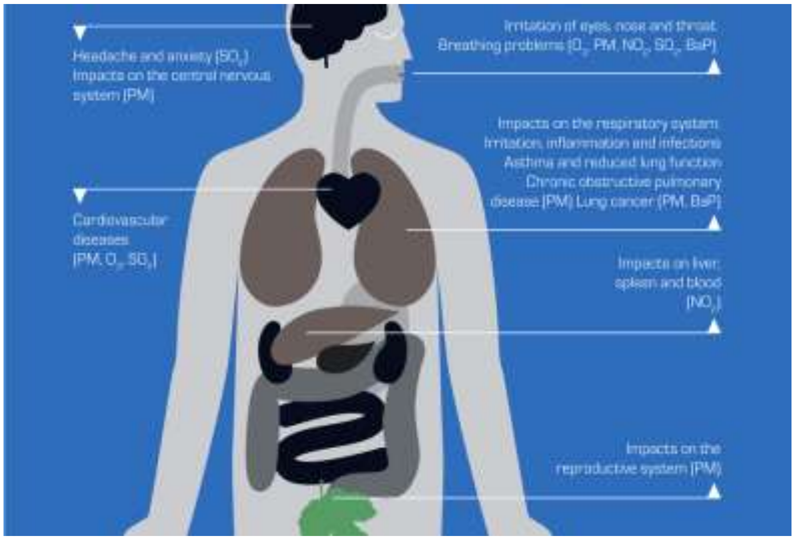

Figure 3: The range of health impacts associated with PM and other air pollutants. *Source: Air Quality Measurement Series: Particulate matter*

Particulate matter is the totality of all solid and liquid particles suspended in air cushion many of which are precarious. This heterogeneous mixture includes both organic and inorganic particles, such as dust, pollen, soot, smoke, and liquid droplets. These particles vary greatly in size, constitution and origin. Particles in air are either:

- directly emitted, for instance when fuel is burnt and when dust is carried by breeze, or
- indirectly formed, when gaseous pollutants previously emitted to air turn into particulate matter.

The buoyancy characteristics of particles determine how they are transient in air and how they can be removed from it. These characteristics also govern how far they get into the air passages of the respiratory system. Additionally, they render feedback on the chemical composition and the sources of particles.

Particles have irregular shapes and their aerodynamic behavior is expressed in terms of the diameter of an idealized sphere. The sampling and make-up of particles is based on this aerodynamic diameter, which is usually simply known to as ‘particle-size’. Particles having the same aerodynamic diameter may have different dimensions and forms. Some buoyant particles are over 10,000 times bigger than others in terms of aerodynamic diameter.

Based on size, particulate matter is often divided into three main groups:

- The ***coarse particles*** fraction contains the larger particles with a size ranging from 2.5 to 10 µm (PM_{10} - $PM_{2.5}$).
- The ***fine particles*** (atmospheric particulate matter) fraction contains the smaller ones with a size up to 2.5 µm ($PM_{2.5}$).
- The particles in the fine fraction which are smaller than 0.1 µm are called ***ultrafine particles***. ($PM_{0.1}$)

Most of the total mass of airborne particulate matter is usually made up of fine particles ranging from 0.1 to 2.5 µm. Ultrafine particles often contribute only a few percent to the total mass, though they are the most numerous, representing over 90% of the number of particles (GreenFacts Scientific Board., 2022). This study concentrated on $PM_{2.5}$ as they are more inhalable owing to their minute size and propensity to penetrate deep into the lungs and human circulatory system. As studies have found a close link between exposure to fine particles and health issues like lung disease, heart attack, bronchitis and other respiratory problems immediately after the lockdown restrictions, it becomes pertinent to investigate the indices of this pollutant in homes during and after the Covid19 lockdown. The next section identified the study location, distribution of sample units and research design.

RESEARCH DESIGN

This section will comprise of five sub-sections:

a. Site study of Egbeada Federal Housing Estate, Owerri, Imo State, Nigeria
b. IAQ standards from World Health Organization (WHO) and the nation's National Ambient Air Quality Standards for Particle Pollution
c. Sampling and sampling technique adopted
d. Instrumentation
e. Data collection.

Study Location: Egbeada Federal Housing Estate

The Egbeada Federal Housing Estate is the primary study area of this research. It is located along Egbeada – Orlu road, off Owerri – Onitsha road, Owerri Imo State. On the north, south, east and west lie Ndegwu Autonomous community, Chinax Farms, Arugo Gardens Estate and A.A. Rano filling Station. Covering an area of approximately 192,053.81 m^2, the phase I settlement contains nine building types for occupants ranging from bungalows to duplexes. It also contains a shopping mall, green areas and elaborate roadways and walkways. Subsisting building types include:

a. House Type 'A' - 3 Semi-detached Bungalow
b. House Type 'A" Option (B) – 3 bedroom Detached Bungalow
c. House Type 'B' - 3 Bedroom Detached Bungalow
d. House Type 'C' - 4 Bedroom Detached Bungalow
e. House Type 'D' - 4 Bedroom Semi-detached Duplex
f. House Type 'E' - 5 Bedroom Luxury Duplex
g. House Type 'F' - 5 Bedroom Detached Duplex
h. House Type 'G' - 3 Bedroom Detached Duplex, and
i. House Type 'H' - 4 Bedroom Semi-detached Duplex as shown in figure 4.

The Federal Government, in conjunction with Tangent Limited, 10 Mbari Street, Ikenegbu Layout, Owerri, Imo Nigeria, are major stakeholders in its design and construction

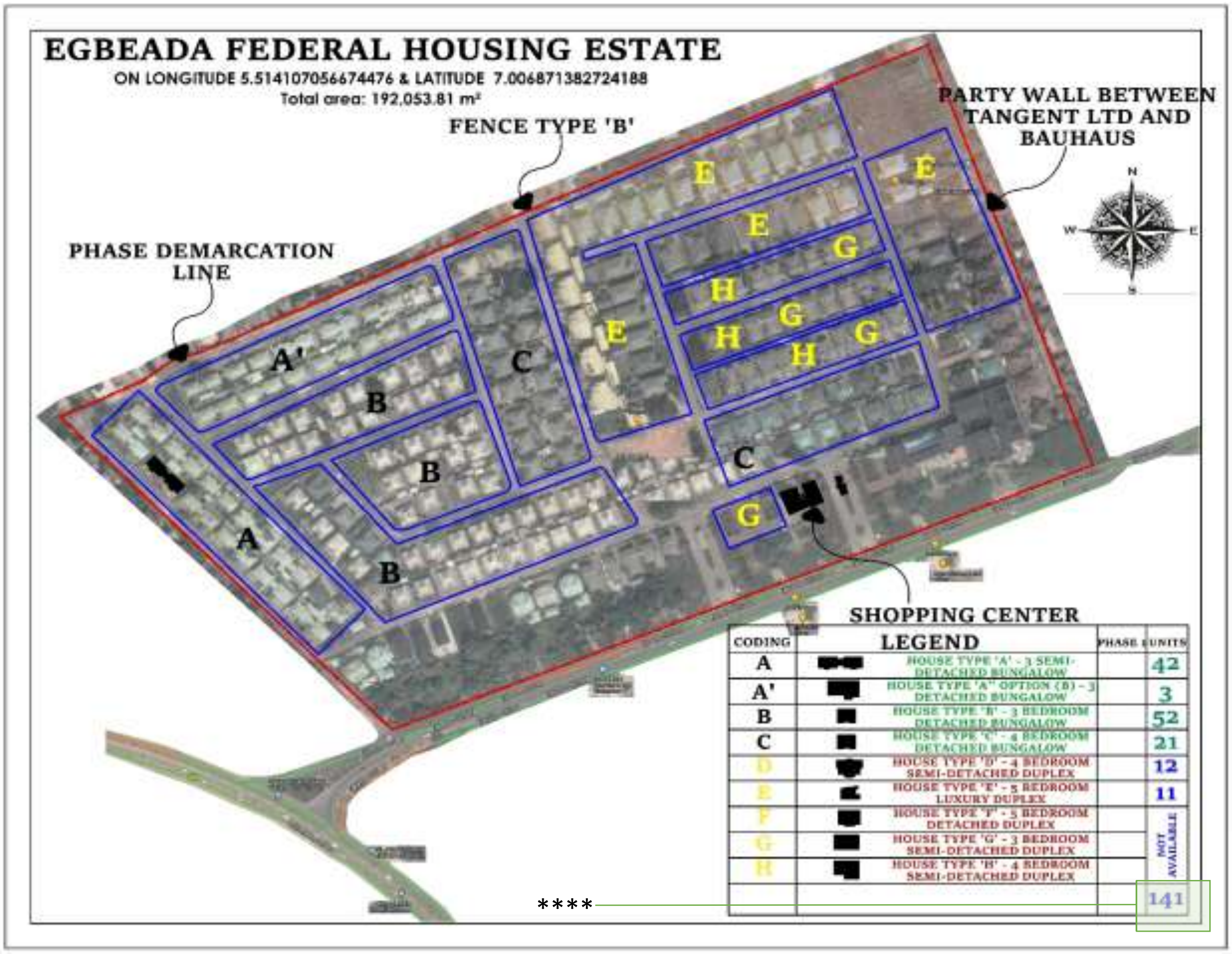

Figure 4: Site layout plan of Egbeada Federal Housing Estate, Owerri, Imo State showing entry points, building types and approximate area. *Source: Researchers' instrumentation paraphernalia*

*****The number of buildings captured by the developers did not take into consideration 'F', 'G' and 'H' segments of the estate. The figure quoted as total number of units was as indicated in the layout document. See **Figure 4a** for the original layout document. This document was redrafted with guided satellite imagery.*

Building types 'A', 'A'', 'B' and 'C' are various forms of bungalows for single and multiple family units while building types 'D', 'E'. 'F'. 'G'. 'H' are duplexes. Ordinarily, it is expected that bungalows have higher occupant density that duplexes as they would be relatively cheaper to either rent or own.

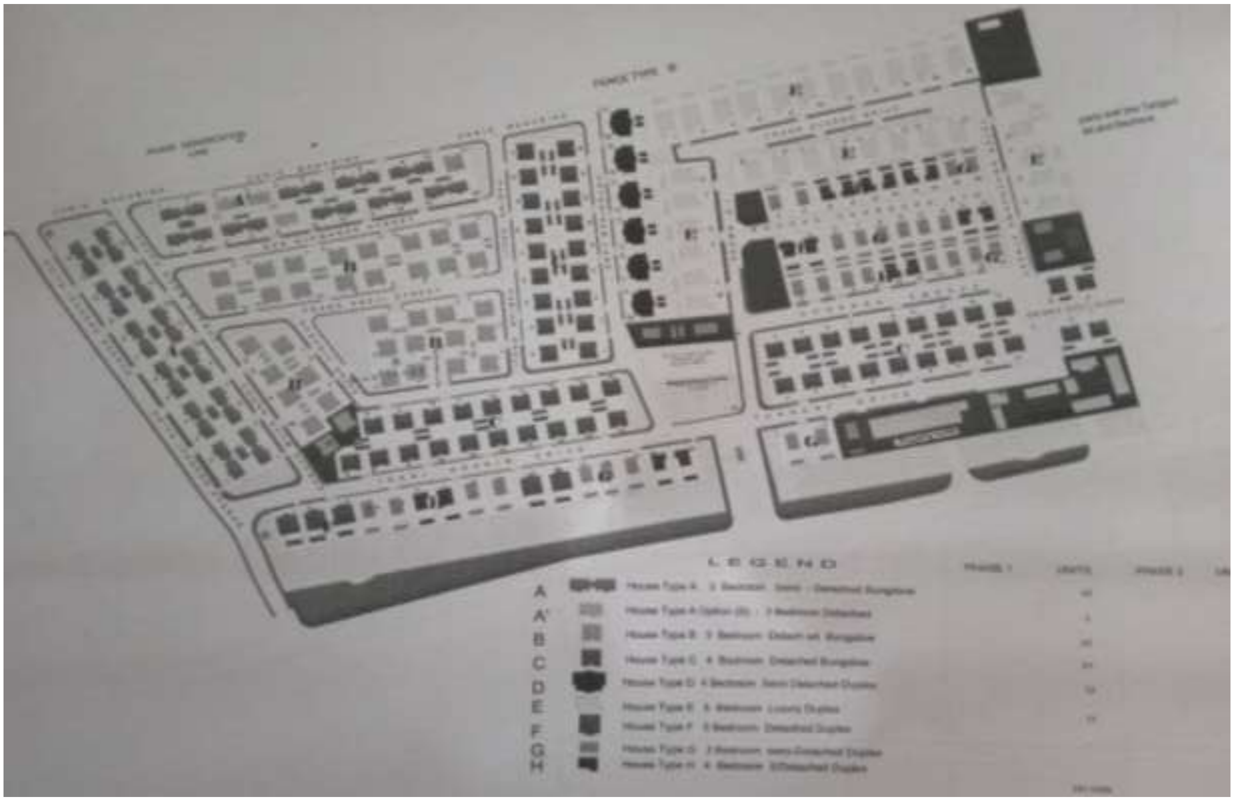

Figure 4a: Original Site Layout of The Egbeada Federal Housing Layout Estate. *Source: Arc. (Mrs.) Emma-Ochu, Federal Polytechnic Nekede Owerri, Imo State.*

*****The number of buildings captured by the developers did not take into consideration 'F', 'G' and 'H' segments of the estate. The figure quoted as total number of units was as indicated in the layout document.*

Standards

Standards that guided this study include the National Ambient Air Quality Standards for Particle Pollution and World Health Organization Air Quality Guideline Values for $PM_{2.5}$.

On Dec. 14, 2012 the U.S. Environmental Protection Agency (EPA) strengthened the nation's air quality standards for fine particle pollution to improve public health protection by revising the primary annual $PM_{2.5}$ standard to 12 micrograms per cubic meter (μg/m^3) and retaining the 24-hour fine particle standard of 35 μg/m^3 (The National Ambient Air Quality Standards for Particle Pollution, 2022). The existing annual standard has been in place since 1997 while the current 24-hour $PM_{2.5}$ standard was issued in 2006.

WHO's AQG levels are formulated, together with interim targets for pollutants including $PM_{2.5}$, PM_{10}, ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide (WHO, 2021). The evidence-informed derivation of each AQG level and an indication of the reduction in health risk associated with the achievement of consecutive interim targets can be found in Table 1. Encircled are the values that strongly concern this study.

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Table 1:Recommended AQG levels and interim targets

Pollutant	Averaging time	Interim Target				AQG level
		1	2	3	4	
$PM_{2.5}$, µg/m^3	**Annual**	**35**	**25**	**15**	**10**	**5**
	24-hours	**75**	**50**	**32.5**	**25**	**15**
$PM_{2.5}$, µg/m^3	Annual	70	50	30	20	15
	24-hours	150	100	75	50	45
O_3, µg/m^3	Peak season	100	70	-	-	60
	8-hours	160	120	-	-	100
NO_2, µg/m^3	Annual	40	30	20	-	10
	24-hours	120	50	-	-	25
SO_2, µg/m^3	24-hours	125	50	-	-	40
CO, mg/m^3	24-hours	7	-	-	-	4

Source: WHO global air quality guidelines: particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. Executive summary

Sampling and sampling techniques

Several factors were considered before targeting a particular building unit was selected.

1. Bungalow units are most useful for the purposes of the research as observations and surveys conducted during interaction sessions revealed that 82% of these units do not have clean-up technologies, HVAC systems nor air purifying gadgets installed. These appliances can severely compromise data.
2. Observations indicated that such units have relatively high occupant-density compared to duplexes. As such, subsisting indoor environment will have greater impact on more persons and individuals resident in such spaces. In duplexes, occupant-density is lower thus informing milder impact of indoor environment on fewer persons.
3. The design of the bungalow units showed a pattern of spatial open functionality. Spaces are bigger and less restrictive. This pattern allows for a much more dynamic study of diffusion pattern of pollutants. Researchers will also find it easier to correlate data of several spaces from one take-off area. This is unlike in duplexes where the design pattern is much more compartmentalized. This means that diffusion pattern of pollutants is localized at particular places. Data readings must be captured from all spaces before a much more comprehensive study can be feasible. In this era of insecurity, this feat would be difficult to attain as very few persons would allow anyone to make ingress into private zones.
4. Bungalow units comprised of 118 buildings out of a total number of *141 buildings** (see figure 4) of the estate. This indicated 83.68% of samples selected for the study. The bungalow units can be found in ‘A’, “A’’, ‘B’ and ‘C’ segments of the site layout. One (1) bungalow is selected for study from each segment.

A non-probability sampling, purposive sampling technique was used to select building units from all four (4) identified segments of the estate.

Instrumentation

The $PM_{2.5}$ particulate matter monitor PCE-RCM 05 was used to continuously measure the particulate matter content at the selected building units. The PCE-RCM 05 $PM_{2.5}$ screen shows $PM_{2.5}$ particulate matter as well as temperature and humidity on the display. The measuring range of the PCE-RCM 05 monitor ranges from 0 - 500 µg / m³ $PM_{2.5}$. This makes the $PM_{2.5}$ meter an optimal test instrument to constantly have an overview of the fine dust content. Below the large measured value display of the $PM_{2.5}$ content, the $PM_{2.5}$ monitor provides quick information about the air quality with the aid of pictograms.

The PCE-RCM 05 fine dust monitor is powered by a rechargeable battery which must be recharged, if need be, with its accompanying micro-USB. The LC display is illuminated and easy to read from any angle, for example when the meter is on a desk. In addition to the standard white lighting, the PM2.5 monitor switches the lighting to red in the event of an alarm.

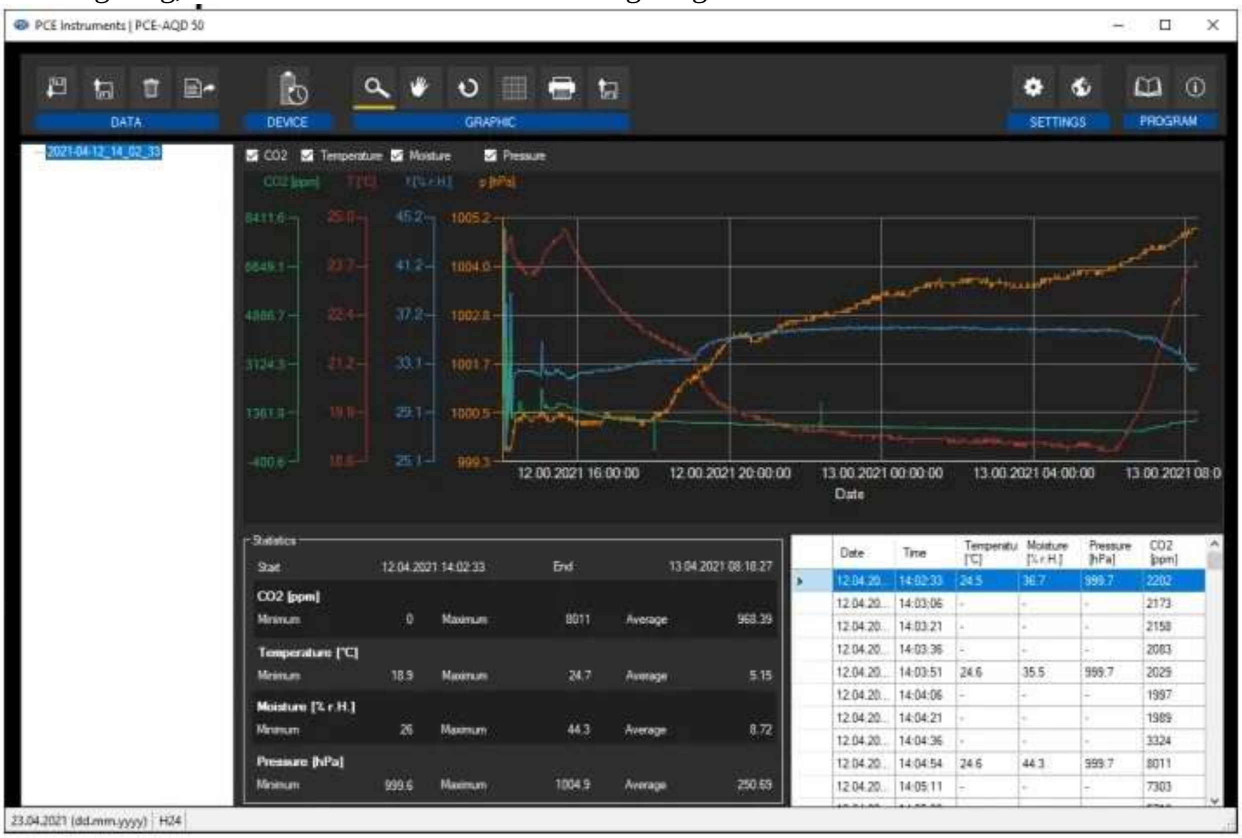

Figure 5: PCE AQD 50 Air Quality PC interface window. *Source: Researchers' instrumentation paraphernalia*

Data captured were extracted with laptops pre-installed with PCE AQD 50 Air Quality PC software. The laptops were configured with operating system Windows 10, USB port (2.0), an installed .NET framework 4.0, a minimum resolution of 120×800 pixels, a printer, processor of 1 GH and a 4 GB RAM.

PCE AQD 50 Air Quality PC user interface consists of a toolbar with functionally grouped icons. Below this toolbar, there is a list of measurement series in the left part of the window. In the upper part, the readings are shown in a graph whereas the lower part contains an overview of statistical data as well as a tabular list of readings. At the bottom of the main window, there is a status bar that contains some important static settings of the programme which can be made through a settings dialogue (date and time format). Data variables can be toggled for extraction. In this study, CO_2 (ppm), temperature, moisture and pressure were all toggled off leaving $PM_{2.5}$ active. This enabled the research team to extract graphs, PM indices and general statistical data for the pollutant on a 30-day/24-hr. cycle.

Data collation

This study commenced in February, 2020 with a pre-survey of building types in the government-owned estate for purposes of building capacity to undertake and conduct case studies within the estate. The 2-month pre-survey enabled the researchers to zero-in on the building types that are most relevant for study and enlighten occupants that are willing to be part of the study (renters and owners) on the need and purpose of the research undertaking. The interactive session also gave room for technical negotiation synergy among researchers and occupants during which the researchers were able to educate the occupants on the workings of the data loggers and how to avoid compromising data of the devices. It also afforded the researchers the opportunity to be more conversant with the population thus dousing unnecessary tension and anxiety when planting the data loggers.

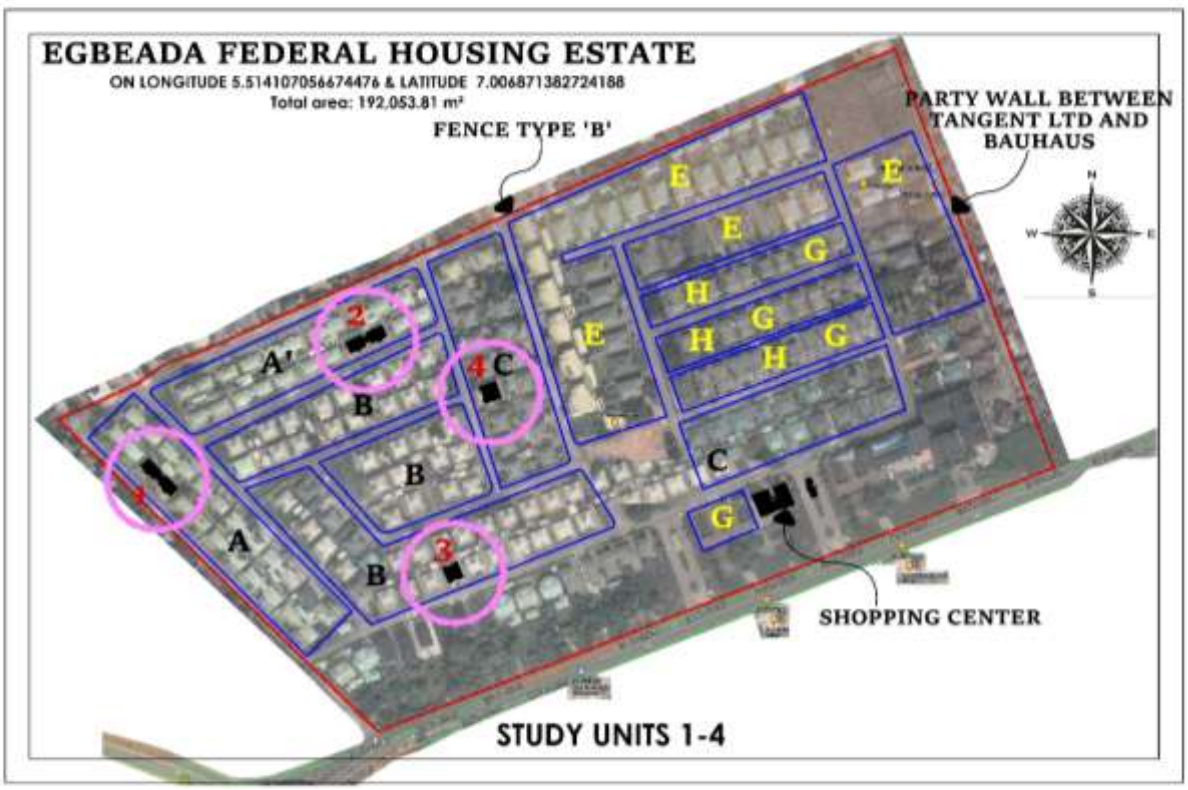

Figure 6: Study units 1-4. *Source: Researchers' instrumentation paraphernalia*

During the Year 01 round of studies, PCE-RCM 05 devices were mounted on specific dates for a 24-hour cycle beginning on the 25th of April, 2020 till the 16th of December, 2020. On a 30-day/24-hour cycle, the data collated are as follows for buildings 1-4 in figure 6.

Table 2: Year 1 (2020) 24-hour $PM_{2.5}$ readings from sample units 1-4, Egbeada Housing Federal Housing Estate, Owerri, Imo State, Nigeria.

YEAR 1: 2020					
No	**Date**	**Building 1 Section 'A'**	**Building 2 Section 'A''**	**Building 3 Section 'B'**	**Building 4 Section 'C'**
		$PM_{2.5}$ readings in µg / m³			
1	25/04/2020 (Saturday)	85.7	89.1	75.1	69.3
2.	25/05/2020 (Monday)	89.4	86.5	70.3	68.9
3.	24/06/2020 (Wednesday)	79.5	66.2	52.5	50.1
4.	24/07/2020 (Friday)	81.4	67.2	55.6	51.2
5.	23/08/2020 (Sunday)	79.3	68.2	56.4	52.3
6.	22/09/2020 (Tuesday)	81.3	66.1	66.2	60.3
7.	22/10/2020 (Thursday)	78.3	62.3	50.2	61.3
8.	21/11/2020 (Saturday)	69.4	68.2	51.3	62.5
9.	16/12/2020 (Wednesday)	73.4	78.3	52.5	51.1
	24-hour mean $PM_{2.5}$ readings in µg / m³	79.7444444	72.4555555	58.9	58.555555

Source: Researchers' data records as at 28th December, 2020

During the Year 02 round of studies, PCE-RCM 05 devices were mounted on specific dates for a 24-hour cycle beginning on the 2nd of January, 2021 till the 3rd of December, 2021. On a 30-day/24-hour cycle, the data collated are as follows for buildings 5-8 in figure 7.

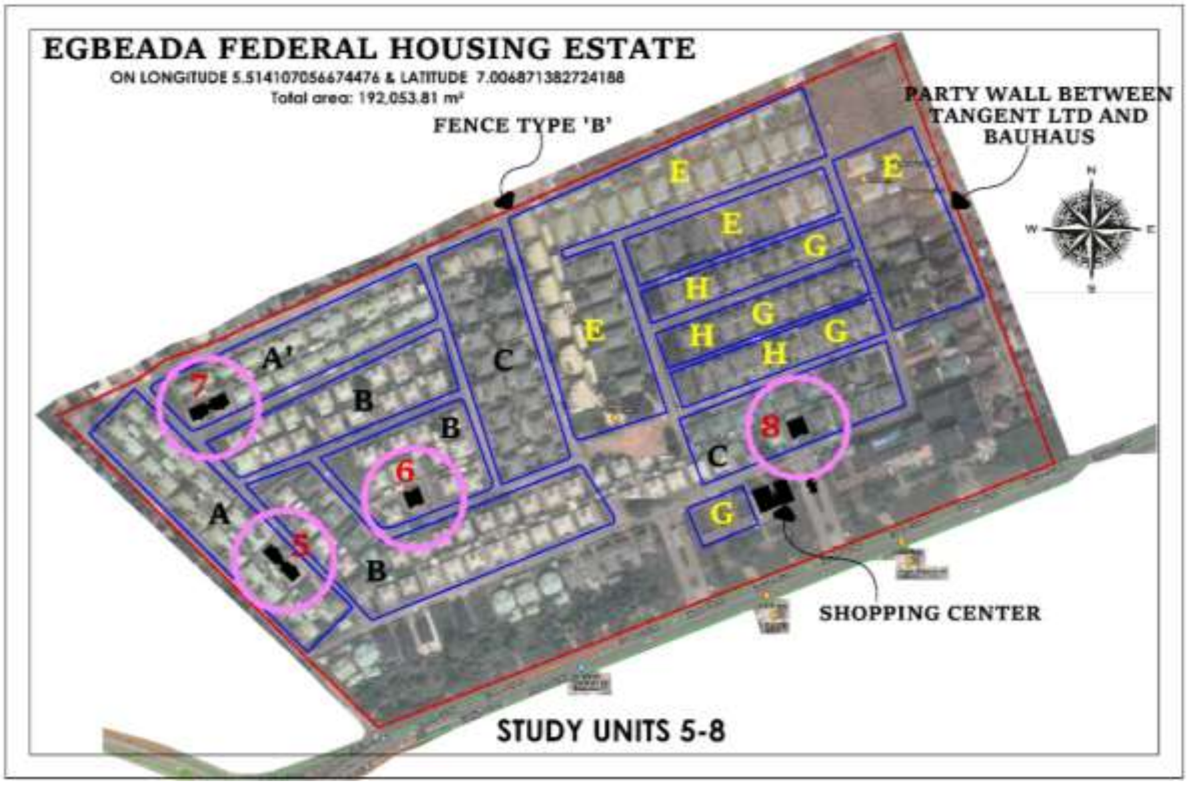

Figure 7: Study units 5-8. *Source: Researchers' instrumentation paraphernalia*

Table 3: Year 2 (2021) 24-hour $PM_{2.5}$ readings from sample units 5-8, Egbeada Housing Federal Housing Estate, Owerri, Imo State, Nigeria.

YEAR 2: 2021					
No	**Date**	**Building 5 Section ‘A’**	**Building 6 Section ‘A’’**	**Building 7 Section ‘B’**	**Building 8 Section ‘C’**
		$PM_{2.5}$ readings in µg / m³			
1	02/01/2021 (Saturday)	71.3	67.5	54.2	50.1
2.	01/02/2021 (Monday)	71.5	63.2	50.2	48.0
3.	03/03/2021 (Wednesday)	70.2	65.2	51.2	49.8
4.	02/04/2021 (Friday)	70.8	66.2	54.1	47.2
5.	02/05/2021 (Sunday)	69.3	60.9	49.2	47.0
6.	01/06/2021 (Tuesday)	68.2	65.2	50.8	49.3
7.	01/07/2021 (Thursday)	66.9	64.9	49.8	49.7
8.	31/07/2021 (Saturday)	66.8	64,3	51.3	50.9
9.	30/08/2021 (Monday)	68.5	68.3	49.8	54.2
10.	29/09/2021 (Wednesday)	65.3	64.2	49.6	58.2
11.	29/10/2021 (Friday)	64.8	60.1	48.2	55.2
12.	28/11/2021 (Sunday)	65.1	65.9	50.4	55.1
13.	03/12/2021 (Friday)	66.2	64.7	51.3	48.6
	24-hour mean $PM_{2.5}$ readings in µg / m³	68.06923077	64.69166667	50.77692308	51.02307692

Source: Researchers’ data records as at 18th January, 2022

RESULTS

Cohort analysis was used to analyze data over time to extrapolate information on the indices of $PM_{2.5}$ in 2020 and 2021 in all identified sections of the estate. Data visualization was also employed to show how particulate matter was distributed during and after the lockdown period.

Figures 8-11 show the 24-hour mean $PM_{2.5}$ levels in sections A, A’, B and C of the Egbeada Housing Estate from January 2020 to December 2021. The columns in pink show PM readings in 2020 while the columns in blue show PM readings in 2021. It is however pertinent to note that readings in 2020 commenced in April while readings in 2021 were captured as from January. As PM readings didn’t commence in January 2020, these researchers found it appropriate to classify all readings taken from from January to March, 2021 as *‘sterile’*. Such data will however be useful to establish PM levels for relevant independent study. Such move was to ensure harmony of data from April to December for both years.

Analysis showed the following results:

a. Buildings in sections A and A’ showed significant and marked spike in 24-hour mean $PM_{2.5}$ readings in µg / m³.
b. Total lockdown in Imo State subsisted within the months of April and May, 2020. This window showed significant spike in the levels of $PM_{2.5}$ readings in µg / m³.
c. Correlation of Year-1 statistics and Year-2 statistics is admissible from April to December for both years.
d. In all sections of the study settlement, 24-hour mean $PM_{2.5}$ levels reduced with gradual ease of lockdown scenarios.

e. 24-hour mean $PM_{2.5}$ readings were higher in hotter months than in colder months.
f. Observations also showed that there were some relationships between occupant density and status of 24-hour mean $PM_{2.5}$ readings.

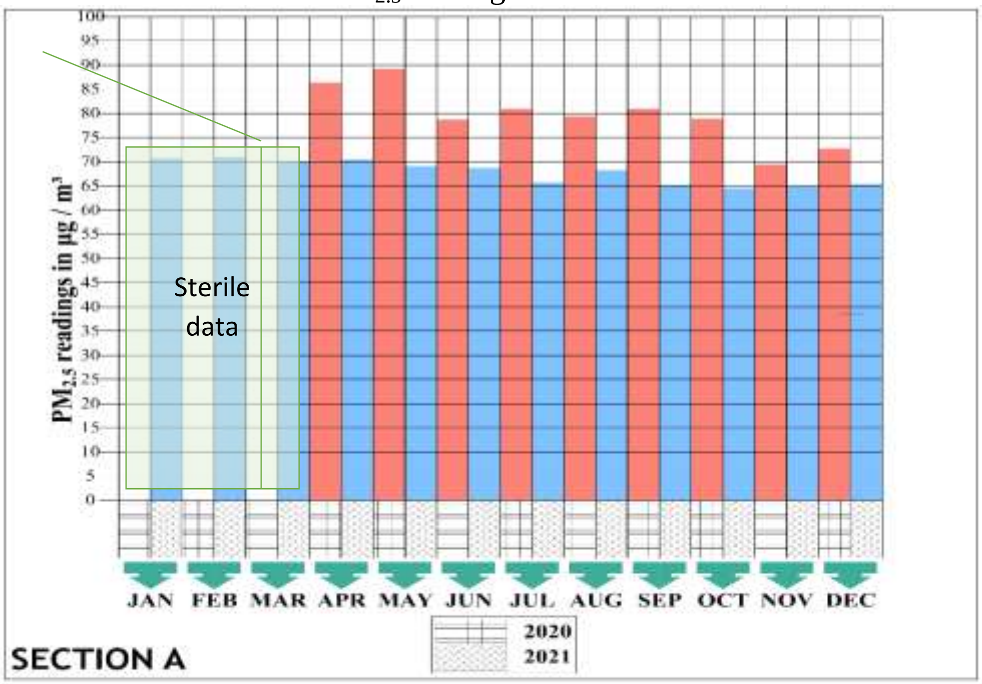

Figure 8: 24-hour mean $PM_{2.5}$ levels in Section A, Egbeada Housing Estate, Imo State. Sou

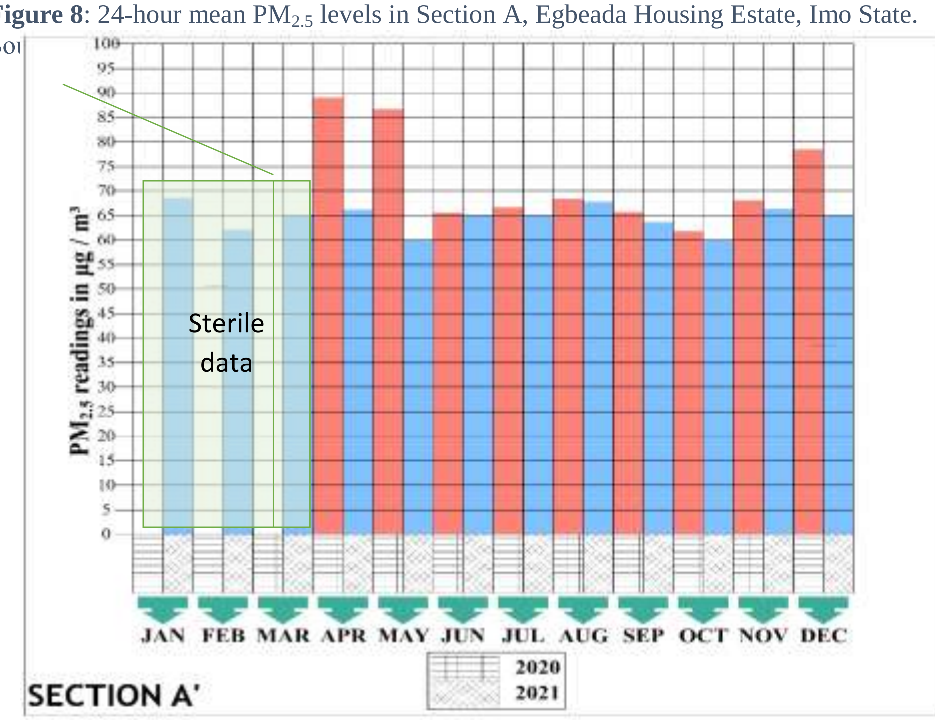

Figure 9: 24-hour mean $PM_{2.5}$ levels in Section A', Egbeada Housing Estate, Imo State. Source: Researchers' cohort analysis sheets.

Figure 10: 24-hour mean $PM_{2.5}$ levels in Section B, Egbeada Housing Estate, Imo State. Source: Researchers' cohort analysis sheets.

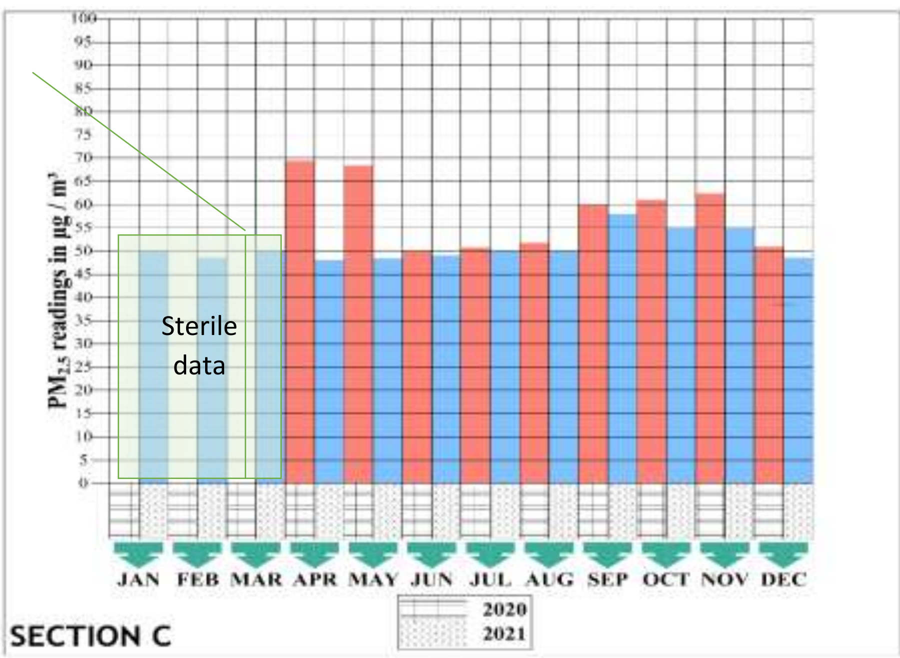

Figure 11: 24-hour mean $PM_{2.5}$ levels in Section C, Egbeada Housing Estate, Imo State. Source: Researchers' cohort analysis sheets.

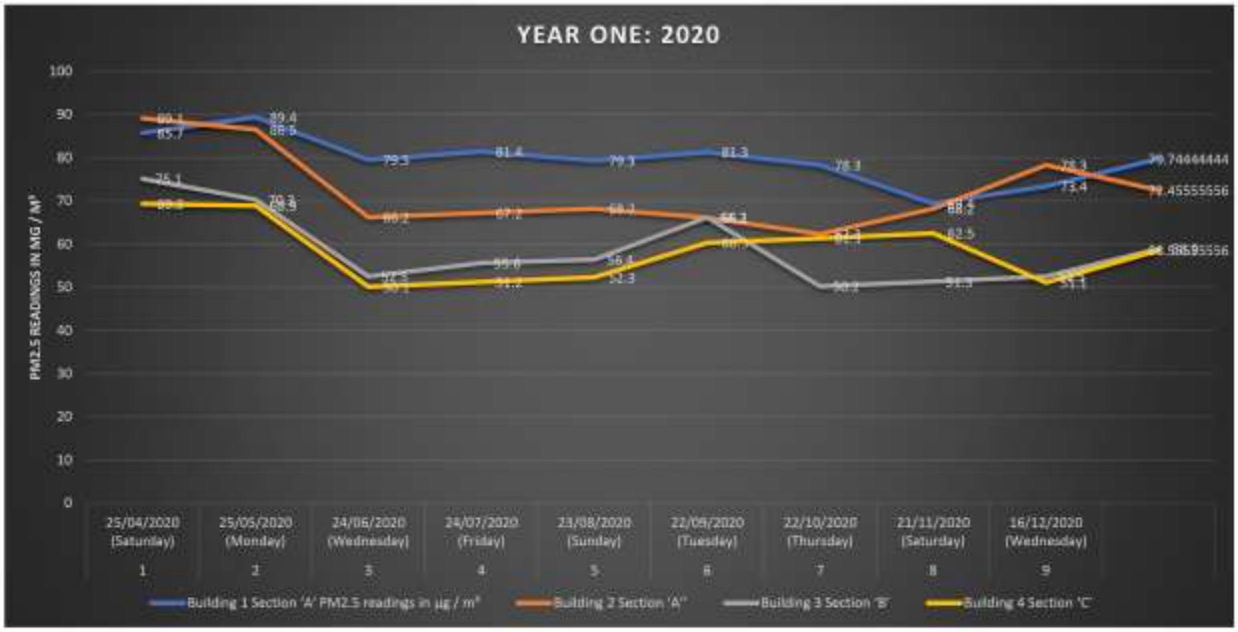

Figure 12: Pollution pattern of 24-hour mean $PM_{2.5}$ levels in 2020, Egbeada Housing Estate, Imo State.
Source: Researchers' cohort analysis sheets.

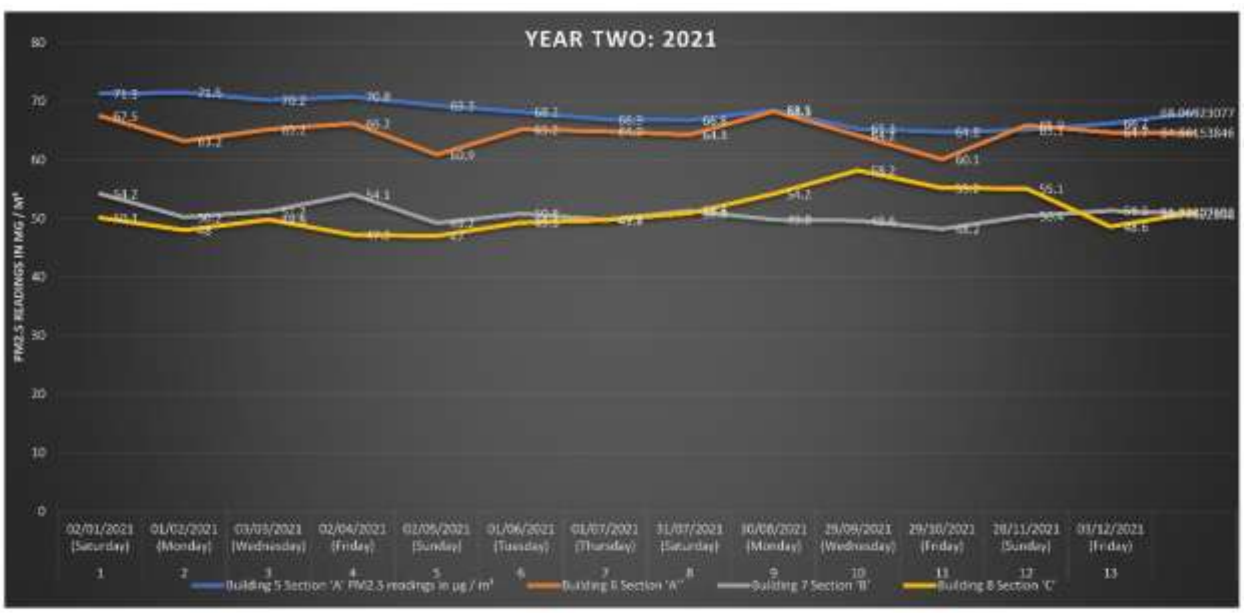

Figure 13: Pollution pattern of 24-hour mean $PM_{2.5}$ levels in 2021, Egbeada Housing Estate, Imo State.
Source: Researchers' cohort analysis sheets.

Interpretation of results

Results are interpreted as follows:

a. Parcellation of settlements were done by the developers into sections viz: A. A', B and C respectively. Particulate matter levels were identified to be higher in sections A and A'. this is not unconnected to the topographical locations of the sections. These sections are on the periphery of the estate as they are in close proximity to extensive hardscapes including the ever-busy Onitsha-Owerri road and perimeter fencing. These hardscapes have the tendency of redirecting solar insolation into the microclimate of these sections thus increasing indoor temperatures and exacerbating the proliferation of particulate matter (Egide, Sulaiman, Mabano, Lamek, & Gabriel, 2018). It is also worthy to note that the Onitsha-Owerri road is a trunk 'A6' road which directs heavy traffic between Onitsha and Owerri (Road numbering systems, 2017). This carriageway has the propensity to generate substantial pollution clouds which can be directed into the estate by seasonal winds thereby further deteriorating indoor air quality of proximal sections. Sections B and C have lower PM levels. This is in agreement with the location of these sections as they are positioned within the core of the estate surrounded by softscapes and natural belts.
b. From figures 12 and 13 above, it can be seen that the months of April and May, 2020 witnessed the highest PM levels in the estate. Figures of particulate matter captured showed that PM readings peaked well above the recommended Air Quality Guideline (AQG) levels and interim targets set by WHO; *$PM_{2.5}$, $\mu g/m^3$ - Annual (5)/24-hour (15)* (World Health Organisation, 2021) and The National Ambient Air Quality Standards for Particle Pollution, Nigeria; *$PM_{2.5}$, $\mu g/m^3$ - Annual (12)/24-hour (35)* (The National Ambient Air Quality Standards for Particle Pollution, 2022). This pattern clearly indicates that the spike in PM levels is connected to the lockdown scenario when persons and individuals carried out most chores and daily activities within their various indoor spaces. Any of such activities, including cooking, operation of coal irons, operation of power generating sets, environmental tobacco smoke (ETS), etc., that necessitated the generation of O_3, NO_2, SO_2 and CO contributed to high levels of indoor particulate matter. Observations also showed that living units that had higher occupant density exhibited such pattern.
c. In all sections of the study settlement, 24-hour mean $PM_{2.5}$ levels reduced with gradual ease of lockdown scenarios. This pattern is a clear indication that occupants could then interact freely with their outdoor spaces while most of their chores could be done outside their private spaces. This also limited that generation of tropospheric O_3 which escalates the formation of particulate matter.
d. Analysis also showed that particulate matter formation peaked during the colder and wet months. This is connected to the penchant use of combustive wood mass and flue stoves to heat up spaces during the cold weather. Humidity during these periods is higher while temperatures are slightly increased due to congregating populations within a small area for purposes of staying warm. PM levels generally spiked when populations also engaged in ETS.
e. These researchers identified further areas of study involving establishing the relationship between occupant density and status of PM with respect to IAQ. Observations indicated that most housing units where there are high occupant density witnessed higher PM

levels as against housing units with lower occupant density. As at the time of this research, efforts are being made to commence understudying this relationship.

CONCLUSIONS AND RECOMMENDATIONS

There has always been a lot of discuss on the health implications of $PM_{2.5}$ in living units, habitable shelters and workplaces. These pollutants are most impactful on health of occupants as they are easily inhalable and can quickly permeate the walls of air sacks in the lungs to cause a varied array of pulmonary and cardiac ailments. The covid-19 outbreak complicated issues as lockdown measures forced individuals to congregate into tightly-knitted colonies in a bid to check the spread of the Sars-Cov-2 virus. As noble as this step was, it created a rise in *flash occupant density (FOD)* where a lot of persons occupied small units of habitation with very restricted options of outward flow of circulation. This created a new scenario where most activities, which could have been done outside a living cell, are now done in closed circuits creating unique pollution islands. Activities like cooking with wood mass and flue stoves, cleaning with detergent plumes, dust percolators, ETS, ironing with coal plates, etc., become precursors of $PM_{2.5}$ with the creation of CO, tropospheric O_3, NO_2 and SO_2. The situation becomes most precarious when there are long periods of power outage making it impossible for such living units to aerate their spaces with mechanical ventilation. This research brought to limelight the impact of the lockdown measure on IAQ by identifying evidence-based narrative on $PM_{2.5}$: indices during and after the lockdown measures, pattern of pollution distribution at various sections of the estate, climatic behavior of pollution clouds and response to occupant density. To the end, the following recommendations suffice:

a. As much as possible, intricate and adequate site analysis of development areas should be carried out during design stages to ascertain and congregate hardscapes to areas where flash pollution clouds could be dispersed safely by seasonal wind patterns. Where this measure cannot be achieved, trees and extensive green belts must be adopted to create *green shields* for living units that are close to man-made lines of force and perimeter fences. Local planning authorities must also make sure that setbacks from perimeter fences must be respected in addition to the incorporation of organic and composite awnings to phenistration openings. This is possible where relevant professionals are placed in respective departments that oversee approval processes. Where such approval processes are not practiced, complete review of approval laws and regulations must be advised by relevant professional bodies, oversight committees of the State Houses of Assembly on Works and Urban Planning and commissioners of works of affected states.
b. This study identified that occupant density (OcD) is directly proportional to PM levels. This issue may be difficult to handle through policy statements as OcD is also a function of financial stability of occupants. To this end, a much more subtle form of solution is advised – **bioremediation**. This involves the use of poaceae and gramineae that have the capacity to breakdown PM into non-lethal compounds. These plants with high accumulation factor are capable of ensuring low-index PM count of indoor spaces through very efficient phytovolatilization processes. Research into phytovolatilization capabilities of certain plants is a research interest of one of these authors.
c. **Tropospheric O_3** is a pollutant, which is harmful to human and ecosystem health. It is also a major part of urban smog. It does not have any direct emissions sources, rather it is

a secondary gas formed by the interaction of sunlight with hydrocarbons – including CH_4 – and oxides of nitrogen, which are emitted by vehicles, fossil fuel power plants, and other man-made sources (UN, 2022). In the troposphere, ozone is the result of the atmospheric combination of a number of precursor pollutants, which have both natural and artificial sources. For O_3 to be checked in indoor spaces, the following practices must be encouraged:

- replace traditional cooking with clean burning modern fuel cookstoves
- replace traditional cooking and heating with clean-burning biomass stoves
- eliminate kerosene lamps
- replace lump coal with coal briquettes for cooking and heating and
- replace wood stove and burners with pellet stoves and boilers (UN, 2022).

d. As much as possible, ETS must be discouraged. Advocacy on this issue must be sustained to protect vulnerable persons like children, the aged, those under care and lactating women. Non-smoking signs must be visibly anchored at public places and enforced while The National Orientation Agency must step up its sensitization programmes on harmful effects of ETS on the home front.

e. OcD may be a bit difficult to manage especially when this issue is hinged on socio-economic implications. This can be managed through the identification of poaceae that have improved total accumulation factor. Provisions for the use and adoption of such identified gramineae must be incorporated into design tenets especially for low-income housing and development. This can be achieved through review of our planning and building regulations across the country.

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