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Assessment of Indoor Household Air Quality Using SentinAir's Cost-effective Sensor

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ABSTRACT: According to the World Health Organization, particulate matter (2.5 m) is responsible for more than 4 million deaths worldwide. In real-time, low-cost sensors have assisted in the measurement of PM indoors. SentiAir, a low-cost instrument used in this study, monitors particulate matter (1, 2.5, and 10), as well as nitrogen dioxide, sulphur dioxide, carbon dioxide, ozone, temperature, and relative humidity. The goal of this study was to place the sensor in a typical household indoor space and evaluate all variables for 30 days as an initial investigation assessment. The sensor's proper procedure was strictly observed. PM_1 (17.80 µg/m3), $PM_{2.5}$ (25.21 µg/m^3), PM_{10} (27.61 µg/m^3), CO_2 (419.7 ppm), O_3 (24.75 ppb), NO_2 (66.52 ppb), SO_2 (48.04 ppb), temperature (34.1 °C), and humidity were the results (mean) (64%). Once those findings were compared to those of the WHO, it was discovered that $PM_{2.5}$ and PM_{10} were well within the 24-hour guideline values of 25 and 50 µg/m^3, respectively. However, $PM_{2.5}$ may pose a risk. Temperature and humidity had a significant impact on the PM and gases. Cooking, especially frying and baking, produced a great increment in PM indoors.

KEYWORDS: SentinAir; Indoor air; $PM_{2.5}$; NO_2; SO_2; Cooking; WHO

1. Introduction

Outdoor and indoor pollutants are worldwide problems that contribute to morbidity and mortality [1]. Individuals in the present day spend ldwi of their time indoors, subjecting themselves to indoor air pollutants for longer durations than those who spend the majority of their time outdoors [2]. As a result, distinguishing and assessing indoor air quality is critical in order to understand its components and the involvement of potentially harmful concentration levels of chemical species hazardous to people's health, as well as identifying factors responsible [3]. In 2016, indoor exposure was associated with numerous health issues, such as respiratory diseases and 3.8 million deaths worldwide [4]. Pollutants commonly measured in indoor air quality (IAQ) monitoring include carbon dioxide, carbon monoxide, formaldehyde, total volatile organic compounds, particulate matter, and microorganisms [5]. Low-cost sensors have, in recent years, evolved from a cost-effective option to costly and precise devices used in long-term pollution assessment [6–8]. In terms of consistency, long-term reliability, and precision, low-cost air pollution sensors have their shortcomings and inconsistencies [7, 9]. Low-cost sensors, on the other hand, enable the mobilization of a much greater number of units, and their mobility and small size make them suitable for use in microenvironments where traditional gadgets would be too difficult. The latter property, in particular, could make low-cost sensors extremely useful for identifying indoor air pollution. SentinAir, the low-cost sensor used in this study, is unique to the indoor air quality assessment in this region of Africa [10]. It analyzes more pollutants and weather parameters than many low-cost sensors on the market. Consequently, if likened to many pieces of equipment, it clearly outperforms them. The main objective of this study is to evaluate the pollutants (PM_1, $PM_{2.5}$, PM_{10}, carbon dioxide, ozone, nitrogen dioxide, and sulfur dioxide) and weather variables (temperature and relative density, or RH) at the preferred residential location.

Table 1. Experimental studies on Indoor Household Air Quality exposure assessment from different countries.

S/N	Country	Research Title	Findings	Ref
1.	Egypt	Assessment of Indoor Air Quality in Academic Buildings Using IoT and Deep Learning	The results showed the high effectiveness of the IoT device in transferring data via Wi-Fi with minimum disruptions and missing data. The average readings for temperature, humidity, air pressure, CO_2, CO, and $PM_{2.5}$ in the presented case study are 30 ◦C, 42%, 100,422 pa, 460 ppm, 2.2 ppm, and 15.3 μ/m3, respectively. The developed model was able to predict multiple air parameters with acceptable accuracy.	[11]
2.	USA	Assessment of Indoor Air Quality in Residential Buildings of New England through Actual Data	25% of a specific timeframe, the occupants have been exposed to concentration levels of CO_2 above 1000 parts per million (ppm),	[12]
3.	Mumbai, India	Assessment of indoor air quality and housing, household, and health characteristics in densely populated urban slums	Significantly higher indoor $PM_{2.5}$ was observed during winter (111 ± 30 μg/m^3) than in summer (36 ± 12 μg/m^3). The winter-time indoor levels were similar to or higher than the concentrations observed in other urban slum homes using biomass fuels for cooking The contribution of indoor and local outdoor sources was significantly higher for Lung Deposited Surface Area (33%) and Black Carbon (43%) compared to $PM_{2.5}$ (19%)	[13]
4.	Norway	Assessing the indoor air quality and their predictor variable in 21 home offices during the Covid-19 pandemic in Norway	Temperature, RH, CO_2, formaldehyde, and TVOC were measured in 21 home offices. Study IAQ during home office due to the COVID-19 pandemic. Study frequency of surpassing pollutants health thresholds. Generalized estimation equations to study the significant parameters to control pollutants.	[14]

S/N	Country	Research Title	Findings	Ref
5.	Cyprus	Assessment of indoor and outdoor air quality in primary schools of Cyprus during the COVID–19 pandemic measures in May–July 2021	A primary school population-representative study of indoor air quality was conducted in Cyprus in May-July 2021. Natural ventilation measures, like opening windows and doors during class hours, helped in maintaining adequate ventilation. The study took place during the summer period with indoor air temperature being above the recommended value most of the school time. A third of the 24-hour indoor $PM_{2.5}$ measurements exceeded the WHO recommended value.	[15]
6.	Malaysia	Indoor-Outdoor Air Quality Assessment in Nurseries	all chemicals contaminants at the two nurseries did not exceed the standard except CO_2 for indoor concentration Indoor-Outdoor (I/O) ratio stated that PM_{10} concentrations were influenced by the outdoor contaminant for both study areas	[16]
7.	India	Indoor Air Quality Assessment In A School Building In Chennai City, India	Hourly the CO_2 concentration inside the school room is 927 ppm during morning working hours Concentration is close to the standard value the f 1000 ppm specified by the National Institute for Occupational Safety and Health (NIOSH), USA	[17]
8	Kraków, Poland	Exposure Assessment for Indoor Air Pollution Associated With Household Fuel Heating in Urban Environment	Mean outdoor PM_{10} concentrations were higher in average than one corresponding indoor levels The mean 24 hr average exposure concentration ranged from 11.4 to 181.2 μg/m^3 in municipal supply and solid fuel heating households, respectively. contribution of outdoor PM_{10} concentration to indoor exposure varied from 33–75% depending on outdoor level and the type of heating source which itself explained 5–20% of variance.	[18]
9.	Malaysia	Preliminary Assessment of Indoor Air Quality in Terrace Houses	The average indoor concentrations of CO, CO_2, and PM_{10} at the naturally ventilated residential buildings were below the limits of Malaysian guideline standards except for the indoor climate parameters. The indoor/outdoor ratios concentration of all air pollutants was found to be below one which indicates that outdoor air influences indoor air	[19]
10.	Nigeria	Assessment of Particulate Matter ($PM_{2.5}$) in Residential Staff Quarters of Covenant University, Nigeria	Indoor levels of $PM_{2.5}$ with the highest and least mean values of 91.0±5.0 and 34.0±4.0 μg/m^3, respectively. $PM_{2.5}$ indoor concentration was found to be higher than the World Health Organisation guideline value of 25 μg/m^3	[20]
11.	China	Personal exposure to ambient $PM_{2.5}$, PM_{10}, O_3, NO_2, and SO_2 for different populations in 31 Chinese provinces	The infiltration factor and exposure factor are modeled with MC modeling in China. Chinese expose to 68%, 42%, 34%, 50% and 40% of outdoor $PM_{2.5}$, PM_{10}, O_3, NO_2 and SO_2 annually. Infiltration factor and exposure factor: southern China > northern China. Infiltration factor and exposure factor: summer > spring/autumn > winter. Exposure factor: children > adults, adult male > adult female.	[21]

2. Materials and Methods

2.1. Sampling sites.

The monitoring station in this study is Oba-Ile in Akure, Ondo State, Nigeria (latitude and longitude: 7° 16' 04" N, 5° 14' 29.1" E). It is a residential building surrounded by unpaved roads (Figure 1). The building is made of a big parlor and three rooms. There have been no known major point sources of emissions in the immediate vicinity. Although Oba-Ile has experienced rapid urbanization, traffic, and population growth in the last decades, The terrace houses have opposite sides exposed to the environment, while the remaining two sides share common walls with the adjacent houses. The living room of the building was ventilated by natural ventilation through open windows or mechanical ventilation using a fan.

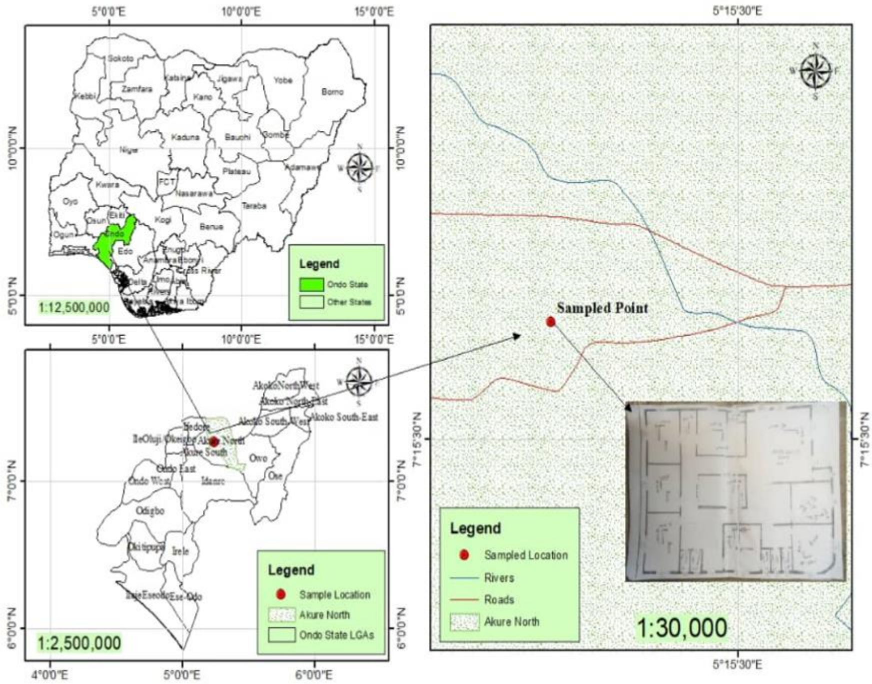

Figure 1. shows the location of the site.

2.2. Sample collection and analysis.

Monitoring was carried out for 32 days as an initial investigation assessment in a large parlor (the living room) and three rooms for a period of 8 hours in each room from 9.00 am to 5.00 pm. PM_1, $PM_{2.5}$, PM_{10} as well as NO_2, SO_2, CO_2, O_3, temperature, and relative humidity data were measured (captured) every 60 seconds using SentinAir system version 1.3 (Figure 2). The low-cost sensor was developed and tested by a team of researchers from the Italian National Agency for New Technologies, Energy, and the Environment (ENEA), Department of Sustainable Development, Brindisi Research Center, Italy [22, 23]. The sensor procedure was strictly adhered to. The sensor box was mounted on a rack approximately 4 meters above the ground at the center of each room to avoid interference during monitoring. The residential building was about 6 meters away from the untarred roads. At the end of the monitoring, the sensor data obtained was checked and analyzed. The Minitab version was used to calculate the basic description, the Pearson sample correlation coefficient (r), the matrix plot, and the boxplot.

Figure 2. (a) Outbox of the low-cost sensor (b) Inbox of the sensor [22, 23].

3. Results and Discussion

The basic description of the parameters is shown in Table 1. The hourly mean levels were averaged. Pollutant average levels are: PM_1 (17.80 µg/m^3), $PM_{2.5}$ (25.21 µg/m^3), PM_{10} (27.61 µg/m^3), CO_2 (419.7 ppm), O_3 (24.75 ppb), NO_2 (66.52 ppb), SO_2 (66.52 ppb), and CO_2 (48.04 ppb). The WHO guidelines, PM_1, $PM_{2.5}$ (25 µg/m^3 – 24 h mean), PM_{10} (50 µg/m^3 – 24 h mean), SO_2 (20 µg/m^3 – 24 h mean), NO_2 (200 µg/m^3 – 1 h mean), and O_3 (100 µg/m^3 – 8 h mean), when compared with the results obtained in this study, had higher levels. The maximum levels of O_3, NO_2, and CO_2 concentrations are 79, 282, and 1003.3 ppb, respectively. The maximum concentration of CO_2 measured was in the kitchen (room 2), while the minimum concentration of CO_2 obtained in room 1 (317 ppb) was occupied by three occupants compared to the big parlor (more than eight, especially during football matches) and kitchen, where cooking was done with a minimum of five occupants. Occupational Safety and Health Administration (OSHA) [24] has established a permissible exposure limit (PEL) for CO_2 of 5,000 parts per million (ppm**)** (0.5% CO_2 in air) averaged over an 8-hour workday (time-weighted average or TWA). The average concentration of CO_2 for all rooms in the building did not exceed the recommended standard level except on a few occasions in the kitchen during frying, baking, and other cooking. The concentrations of CO_2 in the parlor were influenced by the number of occupants, as the primary source of CO_2 is human respiration.

Table 1. The Basic Description

Parameters	PM_1	$PM_{2.5}$	PM_{10}	SO_2	NO_2	O_3	CO_2
Mean	17.8	25.2	27.6	48.8	66.5	24.8	419.72
Std Dev.	5.3	7.8	11.7	23.0	45.0	9.2	102.0
Minimum	1.0	2.0	2.0	0.0	0.0	0.0	303.60
Maximum	34.0	51.0	161.0	79.0	282.0	79.0	1003.30
Skewness	-0.3	-0.2	3.2	-1.2	1.9	0.5	2.43
Kurtosis	0.1	-0.2	32.8	0.1	4.6	5.0	6.78
Ist Quartile	15.0	21.0	22.0	43.0	40.0	20.5	361.45
3rd Quartile	21.0	31.0	32.5	64.0	79.0	30.0	436.25

Units: PM_1 - µg/m^3, $PM_{2.5}$ - µg/m^3, PM_{10} - µg/m^3, SO_2 – ppb, NO_2 – ppb, O_3 – ppb

The maximum levels of $PM_{2.5}$ and PM_{10} obtained in this study were higher than the WHO limits. The $PM_{2.5}$ results were lower than the 36–111 g/m^3 recorded by Anand and Phuleria [13] in India and 34–91 µg/m^3 [20]. The PM_{10} reported in this study was in agreement with the results (91–137 µg/m^3) obtained by Muhamad-Darus et al. [19] and Mansor et al. [16]. The residential combustion of open fires, cooking, frying, baking, heating, and lighting exposes the home to pollutants from within and outside of the building. This clearly shows a higher risk of air pollution-related illnesses [25]. Furthermore, the maximum SO_2 concentration in this study is twice as high as the standard values obtained, but it agrees with those obtained by Hu et al. [21] in China. The WHO warned that a sulphur dioxide level of 500 µg/m^3 should not exceed the average period of 10 minutes because health impacts have been linked to respiratory tract inflammation, which induces cough, mucus secretion, aggravation of asthma, and chronic bronchitis, which makes people vulnerable to breathing issues. Sulfur dioxide levels above 200 µg/m^3 are toxic gases that cause inflammation of the airways. The main source of nitrate airborne particulate is NO_2, which contributes substantially to $PM_{2.5}$ with exposure to UV light.

Table 2 summarizes various parameters' variable correlations. Temperature, RH (r = -0.77), and SO_2 (r = 0.66), according to the table, have moderate relationships (r = -0.77); however, RH has a relationship (r = 0.32-0.39) with all of the parameters. NO_2 has weak relationships with O_3 and CO_2 (r = 0.63 and 0.50, respectively). SO_2 has low correlations (r = 0.01-0.27) with PM_1, $PM_{2.5}$, and PM_{10}. The findings demonstrate a significant relationship between PMs (r = 0.94–0.97), but poor relationships between PMs and CO_2 (r = 0.05–0.07). Table 2 demonstrates a weaker and more moderately significant relationship between pollutant concentrations and meteorological parameters. The particulate matter relationship may be a result of a positive relationship with global radiation at a significant 0.05 level. Global radiation fuels photochemical reactions in the atmosphere, resulting in the formation of particulate matter [26]. The relationship between RH and $PM_{2.5}$ demonstrates that relative humidity has no effect on fine particle scavenging. The fact that temperature and O_3 have a positive correlation suggests temperature has a positive effect on photochemical reactions [26].

Table 2. The relationships between the pollutants and the meteorological parameters.

	Temperature	**RH**	**NO_2**	**O_3**	**SO_2**	**PM_1**	**$PM_{2.5}$**	**PM_{10}**	**CO_2**
Temperature	1								
RH	**-0.77**	1							
NO_2	-0.31	0.39	1						
O_3	0.24	-0.14	**0.63**	1					
SO_2	**0.66**	-0.47	-0.30	0.28	1				
PM_1	0.12	-0.15	0.20	0.30	0.01	1			
$PM_{2.5}$	0.12	-0.15	0.19	0.30	0.01	**0.99**	1		
PM_{10}	0.10	-0.16	0.18	0.28	0.01	**0.94**	**0.97**	1	
CO_2	-0.13	0.32	**0.50**	**0.61**	0.27	0.06	0.07	0.05	1

4. Conclusion

This report is part of a study that was conducted inside a housing complex using a low-cost sensor. The sensor's proper procedure was used to measure PM_1, $PM_{2.5}$, PM_{10}, carbon dioxide, sulphur dioxide, nitrogen dioxide, and ozone, as well as temperature and relative humidity. The mean $PM_{2.5}$ and PM_{10} levels have been reported to be within the WHO limits for the past 24 hours. Furthermore, the level of sulfate dioxide is twice as high. A sulfur dioxide concentration of 500 µg/m^3 should not last more than 10 minutes, according to the World Health Organization. Ozone, sulfur dioxide, and carbon dioxide concentrations were high. Household combustion of polluting fuels from open fires or traditional kitchen equipment for cooking, heating, and lighting exposes the home to pollutants from within and out. According to the results, the high levels of the pollutants may lead to an increased risk of air pollution-related diseases.

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Conflict of Interest

There is no conflict of interest

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