Journal of Materials and Environmental Science
ISSN : 2028-2508
e-ISSN : 2737-890X
CODEN : JMESCN

J. Mater. Environ. Sci., 2026, Volume 17, Issue 7, Page 1139-1159

http://www.jmaterenvironsci.com

Charcoal production workers; health impacts and ambient air quality around kiln site in Abia State, Southeast Nigeria

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Received *14 Oct 2025,*
Revised *06 July 2026,*
Accepted *07 July 2026*

Keywords:
- ✓ *Air quality;*
- ✓ *Charcoal Production;*
- ✓ *Kiln Site;*
- ✓ *Health risks;*
- ✓ *Environmental Pollution*

Citation*: Okafor A. T., Okimiji O. P., Taiwo A. Omede C. E. (2026) Charcoal Production Workers, Health Impact and Ambient Air Quality around Kiln Site in Uzuakoli Abia State, Nigeria. J. Mater. Environ. Sci., 17(7), 1139-1159*

Abstract: The study investigates the environmental and health impacts of conventional charcoal-making in Uzuakoli, Abia State, Nigeria. Over a duration of three months, a handheld Aeroqual monitor (Series 500) with interchangeable and removable gas sensor heads was used to conduct real-time monitoring of air quality for PM2.5, PM10, CO_2, CO, VOCs, and HCHO emissions. The PM sensors detected concurrent measurements of PM2.5 and PM10. Twelve respondents at the kiln site were given a well-structured questionnaire. The data collected were analysed using both descriptive and inferential statistics, specifically utilising SPSS Version 20.0. The results indicate that mean concentrations of $PM_{2.5}$, PM_{10}, CO_2, CO, VOCs, and HCHO exceeded both World Health Organization (WHO) and National Ambient Air Quality Standard (NAAQs). Strong positive associations were found between $PM_{2.5}$ and PM10 (r = 1.00**), PM2.5 and CO (r = 0.888**), PM10 and CO (r = 0.888**), and VOCs and HCHO (r=0.994**). Temperature and relative humidity were identified as key climatic drivers of these pollutants' levels. The socio-demographic profiles revealed that persons between the ages of 31 and 40 were most vulnerable to exposure. Despite earning between #20,000 and #30,000 weekly, workers faced significant health issues, including dizziness, catarrh and sputum production. Although 83.3% of the participants reported having substantial information about air pollution, with 50.0% expressing awareness from various media channels such as radio, television jingles, advertising, and educational programmes All respondents (100.0%) recommended implementing various measures to combat air pollution from charcoal production, including reducing forest fires, smoking, open burning, dispersion, and using substitute materials or processes. Other suggested measures include local ventilation, isolation, compliance with workplace p rocedures, and maintaining environmental hygiene. Workers involved in charcoal manufacture are exposed to significant emissions, which might potentially lead to health hazards. Workers should implement suitable measures to control hazards and utilize advanced equipment that emits minimal emissions. Implementing pollution mitigation tactics and conducting public awareness programs would be effective methods to decrease the release of harmful air pollutants in the vicinity of charcoal kiln sites.

1. Introduction

Charcoal has been widely utilized for industrial and home applications on a global scale. Charcoal production presents environmental hazards as a result of its ineffective carbonization methods (Njenga *et al.*, 2013). Although charcoal has negative environmental impacts, its acquisition and use are deeply rooted in daily life from both an economic and cultural perspective. Charcoal has several advantages as a fuel as compared to biomass. These include a better heating value and easier storage, as stated by Antal and Gronli in 2003. Charcoal kilns are usually created in kilns where wood is subjected to pyrolysis at high temperatures without the presence of air (Tippayawong *et al*., 2010). These kilns can have different shapes and sizes, ranging from earth mounds to brick or massive metal constructions (Pennise *et al.*, 2001). Charcoal manufacturing in Africa relies heavily on the usage of earth mounds and brick kilns (Sparrevik *et al.*, 2015). According to Alem *et al*. (2010), the manufacture of charcoal results in environmental contamination and the depletion of forest resources in the surrounding region. Charcoal kilns release substantial quantities of particulate matter, carbon monoxide, nitrogen dioxide, and sulphur dioxide (Pennise *et al*., 2001), which modify the physical and chemical properties of the atmosphere (Crutzen and Andreae, 1990) and contribute to the phenomenon of global warming (Chidumayo and Gumbo, 2013). The emissions mentioned in the previous text also have an effect on human health, as demonstrated by studies conducted by Tzanakis *et al*. (2001), Orru *et al*. (2011) and Abidin *et al*. (2014).

Monitoring charcoal manufacturing kilns in underdeveloped nations is difficult because they are in operations for long periods, often lasting many days or even weeks (Smith *et al*., 1999). Several studies have carried out on-site monitoring of gas emissions from charcoal kilns (Smith *et al.*, 1999; Pennise *et al.*, 2001; Faé Gomes and Encarnação, 2012; Sparrevik *et al*., 2015). Biomass, which includes charcoal, is being increasingly recognised as a feasible fuel source (Mwampamba and Dutt, 2013). In Africa, both rural and urban communities depend on charcoal because of its high energy value and lighter weight compared to other biomass fuels (Sugumaran and Seshadri, 2009). Charcoal production involves workers being directly exposed to wood smoke, which is a complicated combination of gaseous, solid, and liquid particles produced from kilns (Bruns *et al*., 2015). Wood smoke comprises volatile organic compounds, carbon oxides, sulphur oxides, nitrogen oxides, and ammonia (Bruns *et al*., 2015). These substances can irritate the respiratory tract, worsen chronic bronchitis and asthma, and contribute to respiratory disorders (Naeher *et al*., 2007). The presence of fine particles in the smoke presents a hazard to individuals who are not directly involved in the production process. Air pollution is responsible for about 6% of all deaths worldwide, according to Cohen *et al*. (2005). In Africa alone, there are more than 170,000 deaths each year due to air pollution, as reported by WHO (2014). Air pollution-related diseases in Nigeria result in a minimum of 1 in 10,000 deaths each year. The majority of research conducted on charcoal production in Nigeria, specifically 90%, largely examines the economic advantages, the reduction of poverty among rural charcoal producers, and the impact of different wood species on charcoal characteristics (Ogunsanwo *et al.*, 2007; Tunde *et al.*, 2013; Po *et al*., 2011). The fundamental procedure of charcoal manufacture entails the carbonization of wood, which results in the emission of smoke from kilns. Charcoal workers are consistently exposed to this smoke (Souza *et al.*, 2005). The smoke is composed of pollutants including particulate matter, polycyclic aromatic hydrocarbons (PAHs), carbon monoxide (CO), nitrogen oxides (NOx), sulphur oxides (SOx), and volatile organic compounds (VOCs). These pollutants have the potential to cause health problems such as cancer, heart and lung diseases, and impaired oxygen transport due to exposure to carbon monoxide (CO) (Anon 2011). A study conducted in Greece by Tzanakis *et al*. (2001) found that charcoal workers had a considerably higher occurrence of coughing, bringing up phlegm, wheezing, and difficulty breathing compared to persons who were not exposed to smoke. "In addition to its impact on the environment, the manufacture of charcoal presents substantial health risks to humans (UNDP, 2005). Some of the problems typically reported by charcoal makers include backache, fever, and cough. The repetitive motion involved in the manufacturing of charcoal, namely the handling of heavy wood, can result in discomfort and stiffness in the lower back and muscles (Tzanakis *et al*., 2001). Regrettably, several individuals involved in charcoal production meet with fatal outcomes as a result of accidents that occur during tree felling, kiln preparation, and the loading of charcoal onto lorries. In addition, producers are exposed to gases and smoke, and the heat produced during charcoal manufacture adds to several health issues, including respiratory disorders, coughing, painful hands, weariness, and chest pain. Additional symptoms include the creation of phlegm, difficulty breathing, and coughing up blood. Charcoal combustion presents fewer health hazards compared to wood, making it a more desirable fuel for household purposes due to its lower smoke emissions (Woolley *et al*., 2021).

Charcoal smoke is an intricate combination of liquid, solid, and gaseous elements that can interfere with cellular operations and result in several health issues, such as delayed reflexes and coagulation disorders (Kumi *et al*., 2012; Dost, 1991). Other health consequences encompass prenatal disorders (such as infants being born with low birth weight or stillbirths), ocular ailments (such as cataracts), and related illnesses (Kumi *et al*., 2012). Indoor exposure to charcoal emissions presents significant health hazards, particularly for susceptible populations including children, pregnant women, lactating mothers, elderly individuals, individuals with respiratory and cardiovascular conditions such as COPD and asthma, and those with limited healthcare access (Public Health England, 2018). Charcoal manufacture requires deliberate cutting down trees for commercial purposes, resulting in the loss of forested areas (Eniola, 2014).
Charcoal companies are compelled the gather wood for charcoal production due to promptly acquisition of woodlands by illegal means (Emeodilichi, 2018). This approach leads to the exhaustion of significant wood fuel species such as mahogany and shea trees, which were once plentiful (Pabi and Morgan, 2002). Ogundele *et al*. (2011) and Oguntunde *et al*. (2008) conducted studies that revealed a slight increase in soil pH in charcoal production sites. This increase in pH leads to a reduction in soil bulk density and an increase in surface temperature, infiltration rates, and surface albedo when compared to areas where charcoal production does not take place (Chidumayo and Gumbo, 2012). The little knowledge about the ecological consequences of charcoal manufacturing presents a significant problem. A significant number of individuals lack awareness regarding the detrimental consequences of charcoal manufacture on their immediate environment. Poverty and education levels are key factors that affect knowledge of environmental issues. Moreover, the inadequate execution and enforcement of forestry policies by consecutive administrations impede endeavors to safeguard the environment. Despite Nigeria's laudable policy on forestry and related problems, their successful execution is often hindered by changes in government and a lack of concentration. At times, the absence of evaluation units hinders the strict implementation of measures. Charcoal production has a highly harmful effect on the ecology and climate, resulting in serious repercussions for human health and pollution. Hence, the objective of this study is to evaluate the air quality and its health consequences on individuals employed in charcoal manufacturing at kiln sites in Uzuakoli, Abia State. The study aims to achieve the following objectives: (i) measure the concentration of specific gases and particulate matter, (ii) assess the socioeconomic effects of charcoal production on households in the study area, (iii) quantify the pollutants released during charcoal production and evaluate their environmental consequences, and (iv) investigate the awareness of residents and workers regarding sources, levels, impacts, and mitigation strategies related to air pollution. By addressing these objectives, we may get valuable insights into how to reduce environmental issues caused by charcoal manufacturing. This will help promote sustainable environmental management and minimize the health risks connected with it.

2. Materials and Methods

2.1 Study Area

The research was carried out in Uzuakoli, which is located in the Bende Local Government Area of Abia State, Nigeria. Uzuakoli is situated in the northern part of Abia State. Uzuakoli is situated in the coordinates of 5°37'15"N latitude and 7°37'23"E longitude. The Local Government Area of Uzuakoli has a population of 52,300, according to the National Bureau of Statistics in 2016. Uzuakoli is bordered to the north by Cross River State, Afikpo, and Ohazara LGAs of Ebonyi State; to the west by Isukwuato; to the east by Ohafia and Arochukwu LGAs; to the southwest by Umuahia North and South LGAs; and the south-south by Ikwuano LGA (Offor *et al*., 2020). The research area is located in the subequatorial region of Nigeria, which is known for its high temperatures, averaging 24°C during the day. The area experiences bimodal high conventional rainfall, ranging from 2200-2400mm, together with high humidity and substantial cloud cover (Onyekwelu *et al*., 2024). The area is located in the tropical forest high-forest vegetation zone and is characterized by the presence of many tree species like bamboo (Bomusceae family), mango (Mangifera indica), tamarind (Tamarindus indica), neem (Azadirachta indica), cashew (Anacardium occidentale), and oil palm (Elaeis guineensis), among others (Onyekwelu *et al*., 2024). The primary watercourses in the study region consist of the Avu, IyiAkwa, Ogboko, Igwu, and Aha rivers and streams (Onyekwelu *et al.*, 2024). These rivers and streams are vital sources of water for domestic, agricultural, and recreational uses. The Bende-Ameki group is a geological formation situated in Bende, consisting mainly of shale, sandstone, and siltstone (Onyemaechi1 and Nwachukwu, 2018). The area's topography has distinct physiographic changes in landforms, such as low plains, ridges, residual, and conical hills (Onyekwelu *et al.*, 2024). Uzuakoli has a lengthy historical background that traces back to the period of the slave trade, during which its market, Agbo Agwu, played a crucial role as a hub for the exchange of slaves (Onyemaechi1 and Nwachukwu, 2018). The local government region primarily relies upon on agriculture as the main occupation of its people. This includes the cultivation of food crops like rice, maize, cassava, plantain, and banana, as well as the husbandry of small ruminant animals (Offor *et al.*, 2020). In addition, certain individuals partake in the creation of crafts, carpentry, commerce, and various other activities. The Local Government Area (LGA) consists of eleven communities: Ozuitem, Ugwueke, Okporoenyi, Itumbuzo, Umuju-ezechi, Umu-menyi, Igbere, Item, Alaye, Nkpa, and Uzuakoli, as reported by Offor *et al.* (2020).

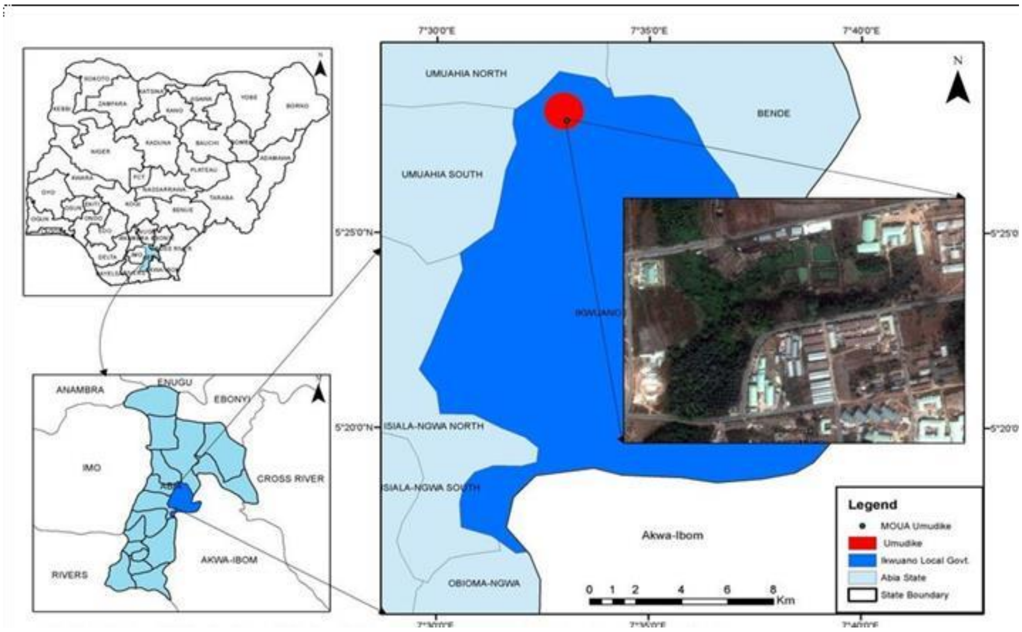

Figure 1: Map of the study area

Methodology

2.2 Experimental sampling techniques and pollutant measurement

Three sampling sites (SPP1–SPP3) were selected within the kilns area to analyse emissions from the charcoal manufacturing kilns. The air pollutant parameters, including particulate matter (PM10), carbon monoxide (CO), carbon dioxide (CO2), particulate matter (PM2.5), volatile organic compounds (VOC), and formaldehyde (HCHO), were evaluated on a weekly basis for three months at each sample station during the dry season of 2023. The sample locations' geographical coordinates, specifically their latitude and longitude, were determined using a Garmin GPS device of the GPSMAP 76CSX model. The windward direction at the sample locations was assessed using a handheld portable gas analyzer (multi-RAE PGM-6208) to determine CO_2, CO, HCHO, and VOC levels. A PDR.1000AN Air Metric Sampler kit was utilised on-site to measure $PM_{2.5}$ and PM_{10} data. The measurements were obtained using a digital metre, at a distance of 2 metres from ground level, which is the area where humans are most likely to be exposed. The data were collected as a time-weighted average. This technique was replicated to ensure precision and dependability, and the monitoring measurements were obtained three times. As per the manufacturer's advice, the equipment underwent calibration both before and after processing each batch of samples. The measuring procedures employed in this work to monitor the reported criterion pollutants adhered to the methodologies suggested by Odekanle *et al.* (2017) and Payus *et al.* (2020). The instruments utilised in the tests feature a cutting-edge selection of interchangeable field-replaceable sensors, including electrochemical, combustible, infrared, photoionization detector (PID), and gamma radiation sensors. These sensors are designed to cater to a diverse range of applications and are considered top-of-the-line in the industry. The instruments are electronic devices that measure the average value of a quantity over a specific period. The main source of uncertainty in the devices is their lack of calibration before usage, which may lead to imprecise data measurements. In addition, failing to zero, erase, or reset the current data after use can have an impact on the measurements during the next sample period. The multi-RAE PGM-6208, a portable gas analyzer, was calibrated using the 'Two-point field calibration for zero and standard reference gases' method, specifically employing span gas. The detection limits for VOC range from 100 to 2,000,000 mg/m³, for CO_2 range from 0 to 2,000 mg/m³, for HCHO range from 0 to 10 mg/m³, for CO range from 0 to 500 mg/m³, and for VOC range from 0 to 1,000 mg/m³. The Air Metric Sampler (PDR.1000AN) was calibrated for measuring $PM_{2.5}$ using two reference filter collectors and two master real-time monitors (Thermo Electron Data RAM 4). The detection limit for this calibration was set at 0.01–10 µg/m³.

2.3 Air pollutant data and quality assurance

In situ ambient air and meteorological sampling were conducted utilizing a range of calibrated hand-held devices. Air pollution parameter monitoring was carried out in one-hour triplicate intervals, adhering to the limits USEPA (2019) and FMEnv (1999) established. A variety of instruments were used to obtain hourly measurements of air pollutant concentrations, following the manufacturer's guidelines for calibration of both gases and particulates. The data were generated using the equipment's established standards and methodologies. Before doing the study, the raw data was screened to verify the accuracy of the air pollutant data collected. Any data points that had missing values or extreme outliers were excluded. The monthly means were calculated using the average data from each week, and a total of four weeks of valid data were used. The link and influence of these pollution factors were calculated using validated data from the sample year. The absence of data revealed uniform patterns among the chosen sample locations. The concentrations of air pollutants at the sampling sites were determined based on the levels at the kiln site. This study incorporated several baseline requirements, such as the 1-hour and 24-hour mean concentrations given by NAAQS (2012) and WHO (2006). Hence, the data for this study were obtained from two primary endeavors: the assessment of pollution levels at the Kiln Site and the distribution of questionnaires to participants.

2.4 Questionnaire Administration

A survey was conducted to collect socio-demographic information from the participants, as well as information on the sources and impacts of air pollution, length of exposure, experiences of respiratory and other health consequences caused by air pollution, strategies for adaptation and control, and proposed remedies. In addition, the charcoal workers in the kiln study region were requested to fill out a questionnaire concerning potential health risks associated with charcoal manufacture. The survey included inquiries regarding occupational complaints, classifying symptoms as work-related if they were reported during working hours. Workers were surveyed regarding instances of physical injuries, illnesses, vertigo, burns, eye irritation, respiratory issues such as coughing and wheezing, sinusitis, and lung disorders. The duration of daily exposure to wood smoke in the kilns was also documented. The survey also had inquiries regarding age, gender, duration of time spent in the workplace, and smoking behavior. Workers were given the option to participate in the study voluntarily, and their agreement was obtained after providing them with relevant information.

2.5 Sample size and sampling technique

The sample size was estimated based on the single proportion formula:

$$N = Z^2 \; Pq / d^2 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 1$$

The population percentage is denoted by (p), while (q) is equal to (1 - p). The tolerated error is represented by (d), while the reliability coefficient at a 95% confidence interval is denoted by (Z). The necessary sample size is denoted by (N) (Barman *et al*., 2015). As far as we know, there is either no existing literature or very limited information available on abattoir waste management practices, attitudes, and knowledge. The necessary sample size for the inquiry was determined by employing the population proportion (P = 0.5) (Kumsa, 2019). A preliminary investigation was carried out to calculate the value of (p), and its findings were used to establish the size of the sample. Utilizing standard values in this method to determine sample size may result in a more precise estimation of (p). When an accurate estimation of (p) is unavailable, this method is commonly used (Wesson, 2006). The pilot study, which was incorporated into the main survey, was carried out at three kiln locations and included a total of 12 workers (4 from each site).

Correctional formular:

$$Nf = \frac{ni}{1+ni/N} \text{ and } 5\% \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. 2$$

Once the participants for the non-response rate were chosen, a total sample size of 12 respondents was established. The value of the variable (p) utilized in this analysis was ascertained based on the cumulative practice score obtained from the pilot study. Every employee at the designated kiln location was given a pretested questionnaire, leading to a sample size of twelve. Several surveys were removed from the study due to either respondents' refusal to participate or missing data. One of the three kiln locations used in the main study was also used for the pilot project, whereas the other was selected through simple random sampling.

2.6 Statistical Analysis

The data collected throughout the study was inputted into an Excel spreadsheet and subsequently exported to SPSS (Version 20.0) for analysis. The data were analyzed using both descriptive statistics and Analysis of Variance (ANOVA).

3. Results and Discussion

3.1 Temporal mean concentrations of air quality and meteorological parameters in the kiln site

The average concentration of formaldehyde (HCHO) varied from 0.004 to 1.999 mg/m³, with a notable distinction ($F = 85.638$, $p = 0.001$), suggesting that the measurements taken at SPP 2 and SPP 3 surpassed the 24-hour permitted limit set by the World Health Organization (WHO) of 0.122 mg/m³ (Table 1). The VOC mean values ranged from 0.012 to 9.999 mg/m³, indicating a considerable difference ($F = 191.450$, $p = 0.001$) among the kiln locations. The mean levels of CO, ranged from 787 to 1280 mg/m³, and there was no statistically significant difference ($F = 0.963$, $p = 0.492$) seen across the research region. These readings surpassed the World Health Organization's 24-hour allowable limit of 0.141 mg/m³. The average concentration of carbon monoxide (CO) varied between 2.10 and 6.17 mg/m³, and there was no notable change ($F = 0.086$, $p = 0.53$) found in the study region. The measured values fell within the limits set by the National Ambient Air Quality Standards (NAAQS) for 8 hours (11.1 mg/m³) and the World Health Organization (WHO) for 24 hours (30.8 mg/m³). The results demonstrate that optimal burning of wood necessitates sufficient oxygen availability, resulting in the formation of carbon dioxide and water without any observable smoke. Conversely, incomplete combustion results in the generation of smoke. The findings suggest that charcoal manufacture entails long periods of wood burning that is not fully complete, leading to the emission of harmful smoke gases (Tzanakis *et al*., 2001). The results align with previous research that has documented the health hazards linked to charcoal manufacture (Hamatul *et al*., 2016; Woolley *et al*., 2020). The primary health consequences linked to carbon monoxide (CO) exposure during charcoal manufacturing arise from its high affinity for the haemoglobin molecule, resulting in the formation of carboxyhemoglobin (COHb) (WHO, 2019). Carboxyhemoglobin (COHb) reduces the ability of blood to transport oxygen, which has a negative impact on organs that require a significant amount of oxygen, such as the heart and brain. Carbon monoxide can attach to cytochrome oxidase, which can potentially decrease the utilization of oxygen by cells (WHO, 2019).

The average $PM_{2.5}$ values varied between 16.5 and 75.8 µg/m³, and there were noticeable variations ($F = 1.783$, $p = 0.289$) among the kiln sites. The average levels measured at SPP 2 and SPP 3 were higher than the National Ambient Air Quality Standards (NAAQS) 8-hour limit of 35 µg/m³ and the World Health Organization (WHO) 24-hour limit of 25 µg/m³. The PM_{10} mean values exhibited substantial variance ($F = 1.784$, $p = 0.280$) among the research sites, ranging from 169 to 848 µg/m³. These results surpassed the 24-hour limitations set by the World Health Organization (50 µg/m³). This finding suggests that apart from the primary byproducts of combustion (carbon dioxide and water), wood smoke contains more than 200 other organic chemicals (Naeher *et al*., 2007), many of which have been proven to have immediate or long-term health impacts on those who are exposed to them. The findings indicate that wood smoke is an intricate combination of gases, liquids, and solid particles (aerosols) that are created when wood and other wood products like charcoal, wood pellets, and sawdust are incompletely burned or undergo pyrolysis at high temperatures and low amounts of oxygen (Tolede, 2008). The average temperature values varied between 30.2 and 33.3°C, and there was no noticeable difference ($F = 0.055$, $p = 0.981$) in temperature among the kiln locations. These values fell within the permitted limits set by the World Health Organization. The mean values of relative humidity ranged from 94.2% to 96.5%, with noticeable variation ($F = 3.570$, $p = 0.125$) among the study sites. The measured readings surpassed the 24-hour (70%) acceptable limits set by the World Health Organization (WHO). The results suggest that wood smoke contains harmful substances such as carbon monoxide, nitrogen oxides, formaldehyde, and polycyclic aromatic hydrocarbons (PAHs), including cancer-causing agents like benzo(a)pyrene (Naeher *et al*., 2007; Bruce *et al*., 2000). The findings align with research that indicates a growing need for and reliance on wood fuels, particularly among impoverished populations, in numerous developing nations. This trend is driven by the limited availability of fossil fuels and a rising focus on sustainable energy generation (Nielsen *et al*., 2008; Sepp, 2014).

Table 1: Mean Concentration of Air Quality and Meteorological parameters in Kiln site.

Location	HCHO mg/m³	VOC mg/m³	CO_2 mg/m³	CO mg/m³	$PM_{2.5}$ µg/m³	PM_{10} µg/m³	Temp (°C)	RH (%)
SPP 1	0.004	0.012	787	3.70	16.5	169	30.2	94.3
SPP 2	1.672	0.551	1.040	6.17	27.1	303	33.2	94.2
SPP 3	1.999	9.999	1.280	2.10	75.8	848	33.3	96.5
NAAQS (2024) (8hrs)	0.08	-	--	11.1	35	--	--	--
WHO (2018) (24hrs)	0.122	--	0.141	30.8	25	50	35	70
ANOVA; P-value	85.638,0.001	191.45,0.001	0.963,0.492	0.086, 0.053	1.783, 0.289	1.784,0.280	0.055, 0.981	3.570,0.125

3.2 Relationship between air pollutants and meteorological parameters

The results in Table 2 show a significant positive association between $PM_{2.5}$ and PM_{10} ($r = 1.000^{**}$), PM2.5 and CO ($r = 0.888^{**}$), PM2.5 and VOC ($r = 0.708^{*}$), and PM2.5 and HCHO ($r = 0.767^{*}$). Consequently, a rise in one variable will result in a corresponding increase in the other variables. Similarly, there is a significant and positive connection between PM_{10} and CO ($r = 0.888^{**}$), VOC ($r = 0.708^{*}$), and HCHO ($r = 0.767^{*}$). Furthermore, there exists a strong positive correlation between carbon monoxide (CO) and carbon dioxide (CO2) with a correlation coefficient (r) of 0.721*. Similarly, there is a highly significant positive correlation between volatile organic compounds (VOC) and formaldehyde (HCHO) with a correlation coefficient (r) of 0.994**. This suggests that a rise in levels of CO, CO_2, VOC, or HCHO will result in a corresponding increase in the levels of the linked parameters. The study findings indicate that the combustion of charcoal produces a significant amount of air pollutants, including particulate matter (PM), carbon monoxide (CO), nitrogen oxides (NOx), sulfur oxides (SOx), formaldehyde, benzene, 1,3-butadiene, polycyclic aromatic hydrocarbons (PAHs), and carcinogens such as benzo[a]pyrene. These toxic organic compounds have the potential to harm human health (Mishra and Retherford, 2017). Exposure to these air pollutants has been associated with pneumonia, decreased birth weight, acute respiratory infections (ARI), and premature death in children, while adults suffer from chronic obstructive pulmonary disease (COPD) and chronic bronchitis (Bruce *et al*., 2010; Po *et al*., 2011; Mishra and Retherford, 2017; Fullerton *et al*., 2019).

Table 2: Correlation between the explanatory parameters and air pollutants

Parameters	$PM_{2.5}$ (µg/m^3)	PM_{10} (µg/m^3)	CO (mg/m^3)	CO_2 (mg/m^3)	VOC (mg/m^3)	HCHO (mg/m^3)	Temp (°C)	RH (%)
$PM_{2.5}$(µg/m^3)	1							
PM_{10}(µg/m^3)	1.000**	1						
CO(mg/m^3)	0.888**	0.888**	1					
CO_2(mg/m^3)	0.629	0.629	0.721*	1				
VOC(mg/m^3)	0.708*	0.708*	0.624	0.218	1			
HCHO(mg/m^3)	0.767*	0.767*	0.687	0.259	0.994**	1		
Temp (°C)	0.223	0.222	0.612	0.504	-0.010	0.052	1	
RH (%)	0.490	0.489	0.389	0.619	0.517	0.494	-0.004	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

3.3 Influence of meteorological parameters on air pollutants

The data presented in Table 3 indicates that there is a moderate correlation between relative humidity and the levels of CO_2 (r2 = 64.0%), CO (r2 = 52.8%), VOC (r2 = 26.7%), PM_{10} (r2 = 29.0%), $PM_{2.5}$ (r2 = 29.0%), and HCHO (r2 = 24.7%). Similarly, there was a moderate to weak correlation reported between temperature and CO2 (r^2 = 64.0%), CO (r^2 = 52.8%), VOC (r^2 = 26.7%), PM_{10} (r^2 = 29.0%), $PM_{2.5}$ (r^2 = 29.0%), and HCHO (r2 = 24.7%). The correlation between relative humidity, temperature, and CO2 was determined to be moderate, with a coefficient of determination (r^2) of 64.0%. Statistically significant and non-significant correlations were found between the meteorological and air pollution indicators. The study's findings suggest that the incomplete combustion of charcoal results in the release of organic molecules and other chemicals that are harmful to human health. Contaminants present in biomass fuels can result in the creation of inorganic substances such sulphur dioxide, nitric oxide, and ammonia (Smith, 2016). Therefore, it has been demonstrated that elevated levels of air pollutants resulting from human activities, such as the manufacturing and storage of charcoal, can have detrimental impacts on human health (Allen *et al*., 2019). The health consequences encompass lung cancer, asthma, nasopharyngeal and laryngeal cancer, tuberculosis, neonatal illnesses, as well as ocular ailments like cataracts and blindness (Bruce *et al*., 2010).

Table 3: Linear regression analysis meteorological parameter and air pollutant

Parameters	Regression Model	r^2 (%)	St. Error of the Estimate	Sig. Level
CO_2	Y_{CO2} = -249.8+37.054X_{Temp}+2.456X_{RH}	64.0	137.9	0.078
CO	Y_{CO} = -502.396+16.840X_{Temp}+0.581X_{RH}	52.8	59.27606	0.153
VOC	Y_{VOC} = 0.335+ -0.014X_{Temp} + 0.047X_{RH}	26.7	4.53766	0.460
PM_{10}	Y_{PM10} = -726816.7+24337.9X_{Temp}+2870.6X_{RH}	29.0	286846.01	0.425
$PM_{2.5}$	$Y_{PM2.5}$ = -650490.0+21785.0X_{Temp}+2566.7X_{RH}	29.0	256263.5	0.424
HCHO	Y_{HCH0} = -0.522+0.017X_{Temp}+0.008X_{RH}	24.7	0.85404	0.491

3.4 Socioeconomic profile of the charcoal production workers

Table 4 displays the socio-demographic characteristics of the respondents, indicating that 23.1% of them were between 31-35, 36-40, and 40-45 years. In addition, 15.4% of the individuals fell into the age range of 26-30 years, whilst 7.7% were in the age range of 21-25 years. The results of this study indicate that various age groups of kiln site workers exhibit distinct levels of well-being, save for a few cases where they did not associate the physical environment, they resided in with their own health. This outcome indicates that they are currently in the stage of their lives where they are most productive. This is consistent with the results of Oladimeji *et al*. (2018), who found that labour productivity is influenced by age. This finding aligns with the study conducted by Adeniji *et al.* (2015), which found that 59% of participants fell within the age range of 20-39 years. This age group is typically considered the most active in terms of energy-demanding activities, unlike the practices observed in other regions, particularly Asia, as reported by Bhattarai *et al*. (1998). In Asia, individuals aged 50-60 years are involved in charcoal production. The findings align with the study conducted by the Stockholm Environment Institute (SEI) in 2002, which revealed that adults between the ages of 35 and 45 are the primary contributors to charcoal production.

Table 4: **Demographic profile of the respondents**

Variables	Frequency (Freq)	Percentage (%)
Age		
21 – 25		17.7
26 –30		215.4
31 – 35		323.1
36 – 40		323.1
41 – 45		323.1
Gender		
Male		1292.3
Female		17.7
Marital Status		
Single		430.8
Married		861.5
Religion		
Christianity		1292.3
Traditional Worshipper		17.7
Muslim		--
Educational Qualification		
No Formal Education		17.7
Primary Education		538.5
Secondary Education		753.8
Tertiary Education		--
Working Experience		
1 – 5yrs		--
6 – 10yrs		17.7
11 – 15yrs		538.5
16 – 20yrs		538.5
Above 20		215.4
Estimate of charcoal quantity per day		
1 – 3bags		
4 – 6bags		17.7
7 – 9bags		538.5
Above 9		753.8
Estimate of charcoal quantity per week		
Less than 10 bags		17.7
10 – 20bags		17.7
21 – 30bags		1184.6
Amount earn per week in charcoal production		
Less than ₦20,000		323.1
₦20,000 – ₦30,000		430.8
₦31,000 – ₦40,000		430.8
₦41,000 – ₦50,000		17.7
Above ₦50,000		--

In the research area, the male respondents constituted 92.3% of the total, while the female respondents accounted for 7.7%. Therefore, the results indicate that female participants have a higher level of exposure to noise pollution. The respondents' findings provide valuable insights into male perspectives on air pollution and the health hazards linked to charcoal manufacturing. It is worth noting that the proportion of female respondents is quite low compared to their male counterparts. This discovery is consistent with the findings of SEI (2002), which showed that there is a greater level of male participation in the manufacturing of charcoal. The CHAPOSA (2002) survey in South Africa revealed that 70.0% of charcoal producers were male. The findings align with the study conducted by Adeniji *et al.* (2015), which revealed that 91% of charcoal producers in their research region were males. This can be attributed to the physically strenuous nature of commercial charcoal production, as highlighted by Goanue (2009). The study site's participants had a marital status distribution of 30.8% singles and 61.5% married individuals. The results suggest that a significant number of married individuals reported experiencing various health hazards related to charcoal production, while singles were found to be the primary contributors to charcoal production. This statement is in opposition to the findings of Ogara (2011), who observed a greater proportion of married individuals engaged in the manufacturing of charcoal. Adeniji *et al*. (2015) also discovered that 73% of charcoal producers in Niger State, Nigeria, were married, whereas 24% were unmarried. Christian religious worshippers were 92.3% of the total, and traditional worshippers constituted 7.7%. The findings indicate that religious membership has little impact on the type of employment individuals pursue, as long as it fulfils their requirements and promotes their welfare.

Therefore, there is no statistically significant impact of socio-economic determinants on charcoal production. Table 4 indicates that 7.7% of individuals had no formal education, 38.5% had elementary education, and 53.8% had secondary education in the study site. The findings suggest that even though charcoal workers with limited primary and secondary education possess a fundamental comprehension of air pollution and its health consequences, they continue to pursue this occupation due to their own sense of fulfilment. This finding aligns with the research conducted by Ogara (2011), which indicated that the majority of individuals engaged in charcoal manufacture lack formal education, namely those who had dropped out of junior classes. According to the respondents ' job experience, 7.7% had worked for 6-10 years, while 38.5% had worked for 11-15 years and 16-20 years correspondingly at the study location. In addition, 15.4% of the participants had been employed at the kiln production site for 20 years or more.

According to the interviewees, these findings indicate that charcoal manufacture is their main means of making a living, as they find it difficult to secure high-paying employment. The extensive experience of the charcoal producers demonstrates that commercial charcoal manufacture is a lucrative and flourishing industry, acting as a significant source of income. According to the respondents, the estimate of charcoal production per day is as follows: 7.7% generate 4-6 bags, 38.5% produce 7-9 bags, and 53.8% produce more than 9 bags per day. This indicates a strong need for charcoal for multiple uses, emphasizing its important function as a source of energy. The extraction of fuel wood in emerging nations is in direct competition with other energy sources for household use. The demand for fuel wood is increasing in tandem with population expansion, with an annual demand growth rate ranging from three to four percent, varying by country (Luwaya, 2015). The utilization of wood fuel for household cooking by low- income households worsen deforestation in developing nations, where fulfilling the energy needs of the expanding population is a constant struggle (Luwaya, 2015). The survey results indicate that 7.7% of respondents create a minimum of 10 bags and up to 20 bags of charcoal every week, while the majority (84.6%) produce between 21 and 30 bags per week. This discovery highlights the significant demand for charcoal as a feasible substitute for energy. Nigeria is classified as one of the world's largest producers and consumers of charcoal, according to Rotowa *et al*. (2019). Research suggests that the limited accessibility and affordability of alternative fuels in Nigeria has led numerous households to resort to using charcoal for cooking purposes (Nwofe, 2013). The survey results show that 23.1% of respondents make at least ₦20,000 per week from charcoal manufacturing. Additionally, 30.8% earn between ₦20,000 and ₦30,000 per week, and 7.7% earn between ₦31,000 and ₦40,000 per week. This illustrates that charcoal manufacture is a profitable enterprise, despite the harmful effects it has on human health, as indicated in Table 4. The results indicate that the increasing need for charcoal in urban areas creates chances for generating revenue from charcoal production, especially in regions where it is extensively traded and sold in urban marketplaces (Arnold *et al*., 2006; Kambewa *et al*., 2007; Luoga *et al*., 2000; SEI, 2002). The charcoal market provides urban households with a cost-effective, handy, and dependable energy source, together with related services, at consistently steady rates (Desanker and Zulu, 2001; Ellegård and Nordstrom, 2003; MARGE, 2009; Richardson, 2010).

3.5 Awareness of the sources, levels and impacts of air pollution in the study area

Figure 2 shows that 83.3% of the participants possess substantial knowledge on air pollution, whilst 16.7% do not. The findings suggest that most charcoal production workers have a fundamental understanding of the consequences of their labour, such as air pollution and the potential long-term health risks. This is consistent with previous research conducted by Friends of the Earth (2002), Makhabane (2002), Songsore (2003), Kammen *et al*. (2005), UNDP (2005), GTZHERA (2009), Ottu-Danquah (2010), and Msuya *et al*. (2011). These studies have documented similar problems in African countries where charcoal production is widespread, including ecosystem degradation, deforestation, increased erosion, infertile land, low crop yields, accelerated climate change, and threatened biodiversity. Figure 3 illustrates the methods by which participants were aware of air pollution caused by charcoal production. The findings indicate that 50.0% of participants acquired knowledge about air pollution through radio and television jingles, ads, and enlightenment programmes. In contrast, 33.3% and 16.7% obtained this information through school and other sources, respectively.

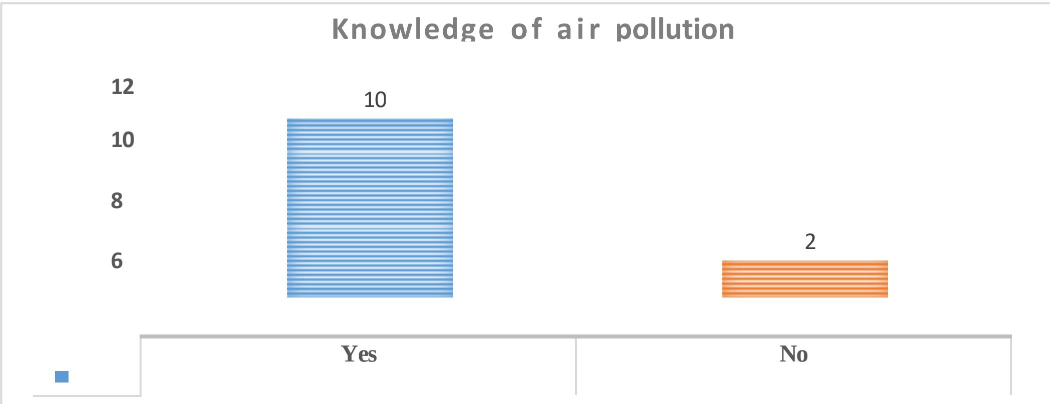

Figure 2: **Knowledge of air pollution**

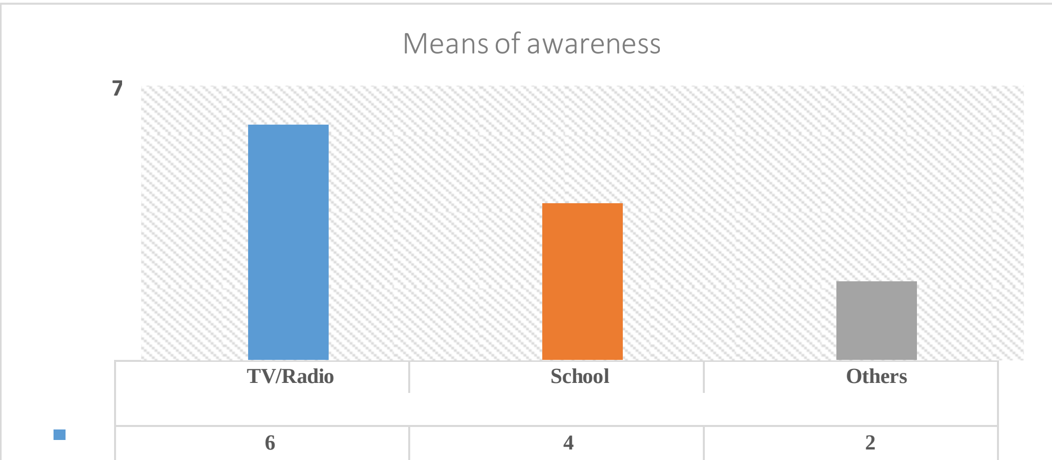

Figure 3: Means of awareness

Therefore, it can be inferred that the participants gained information regarding the effects of charcoal manufacturing on the environment through government-initiated awareness initiatives that were distributed through several media platforms. These findings indicate that in order to maintain the sustainability of community livelihoods, it is crucial to efficiently manage, distribute, and monitor their resources. The objective of this strategy is to establish a system for monitoring, managing, and actively sharing information on the availability and quality of resources. This system is intended to govern community activities and resource consumption (Islam and Walkerden, 2017). The sources of air pollution were determined in Figure 4, with 100.0% of respondents reporting encountering air pollution from smoke. The findings emphasize that the effects of air pollution resulting from charcoal manufacturing are becoming more apparent and are inflicting significant harm on both human health and the overall environment. These findings indicate that crystalline silica, which is a significant constituent of particulate matter, is categorised as a confirmed human carcinogen and is linked to systemic autoimmune disorders (IEA, 2012). The extensive dependence on charcoal production and utilisation has resulted in numerous health risks during the production process (Bailis *et al*., 2015). As a result of their participation in charcoal manufacture, many individuals experience a wide range of health issues, including acute and chronic disorders such as headaches, respiratory infections, coughing, sputum production, difficulty breathing, and coughing up blood (UNDP, 2015).

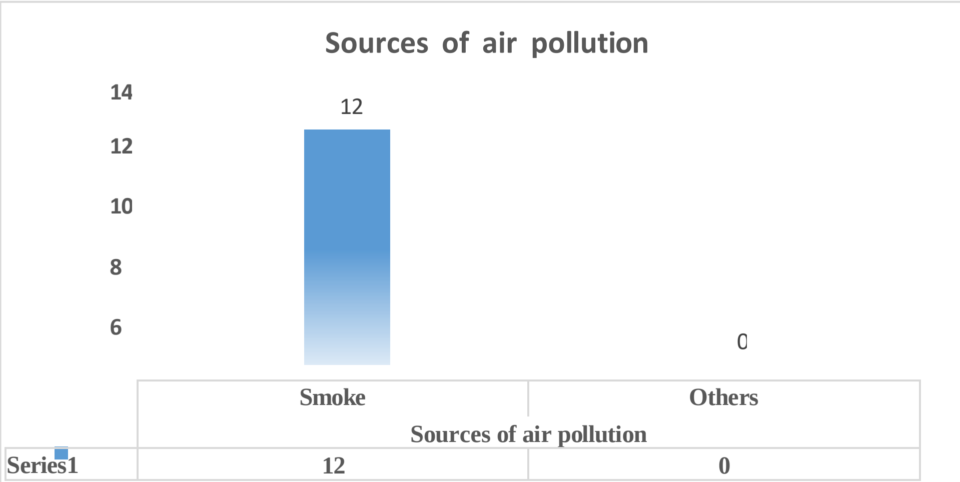

Figure 4: Sources of air pollution

Figure 5 indicates that all of the respondents reported significant levels of air pollution during charcoal manufacturing near the kiln site. This discovery demonstrates that the influence of air pollution originating from the production site has an effect on the neighbouring community. The results align with previous research that has raised concerns regarding deforestation and forest degradation linked to charcoal production in numerous countries (Hofstad *et al*., 2009; Ahrends *et al*., 2010; Pereira *et al*., 2001; Ribot, 1993). Furthermore, studies conducted by Kammen and Lew (2005), Adam (2009), Akagi *et al*. (2010), and Pennise *et al*. (2001) have demonstrated that the emissions released throughout the process of charcoal manufacturing have a substantial impact on global warming when compared to the emissions generated by burning charcoal. Figure 6 illustrates the frequency of air pollution at the kiln site, indicating that 50.0% of participants experienced air pollution during both morning and afternoon sessions.

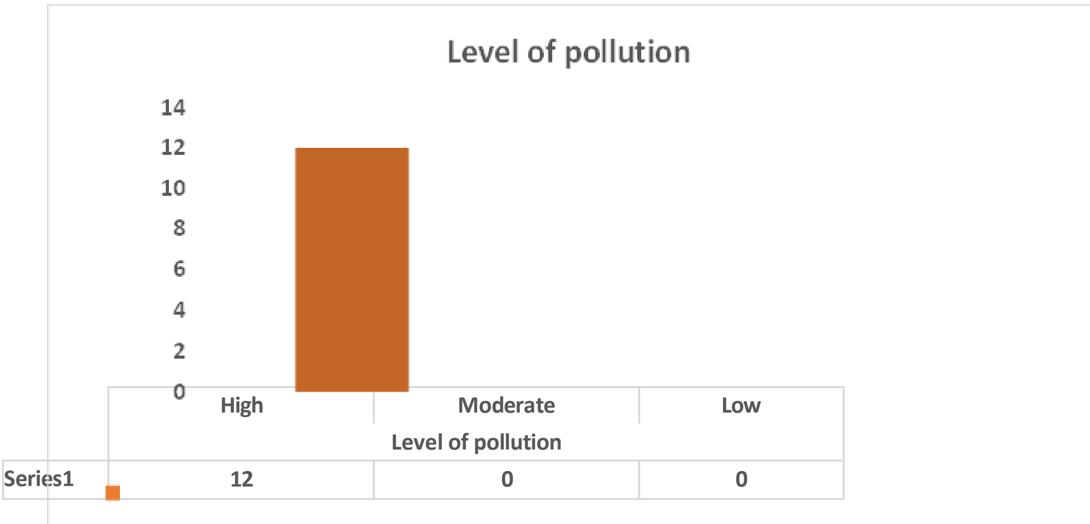

Figure 5: Level of pollution

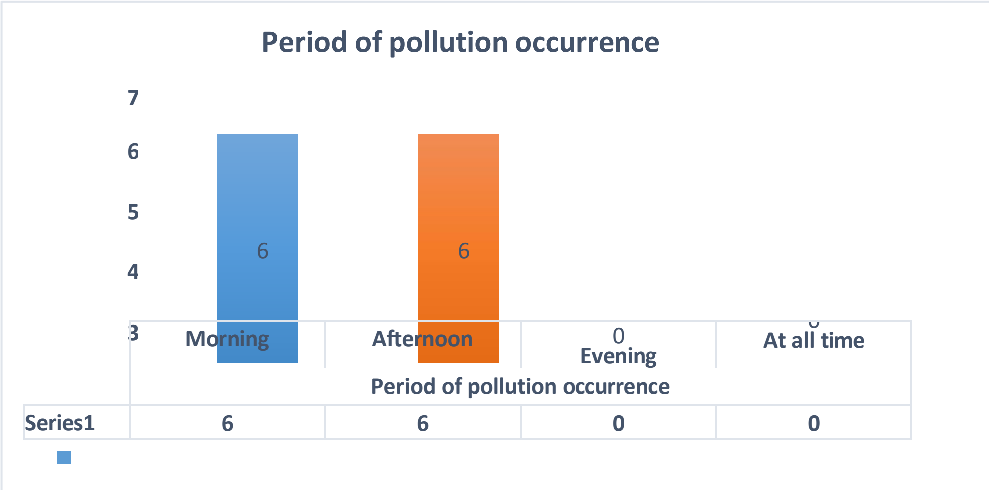

Figure 6: Period of pollution occurrence

According to Tzanakis *et al*. (2001), this suggests that the process of making charcoal begins in the morning and lasts until the afternoon. It involves burning wood for long periods of time with incomplete combustion, resulting in the generation of harmful smoke gases. Research has also shown that those involved in charcoal production frequently operate in close proximity to rudimentary kilns that generate high temperatures and release harmful substances, so exposing themselves to the danger of poisoning.

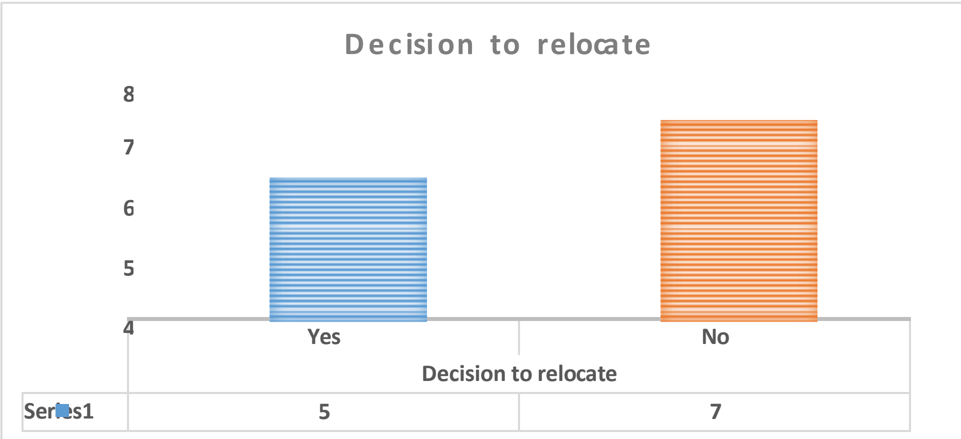

Figure 7: Decision to relocate

3.6 Perceived symptoms and health effect of charcoal production on workers

The data presented in Table 5 indicates that the chi-square test yielded significant levels below 0.05 for all the components. Additionally, the observed values for eye irritation, dry throat, headache, sneezing, skin irritation, shortness of breath, and cough were higher than the critical chi-square value of 5.991. Thus, the variables are not entirely uncorrelated. The results indicate that the obtained values are not independent, suggesting a correlation between them due to the fact that the P-values are below 0.05. These findings align with previous research that have shown that these pollutants have a detrimental impact on public health by increasing the risk of cancer, heart and lung disorders, and impairing the body's ability to transport oxygen in situations of carbon monoxide exposure (Ghosh *et al*., 2016). In addition, nitrogen and sulphur oxides induce irritation in the lungs, which results in inflammation of the airways and can lead to airway obstruction and other serious consequences (Dost, 2011). Table 6 shows that the p-value for the chi-square test of the variables was higher than the 0.05 significant level. Additionally, the observed values for dizziness, catarrh, and sputum production were greater than the crucial chi-square value of 5.991. Hence, these factors are not entirely uncorrelated. The results reveal that the obtained values are unrelated, implying no correlation between them as the P-values exceed 0.05. However, the presence of components such as nausea, chest pain, and bodily discomfort is not independent, indicating a correlation between them due to the fact that their P-values are less than 0.05. The findings of this study indicate that a significant proportion of those engaged in charcoal production encountered symptoms like ocular irritation, parched throat, cephalalgia, nasal discharge, dyspnea, and coughing. These symptoms can be ascribed to emissions resulting from charcoal manufacturing and the unfavourable working circumstances that these individuals are exposed to throughout and following the production stages. Souza *et al*. (2005) affirmed that the work environment has an impact on human health, providing evidence for this claim. Ediagbonya and Tobin (2013) conducted a study in Sapele, Nigeria to evaluate the relationship between air pollution and respiratory health. They surveyed 400 participants and found that the prevalence of respiratory symptoms was as follows: cough (10.5%), phlegm (21.3%), wheezing (13.5%), trouble in breathing (14.8%), chest discomfort (13.8%), and sore throat (10.3%). The impact of charcoal dust on lung function can be elucidated by occupational exposure to particles, whereby the ingress of dust particles into the lungs instigates inflammatory responses, resulting in pulmonary fibrosis and a decrease in FVC and FEV1 values (Longo *et al*., 2011).

Table 5: Health effects of charcoal workers using chi-square model

Response	**Eye irritation**	**Dry throat**	**Headache**	**Sneezing**	**Skin irritation**	**Shortness of breath**	**Cough**
Always	1	1	1	1	1	0	0
Frequently	4	3	2	2	1	1	1
Occas.	7	8	8	9	10	11	10
Rarely	0	0	1	0	0	0	1
X^2	4.500	6.500	11.333	9.500	13.500	8.333	13.500
Sig.	0.105	0.039	0.010	0.009	0.001	0.004	0.001

Table 6: Health effects of charcoal workers using chi-square model (Cont'd)

Response	**Dizziness**	**Nausea**	**Catarrh**	**Sputum production**	**Chest pain**	**Body pain**
Always	0	0	0	0	0	0
Frequently	1	1	2	1	3	4
Occas.	9	5	9	10	9	8
Rarely	2	6	1	1	0	0
X^2	9.500	3.500	9.500	13.500	3.000	1.333
Sig.	0.009	0.174	0.009	0.001	0.083	0.248

Decision Rule: If X^2 calculated> X^2 tab accept the alternate and reject Null hypothesis. Otherwise accept hypothesis. X^2-tab(critical) value = 5.991; df = 2

3.7 Measures in combating environmental air pollution from charcoal production

According to Figure 8, all of the respondents (100.0%) recommended various measures to combat environmental air pollution caused by charcoal production. These measures include reducing forest fires, smoking, and open burning, promoting dispersion, using safer materials or processes as substitutes, implementing local ventilation and isolation, ensuring compliance with workplace procedures, and maintaining environmental hygiene. The findings suggest that the majority of charcoal production workers are receptive to implementing control measures established by governmental or non-governmental organizations in order to reduce air pollution resulting from charcoal production.

Consequently, the hazards and adverse effects linked to the rise in charcoal production require carefully designed strategies. These policies should incorporate the implementation of tree planting and forest preservation measures, as they serve as primary sources of raw materials for charcoal manufacturing (Mugo and Ong, 2006; Olalekan *et al.*, 2019; Suleman *et al.*, 2019). Moreover, policies should specifically focus on the management and oversight of sites and areas that are specifically authorized for the production of charcoal (Raimi *et al*., 2018). It is important to safeguard areas that are already overwhelmed with the supply of wood for charcoal, and it is necessary to establish rules for any site that is recognized as a source of wood for producers (Raimi, 2019). Advanced technology has the potential to greatly decrease indoor air pollutants, leading to improved health conditions, especially for women and children who predominantly rely on charcoal and sawdust for household usage (Raimi *et al.*, 2018; Raimi, 2019; Raimi *et al*., 2020). In addition, all of the respondents (100.0%) stated that they do not utilize air purification systems such as separators or collectors, absorption or incineration methods, or waste disposal mechanisms in the study region. The findings suggest that charcoal producers in the research area have implemented the majority of the indicated steps to regulate air pollution levels, highlighting the significance of policy development in implementing effective control measures. This highlights the importance of cultivating a population that is knowledgeable about the environment, both through structured and informal environmental education, in order to increase awareness about important environmental issues (Raimi *et al*., 2019). Advanced technologies offer potential for improving charcoal production processes to eliminate or substitute hazardous methods with safer alternatives (Climate Teck Wiki, 2012). Additional potential policy alternatives include of the co-management of charcoal production derived from public or protected forests (Zulu, 2010) and the utilization of hybrid institutional frameworks that integrate community and household-level charcoal production from plantations.

4. Conclusion

The study evaluated the air quality and its health consequences on workers involved in charcoal manufacture at a kiln site in Uzuakoli, Abia State, Nigeria. The results indicated that the mean values for HCHO, $PM_{2.5}$, PM_{10}, and RH exceeded the acceptable limits set by the World Health Organization (for a 24-hour period) and the National Ambient Air Quality Standards (for an 8-hour period). Strong relationships were found between $PM_{2.5}$ and PM_{10} at a significance level of 1% (correlation coefficient = 1.00**), $PM_{2.5}$ and CO (correlation coefficient = 0.888**), PM_{10} and CO (correlation coefficient = 0.888**), and VOC and HCHO (correlation coefficient = 0.994**). The key climatic parameters that have been found to influence air pollutants such as CO_2, CO, VOC, PM_{10}, $PM_{2.5}$, and HCHO are relative humidity and temperature, both of which were measured at 64.0%. The socio-demographic profiles revealed that persons in the age groups of 31-35 years and 36-40 years displayed apprehension regarding the consequences of air pollution. Male individuals had a higher susceptibility to the adverse effects of air pollution compared to their female counterparts. The study also found strong correlations between air quality and different age groups that are prone to severe illnesses. In addition, a significant proportion of married individuals (61.5%) had a strong vulnerability to air pollution. Significant variables contributing to pollution were discovered as primary and secondary education levels, as well as Christian religious worship. The workers had an average experience of 16-20 years. They were able to produce an estimated quantity of more than 9 bags of charcoal per day and 21-30 bags per week. The weekly earnings fluctuated between ₦20,000 and ₦30,000 on average. Moreover, 83.3% of the participants stated that they possessed substantial knowledge of air pollution, with 50.0% specifically mentioning their awareness through mediums such as radio, television jingles, advertising, and educational programmes. The main cause of air pollution was determined to be smoke, which was found to be present at high levels near the kiln site throughout both morning and afternoon periods (50.0%). Furthermore, a significant proportion of 41.7% indicated a desire to move elsewhere as a result of their concerns regarding air pollution. The chi-square analysis revealed that individuals reported experiencing dizziness, catarrh, and sputum production as perceived health impacts. 100% of the respondents recommended implementing various measures to combat air pollution from charcoal production. These measures include reducing forest fires, smoking, open burning, dispersion, and using safer materials or processes. Other suggested measures include improving local ventilation, isolating the production area, ensuring compliance with workplace procedures, and maintaining environmental hygiene. The results emphasized that the majority of workers at charcoal producing facilities do not utilize personal protective equipment, thereby heightening their vulnerability to health and safety hazards. There was no statistically significant impact of socioeconomic characteristics on the profitability of charcoal manufacturing. Charcoal manufacturing, despite its economic significance, has had a disproportionately negative impact on environmental degradation and local air quality. This has resulted in respiratory health issues for both producers and adjacent communities. Hence, it is imperative to provide charcoal workers with control measures in order to alleviate health hazards linked to exposure. The study proposes shifting attention away from exclusive modern energy services towards traditional and widely available energy sources, taking into account their substantial economic, environmental, and social effects. Implementing pollution mitigation tactics and conducting public education initiatives are crucial in mitigating the release of harmful air pollutants in and near charcoal kiln regions. Comprehensive environmental education, particularly targeting individuals involved in charcoal production, is essential for effectively tackling health and pollution issues.

Acknowledgement: All the authors are acknowledged for making this article successful

Disclosure statement: *Conflict of Interest:* The authors declare that there are no conflicts of interest.

Compliance with Ethical Standards: This article does not contain any studies involving human or animal subjects.

References

Abidin E. Z., Semple S., Rasdi I., Ismail S. N. S., Ayres J. G. (2014) The relationship between air pollution and asthma in Malaysian school children. *Air Quality Atmosphere and Health*, 7, 421–432.

Adam J.C (2009) Improved and more environmentally friendly charcoal production system using a low-cost retort- kiln (eco- charcoal). *Renew Energy*, 34, 1923–1925.

Adam, J. C. (2009) Improved and more environmentally friendly charcoal production system using a low-cost retort–kiln (Eco-charcoal). *Renew Energy*; 34, 1923–1945.

Adeniji O., Zaccheaus O. S., Ojo B. S. Adedeji A. S. (2015) Charcoal production and producers' tree species preference in Borgu local government area of Niger State, Nigeria, *Journal of Energy Technologies and Policy*, 5(11), 1–8.

Ahrends A, Burgess N.D, Milledge S.A.H, Bulling M.K, Fisher B, Smart J.C.R. (2010) Predictable waves of sequential forest degradation and biodiversity loss spreading from an African city. PNAS 1–6. http://dx.doi.org/10.1073/pnas.0914471107

Akagi S. K., Yokelson, R. J., Wiedinmyer C., Alvarado M.J., Reid J.S., Karl T. (2010) Emission factors for open and domestic biomass burning for use in atmospheric models. *Atmospheric Chemistry and Physics* 0:27523–602.

Alem S., Duraisamy J., Legesse E., Seboka Y., Mitik E. (2010) Wood charcoal supply to Addis Ababa City and its effect on the environment. *Energy and Environment*, 21(6), 601–609.

Anon. (2011). What is in wood smoke and solid fuel emission burning issues? Clean Air Revival Inc.www.burningissues.org/smoke.htm

Antal, M. J. and Gronli, M. (2003) The art, science, and technology of charcoal production. *Industrial and Engineering Chemistry Research*. 42, 1619–1640. http://dx.doi.org/10.1021/ie0207919

Arnold J. E. M., Köhlin, G., Persson R. (2006) Wood fuels, livelihoods, and policy interventions: changing perspectives. *World Development;* 34(3), 96–611.

Bailis R., Ezzati M., Kammen D.M. (2015) Mortality and greenhouse gas impacts of biomass and petroleum energy futures in Africa. *Science* 308, 98-103.

Barman K., Asrey R., Pal R.K., Jha S. K., Sharma S. (2015) Influence of Different desapping Agents on the Incidence of sapburn, ripening behavior and quality of Mango. *Journal of Food Science Technology*, 51,161-170. https://doi.org/10.1007/s13197-013-0995-x

Bede-Ojimadu O., Orisakwe O. E. (2020) Exposure to wood smoke and associated health effects in sub- Saharan Africa: A systematic review. *Annals Global Health*; 86, 32.

Bhattarai J., Akiyama E., Habazaki H. (1998) The passivation behavior of sputter-deposited W- Ta alloys in 12 M HCl, *Corrosion Science,* 40(4-5), 757–779.

Bruce N., Perez-Padilla R., Albalak R. (2010) Indoor air pollution in developing countries: a major environmental and public health challenge. *Bulletin of the World Health Organization* 78, 1080–1092

Bruns E.A., Krapf M., Orasche J. (2015) Characterization of primary and secondary wood combustion products generated under different burner loads. *Atmos Chem Phys*, 15,2825–2941.

Charcoal production in South Africa (CHAPOSA) (2002) INCO-DEV ERBIC18CT980278 University Eduardo Mondlane Mozambique Individual partner report, pp. 70-72.

Chidumayo E. N., Gumbo D. J. (2013) The environmental impacts of charcoal production in tropical ecosystems of the world: A synthesis. *Energy for Sustainable Development*, 17, 86–94.

Chidumayoa E.N, Gumbob D. J. (2012) The environmental impacts of charcoal production in tropical ecosystems of t he world: a synthesis. *Energy Sustainable and Development* 17:86. https://doi.org/10.1016/j.esd.07.004. Google Scholar

Climate Tech Wiki. (2012) Charcoal production for cooking and heating. Clean Technology Platform.

Cohen A. J, Ross Anderson H, Ostro B (2005) The global burden of disease due to outdoor air pollution. *Journal of Toxicology Environmental Health* A; 68, 1301–1307.

Crutzen, P. J. and Andreae, M. O. (1990) Biomass burning in the tropics: Impact on atmospheric chemistry and biogeochemical cycles. Science, 250, 1669–1678.

Desanker P., Zulu L. (2001) Gender, energy, development and environmental change in Southern Africa. Southern Africa Gender and Energy Network and the Minerals and Energy Policy Centre (SAGEN & MEPC); http://www.energia.org/nc/knowledge-centre/publications-database (accessed January 5, 2025).

Dias E. C., Assuncao A. A., Guerra C. B. (2002) Labor process and workers' health in charcoal production in Minas Gerais, Brazil. Cad Saude Publica, 18, 69–77.

Dost F.N. (2011) Acute toxicology of components of vegetation smoke. *Rev Environ Contam Toxicol* 119,1–46

Ediagbonya T.F, Tobin A.E (2013) Air pollution and respiratory morbidity in an urban area of Nigeria. *Greener J Environ Manag Pub* Saf 2(1), 010

Ellegàrd A, Nordström M. 2003 Deforestation for the poor? *Renew Energy Dev*, 16(2):4–6.

Emeodilichi HM (2018) Assessment of charcoal production processes and the environment impact in kaduna Nigeria. *Resour Environ*, 8(5), 223–231. https://doi.org/10.5923/j.re.20180805.02

Eniola P. O. (2014) Perceived environmental and health effects of charcoal production among rural dwellers in agro-ecological zones of Nigeria. U.I PhD thesis. 2014. Google Scholar

Ezzati, M., Kammen, D. M. (2002) The health impacts of exposure to indoor air pollution from solid Fuels in developing countries: knowledge, gaps, and data needs. *Environ Health Perspect*, 110, 1057–1068.

Fae-Gomes G. M., Encarnaçao F. (2012) The environmental impact on air quality and exposure to carbon monoxide from charcoal production in southern Brazil. *Environmental Research*, 116, 136–139.

FAO (2018) Faostat on charcoal, Food and Agricultural Organization of the United Nations, 2017. pp 34–45. Google Scholar

FEMEnv. 1999 National Emission Standards for Hazardous Air Pollutants for Source Categories; Portland cements Manufacturing Industry. Federal Register, 1999. Available online: *https://www.gpo.gov/fdsys/pkg* (accessed on 14 Jun.2025).

Food and Agriculture Organization of the United Nations (FAO). 2010. Criteria and indicators for sustainable wood fuels. Rome: FAO Forestry paper; 103. Available from: www.fao.org.

Friends of the Earth, Ghana. (2002). More trees destroyed by charcoal producers. FOELINE. Accra, Ghana, p. 34.

Fullerton D.G., Semple S., Kalambo F., Suseno A., Malamba R., Henderson G., Ayres J.G., Gordon S.B. (2019) Biomass fuel use and indoor air pollution in homes in Malawi. *Occup Environ Med*, 66:777–783

Ghosh S., Pal A.K., Saxena N.C. (2016) Impact of road way traffic and transport on human health: energy *Environ. Monitor*, 12:101–107

Goanue A. V. (2009) Status of Renewable Energy in Liberia, Presentation of Rural and Renewable Energy Agency, 2009.

GTZHERA (2009). Household energy for sustainable development. Retrieved Aug. 19, 2024. http://www.gtz.de/en/aktuell/12941.htm
Hamatui N., Naidoo R.N., Kgabi N. (2016) Respiratory health effects of occupational exposure to charcoal dust in Namibia. *Int J Occup Environ Health*, 22,240–268.

Harris P. (1999). On charcoal. *Interdis Sci Rev*, 24:301–326.

Hofstad O., Kohlin G., Namaalwa J. How can emissions from woodfuel be reduced? In: Angelsen A,
Brockhaus M., Kanninen M., Sills E., Sunderlin W.D., Wertz-Kanounnikoff S. (2009) Realising REDD+: national strategy and policy options. Bogor, Indonesia: Center for International Forestry Research; 2009. p. 237–49.

Iloeje O. C. (2002) Renewable energy development in Nigeria: status and prospects. Ed. O.E. Ewart. Proceedings of a National Workshop on Energising Rural Transformation in Nigeria: Scaling Sup electricity Access and Renewable Energy market Development. Federal Ministry of Power and Steel, Abuja Nigeria. March 19–20 2001, 180. ICEED
International Energy Agency (2012.) World energy outlook, 2012, energy and poverty (Chapter 13). Retrieved Mar. 14, 2024
Islam R., Walkerden G. (2017) Social networks and challenges in government disaster policies: A Case study from Bangladesh. *Int. J. Disaster Risk Reduct.*, 22, 325-334. https://doi.org/10.1016/j.ijdrr.2017.02.011
Kalu C., Izekor D. (2007). Charcoal enterprise in Benin-city, Edo state. Nigeria. *J Appl Sci Environ Manag*, 11, 63–77.
Kambewa P. S., Mataya B. F., Sichinga W. K., Johnson T. R. (2007) Charcoal: the reality — a study of charcoal consumption, trade and production in Malawi. Small and Medium Forestry Enterprise Series,21. London: International Institute for Environment and Development.
Kammen D. M., Lew, D. J. (2005) Review of technologies for the production and use of charcoal. Rnewable and Appropriate Energy Laboratory report, Energy and Resources Group & Goldman School of Public Policy. Berkeley, CA, USA: University of California. p. 1-19.
Kumsa B. (2019). Cystic echinococcosis in slaughtered cattle at Addis Ababa abattoir enterprise, *Ethiopia. Vet. Anim. Sci.*, 100050.
Kurmi O. P., Lam K. B. H., Ayres, J. G. (2012) Indoor air pollution and the lung in low-and medium-income countries. *Eur Respir J*, 40, 239–254.
Longo D., Fauci A., Kasper D., Hauser S., Jameson J., Loscalzo J. (2011) Harrison's principles of internal Medicine, 18th edn. McGraw-Hill Professional, New York.
Luoga E. J., Witkowski E. T. F., Balkwill K. (2000) Subsistence use of wood products and shifting cultivation within a miombo woodland of eastern Tanzania, with some notes on commercial uses. *S Afr J Bot*, 66(1),72–85.
Luwaya E. (2015) Improvement of conversion efficiency of charcoal kiln using a numerical method. PhD thesis submitted to the Department of Mechanical Engineering, University of Zambia.
Makhabane T. (2002) Gender and sustainable energy issues in Africa: perspectives for the world summit on sustainable development, Regional Paper prepared for the WSSD, ENERGIA Network. Retrieved July 25, 2024 from www.energia.org/pubs/index.asp
Maes W. H., Verbist, B. (2012) Increasing the sustainability of household cooking in developing Countries: Policy implications. *Renewable and Sustainable Energy Reviews*, 16(6), 4204–4221.
MARGE. (2009) Malawi biomass energy strategy, consultancy study for government of Malawi and European Union Partnership Dialogue Facility. Lilongwe, Malawi: *Marche'ageet Gestion de l'Environnement*
Mensah K.E., Damnyag L., Kwabena N. S. 2022. Analysis of charcoal production with recent developments in sub-Sahara Africa: a review. *African Geographical Review*, 41:35–55.
Mishra V, Retherford R. D. (2017) Does biofuel smoke contribute to anaemia and stunting in early childhood? *Int J Epidemiol 36:117–129 of spirometry. Eur Respir J;* 26(2), 319–338. doi:10.1093/ije/dyl234
Msuya N., Masanja E. Temu, A. K. (2011) Environmental burden of charcoal production and use in dares salaam, Tanzania. Journal of Environmental Protection, 2, 1364-1369. Retrieved June 10, 2024. http://dx.doi.org/10.4236/jep.2011.210158
Mugo F., & Ong, C. (2006) Lessons from eastern Africa's unsustainable charcoal business. World

Agroforestry Centre. Working Paper, 2006. https://doi.org/10.5716/WP06119.PDF
Mwampamba T., Dutt G. (2013) What role will charcoal play in the coming decades? Insights from up-to-date findings and reviews. *Energy Sustain Dev*, 17,73–94.
Mwampamba T. H., Ghilardi, A. A., Sander, K., Chaix K. J. (2013) Dispelling common misconceptions to improve attitudes and policy outlook on charcoal in developing countries. *Energy for Sustainable Development*, 17(2),75–85.
NAAQS. 2012. Criteria Air Pollutants Ambient Standards. 2012. Available online: https://epa.gov (accessed on 30 June 2025).
Naeher LP, Brauer M, Lipsett M. (2007) Wood smoke Health Effects: A Review. *Inhalation Toxicology*, 19, 67–106. DOI: https://doi.org/10.1080/08958370600985875
NBS. (2016). National Bureau of Statistics (NBS) (2016). National Population Commission (web)
Nielsen E., Dybdahl M, Larsen P.B. (2008) Health effects assessment of exposure to particles from wood smoke. Miljostyrelsen. Environmental project.; 1235. Available from: http://orbit.dtu.dk.
Njenga M., Karanja N., Munster C., Iiyama M., Neufeldt H., Kithinji J., Jamnadass R. (2013) Charcoal production and strategies to enhance its sustainability in Kenya. Development in Practice, 23(3), 359-371. DOI: 10.1080/09614524.2013.780529.
NL Agency. (2010). Making charcoal production in Sub Sahara Africa sustainable. NL Agency and BTG Biomass Technology Group BV, Utrecht. Google Scholar
Nwofe P. (2013) Comparative Aanlysis of Domestic Energy Use in Nigeria - A Review. Continental *J. Renewable Energy*, 4(1), 7–17.
Odekanle, E. L., Fakinle, B. S., Jimoda, L. A., Okedere, O. B., Akeredolu, F. A., Sonibare, J. A. (2017). nvehicle and pedestrian exposure to carbon monoxide and volatile organic compounds in a mega city. *Urban Clim*,.21, 173–182.
Offor E. I., Amusa T. A., Udochukwu C. J. (2020) Sustainable Agric. *Environ*, 18 (1): 152-164
Ogara J. (2011) Preliminary studies on charcoal production and producers' knowledge of environmental hazards in Nasarawa State, Nigeria, *PATS*, 7: 68–75.
Ogundele A.T., Eludoyin O.S., Oladapo O.S. (2011) Assessment of impacts of charcoal production on soil properties in the derived savanna, Oyo state, *Nigeria. J Soil Sci Environ Manage*, 2(5):142–146. ISSN 2141-2391 ©2011 Academic Journals. Google Scholar
Ogunsanwo O. Y., Aiyeloja A. A., Uzo C. (2007) Production techniques and the influence of wood species on the properties of charcoal in Nigeria, a case study of Oyo State. *Agric J*, 2(1),131–133
Oguntunde P.G., Abiodun B.J., Ajayi A.E., Giesen N. (2008) Effects of charcoal production on soil physical properties in Ghana. *J Plant Nutr Soil Sci* 171, 591–596. Google Scholar
Okello B., T., O'connor T. P., Young T. P. (2001) Growth, biomass estimates, and charcoal production of Acacia drepanolobium in Laikipia, Kenya, ‖ *Forest Ecology and Management*, 142(1-3), 143–153.
Okezie Onyemaechi O., Nwachukwu E. (2018) Microbiological Evaluation of Drinking Water Supplies in Uzuakoli, Bende L.G.A. of Abia State, Nigeria. Pelagia Research Library, *Advances in Applied Science Research*, 9(2), 69-74. ISSN : 0976-8610
Oladimeji Y.U., Adepoju S.A., Galadima S.A., Fagge A.M. (2018) Socio-economic impact of participation in mining and quarrying on poverty alleviation among rural households in Kwara State, Nigeria. *Journal of Agriculture and Environment*, 14 (2), 17-29.
Olalekan R. M., Omidiji, A. O., Williams, E. A., Christianah, M. B., Modupe, O. (2019) The roles of all tiers of government and development partners in environmental conservation of natural resource: A case study in Nigeria. *MOJ Ecology & Environmental Sciences*, 4(3), 114-121.
Onyekwelu C.A., Mba C.L., Ikwechegh E., Nwosu I.G., Akukwe T.I., Asuoha C.G., Okafor U.P., Nnoli C.I., Ossai O.G. (2024) GIS- based site suitability study of rice farm location in Bende local government area, Abia State, Nigeria. *Afr. J. Food Agric. Nutr. Dev*. 24(5), 26312-26332. https://doi.org/10.18697/ajfand.130.24085
Orru H., Maasikmets M., Lai T., Tamm T., Kaasik M., Kimmel V. K., Orru E., Merisalu Forsberg B. (2011) Health impacts of particulate matter in five major Estonian towns: main sources of exposure and local differences. *Air Qual Atmos Health*, 4, 247–258.
Otu-Danquah K. A. (2010) Current status of charcoal demand and supply, and initiatives on improved cook-stoves. A presentation made during a kickoff meeting for TEC/ESMAP survey on the energy access and productive uses for the urban poor, held in the SSNIT Guest House Conference Room, Accra on 11/08/2024, pp. 23.

Pabi O., Morgan E. A. (2002) Land-cover change in the Northern Forest-Savannah Transition in Ghana, Commissioned technical report for the NRSP R7957 project. Retrieved April 23from www.nrsp.org/pubs/index.rsp. Google Scholar

Payus C. M., Vasu Thevan, A. T., Sentian, J. (2020) Impact of school traffic on outdoor carbon monoxide levels. *City Environ. Interact*, 4, 100032. https://doi.org/10.1016/j.cacint.2020.100032.

Pennise D.M., Smith K.R., Kithinji J.P., Rezende M.E., Raad T.J., Zhang J. (2001) Emissions of greenhouse gases and other airborne pollutants from charcoal making in Kenya and Brazil. *J Geophys Res*, 106, 24143–24155.

Pennise D. M., Smith K.R., Kithinji J.P., Rezende M. E., Raad T.J., Zghang J., Fan, C. (2001) Emissions of greenhouse gases and other airborne pollutants from charcoal making in Kenya and Brazil. *Journal of Geophysical Research*, 106 (20), 24143-155.

Pereira C, Brouwer R, Monjane M, Falcão M. (2001) Final report for Mozambique. In: Ellegård A, editor. Charcoal potential in Southern Africa. Stockholm: Stockholm Environment Institute, p. 1-44.

Po J.Y.T., FitzGerald J.M., Carlsten C. (2011) Respiratory. disease associated with solid biomass fuel exposure in rural women and children: systematic review and meta-analysis. Thorax 66:232–239

Public Health England. (2018). Health matters: air pollution England. 2018. Available: https://www.gov.uk/government/publications/healthmatters-air-pollution/health-matters-air-pollution

Raimi M. O., Adio Z. O., Odipe O. E., Timothy K. S., Ajayi B. S., Ogunleye T. J. (2020) Impact of Sawmill Industry on Ambient Air Quality: A Case Study of Ilorin Metropolis, Kwara State, Nigeria. *Energy and Earth Science*, 3(1). *http://dx.doi.org/10.22158/ees.v3n1p1*

Raimi M.O., Omidiji A.O., Adeolu T.A., Odipe O.E., Babatunde, A. (2019) An Analysis of Bayelsa State Water Challenges on the Rise and Its Possible Solutions. *Acta Scientific Agriculture*, 3(8),110-125.

Raimi M. O., Tonye V. O., Omidiji A. O., Oluwaseun E. O. (2018) Environmental Health and Climate Change in Nigeria. World Congress on Global Warming. Valencia, Spain. December 06-07, 2018. Ribot JC. Forestry policy and charcoal production in Senegal. Energy Policy; 21, 543–85.

Richardson R. B. (2010). Ecosystem services and food security: economic perspectives on environmental sustainability. *Sustainability*, 2, 3520–3748. http://dx.doi.org/10.3390/su2113520.

SEI. (2002). (Stockholm Environment Institute). Charcoal potential in southern Africa: CHAPOSA project final report. Stockholm: Stockholm Environment Institute; 2002.

Sepp S. 2014. Multiple-Household Fuel Use – A balanced choice between firewood, charcoal and LPG. Federal ministry of economic cooperation and development technical report. Deutsche Gasellschaft fur Internationale Zusammenrbeit (GIZ). GmbH; 2014: 49

Shackleton C.M., Shackleton S.E., Buiten E., Bird N. (2006) The importance of dry woodlands and rainforests in rural livelihoods and poverty alleviation in Southern Africa. *Rainforest Polit Econ* 9,558–577. Google Scholar

Smith K.R., Pennise D.M., Khummongkol P., Chaiwong V., Ritgeen K., Zhang J., Panyathanya W., R.A. Rasmussen Khalil, M. A. K. (1999) In: Agency USEP, editor. Greenhouse gases from small-scale combustion devices in developing countries. Phase III: charcoal-making kilns in Thailand; EPA-600/R- 99-109. United States Environmental Protection Agency Research and Development, Washington, DC.

Songsore J. (2003) Regional development in Ghana: the reality and the theory. Accra, Ghana:Woeli Publishing Services, pp. 45.

Souza M. S., Magnarelli G.G, Rovedatti M.G, Santa Cruz S., Pechen De D'Angelo A.M (2005) Prenatal exposure to pesticides: analysis of human placental acetylcholinesterase, glutathione S-transferase and catalase as biomarkers of effect. Biomarkers, 10,376–389.

Sparrevik M., Adam C., Martinsen V., Jubaedah G., Cornelissen G. (2015) Emissions of gases and particles from charcoal/ biochar production in rural areas using medium sized traditional and improved ―retort‖ kilns. *Biomass and Bioenergy* 72, 65–73.

Stefan C (2009) Fundamentals of charcoal production. National bioenergy center IBI conference on biochar, sustainability and security in a changing climate, pp 68–92. Google Scholar

Sugumaran P, Seshadri S. (2009). Evaluation of selected biomass for charcoal production. *J Sci Ind Res*, 68,719–23.

Tippayawong, N., Saengow E.., Chaiya N. Srisang, (2010) Production of charcoal from woods and bamboo in a small natural draft carbonizer. *International Journal of Energy and Environment* (IJEE), 1 (5),

911-918.
Toledo R.T. 2008. Wood Smoke Components and Functional Properties. In: Kramer DE, Brown L (eds.), International Smoked Seafood Conference Proceedings. Program; 55–61. https://doi.org/10.4027/isscp.
Tunde A.M, Adeleke EA, Adeniyi EE (2013) Impact of charcoal production on the sustainable development of Asa Local Government Area, Kwara State, Nigeria. *Int Multidiscip J Ethiop* (2), 1–15
Tzanakis N, Kallergis K, Bouros DE, Samiou MF, Siafakas NM (2001) Short-term effects of wood smoke exposure on the respiratory system among charcoal production workers. *Chest* 119(4), 1260–1290. https ://doi.org/10.1378/chest .119.4.1260.
UNDP. (2005). Basing National Development on the Millennium Development Goals. Retrieved August 20,2024. http://www.cifor.cgiar.org
USEPA. (2019). Volatile Organic Compounds Impact on Indoor Air Quality. 2019. Available online: https://www.epa.gov/indoor-airquality-iaq/volatile-organic-compouns (accessed on 11, 2024)
Van Dam, J. (2009). The charcoal transition: greening the charcoal value chain to mitigate climate change and improve local livelihoods. (Rome).
Wesson, P. S. (2006). Wave Mechanics and General Relativity: A Rapprochement. General Relativity and Gravitation, 38,937-944. https://doi.org/10.1007/s10714-006-0273-6
Wilkinson, P., Smith, K. R., Joffe, M., (2007). A global perspective on energy: health effects and injustices. *Lancet*,370,965–978.
Williams A (1993) An overview of the use of woodfuels in Mozambique and some recommendations for biomass energy strategy. National directorate of forestry and wildlife/biomass energy unit, p 250
Woolley K.E, Bartington SE, Kabera T. (2021). Comparison of respiratory health impacts associated with wood and charcoal Biomass fuels: a population-based analysis of 475,000 children from 30 low and middle-income countries. *International Journal of Environmental Resources and Public Health* 18, 9305.
Woolley K. E., Bagambe, T., Singh, A. (2020) Investigating the association between wood and charcoal domestic cooking, respiratory symptoms and acute respiratory infections among children aged under 5 years in Uganda: A cross-sectional analysis of the 2016 demographic and health survey. *International Journal of Environmental Resources and Public Health*, 17,1–14.
World Bank (2004) Harvesting opportunities. Rural development in the 21st century. IV Regional Thematic Forum. Printed from the World Bank Group. Latin America and The Caribbean, p 248.
World Bank. (2009). Environmental crisis or sustainable development opportunity? Transforming the charcoal sector in Tanzania. Washington, DC.
World Health Organization. (2014). Mortality from ambient air pollution. [Internet]. http://www. who. int/ gho/ phe/ outdoor_ air_ pollution/ burden/en/ on
World Health Organization (2019) Environmental health criteria 213: carbon monoxide, 2nd edn. World Health Organization, Geneva.
Zulu, L. C. (2010). The forbidden fuel: charcoal, urban woodfuel demand and supply dynamics, community forest management and woodfuel policy in Malawi. Energy Policy, 38, 3717–3730. http://dx.doi.org/10.1016/j.enpol.2010.02.050.

(2026) ; http://www.jmaterenvironsci.com