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Indoor Air Quality Assessment Using a Low-Cost Sensor: A Case Study of Ikere-Ekiti, Nigeria †

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Abstract: Individuals who use most of their time indoors are especially sensitive to indoor air quality (IAQ), which significantly impacts their general well-being and health. Traditional IAQ measurement techniques, however, are frequently pricy, complicated, and labour-intensive. In this study, we used a low-cost, simple-to-use, and handy sensor system to track the levels of carbon dioxide (CO_2), nitrogen dioxide (NO_2), ozone (O_3), particulate matter ($PM_{1.0}$, $PM_{2.5}$, and PM_{10}), temperature and relative humidity (RH) in a laboratory at the Bamidele Olomilua University of Education, Science, and Technology in Ikere-Ekiti for a month. We contrasted the outcomes with other benchmarks and WHO recommendations. However, the NO_2 levels (144.00–303.00 ppb) exceeded the suggested levels (National Institute for Occupational Safety and Health (NIOSH)—70 ppb; National Ambient Air Quality Standards (NAAQS)—100 ppb; National Environmental Standards and Regulations Enforcement Agency (NESREA)—120 ppb); and World Health Organization (WHO)—25 ppb), suggesting a possible cause of indoor contaminants. We also noticed that the temperature and humidity varied considerably throughout the day, which impacted the inhabitants' thermal comfort and ventilation. The Principal Component Analysis (PCA) findings indicate that particulate matter, the weather, photochemical reactions, and combustion processes are the key contributors to fluctuation in the air quality measurements. Based on their quantities and relationships, these elements can have a variety of effects on both the natural environment as well as well-being. Our monitoring device can give immediate information and warnings, assisting in locating and reducing indoor airborne pollutant sources and enhancing indoor air quality (IAQ). This work shows that adopting a low-cost sensor system for IAQ measurement in underdeveloped nations, where such data are sparse and frequently erroneous, is both feasible and beneficial.

Keywords: air pollution; particulate matter; principal component analysis; meteorological factors; low-cost sensor; Nigeria

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1. Introduction

Indoor air quality (IAQ) issues have received a lot of attention recently because of their considerable effects on human health and well-being [1]. A variety of respiratory and cardiovascular problems can develop as a result of the increase of pollutants like carbon dioxide (CO_2), nitrogen dioxide (NO_2), ozone (O_3), and particulate matter (PM) of different sizes ($PM_{1.0}$, $PM_{2.5}$, and PM_{10}) in indoor environments, which can lower quality of life [1]. IAQ must be rigorously assessed and monitored in order to overcome these issues. While earlier studies have looked at IAQ in a variety of contexts, this study takes a fresh approach by using inexpensive sensors to thoroughly assess the indoor air quality parameters in Ikere-Ekiti, Nigeria.

This study is innovative in that it uses inexpensive sensors to assess a wide range of indoor air quality parameters, including CO_2, NO_2, O_3, $PM_{1.0}$, $PM_{2.5}$, and PM_{10}, in an interior environment and this work is the first of its kind in Ikere-Ekiti. The scope and breadth of IAQ assessments are constrained by traditional research's frequent reliance on pricy monitoring apparatus [1]. Especially in resource-limited places, this work pioneers the use of accessible sensor technologies, enabling extensive data gathering and creating a more inclusive understanding of IAQ dynamics.

Although earlier IAQ studies [2–4] have provided insightful information, they frequently concentrate on certain pollutants or make use of expensive monitoring tools, which limits the breadth and depth of data collection. On the other hand, our study covers a wide range of CO_2, NO_2, O_3, and different PM fractions in addition to single pollutants. Furthermore, the incorporation of low-cost sensors allows for broader spatial coverage and long-term data collection, facilitating a more nuanced analysis of IAQ trends and patterns in Bamidele Olumilua University of Education, Science and Technology, Ikere-Ekiti (BOUESTI).

The primary objectives of this study are: to provide a holistic assessment of indoor air quality by measuring CO_2, NO_2, O_3, $PM_{1.0}$, $PM_{2.5}$, and PM_{10} levels in a medical laboratory indoor environment at BOUESTI health center. This multifaceted approach enables a deeper understanding of IAQ variations and potential sources of pollutants and by correlating the IAQ data with established air quality standards and guidelines, the study intends to evaluate the potential health risks posed by indoor pollutants. Lots of anthropogenic activities take place in this laboratory, unfortunately, in the room there is low ventilation (no fan, air conditioner, or fume extractor). This analysis will shed light on the implications for the well-being of occupants and help formulate recommendations for IAQ improvement strategies.

In conclusion, this paper sets out to advance our understanding of indoor air quality by embracing innovation in sensor technology and adopting a holistic approach. By extending the scope of assessment to encompass multiple IAQ parameters and employing cost-effective sensor solutions, this study seeks to provide actionable insights for policymakers, building managers, and residents to enhance indoor environments and promote public health in BOUESTI and Ikere-Ekiti, Nigeria.

2. Materials and Methods

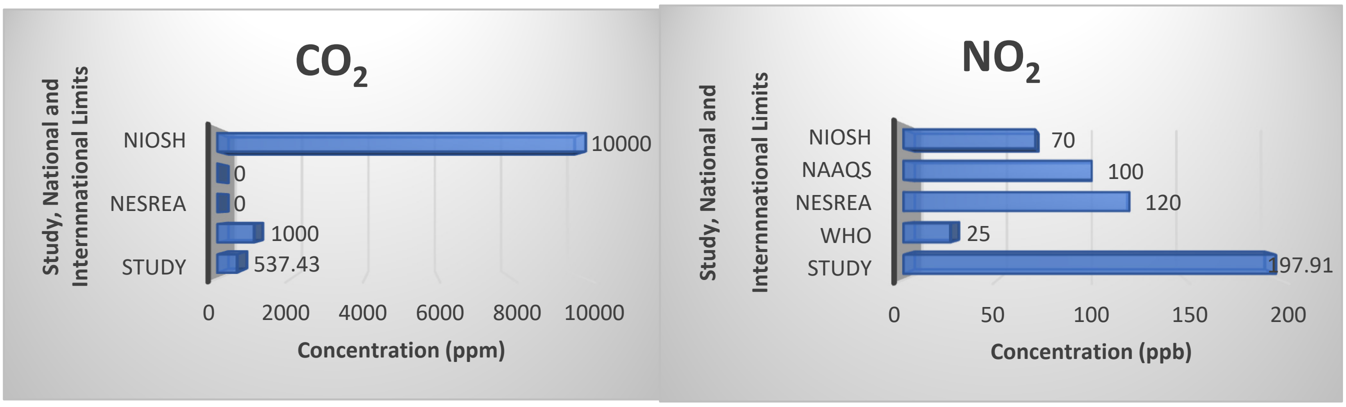
The study area was located at a Medical laboratory at the Bamidele Olomilua University of Education, Science, and Technology Health Center (7.4952° N and 5.1747° E) in Ikere-Ekiti (Latitude: 7.5000° N 5.2333° E), Ekiti State (7.40001° N 5.15000° E), Nigeria, which was situated in the southwest of the nation. In terms of agriculture, transportation, industry, housing, and population, the town and its environs were expanding swiftly. The monitoring was continuous for 24 h during the rainy season period and was done for a month (19 July–18 August 2023) as a preliminary study using a low-cost sensor (Model: SentinAir S3) developed and designed by a group of researchers from the Italian National Agency for New Technologies, Energy, and the Environment (ENEA), Department of Sustainable Development, Brindisi Research Center, Italy [5]. Following the correct procedures [5], the sensor which was suspended four meters in the air while fixed on a rack, was able to detect the presence of carbon dioxide (CO_2), nitrogen dioxide (NO_2), ozone (O_3), particulate matter ($PM_{1.0}$, $PM_{2.5}$, and PM_{10}), temperature, and relative humidity (RH). The pollutants' PCA was established. The locations of the sampling sites were located with the aid of a Garmin satellite navigator. The produced data was statistically examined using Minitab and Excel versions.

3. Results and Discussion

The result (Table 1) reveals CO_2 concentrations of 537.48 ± 46.91 ppm which is lower than the results (856.9 ± 400 and 987 ± 400 ppm) reported by Obisesan and Weli [6], 10,000 ppm NIOSH [7], and 1000 ppm WHO [8] (Figure 1). The figures might vary slightly depending on measurement methods and locations, this value aligns with the overall upward trend observed in recent decades. A comparative analysis of these studies provides a comprehensive view of how CO_2 concentrations have changed over time and across regions. NO_2 and O_3 concentrations vary thus: 197.91 ± 34.93 ppb, 2.03 (Skwenes), 2.61 (Kurtosis) and 0.16 ± 14.72 ppb, −1.55 (Skwenes), 0.83 (Kurtosis). PM_1, $PM_{2.5}$, and PM_{10} levels were measured at 9.59 µg/m^3, 14.14 µg/m^3, and 15.09 µg/m^3, respectively, indicating a gradual increase in particle size. $PM_{2.5}$ and PM_{10} concentrations are higher, reflecting their greater prevalence and potential health risks. A temperature of 32.76 °C can impact particle dynamics. Warmer temperatures may enhance atmospheric turbulence, leading to particle dispersion and dilution, potentially lowering PM concentrations [9]. With a relative humidity of 58.50%, particles could experience hygroscopic growth, causing them to absorb water and become larger. Higher RH might also aid in particle settling, potentially contributing to lower airborne PM levels. Understanding the intricate interplay between PM sizes, temperature, and relative humidity is crucial for accurate air quality assessments and effective pollution management strategies [10].

Table 1. Description of the results of the pollutants and weather parameters.

Parameter	Mean	StDev	CoefVar	Min	Q1	Q3	Max	Skewness	Kurtosis
CO_2 (ppm)	537.48	46.91	8.73	57.60	511.67	557.50	1505.90	2.60	37.62
NO_2 (ppb)	197.91	34.93	17.65	144.00	180.00	193.00	303.00	2.03	2.61
O_3 (ppb)	0.16	14.72	22.96	12.00	68.00	72.00	77.00	−1.55	0.83
$PM_{1.0}$ (µg/m^3)	9.59	5.83	60.78	0.00	5.00	14.00	64.00	1.29	5.92
$PM_{2.5}$ (µg/m^3)	14.14	8.88	62.80	0.00	8.00	20.00	124.00	1.93	11.92
PM_{10} (µg/m^3)	15.09	10.19	67.52	0.00	8.00	20.00	196.00	2.82	23.49
Temp (°C)	32.76	1.45	4.44	23.90	31.00	33.80	35.90	−0.73	2.46
RH (%)	58.50	3.93	6.72	49.50	56.50	60.00	91.90	2.74	14.74



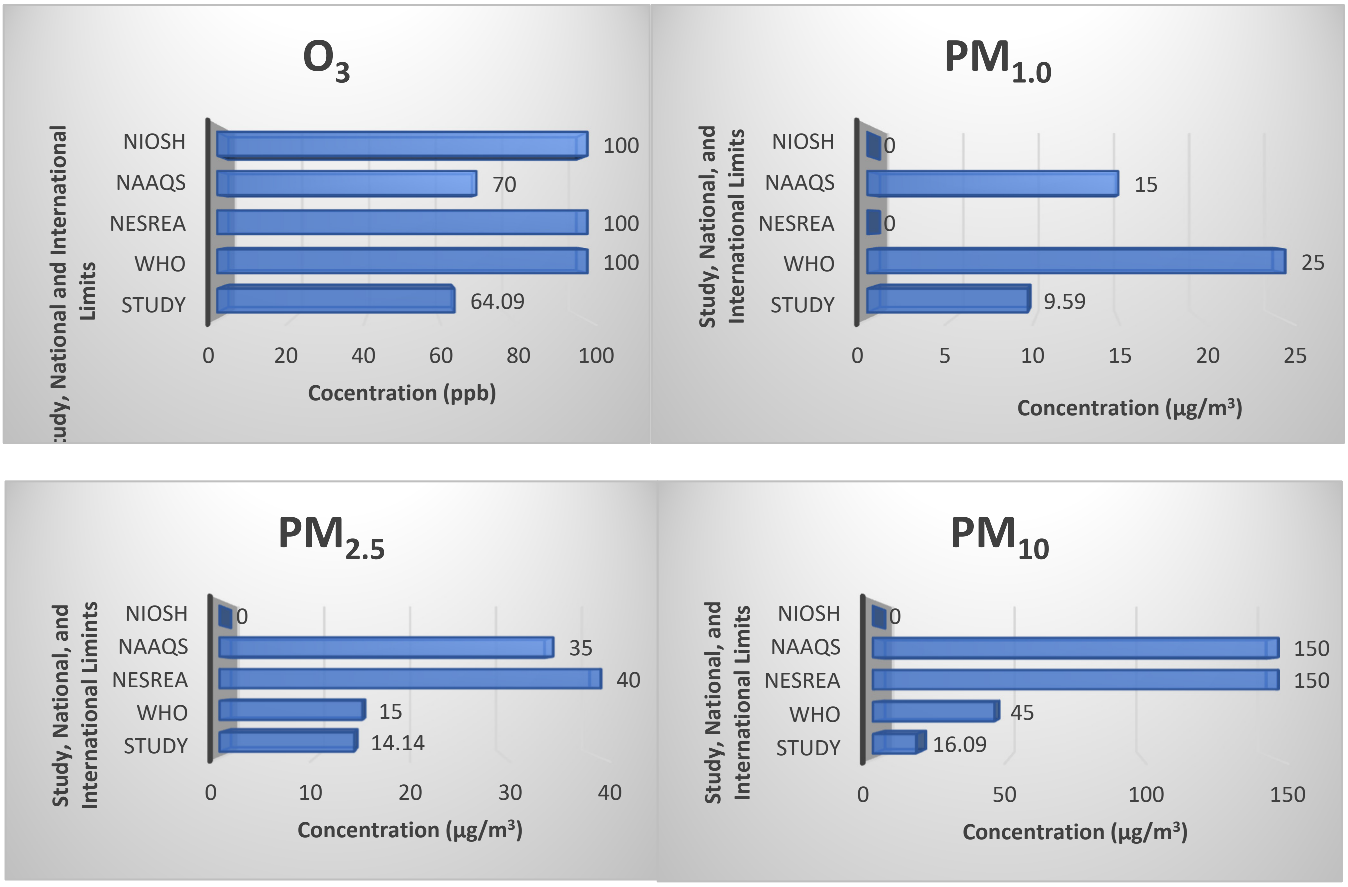


Figure 1. The comparisons of the results with the national and international standards.

Figure 1 shows the NO_2 concentration of 197.91 ppb and contrasts it with daily international guidelines set by NIOSH, NAAQS, NESERA, and WHO. The observed NO_2 concentration surpasses 70 ppb [7], 100 ppb [11], 120 NESERA [12] 120 ppb, and 25 ppb WHO [8] limits. This discrepancy is attributed to excessive NO_2 emission due to heavy vehicular movements within the study area. Effective pollution control measures and collaborative efforts are essential to curb NO_2 levels and ensure a healthier and cleaner environment. The recorded O_3 concentration falls below NIOSH's 100 ppb, NAAQS's 70 ppb, NESERA's 100 ppb, and WHO's 100 ppb limits. While it adheres to most standards, its proximity to these thresholds necessitates vigilant monitoring. Ozone at elevated levels can exacerbate respiratory conditions and harm vegetation. While the observed concentration meets many standards, the closeness to limit values still implies potential health and ecological risks. Impacts of this pollutant can lead to complex health outcomes. The $PM_{1.0}$ concentration of 9.59 μg/m^3 falling below international standards is due to the low volume of vehicular and human activities because the institution is not in session. Maintaining this trend requires efforts to minimize emissions, improve air quality, and safeguard both human health and the environment. The recorded $PM_{2.5}$ concentration is below NAAQS's 35 μg/m^3, and NESERA's 40 μg/m^3, but comparable to WHO's 15 μg/m^3 standard. The differences in standards emphasize the need for harmonization and stringent measures to curb $PM_{2.5}$ pollution. The recorded PM_{10} concentration is below NAAQS's 150 μg/m^3, NESERA's 150 μg/m^3, and WHO's 45 μg/m^3 standards. The reasons for these differences could be due to the location of the monitoring station, meteorological parameters, time of day (especially rush hour), and season [13]. Also, the temperature and humidity did not have much effect due to the presence of standing and ceiling fans working, and window ventilation.

According to the study's PCA results, particulate matter (PM_1, $PM_{2.5}$, and PM_{10}) showed substantial loading in PC1 (0.515, 0.524, and 0.522 respectively). High positive loadings show that PM concentrations tend to rise concurrently, which points to a general source of air pollution that affects a range of particle sizes, like vehicle emissions. The primary causes of variation in the air quality measurements are photochemical reactions and combustion processes, which are connected to atmospheric variables (temperature (−0.549) and relative humidity (0.544) were captured by PC2. Nitrogen dioxide (−0.689) and ozone (0.676) concentration fluctuation was recorded by PC3. This is a sign of intricate interactions in atmospheric chemistry or frequent sources of pollution, such as exhaust from moving vehicles.

4. Conclusions

The study assessed the indoor air quality of a BOUSTI by measuring CO_2, NO_2, O_3, $PM_{1.0}$, $PM_{2.5}$, and PM_{10} levels in a laboratory at the BOUESTI health center. The results obtained were compared to international and national IAQ data established standards and guidelines. Based on the recorded PM1 (9.59 μg/m^3), $PM_{2.5}$ (14.14 μg/m^3), and PM_{10} (15.09 μg/m^3) concentrations, the air quality is within the safe limits of NAAQS's 150 μg/m^3, NESERA's 150 μg/m^3, and WHO's 45 μg/m^3 standards. The simple fact is that the institution is on holiday so there are minimal vehicular and human movements which could have caused elevated pollutants. The temperature and humidity did not have much effect due to the presence of standing and ceiling fans working, and window ventilation

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