JOURNAL OF THE ENVIRONMENT
(JOE)
Available online at https://journaloftheenvionment.com

OPEN ACCESS

ISSN: 0795-0977

Original Research Article

Indoor Air Quality in Households Using Unprocessed Biomass Fuel for Cooking in Mbiono-Ibom, Akwa Ibom State, Nigeria

Umoren, U.E[1], Nzoiwu, C.P[2], Ogbonna, C.E[3] and Egbu, A.U[4]

1.Department of Urban and Regional Planning, University of Uyo, Nigeria

[2]Department of Geography and Meteorology, Nnamdi Azikiwe University, Awka, Nigeria

[3]Depart of Environmental Resource Management, Abia State University,Uturu, Nigeria

[4]Department of Urban and Regional Planning, Abia State University, Uturu, Nigeria

***Corresponding Author**
Umoren, U.E

Abstract

This study assessed indoor air quality in households using unprocessed biomass fuel for cooking in Ibiono-Ibom, Akwa Ibom State. Six priority indoor air quality parameters, namely, carbon dioxide (CO), nitrogen dioxide (NO2), sulphur dioxide (SO2), total volatile organic compounds, and particulate matter (PM 2.5 and PM10) were analysed.Purposive sampling was then employed in selecting ten houses, comprised of five with indoor kitchens and five with outdoor kitchens, for the study. Analysis of Variance (ANOVA) was employed to test the significance ($p < 0.05$) of the observed differences in indoor air quality with respect to the location of kitchens and seasons. The result showed that,exceptfor NO2 and SO2, the mean statistic of all other air quality parameters was higher in the buildings with outdoor kitchens. SO2 and CO concentrations in buildings with outdoor kitchens differed significantly between dry and wet seasons, with CO and SO2 having higher concentrations in the wet season than in the dry season. Other air quality parameters did not vary significantly between wet and dry seasons. Only CO concentration varied significantly in buildings with indoor and outdoor kitchens($p = 0.009$). The concentrations of all pollutants analysed in this study exceeded acceptable limits, which raises serious health concerns for residents.It is crucial to enhance the capacity of residents for easy transitioning to cleaner energy by providing and enhancing opportunities for poor households.

INTRODUCTION

Indoor air pollution is the presence of one or more contaminants in the indoor environment that has a degree of human health risk (Adah et al., 2008)) and is usuallyassociated with combustion of solid fuels such as firewood.In many households of the developing world, indoor air pollution is a major health risk to exposed populations (Olaoye, 2021) and poses a serious environmental concern for the ecosystem (Waweru et al.,2022).Biomass is a renewable energy source and generic term for plant and animal substances such as wood, crop residues and animal dung used for fuel (Colbeck et al., 2010). When burned, the chemical energy in biomass is released as heat (Gelfand et al, 2020).Processed biomass refers to plant, animal, food processing materials, human waste from sewage plants, among others, converted to energy in the form of biogas or biofuel such as ethanol and biofuel (McCalmont et al., 2017). Unprocessed biomass is plant and animal materials used for cooking as solid fuel, including firewood, palm kernel shells, and palm fruit fibre, sawdust, waste from food crops, and animal dung (Jekayinfanet al., 2020; Smith et al., 2016).

Over 1.1 billion people reside in sub-Saharan Africa, which includes Nigeria, with 40% of the population living below the poverty line (World Bank, 2020). This situation is worsened by weak and inefficient energy frameworks that have left many countries in the region to continue to use solid biomass fuels, thereby hindering economic growth and development and creating environmental and health risks. Most poor and rural households are left with no other option than to use biomass solid fuels, which serve as a primary source of energy for cooking and heating for them in spite of available cleaner alternatives such as liquefied petroleum gas. Keles et al. (2017) estimated that about 823 million people in Africa would rely on biomass for cooking and heating by 2030. In parts of Kenya, for instance, Huxhamet al. (2019) observed that the three-stone firewood fire is the most commonly used cooking method despite the significant negative social, environmental, and health impacts associated with its use.

Nigeria is a developing country with an insufficient supply of energy to meet the rapidly growing demand for energy. The increasing energy demand is driven by a very high population growth rate. Biomass resources identified within Nigeria include forest residues, agricultural residues, human and animal wastes, aquatic biomass, and energy crops (Jekayinfaet al., 2020).

The burning biomass in traditional stoves of low efficiency has been linked with emission of large quantities of harmful pollutants such as carbon monoxide (CO), nitrogen dioxide(NO2), and suspended particulate matter (SPM), with serious health and environmental consequences, especially in low and middle-income countries, including Nigeria (Sani et al.,2025;Huxhamet al., 2019;Rivindra, 2019;Karakara, 2018).Baumgartner et al. (2019) noted that household air pollution from cooking and heating with solid fuel stoves was responsible for an estimated 1.6 million premature deaths in China and other parts of Asia in 2017. WHO (2024) also noted that household air pollution accounted for about 3.2 million deaths in 2020.

The study area is noted for its abundant supply of fuel wood (Akwa Ibom State Government Bulletin, 2022), which naturally provides a cheap energy source for cooking for the inhabitants. During bi-weekly market days, numerous pick-up loads of firewood are carted away to neighbouring local government areas for sale. A heavy mass of smoke is noticed during cooking periods. It was also observed that cooking areas, although mostly outside, are situated close to living areas such as sitting rooms and bedrooms.The inhabitants are mainly farmers, and most of the households still use traditional cooking methods such as three-stone or metal-carrier fires, making use of firewood, palm kernel shell, and palm-fruit fiber for cooking. In the rural areas of this local government, settlements are contiguous with the mangrove areas, which are therefore commonly used for firewood extraction with its attendant negative environmental impacts, notable among which is deforestation. These observations justify this study; several studies have reported the wide use of unprocessed biomass for cooking, especially in rural and poor households in Nigeria. In a study of residential indoor air quality in Ibadan metropolis, Jeliliet al. (2025) found that low-density residential areas had significantly better indoor air quality. In addition, they reported that particulate concentrations were higher in high-density and poorer areas, driven by higher use of firewood and charcoal for cooking.Awoyeyeet al. (2025) assessed carbon dioxide and nitrogen dioxide concentrations in a mud building in a rural part of Osun state, where biomass solid fuel was used in cooking.Their findings showed that the concentration of both gases exceeded minimum standards, was lower outside the kitchen area, and varied significantly with the seasons. Sani et al. (2025) assessed household smoke exposure risks in different parts of Nigeria and found that 29% of rural and poor households experienced high smoke exposure risks. In a comparative study of biofuel use in rural households in Bauchi State, Nigeria, Adahet al. (2023) reported that carbon monoxide, hydrogen sulphide, and sulphur dioxide were higher in rural kitchens making use of firewood for cooking compared to those using processed charcoal. In a similar study in Ilorin, Nigeria, Raheem et al. (2022) reported that nitrogen dioxide, sulphur dioxide, and carbon monoxide levels in kitchens in Ilorin were higher in those using firewood and charcoal for cooking compared to those using efficient energy sources such as liquefied petroleum gas. Jeliliet al. (2020) and Oguntoke et al. (2010) reported high levels of indoor air pollutants in another rural south-western Nigeria.In what may be considered one of the pioneer studies on indoor air quality in households using biomass fuel for cooking in the Niger Delta region of Nigeria, Akpafure(2015) reported that indoor air quality in squatter settlements inWarri, Delta State,was poor, with all air quality parameters exceeding regulatory limits due to the use of unprocessed biomass fuels for cooking. A recent study by Abai et al., (2025), focused on indoor air quality in coastal communities of Akwa Ibom state and reported elevated levels of pollutants during the dry season. A related study in Akwa Ibom state includes Ite et al. (2019), which assessed indoor air quality in schools.

The extant literature indicates a paucity of data on indoor air quality in non-coastal areas of Akwa Ibom state, where the study area is situated. Further, current studies in Nigeria have not compared indoor air quality in buildings with indoor and outdoor kitchens. To fill the identified gaps, our study assessed indoor air quality in households using unprocessed biomass fuel for cooking in Ibiono-Ibom, anon-coastal, rural area of Akwa Ibom state, Nigeria. The study covered wet and dry seasons. The objectives of the study were to; (i) Measure indoor air quality in the study area. (iii) Examinethe effects of kitchen location on indoor air quality in the study area. (ii) examine seasonal influence on indoor air quality in the study area

Methodology

Study Area

Ibiono Ibom Local Government Area (LGA) is in Akwa Ibom State, Nigeria, and is located between latitudes 50 41 and 50 221 North and longitudes 70 481 and 70 581 East (Figure 1).

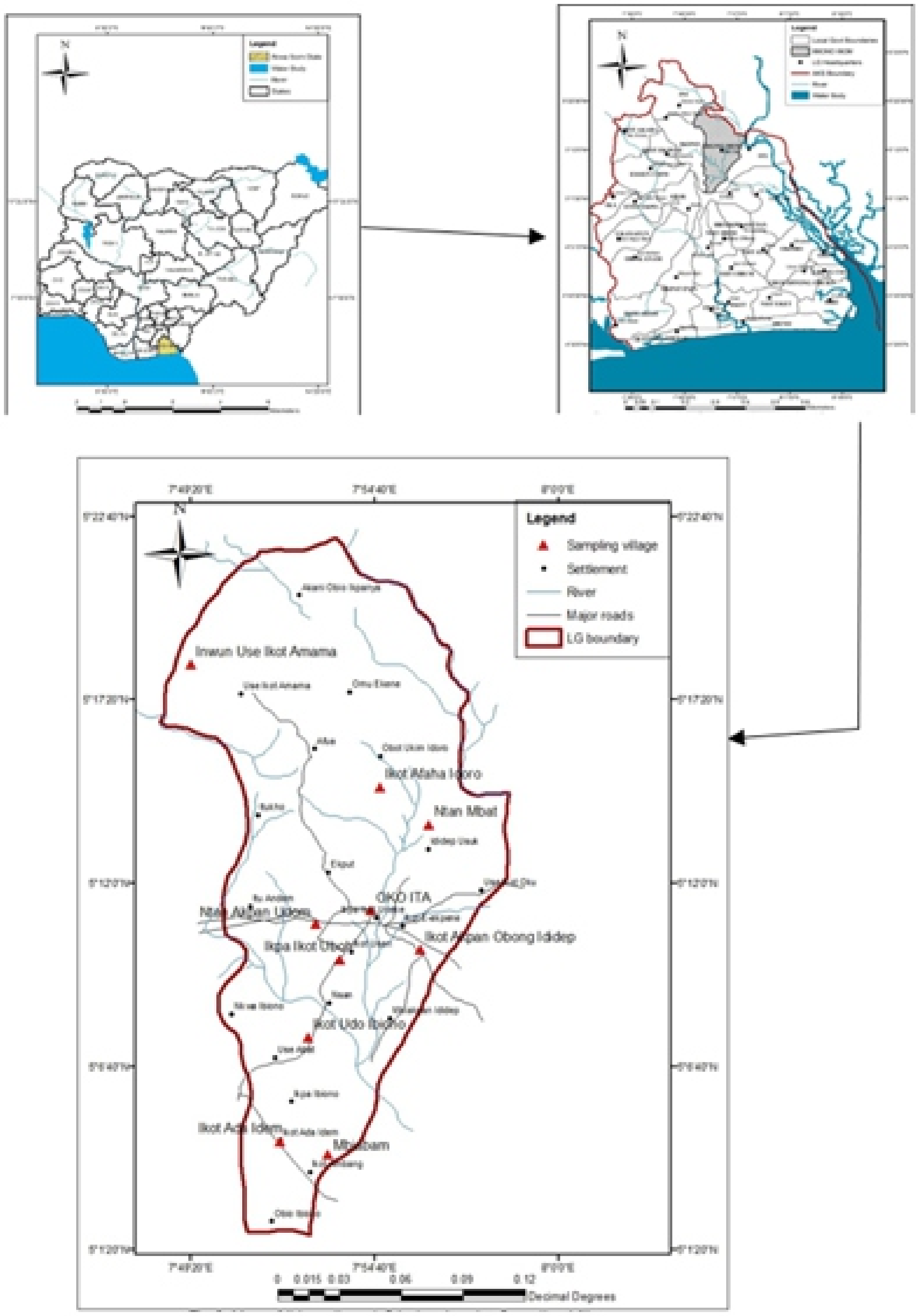

Fig 1: Map of Ibiono Ibom LGA showing the sampling locations

Its administrative headquarters is at Oko Ita. Ibiono-Ibom Local Government Area covers an area of 2,761.76square kilometers; it has nine contiguous clans, seven development areas and two hundred (200) villages. It is bounded on the North by Akamkpa Local Government Area, Cross River State; on the West by Ini and Ikono Local Government Areas, and on the south by Uyo Local Government Area. The conspicuous geographical feature to the East of Ibiono-Ibom is the Cross River, which is rich in aquatic organisms, including fish, reptiles, and mollusks (Akwa Ibom State Bulletin, 2022).According to the National Population Commission (NPC), Ibiono-Ibom has a population of 188,605 (NPC, 2006). The population of the area is 294, 969 projected to 2023using a population growth rate of 3.5%.

The study area is located in the equatorial rain forest region of Nigeria and forms part of the coastal plains of the Cross river, with consolidated alluvial sands. The study are is largely rural and the economy is driven by agriculture, especially farming.

Population and Sampling Procedure

Out of the two hundred villages in the study area, 20 villages, representing ten percent, were randomly selected for the study. Purposive sampling was then employed to select ten houses from the twenty villages for measuring indoor air quality. They comprised five indoor kitchens and five outdoor kitchens. Those selected met the same criteria in terms of floor space, roof height, number and position of windows in accordance with international and professional protocols.

Direct measurement of the concentration of carbon monoxide (CO), nitrogen dioxide (NO2),sulphur dioxide(SO2), volatile organic compounds (TVOC), and particulate matter PM2.5 and PM10was carried out using Steward air quality monitors. These pollutants have important implications for public health (Abuludeet al., 2022). The coordinates of sampling locations were taken with a hand-held Global Position System(Garmin Etrex GPS 32x). Direct reading of values was taken in the morning (07.00am – 12.00noon), daily for two weeks in June and December 2023.Duplicate measurements were taken in five of the households on two consecutive days to validate the measurement of pollutants.

Results

The results obtained from air quality sampling of buildings with indoor kitchen and outdoor kitchens revealed the variations in air quality. Tables 1 and 2 show the summary of descriptive statistics revealing such variations between seasons. With the exception of NO2 and SO2, the mean statistic of all other air quality parameters was higher in buildings with outdoor kitchen. The variance statistic was shown to be high for CO in buildings with indoor kitchen compared to those with outdoor kitchen.

Table 1: Descriptive statistics of air quality within buildings with an indoor kitchen

Air Quality Parameters	Range	Minimum	Maximum	Mean		Std. Deviation	Variance
				Statistic	Std. Error		
NO_2 (PPM)	.3	.1	.4	.240	.0340	.1075	.012
SO_2 (PPM)	.3	.1	.4	.270	.0300	.0949	.009
CO (PPM)	30.0	12.0	42.0	29.900	3.2470	10.2681	105.433
TVOC mg/m3	1.084	1.453	2.537	2.06030	.116064	.367027	.135
PM 2.5 ?G/m3	118.0	126.0	244.0	185.400	13.6098	43.0380	1852.267
PM 10 ?g/m3	186.0	239.0	425.0	339.100	22.4991	71.1484	5062.100

Table 1: Descriptive statistics of air quality in buildings with outdoor kitchens

Air Quality Parameters	Range	Minimum	Maximum	Mean Statistic	Mean Std. Error	Std. Deviation	Variance
NO2 (PPM)	.2	.1	.3	.230	.0213	.0675	.005
SO2 (PPM)	.3	.1	.4	.260	.0267	.0843	.007
CO (PPM)	31.0	13.0	44.0	31.700	2.7164	8.5900	73.789
TVOC mg/m3	1.546	1.555	3.101	2.22930	.139357	.440684	.194
PM2.5 ?G/m3	226.0	124.0	350.0	214.100	25.7416	81.4022	6626.322
PM 10 ?g/m3	372.0	242.0	614.0	373.900	45.4404	143.6952	20648.322

Table 3: Descriptive statistics of air quality during the dry season

	NO_2 (PPM)	SO_2 (PPM)	CO (PPM)	TVOC mg/m3	PM 2.5 ?G/m3	PM 10 ?g/m3
Mean	0.22	0.21	24.1	2.1082	190.8	349.5
Standard Error	0.03266	0.023333	2.583925	0.124101	28.84279	47.5297
Median	0.2	0.2	27	2.106	134.5	273.5
Standard Deviation	0.10328	0.073786	8.171087	0.392443	91.20892	150.3021
Sample Variance	0.010667	0.005444	66.76667	0.154012	8319.067	22590.72
Range	0.3	0.2	21	1.035	226	375
Minimum	0.1	0.1	12	1.533	124	239
Maximum	0.4	0.3	33	2.568	350	614
Sum	2.2	2.1	241	21.082	1908	3495
Confidence Level(95.0%)	0.073882	0.052784	5.845244	0.280737	65.24693	107.5196
WHO air quality guideline (2014)	0.000025	0.00004	0.004	1	15	45

Table 4: Descriptive statistics of air quality during the wet season

	N02 (PPM)	SO2 (PPM)	CO (PPM)	TVOC Mg/m3	PM2.5 µg/m3	PM10 µg/m3
Mean	0.25	0.32	37.5	2.1814	208.7	363.5
Standard Error	0.022361	0.02	1.204159	0.137037	6.62663	19.19274
Median	0.2	0.3	36.5	2.1495	208	378
Standard Deviation	0.070711	0.063246	3.807887	0.433347	20.95524	60.69276
Sample Variance	0.005	0.004	14.5	0.18779	439.1222	3683.611
Range	0.2	0.2	11	1.648	71	167
Minimum	0.2	0.2	33	1.453	167	278
Maximum	0.4	0.4	44	3.101	238	445
Sum	2.5	3.2	375	21.814	2087	3635
Confidence Level(95.0%)	0.050583	0.045243	2.723998	0.309998	14.99048	43.41698
WHO air quality guideline (2024)	0.000025	0.00004	0.004	1	15	45

The observed differences in the air quality between indoor and outdoor kitchens were as obtained from laboratory analysis. ANOVA was used to test if the differences observed weresignificant. Table 2 indicates that there was no significant difference between the quality of air found in buildings with indoor and outdoor kitchens, since the p-value for each of the air quality parameters is higher than 0.05. Similarly, the F-distribution showed that the critical F at 0.05 is 8.28 and is shown to be greater than each of the F calculated values revealed in Table 2. As a result, since the calculated F of 0.062 (NO_2), 0.062 (SO_2), 0.181 (CO), 0.0868 (TVOC), PM 2.5 (0.337) and PM 10 (0.501) was less than the critical F of 8.28, we conclude that this further gives credence to the nonsignificant nature of differences in air quality in buildings with indoor and outdoor kitchens.

Seasonal variations in air quality were evaluated by analyzing air quality for buildings with indoor kitchens and outdoor kitchens for both dry and wet seasons. The result of the analysis indicates that only CO (p = 0.009) has a p-value less than the alpha value of 0.05 and such indicates that the concentration of carbon monoxide in buildings with indoor and outdoor kitchens varies significantly. This significant seasonal variation in CO concentration in the ambient air within and outside of the buildings, notwithstanding the locations of the kitchen, is further supported by the outcome of the descriptive analysis shown in Tables 3 and 4. The mean statistic indicated that the CO concentration has a higher mean concentration during the wet season than during the dry season, with minimum and maximum values of 33ppm and 44ppm in the wet season, compared to 12ppm and 33ppm, respectively, in the dry season. In addition, other air quality parameters were shown not to vary significantly between the dry and wet seasons for buildings with an indoor kitchen.

Similarly, for buildings with an outdoor kitchen, the significance of the observed seasonal variations in air qualitywas tested using ANOVA. Significant values or the p-values were less than 0.05 for SO_2 (0.012) and CO (0.018). The observed statistical outcome implies thatSO_2 and CO concentrations in buildings with outdoor kitchens differed significantly between dry and wet seasons, with CO and SO_2 having higher concentrations in the wet season than in the dry season. Other measured air quality parameters were shown not to vary significantly seasonally.

Furthermore, we attempted to determine whether the varying air quality characteristics measured in the study area differ from the WHO air quality guidelines. This test was performed for both buildings with indoor kitchens and outdoor kitchens. The p-values for all air quality parameters were less than the alpha level of 0.05. Since each p-value is below 0.05, the assumption of no significant difference between the air quality in buildings with indoor kitchens and the WHO air quality guidelines is rejected. This indicates that the concentrations of air quality variables in the buildings differ significantly from the WHO guidelines. Additionally, this supports the observation that pollutant concentrations were higher in buildings with indoor kitchens compared to the WHO guidelines across all cases.

In the same vein, we tried to find out whether air quality for buildings with outdoor kitchens varied significantly from the WHO air quality guidelines. The results indicated that the p-values of the air quality variables were less than the alpha value of 0.05 except for NO_2, which has a p-value of 0.062. Thus, air quality in buildings with outdoor kitchens differed significantly from the WHO guidelines values, with each of the variables measured having a mean concentration value above the recommended guideline.

Discussion

The data revealed that there were considerable variations in air pollutant concentration with respect to seasons. In contrast, significant variations were not found in air pollutant concentrations between indoor and outdoor kitchens. It was evident that the majority of air quality pollutants in the separate categories of buildings, based on indoor and outdoor location of the kitchens, did not vary significantly between dry and wet seasons, except for CO (0.009) for buildings with an indoor kitchen and CO (0.018) and SO_2 (0.012) for buildings with an outdoor kitchen. Further consideration of how these air quality values compare to the WHO air quality guidelines revealed significant variation, since all air quality parameters differed significantly between buildings with indoor and outdoor kitchens. The only exception was NO_2 in buildings with outdoor kitchens, which did vary significantly fromthe WHO standard. The mean statistics of these air quality variables showed that they all exceeded the WHO air quality guidelines. This outcome agreed with the findings of Jelili*et al*. (2025), who reported lower indoor air quality based on PM_{10} being higher thanthe WHO (2024) recommended concentration of 45 µg/m3 for 24 hours. They noted that inhalable particulate pollution in *residential areas with buildings was due to dependence on cooking fuels.*As reported by Abai et al. (2025), the high PM concentrations observed in this study are linked to the use of unprocessed biomass fuels, especially fuel wood, among other factors in the study area. This was found to be particularly higher in buildings with indoor kitchens.

Our findings also agree with those of Adah *et al*. (2023), who reported high levels of CO and SO_2 in rural household kitchens (Tables 1a-d). Further, our results showed that SO_2 and CO had statistically significant differences between the wet and dry seasons, with CO concentration being higher in the wet season. Both seasons also had CO concentrations above the WHO permissible limits. Njoku *et al*. (2016) reported a similar but slightly varied outcome, having reported a higher CO concentration in the dry season in an outdoor study, in contrast to the current study. This seasonal variation in carbon monoxide concentration was also reported in a study in Port Harcourt by Weli and Adegoke (2016). On the contrary, Richard *et al*. (2023) did not find statistically significant variations in CO concentration between the dry and wet seasons in comparison with other pollutants. Furthermore, this study also showed that NO_2 concentrations were lower in the dry season. This result agrees with the findings of Awoyele*et al*. (2025), who reported a similar outcome with NO_2 concentrations in their study. The observed variations in air pollutant concentrations can be attributed to many factors, including meteorological conditions, physical and socioeconomic characteristics of the location, and intensity and efficiency of cooking fuel (Adah *et al*., 2023; Agbo *et al*., 2021).Overall, the findings of this study point to the potential health risks faced by the inhabitants of the study area. Poor quality of indoor air is linked to cardiovascular and respiratory problems (WHO, 2024;Mannan and Al-Ghandhi, 2021)

Conclusion

The study assessed the variations in air quality in buildings with indoor and outdoor kitchens in the Ibiono Ibom area of Akwa Ibom State. The findings of this study support the fact that air quality status of buildings using inefficient energy sources such as biomass fuel for cooking, was poor and usually exceed acceptable limits such as the WHO recommended level. The health impact of elevated levels of PM10 and PM2.5, as well as CO and other measured variables, is enormous. To a large extent, this research has achieved the main objectives. This study hereby recommends increased community engagement and public enlightenment to educate households, especially rural households, on the health-related impacts of using unclean fuel sources. Government and relevant stakeholders needs to provide and improve access to opportunities towards achieving Goal 7 of SDGs, which is ensuring sustainable and sustained access to affordable and clean energy.

References

Abai, E.J., Ite, A.E, and Ibok, U.J. (2025). Seasonal assessment of indoor air quality in coastal communities of Akwa Ibom state, Nigeria. Researchers Journal of Science and Technology5 (5), 1-29.

Abukude, F.O., Feyisetan, A.O., Arifalo, K.M., Akinnusotu, A., and Bello, L.F. (2022). Indoor particulate matter assessment in a northern Nigeria abattoir and a residential building., Journal of Atmospheric Science Research, 5,4: 20-28

Adah, A.J.,Daniel, T., and Akpaso, D.U. (2023). Estimation of indoor air pollutants and health implications due to biomass burning in rural household kitchens in Jos, Plateau State, Nigeria. Environmental Sciences Proceedings, 2023,27,29. https:// doi.org/10.3390/ecas2023-16345

Adah, C., Idiodi, J., and Fakinle, B. (2008). Indoor air quality of kitchens in rural households in Nigeria: Implications for women's health. International Journal of Environmental Health and Research, 18, 131-144.

Agbo, K.E., Walgraave, C., Eze, J.I., Uwuoke, P.E., Ukoha, P.O., Van Langenhove, H (2021). Household indoor concentration levels of NO2, SO2 and O3 in Nsukka, Nigeria. Atmospheric Environment, 244, (2021)117978. Doi.org/10.1016/j.atmosenv.2020.117978

Akpafure, R. (2015): An Assessment of Indoor Air Quality in Selected Households in Squatter Settlements, Warri, Nigeria. Advances in Life Sciences 5(1): 1-11.

Akwa Ibom State (2022). Building Regulation. A Publication of Akwa Ibom State Government.

Akwa Ibom State Government Bulletin (2022). Statistics of Akwa Ibom State of Nigeria 2022 edition. Directorate of Statistics, Ministry of Economic Development, Uyo.

Awoyeye, O.M., Kamiyo, O.M and Adewumi, O.O (2025). Evaluation of household air pollution of carbon monoxide and nitrogen oxide concentration during dry and wet seasons in a mud building that uses biomass solid fuel for cooking in the rural area of Ifewaru, Osun State, Nigeria. Journal of Applied Science and Environmental Management, 29(5):1568-157

Baumgartner, J.; Clark, S.; Carter, E.; Lai, A.; Zhang, Y.; Shan, M.; Schauer, J. J.; Yang, X. (2019): Effectiveness of a household energy package in improving indoor air quality and reducing personal exposures in rural China. Environmental Science Technology.,53, 9306-9316.

Colbeck, I., Nasir, Z.A., Ali, Z and Ahmad, S (2010), Nirogen dioxide and household fuel use in Pakistan, Science of the Total Environment, 409, 2, 357-363

Gelfand, I., Hamilton, S. K., Kravchenko, A.N. (2020): Empirical evidence for the potential climate benefits of decarbonizing light vehicle transport in the US with bioenergy from purpose-grown biomass with and without BECCS. Environ mental Science Technology, 54, (5): 2961-2974.

Huxham M., Jung J. (2019). Indoor Air Pollution. Oxford University Press, (http://creative commons.org/licenses/by-nc/4.0), accessed 20-08-2025.

Ite, A.E., Harry, T.A., Obadimu, C.O and Ekwere, I.O (2019). Comparition of indoor air quality in schools:urban vs industrial oil and gas zones I n Akwa Ibom stat – Nigeria. Journal of Environmental Pollution and Human Health, 7 (1), 15-26.

Jekayinfa, S. O., Orisaleye, J. I., Pecenka, R. (2020): An Assessment of Potential Resources for Biomass Energy in Nigeria.https://doi.org/10.3390/resources9080092.

Jelili, M.O., Abolade, O., Alabi, A.T., and Manunye, J (2025). Residential indoor air quality assessment in Ibadan metropolis, Nigeria. Discover Environment, (2025)3, 87. Doi.org/10.1007/s44274-025-00286-8

Jelili., M.O., Alabi, A.T., Gbadegesin, A.S (2020). Comparative analysis of indoor and outdoor particulate matter concentrations and air quality in Ogbomosho, Nigeria. Journal of Health and Pollution, 10(28): 1-16

Karakara, A. A. (2018). Energy-poverty Nexus: Conceptual Framework Analysis of cooking Fuel consumption in Ghanian Households. Developing Country Studies, 8(11): 1-10

Keles, S.; Bilgen, S.; Kaygusuz, K. (2017): Biomass energy source in developing countries. Journal of Engineering Research and. Applied Science,6, (1), 566-576.

Mannan, M., and Al-Ghandi, S.G. (2021). Indoor air quality in buildings: a comprehensive review on the factors influencing air pollution in residential and commercial structures. International Journal of Environmental Research and Public Health, 18 (6),

McCalmont, J. P.., Hastings, A., McNamara, N. P., Richter, G. M. (2017).Environmental costs and benefits of growing Miscanthus for bioenergy in the UK. GCB Bioenergy, 9(3): 496 -500.

National Population Commission (2006). Population by Local Government Area and Sex. Retrieved May 28, 2025, from National Population Commission: http//population.gov.ng/core-activities/surveys/dataset/2006-phc-priority-tables

Njoku, K. L., Rumide, T. J., Akinola, M. O., Adesuyi, A. A., and Jolaoso, A. O. (2016). Ambient Air Quality Monitoring in the Metropolitan City of Lagos, Nigeria. Journal of Applied Sciences and Environmental Management, 20(1), 178–185. https://doi.org/10.4314/jasem.v20i1.

Oguntoke, O., Opeolu, B.O., and Babatunde, N. (2010). Indoor air pollution and health risks among rural dwellers in Odeda area, south-western Nigeria. Ethiopian Journal of Environmental Studies and Management, 3 (2): 39-45

Olaoye, I.J., Akingbade, A.V., and Alatise, I (2021). Assessment of indoor air quality and health impacts associated with the use of different types of cooking stoves amongst rural households in Kwara state, Nigeria. Journal of Applied Science and Environmental Management, 25, 1, 29-39

Raheem,M.A., Jimoh, G, and Abdulrahim, H (2022). Assessment of kitchen air pollution: Health implications for the residents of Ilorin South, Nigeria. Journal of Environment and Public Health 17, 20227689141.doi:10.1155/2022/768914

Richard G., Izah S. C., Sawyer E. W.,Ogwu M. C (2023). Seasonal Variations in the Concentration of some Atmospheric Pollutants along a major Highway in Southern Nigeria, Vol. 30(1): 10-25.

Sani, J., Garba, I.W. and Ahmed, A. and Ahmed, M.M.

(2025). Understanding household smoke exposure risks (SER) in Nigeria: A regional analysis from the 2018 NDHS. BMC Public Health25, 1351 (2025). https://doi.org/10.1186/s12889-125-22556-z

Smith, K. R., Mehta, S.,Maeusezahl-Feuz, M. (2016): Indoor air pollution from household use of solid fuels, International Journal of Sustainable Built Environment, 5, 1435-1450.

Rivindra, K (2019). Emission of black carbon from rural household kitchens and assessment of life-excess cancer risks in villages of North India. Environment International, 122, 201-212. doi:10.1016/j.envint.2018.11.008.

USEPA (2023). Ideal Indoor Air Quality. .

Waweru, D., Mose, N., Otieno, S. (2022). Household Energy Choice in Kenya: An Empirical Analysis of the Energy Ladder Hypothesis: Journal of Energy Research and Reviews, 104: 12-19.

Weli VEand Adegoke J. O. (2016). The Influence of Meteorological Parameters and Land Use on the Seasonal Concentration of Carbon Monoxide (CO) in the Industrial Coastal City of Port Harcourt, Nigeria.Journal of Pollution Effects & Control, 4 (4), 1-8.

World Bank. (2020). The African Continental Free Trade Area: Economic and Distributional Effects. Washington, DC: World Bank.

https://www.wto.org/english/thewto_e/acc_e/afcfta_feb11maryla.pdf

World Health Organisation (2002): WHO guidelines for indoor air quality: selected pollutants. WHO Publications, Geneva.

World Health Organisation (2024). Household air pollution.www.who.int/news-room/fact-sheets/ accessed 12/11/2025