Understanding the association of individual pollutants with pneumonia episodes in children under five in Abuja, Nigeria

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Abstract

Background

Pneumonia kills nearly one million children under the age of five globally, every year. Despite reductions in global pneumonia mortality, progress in the highest-burden countries remains slow. 60% of all pneumonia fatalities occur in 10 countries of which Nigeria is currently number one overtaking India. Equally, air pollution remains a major public health concern worldwide. Globally air pollution is responsible for over 7 million deaths annually. Exposure to high levels of pollution is constantly on the rise, especially in urban cities. Exposure to air pollution alters lung health in many ways leading to the exacerbation of respiratory illnesses. Consequently, this would increase the risk of developing pneumonia especially in vulnerable populations such as children where the respiratory tract is still underdeveloped.

Several reviews have been published looking at the effect of indoor air pollution and the effect this has on pneumonia in children. However, there was no standard assessment for exposure across studies. Also, a combination of different study designs, sample sizes, follow up period and dose-response makes the conclusions hard to interpret. Indoor concentrations of carbon monoxide (CO), particulate matter (PM), and more recently black carbon (BC) concentrations have been associated with respiratory infections in children. Unfortunately, the current understanding of the association of indoor air pollution on pneumonia in children under five is, inconclusive and only partially understood. This study aims to plug this important gap in the literature and is the first study investigating the association of individual pollutant components (PM_1, $PM_{2.5}$, CO and Black Carbon) and childhood pneumonia in Abuja Nigeria using primary field observations.

Objective: To investigate the impact of indoor air pollution on childhood pneumonia episodes in Abuja, Nigeria, the key aims of this study were;

1. To undertake a systematic literature review (Published).
2. To identify areas with a higher incidence of pneumonia and high pollution exposure in Nigeria using the 2013 Demographic Health Survey (DHS) data (under review Environmental Health Perspectives).

3. To investigate the association between PM (1 and 2.5), CO and BC and pneumonia episodes in children under five (under review Environmental Health and Pollution Research).

4. To explore health professionals' perspectives on the effect of household air pollution and childhood pneumonia episodes. Exploring, strengths, weaknesses, gaps and opportunities within the healthcare system (manuscript under preparation).

Methods

Secondary data analyses included the national and subnational representative data from Nigeria obtained from the 2013 round of the Demographic Health Survey (DHS) was used for air pollution and ARI hotspot identification. Furthermore, primary data collection used a mixed-method approach case-control (quantitative) and key informant interviews (qualitative) to assess the effects of air pollution and pneumonia in children under-five. The case control study measured $PM_{2.5}$, CO, BC and PM_1 using PATS+, a phone-based system developed by NEXLEAF ANALYTICS and SidePak Personal Aerosol Monitor AM510 (TSI Inc, MN, USA) in 150 cases and 140 controls. Semi-structured interviews were conducted with 19 healthcare professionals. Quantitative data was managed and analysed using STATA TM 16, whilst qualitative data was managed and analysed with NVivo TM 12.

Results

Secondary data analyses from the 2013 DHS in Nigeria indicated that biomass fuel and improved housing were positively associated with ARI. Being exposed to biomass fuel increased the risk of ARI by 55% in children under five. The results of the STAR model showed that living in an improved house has a protective effect against ARI and reduces the risk of ARI by 28%. The risk maps showed that more than half of the children under five population were at increased risk for acquiring ARI due to burning of biomass fuel and emitted $PM_{2.5}$. Furthermore, the Nigerian population subject to high levels of air population also showed a treatment-seeking rate of less than 50% in cases of fever.

Primary data from the case control study indicates that the mean $PM_{2.5}$ was higher in control households compared to cases households. $PM_{2.5}$ highest mean recorded for controls was

177 μg/m^3 and 129 μg/m^3 for cases. There was a significant difference between cases and controls for 10 hours (*p*-value 0.0147), 15 hours (*p*-value 0.0111) and 20-24 hours (*p*-value 0.0296) for $PM_{2.5}$.

No significant difference in CO concentration was observed between cases and controls, the highest CO mean concentration recorded being 2930 μg/m^3. Similarly, PM_1 was consistently higher in controls compared to cases. However, this difference was not significant from exposure to PM_1 between cases and controls (*p*-value>0.05), with the highest PM_1 mean concentration recorded being 91 μg/m^3.

There was a significant difference (*p*-value 0.0260) in exposure to Black Carbon (BC) between cases and controls. BC was higher in households of cases compared to controls, with the mean average of BC for cases 4350 μg/m^3 and controls 4126 μg/m^3. In this study, BC was positively associated with a pneumonia episode. We also report the importance of unmodifiable and behaviourally modifiable factors on pneumonia episode in children.

Finally, key informants interviews with healthcare professionals provides a deeper insight into the perception of household indoor air pollution and childhood pneumonia amongst these stakeholders. Healthcare professionals complained of the lack of funding to the lack of equipment and support needed for the treatment of their patients. Also, lack of awareness regarding health risks from household air pollution, level of education, poverty, treatment-seeking behaviour, lack of research and funding and effective implementation of policies were amongst the themes that emerged from the interviews with frontline healthcare experts.

Conclusion:

Pollution is widely investigated using proxy indicators for pollutants in developing countries. Also, pollutant components such as $PM_{2.5}$, PM_1, BC and CO are often investigated in isolation. Therefore, the gap still exists for the simultaneous measurement of key pollutants in association with pneumonia.

Biomass fuel and $PM_{2.5}$ increase the risk of ARI in under five children in Nigeria. Strategies to reduce air pollution exposure and increase treatment seeking should be explored as a means to reduce the disease burden and potentially ARI related mortality in under five children in Nigeria.

We show that children present during cooking, number of available windows and MUAC showing red all increased the likelihood of a pneumonia episode. We recommend household level behaviour changes and targeted IMCI including early effective detection and treatment of childhood pneumonia particularly in high pollution areas in Nigeria.

This research is particularly important as a starting point for policy review since the vast majority of affected countries like Nigeria with high childhood pneumonia mortality and morbidity have difficulty implementing their current laws or policies needed to guide both national responsibilities and international engagements in tackling childhood pneumonia. Evidence presented in this research revealed the context of this, from the Nigerian perspective by providing nationwide hotspot maps. Although focused on only one country, the findings of BC being associated with pneumonia episodes have a broader relevance as indoor air pollution and childhood pneumonia challenges inevitably contribute to similar health and social burdens worldwide.

Acknowledgement

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Publication from thesis work

Peer-Reviewed Publications.

- **Adaji E,** Ekezie W, Clifford M, Phalkey R. Understanding the effect of indoor air pollution on pneumonia in children under 5 in low- and middle-income countries: a systematic review of evidence. **Environmental Science and Pollution Research**. 2018;26(4):3208-3225. (Published) **Based on findings from the systematic review.**

- Bisanzio D*, **Enemona Emmanuel Adaji***, Martello E, Tusting L, Dambach P, Phalkey R. Spatial heterogeneity of cooking fuel and $PM_{2.5}$ contribution to the occurrence of acute respiratory infections in under-five children in Nigeria. (Manuscript in preparation) **Based on findings from secondary analyses of the 2013 DHS Survey.**

- **Enemona Emmanuel Adaji**, Michael Clifford, Jack Gibson, Magdalena Opazo Breton and Revati Phalkey. Association between specific indoor air pollutants and pneumonia episodes in children under five in Abuja, Nigeria: A case-control study. **CHEST.** (Submitted 28/02/2021) **Based on findings from the Case Control Study.**

- **Enemona Emmanuel Adaji**, Michael Clifford, Magdalena Opazo Breton and Revati Phalkey. Health professionals' perspectives on the effect of household air pollution and childhood pneumonia. Exploring, strengths, weaknesses, gaps and opportunities within the healthcare system: A qualitative study. (In preparation) **Based on Key Informant Interviews.**

Conference presentations and posters

- NCAS Air Quality Symposium 2019 (27-28 November 2019, University of Leeds, UK) – Oral
  The impact of indoor air pollution on pneumonia in children under five years

- Sue Watson Postgraduate Presentation (27 March 2019) – Oral
  Understanding the effect of indoor air pollution on pneumonia in children under five in low- and middle-income countries.

- University of Nottingham Faculty of Medicine Postgraduate Research Forum 2017, UK (29th June 2017) – Oral & Poster
  Understanding the effect of indoor air pollution on pneumonia in children under five in low- and middle-income countries.

- NCAS Introduction to Atmospheric Science (16 – 20th January 2017) – Poster
  Understanding the effect of indoor air pollution on pneumonia in children under five in developing countries.

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Abbreviations

ALRI	Acute Lower Respiratory Infection
ARI	Acute Respiratory Infection
BAD	Brake Abrasion Dust
BC	Black Carbon
CI	Confidence Interval
CO	Carbon Monoxide
COPD	Chronic Obstructive Pulmonary Disease
DALY	Daily Adjusted Life Years
DEP	Diesel Exhaust Particle
DHS	Demographic Health Survey
HAP	Household Air Pollution
Hib	Haemophilus In Uenzae Type B
HIV	Human Immunodeficiency Virus
ICS	Improved Cook Stove
IHME	Institute For Health Metrics And Evaluation
IMCI	Integrated Management Of Childhood Illness
IQR	Inter Quartile Range
LBW	Low Birth Weight
LPG	Liquid Petroleum Gas
MUAC	Mid-Upper Arm Circumference
NHIS	National Health Insurance Scheme
OR	Odds Ratio
PHC	Primary Healthcare Center
PM	Particulate Matter
PR	Prevalence Ratio
QGIS	Quantum Geographic Information System
RR	Risk Ratio
SARS-Cov-2	Severe Acute Respiratory Syndrome Coronavirus 2
SEDAC	Socioeconomic Data And Applications Center
SES	Socio Economic Status
STAR	Structural Additive Regression
UNICEF	The United Nations Children's Fund
VOC	Volatile Organic Compunds
WHO	World Health Organization

1 Introduction Chapter

Air pollution is a big problem of the modern world with impacts on health, wellbeing and climate mitigating issues. Worldwide an estimated seven million people are killed each year from air pollution. According to the WHO, 9 out of 10 people breath in toxic air that exceeds their set air quality guidelines with the highest exposures concentrating within low- and middle-income countries [1, 2]. From household exposures to smog hanging over cities, air pollution is now a major threat to health. The combined effect of outdoor and indoor air pollution on health cannot be overstated because of its role in increased mortality from stroke, heart disease, chronic obstructive pulmonary disease, lung cancer and acute respiratory infections making up the seven million deaths [3].

1.1 Indoor air pollution

Most of the world population spend more time indoors. Furthermore, exposure to high levels of indoor pollution in developing countries is thought to account for 76% of global pollution burden [4, 5]. Also, around 3 billion people mostly poor, who live in low- and middle-income countries still cook using solid fuels (such as wood, crop wastes, charcoal, coal and dung) and kerosene in open fires and inefficient stoves [6]. These cooking practices are inefficient, and use fuels and technologies that produce high levels of household air pollution with a range of health-damaging pollutants, including small soot particles that penetrate deep into the lungs. In poorly ventilated dwellings, indoor smoke can be 100 times higher than acceptable levels for fine particles. Exposure is particularly high among women and young children, who spend the most time near the domestic hearth [7].

Impacts on health

3.8 million people a year die prematurely from illness attributable to the household air pollution caused by the inefficient use of solid fuels and kerosene for cooking. Among these 3.8 million deaths: 27% are due to pneumonia, 18% from stroke, 27% from ischemic heart disease, 20% from chronic obstructive pulmonary disease (COPD) and 8% from lung cancer [2]. The risk of childhood pneumonia is double from exposure to household air pollution, in children under five this exposure is responsible for 45% of all pneumonia deaths. Also, in adult exposure to household pollution is responsible for acute lower respiratory infections (pneumonia) and leads to 28% of deaths within the adult population [8-17]. Whilst daily exposure to household air pollution from cooking with solid fuels and kerosene has been associated with 12% death rate from stroke [17].

Furthermore, approximately a million deaths making up 11% of all deaths from ischemic heart disease can be linked to constant exposure to household air pollution [17-21]. Similarly, exposure to household air pollution in low- and middle-income countries leads to 25% of deaths from chronic obstructive pulmonary disease (COPD). When it comes to exposure to smoke, women are mostly affected, which makes them twice as likely to be diagnosed with COPD when compared to women who use cleaner fuels. In men with increased risk of COPD from smoking, exposure to pollution from household air pollution almost doubles their risk [16, 17, 22, 23]. Additionally, exposure to carcinogens from household air pollution from using kerosene or solid fuels such as wood, charcoal or coal has been attributed to a 17% risk of lung cancer mortality [17].

In general, the small constituents of particulate matter from indoor smoke enters and damages the lungs and airways causing inflammation, this leads to the weakening of the immune system to fight against any infection and also, within the blood reduces the oxygen-carrying capacity [17, 24, 25]. Low birth weight, tuberculosis, cataract, nasopharyngeal and laryngeal cancers have all been linked with exposure to household air pollution.

Whilst there are vast health effects of exposure to air pollution, children have been identified to be the most vulnerable group exposed to the effect of air pollution due to their underdeveloped organs. Also, globally the leading cause of death in children under five is pneumonia, which means pneumonia causes more child deaths than any other diseases [11, 14, 26-28]. Therefore, this thesis would be focusing on the effect of household exposure of air pollution in children under 5.

1.2 Global burden of pneumonia

There has been considerable effort in reducing childhood mortality in the 20th century, with the total numbers of global deaths been halved from ~13 million deaths in 2018 [29]. This progress notwithstanding, there is a disproportionate disparity in this decline across different geographical regions with sub-Saharan Africa maintaining the highest mortality rates in children under five. The mortality rate in children in sub-Saharan Africa is 15 times worse than developed countries [1]. Pneumonia or other acute respiratory infections (ALRI), as well as childhood diarrhoea are the leading cause of paediatric death globally

[24, 30, 31]. In this thesis, the main focus was on factors that exacerbate pneumonia disease episode in children under five.

Pneumonia is a respiratory infection that affects the lungs, it is an inflammatory disease characterised by the build-up of fluid in the alveolus of diseased patients leading to the obstruction of normal breathing [24, 25]. Pneumonia is one of the most serious forms of ALRI. Pneumonia is caused predominantly, but not solely by bacteria, viruses and fungi [24, 25]. In children, bacterial pneumonia is mostly caused by Streptococcus pneumoniae whilst Haemophilus in uenzae type b (Hib) is the second largest cause [24, 25]. Respiratory syncytial virus mainly causes viral pneumonia whilst Pneumocystis jiroveci is the major cause of fungal pneumonia in children [32].

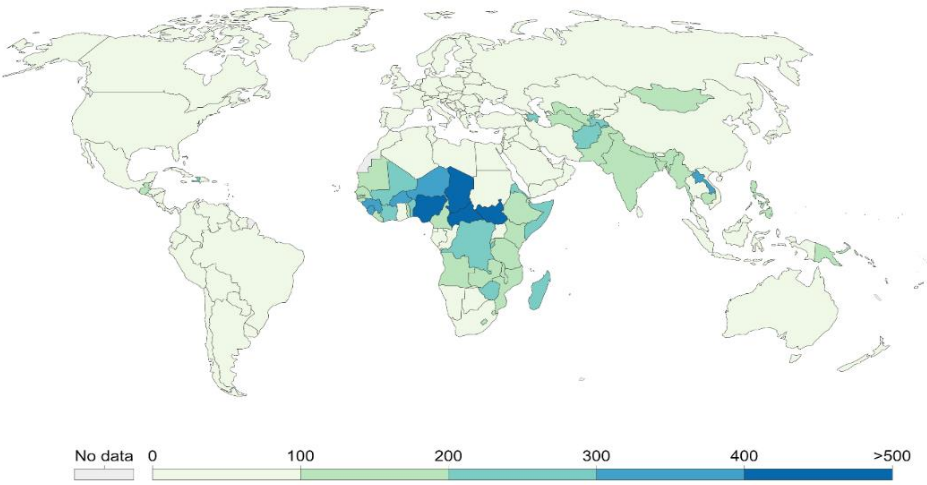

Figure 1: Pneumonia deaths of children under five in across the world in 2017. The annual deaths per 100,000 children [33]. Permission to reuse this picture was obtained from its creators.

Pneumonia kills more than 800,000 children under five each year globally [34]. Of this staggering number, the highest number of deaths in a single country was recorded in Nigeria at 162,000 deaths in 2018 [1]. A UNICEF report has shown that one in six children would develop pneumonia at least once before the age of ten particularly in the poorest parts of low and middle-income countries [31]. Pollution, undernutrition and compromised immunity are the biggest risk factors for pneumonia in children under five [3]. Although five countries from low- and middle-income countries index dominates the global pneumonia deaths, they are also the countries lacking in air quality measurements [35]. This section will be discussed further in subsequent chapters. The next section will focus on the relationship between indoor air pollution and pneumonia.

1.3 Indoor air pollution and pneumonia

Pollution refers to the introduction of substances that are harmful to human health and the environment [36]. These harmful substances are called pollutants. Examples of these pollutants include particulate matter, Carbon monoxide (CO) and Black carbon [36]. The levels of all forms of pollution is increasing and so are the reports of different health conditions linked to its exposure (Table 1).

Pollution can exacerbate the risk of respiratory diseases in many ways. Mechanically, air pollutants have been described as suitable transporters of viruses such as SARS-Cov-2, thereby propagating viral transmission [37]. Furthermore, exposure to air pollutants have been shown to promote the production of free radicals which contribute to oxidative stress leading to lung injury [38]. These effects jointly act to reduce the innate resistance of the lungs to viral and bacterial infections [38]. Furthermore, the epithelial cells lining the alveolar are specialised in secreting cytokines and radicals in response to foreign evading bodies [39, 40]. These mediate the recruitment of inflammatory cells such as macrophages and phagocytes to the site of evasion, which then engulfs and digests these foreign organisms. However, high levels of air pollution can lead to a compromise in this sterilisation and filtration mechanism of the respiratory tract, therefore, increasing the risk of the development of ALRIs including pneumonia [39]. For example, experimental research has shown that pollutants from cigarette smoke can impair ciliary function in in-vitro models [39]. More so, the mucociliary apparatus and cellular immune defences have also been shown to be significantly reduced by nitrogen dioxide [39].

Children are at risk because of their increased resting metabolic rate and a higher rate of oxygen consumption per unit body weight compared to adults [11, 39, 41-43]. Children are continuously undergoing organ development; this coupled with an elevated surface area per unit body weight increases the oxygen demand and respiratory rates [44]. In addition to an increased oxygen requirement, which is relative to their size, children have narrower airways compared to adults. Thus, whilst a pollutant may cause a mild irritation in the adult airways, it can potentially result in a more significant obstruction in the airways of a young child [43, 45, 46]. Altogether, exposure of children to pollution would increase the risk of developing ARI including pneumonia where the respiratory tract is still developing [47, 48].

Table 1: Studies investigating individual air pollutants and their effects on health.

Pollutant	Disease links	Study type	References
$PM_{2.5}$	• Air-way damage • Asthma • Decline in lung function • Chronic obstructive pulmonary disease (COPD) • ALRI • Pneumonia • Cancer • Coronavirus	• Longitudinal/ Panel studies • In-vivo • Case-control • Cross-sectional study • Case-Crossover Study • Cohort • Time series	• [49-51] • [52-55] • [12, 14, 15, 56-58] • [16, 22, 23] • [59-62] • [21, 63, 64] • [49, 65, 66] • [37]
PM_1	• Cardiovascular disease • Hospital visits	• Cross-sectional study • Longitudinal	• [18-21]
CO	• ARI • Pneumonia • Asthma	• Case control • Cross-sectional study	• [13, 67, 68]
Ozone	• Asthma	• Case-Crossover Study • Longitudinal/ Panel studies	• [64]
VOC	• Asthma	• Health risk assessment	• [69-71]
BC	• Asthma • Pneumonia	• Cohort • In-vitro	• [40, 63, 72]

PM has been previously reported as the key mediator of inflammation and compromised immune defences that is linked to the development of ALRIs [39]. Particulate matter refers to a mixture of solid and liquid particles suspended in the air which can be visible or invisible [73]. Primary sources of particulate matter include the incomplete combustion of substances such as biomass fuels, organic matter, automobile emissions, atmospheric dust, household cooking and finally, secondary sources can be from chemical reactions in the atmosphere [45]. PM in itself is complex, because it is made of different components such as sulphates, nitrates and black carbon [43, 45, 46]. PM exists in different sizes usually denoted in µm, from PM_{10} to PM_1 [73, 74]. Accumulating evidence shows that PM ($PM_{2.5}$

and PM_1) is dangerous to human health as it is able to penetrate nostril cilia and travel to the lungs [21]. Exposure to PM, have been linked to health outcome ranging from metabolic disorders, cancers, respiratory health disorders across health groups [21, 59-61]. PM do not only differ in size but it also differs in composition affected by season and location [74-76]. There are limited studies on the composition and effect of $PM_{2.5}$ in Nigeria on respiratory infections like pneumonia. In children, whilst the effect of $PM_{2.5}$ on health outcomes is usually been well researched, there is limited research on PM_1 [21]. PM_1 the smallest detectable fraction of PM, is possibly the most dangerous as it can easily by-pass air filtration systems and travel through nostrils, into lungs and blood vessels and blood streams [21]. The link of PM_1 to childhood pneumonia remains largely unexplored.

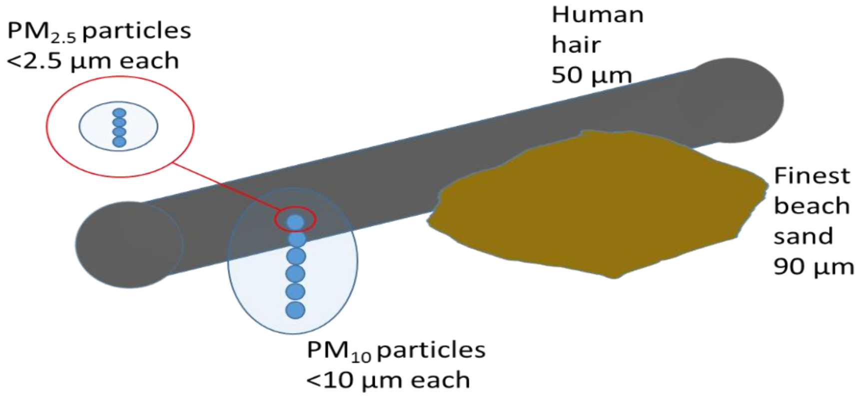

Figure 2: An illustration of the true size of $PM_{2.5}$ on a strand of human hair (Picture Credit: Author)

More recently, black carbon (BC), a component of PM has been described as the main mediator of the effects of PM [39]. BC has been reported to significantly affect the behaviour of *S. pneumoniae* by altering the structure and proteolytic degradation of the biofilm, therefore promoting its tolerance to multiple antibiotics. Furthermore, BC promotes the spread of bacteria to the lungs and consequently exacerbates the disease occurrence [40, 72]. Although, these studies have looked at the pathological relationship between the PM, BC and respiratory diseases in vitro, the consensus on disease association remains contested.

1.4 Current landscape of HAP in Nigeria and other developing countries

Interest, awareness, and research is rising in Nigeria and across developing countries with regards to the health effects of poor air quality. However, the problem is multifaceted. A combined threat from both indoor and outdoor sources increases exposure levels. WHO reports have shown some Nigerian cities with pollution levels 30 times higher than their recommended guidelines. According to Dr Maria Neira, WHO Director, Department of Public Health, Environmental and Social Determinants of Health "The contributing factors to pollution are a reliance on using solid fuels for cooking, burning waste and traffic pollution from very old cars," [77]. High household exposure could be due to unreliable electricity supplies, which leads many Nigerians to rely on generators, which expels dangerous noxious fumes often in unventilated areas. Also, on the street, car emissions go largely unregulated.

Furthermore, Dr Maria Neira adds: "In Africa, unfortunately, the levels of pollution are increasing because of rapid economic development and industry without the right technology" [77]. Indeed, Nigeria has overtaken South Africa to become the largest economy in Africa from industries like agriculture, telecoms and oil amongst others all driving this growth. However, this is at the cost of the environment [78].

A World Bank report showed that 94% of the population in Nigeria is exposed to air pollution levels that exceed WHO guidelines (compared to 72% on average in Sub-Saharan Africa in general) [79] and air pollution damage costs about 1% post of Gross National Income [79].

These trends though are not unique to Nigeria. A study by Salje *et al* [80] showed exposures in Bangladesh that exceeded 1000 $\mu g/m^3$. Also, Siddiqui *et al* reported exposures higher than WHO guidelines from cooking fuels in Pakistan's households [81]. Whilst there have been a steady increase in the study of indoor air pollution and its harmful effect on children below the age of five, there is lack of quantitative measurements of the indoor pollutants. Biomass fuels use is mostly used as a proxy for $PM_{2.5}$ whilst BC and PM_1 is usually largely ignored in measurements. A well-rounded approach with concomitant measurement of the different air pollutants is therefore needed to better understand the link between behaviour, pollutants and pneumonia outcomes in children especially in developing countries, where the problem is rife.

Often, research carried out in low and middle-income countries has focused mainly on the risk factors associated with childhood pneumonia [82, 83]. These studies are limited because they depend on self-reported questionnaires on exposures, which are subject to several forms of study biases. The use of a specific instrument to quantify household airfurther pollution (HAP) has enabled researchers to identify pollutants such as PM involved in causing respiratory illnesses like asthma and ARI in rural and urban areas in France [82] and low and middle-income countries such as Eastern Indonesia [84]. Several reviews have been published looking at the effect of indoor air pollution and the effect this has on pneumonia in children. However, there was no standardised systemic approach for exposure to these pollutants across studies [11, 39, 41, 85-89]. Also combination of different study designs, sample sizes, follow up period and dose response render the evidence inconclusive on range of exposures [11, 39, 41, 85-89]. Finally, within these studies, there was no consensus on what variables should be adjusted for amongst the study population [11, 39, 41, 85-89]. Globally, indoor concentrations of carbon monoxide (CO), particulate matter (PM), or more recently volatile organic compounds (VOC) and black carbon (BC) concentrations have been associated with respiratory diseases amongst children [84, 90-92]. Unfortunately, the effect of HAP on pneumonia in children under five is unclear, inconclusive, and only partially understood because of some gaps and conflicting information regarding specific pollutants.

1.5 Rationale and justification for this study

Within the literature there has been a rise in research looking into the health impact of exposure of children to HAP in developing countries however majority of the studies use proxy indicators as a measure of indoor air pollution [12, 14-16, 22, 23, 57, 58]. The cost of equipment needed for real time measurements are mostly out of reach to researchers in developing countries [93, 94]. When proxies are used as indicators for indoor air pollution in households, they fall short to reflect the true measure of effect [95, 96]. This could be misleading, as the true effect of pollution and health could be underestimated or overestimated [47, 97]. Of note, there were no studies investigating the effect of BC and PM_1 on childhood pneumonia in a LMIC to date.

Air pollution research and guidelines have exclusively focused on $PM_{2.5}$ [84, 98], including those proposed by the World Health Organisation rather than the sources or components [91, 92, 99]. Emerging research shows that BC has a higher health-related impact compared to $PM_{2.5}$ [72]. $PM_{2.5}$ in itself is a complex pollutant made up of components like sulphates, nitrates and black carbon [100]. Previous studies have shown that an intervention targeted generally at PM reduction does not necessarily lead to a corresponding decrease in all the components of PM [101-103]. For example, the development of improved cookstoves aimed at reducing PM mass resulted in higher BC concentrations [101-103].

Furthermore, there is a very high mortality rate from pneumonia in children under five in Nigeria. More so, there is a lack of Nigerian specific empirical evidence in factors contributing to this high mortality rate. It is therefore important to investigate the influence of HAP associated with childhood pneumonia in Nigeria, in order to develop, improve and promote a site-specific environmental public health intervention. This study aims to generate robust empirical evidence to support potential review of existing polices and set the precedent for new ones.

To investigate the impact of indoor air pollution on childhood pneumonia episodes in Abuja, Nigeria, the key aims of this study using a combination of secondary and primary data were:

1. To undertake a systematic literature review to assess the existing literature around the association of indoor air pollution and an episode of childhood pneumonia in low and middle-income countries (Published).

2. To identify areas with a higher incidence of pneumonia and high pollution exposure in Nigeria using the 2013 Demographic Health Survey (DHS) data (secondary data analyses).

3. To investigate the association between PM (1 and 2.5), CO and BC and pneumonia episodes in children under five in Abuja (case control investigation using primary data).

4. To explore health professionals' perspectives on the effect of household air pollution and childhood pneumonia episodes. Exploring, strengths, weaknesses, gaps and opportunities within the healthcare system (primary qualitative data from key informant interviews).

By adopting a mixed-method approach, a common limitation of quantitative study which is the limited ability to explain the 'how' or 'why' of research findings was compensated for, by the qualitative study. Similarly, as qualitative studies are often more descriptive and provide a limited opportunity for applicability of findings due to the small sample sizes, the presence of the quantitative elements balances this out.

A case-control study was an efficient design, in that an entire study population does not need to be followed over time as is needed in a cohort study. The design has the potential to answer the research questions more easily and quickly than cohort or intervention studies without the potential for loss to follow-up. A case control also helped us avoid ethical issues such as the need to intervene in serious problems in prospective cohort studies (e.g. if studying risk factors for severe lower respiratory tract infections researchers may be ethically required to intervene to treat this outcome) or ethical difficulties in conducting randomised controlled trials (e.g. inability to randomise when assessing effects of gestational drug use on children's congenital malformations). This study was carried out over a period of 12 months (January 2018 to January 2019) in Abuja Nigeria.

2 Systematic Literature Review [47].

The main objective of this review was to segregate indoor air pollution into its different constituents and investigate the evidence available on how solid fuel use, $PM_{2.5}$, carbon monoxide (CO), BC and other risk factors individually affect pneumonia episodes in children under five in low- and middle-income countries.

To assess the existing literature around the association of indoor air pollution and an episode of childhood pneumonia in low and middle-income countries, five electronic databases were searched to identify peer reviewed articles, these included EMBASE, PUBMED, EBSCO/CINAHL, SCOPUS and Web of Knowledge. Also, four additional databases were used to identify grey literature including WHOLIS, IRIN, WMO-WHO and IPCC. MESH terms and keywords used in the search include: pollution (pollution, air pollution, indoor air pollution, carbon monoxide, carbon dioxide, nitrogen monoxide, nitrogen dioxide, particulate matter, sulphur dioxide, ozone, volatile organic compound and black carbon) and health (pneumonia, acute lower respiratory infection, respiratory health) and children under five (infant, infancy, new born, baby, adolescent, toddler, paediatric, kids, child, children under five, young people) and finally in low and middle income countries. Reference list of selected papers was hand searched for relevant studies. The search strategy was customised to each database (Appendix 1: Systematic Review search strategy).

The inclusion criteria were set at full-text articles investigating the effect of indoor air pollution on pneumonia in children under 5 residing in low- and middle-income countries (as defined by the World Bank [104]), with a sample size above 100. The inclusion was not restricted by study design, language or year of publication. All qualitative studies were excluded. Selection of studies were not restricted to year of publication or study design. Studies whose outcome measure was either diagnosed pneumonia or confirmed presence of symptoms (fast breathing, fever, cough, and chest indrawing) in children under 5 were included.

The PRISMA guidelines was used for the review process. Also, assessing methodological quality entailed and the risk of bias for each study was done using the Newcastle-Ottawa Scale [105-107] (Appendix 3: NEWCASTLE - OTTAWA QUALITY ASSESSMENT SCALE CASE CONTROL STUDIES). The risk of bias for each study was divided into low, medium, and high across the following domains: selection of participants (selection bias), sample size justification (selection bias), outcome measurement and confounding adjustment.

Identification of literature-based evidence

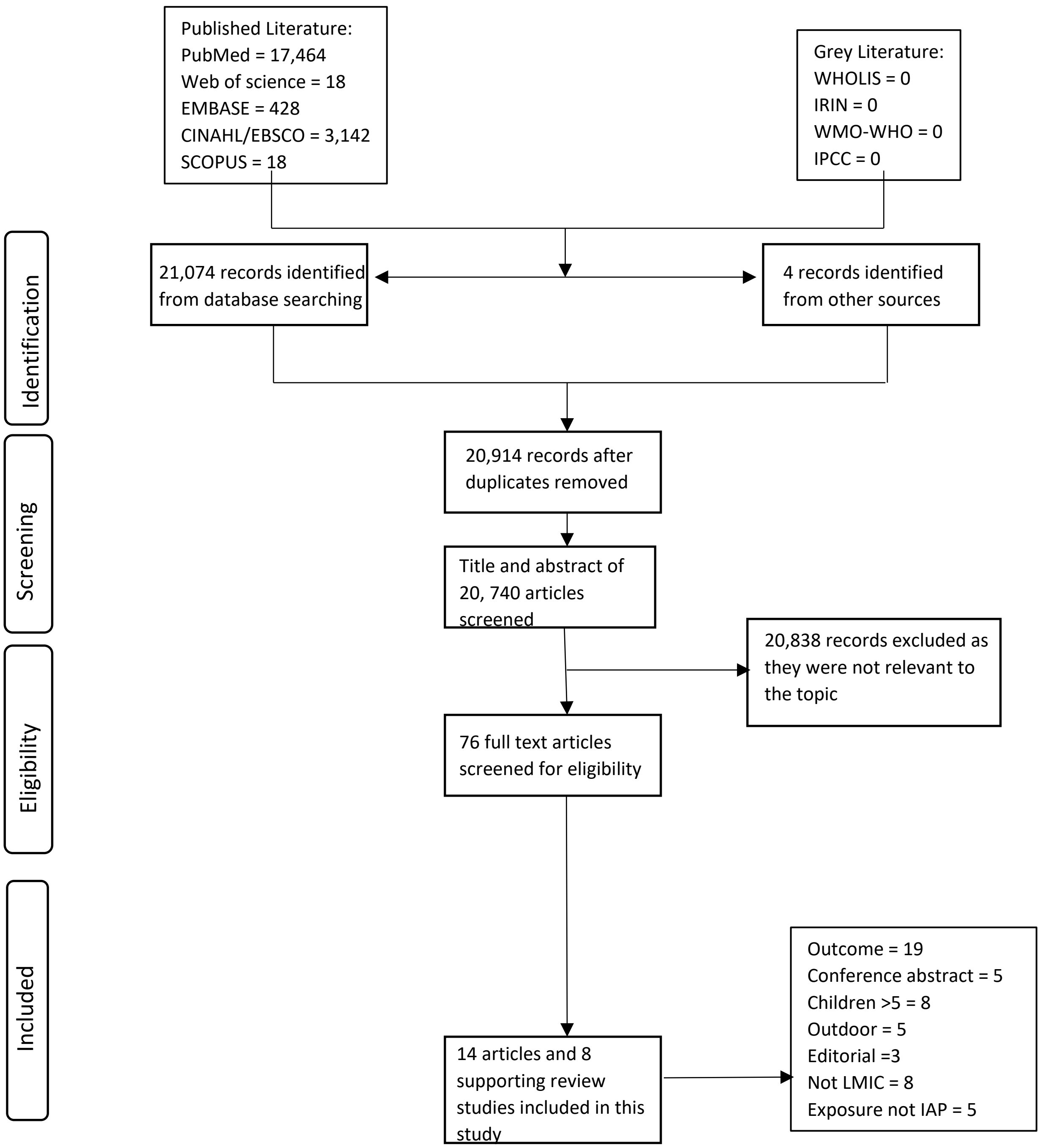

Figure 3: shows the flow of studies from identification to data extraction from databases based on the PRISMA guidelines.

The electronic search resulted in 21,074 papers. All papers were imported into Endnote, and 164 duplicates were identified and removed. After reading through the titles and abstracts 20,838 papers were removed due to lack of relevance to the current study. The remaining 76 papers were selected for full text review, of which 64 were excluded for reasons in appropriate age range (17), non-relevant outcome (15), conference abstracts (8), editorials (4), high-income countries (8) and not focused on indoor air pollution (12). In addition, eight (systematic) review papers were considered relevant and included as supporting documents.

The twenty studies included in this review consists of nine case-control studies [13, 14, 16, 22, 23, 57, 58, 67, 98], one cohort study [15], one cross-sectional [12], one mixed method study[84] and eight reviews [11, 39, 41, 85-89]. The country with the highest number of studies regarding indoor air pollution and pneumonia was India with 4 studies in total [16, 23, 57, 58], followed by Nepal two studies [12, 14], Gambia with two studies [13, 67], Bangladesh with one study [98], Tanzania with one study [22], Indonesia with one study [84] and Botswana with one study [15]. The studies were conducted between 1994 and 2014 with the majority covering the period 2007 – 2014.

The sample size and the age grouping of children under age five years in each study varied and ranged from 117 to more than 600,000 and from age 0 to 60 months, respectively. Majority of the studies were carried out in peri – urban cities, with only two studies looking at both urban and rural [57] and peri urban and rural [14]. Eleven studies collecting primary data [13-16, 22, 23, 58, 67, 84, 98], with only two using secondary data [12, 57]. The main findings from each study are summarized in Table 2. Solid fuel use was found to be significantly associated with childhood pneumonia in a majority of the studies (eight studies, 67%) [12, 14-16, 22, 23, 57, 58]. Exposure to particulate matter ($PM_{2.5}$) showed no significant association in two studies (17%) [84, 98]. Also, exposure to carbon monoxide (CO) showed no significant association in two studies (17%) [13, 67].

Because of the discrepancies in the objectives and designs of the studies included in the review, it was difficult to summarize the findings. Literature description was done in four subsections according to exposures investigated which includes solid fuel use, CO, $PM_{2.5}$ and general risk factors.

2.1 Exposure to Solid fuel use

Six (50%) studies investigated the association between solid fuel use and childhood pneumonia. All six studies found positive associations between solid fuel use and childhood pneumonia. Boor *et al* (2001) from India reported that any cooking fuel other than liquid petroleum gas was associated with pneumonia in children under five (OR 2.5: 1.51-4.16). Karki *et al* (2014) from Nepal identified a significant association for the type of cooking fuel (chulo) used in the household with increased pneumonia in children (OR 3.76: 1.20-11.82). Furthermore, Bassani *et al* (2010) from India reported that solid fuel use significantly increased all cause child mortality for boys (PR 1.30: 1.08-1.56) and girls (PR 1.33: 1.12-1.58), also, association with non-fatal pneumonia was observed for boys (PR 1.54: 1.01-2.35) and girls (PR 1.94: 1.13-3.33). Kelly *et al* (2015) from Botswana found that household use of wood as a common fuel, increased the risk of pneumonia treatment failure at 48 hours (RR 1.44: 1.09-1.92). Dhimal *et al* (2010) from Nepal established a total of 1284 daily adjusted life years (DALY) were lost due to pneumonia and about 50 percent of it was attributed to indoor smoke from solid fuels used for cooking. Sharma *et al* (1998) from India stated that pneumonia was common across all study groups using both kerosene and wood as sources of fuel. In contrast, PrayGod *et al* (2016) from Tanzania reported that fuel type was not significantly associated with pneumonia. Shibabta *et al* (2014) from Indonesia also confirmed this by reporting that the use of unhealthy cooking fuels was not significantly associated with pneumonia.

2.2 Exposure to CO

Two out of the twelve studies investigated the effect of carbon monoxide (CO) on childhood pneumonia. Howie *et al* (2016) from Gambia found no association between pneumonia and individual CO exposure as a measure of indoor air pollution in households. Furthermore, Dionosio *et al* (2012) from Gambia also found no association between CO and childhood pneumonia. However, Dionosio observed that burning insect coils, using charcoal and measurement done during the rainy season were associated with higher exposure to CO.

2.3 Exposure to $PM_{2.5}$

Two out of the twelve studies investigated the effect of particulate matter with Particles less than or equal to two and half micrometres in diameter ($PM_{2.5}$) on childhood pneumonia. Out of the ten studies that looked at $PM_{2.5}$, only two directly measured $PM_{2.5}$ [84, 98], whilst eight used solid fuel use as a proxy indicator for $PM_{2.5}$ [12, 14-16, 22, 23, 57, 58]. Ram *et al* (2014) from Bangladesh found no association between $PM_{2.5}$ and childhood pneumonia. However, Ram stated that, particulate matter exposures were higher in cooking and living spaces of case households. In bivariate analysis, cooking spaces of case households were 1.64 times more likely to have $PM_{2.5}$ exceeding 100 µgm-3 for four or more hours than those of control households. Similarly, cooking spaces of case households were 1.70 times more likely to have $PM_{2.5}$ exceeding 250 µgm-3 for one or more hours than those of control households; living spaces of case households were 1.65 times more likely to have $PM_{2.5}$ exceeding 250 µgm-3 for 30 or more minutes than those of control households. There was no significant relationship between increasing duration of hours that $PM_{2.5}$ exceeded 100 µgm-3 or 250 µgm-3 in either location or pneumonia case status. None of the $PM_{2.5}$ measures was significantly associated with pneumonia in multivariate analysis. Shibata *et al* (2014) from Indonesia also confirmed this as there was no association found between $PM_{2.5}$ levels when cases were compared with controls.

Table 2: Studies showing association between indoor air pollution and childhood pneumonia

No	Country	Name/ Year of study	Setting	Study design	Study period	Primary/secondary data	Age in months	Exposure	Data collected using	Sample size	Outcome Parameter	Main result
1	India	Broor *et al* . 2001 [58]	Peri-urban	Case-control	March 95 – February 97	Primary	<60	Solid fuel use	Questionnaire	512	Single disease episode	Cooking fuel other than LPG (OR 2.5: 1.51-4.16)
2	India	Sharma *et al* 1998 [23]	Peri-urban	Case-control	November 1994-February 1995	Primary	<12	Fuel used for cooking	Questionnaire	642	Multiple Disease episode	Pneumonia was the most common illness in both fuel groups used at home for both wood and kerosene
3	India	Bassani *et al* 2010 [57]	Urban/rural	Case-control	February 1998	Secondary	<48	Solid fuel use	Survey data	616,391	Mortality and Single disease episode	Overall, solid fuel use among children ages 0-4 years with pneumonia was higher than children without pneumonia (Boys PR 1.5: 1-2.4) (Girls PR 1.9: 1.1-3.3)
4	Nepal	Dhimal *et al* 2010 [12]	Peri-urban	Cross-sectional	October 2008-January 2009	Primary and secondary	<60	Fuel used for cooking	Questionnaire	545,777	Single disease episode	The solid biomass fuel was the primary source of energy for cooking which attributed to about 50% of the burden of pneumonia in children
5	Botswana	Kelly *et al* 2015 [15]	Urban/peri-urban	Cohort study	April 2012-April 2014	Primary	<24	Wood smoke exposure	Questionnaire	284	Single disease episode and mortality	Household use of wood as a cooking fuel increased the risk of treatment failure at 48 hours (RR: 1.44, 95% CI: 1.09-1.92, P=0.01). This association differed by child nutritional status (P=0.02), with a detrimental effect observed only among children with no or moderate undernutrition.

6	Gambia	Dionosio *et al* 2012 [13]	Urban/peri-urban	Case-control	July 2007-January 2011	Primary	<60	Exposure to CO	CO Measurement Questionnaire	1181	Single disease episode	The season was associated with exposure in the highest quartile, with an OR 4.2: 3.1-5.7 for measurements in the rainy season compared with the dry season. Children living in homes using purchased firewood or charcoal as the main fuel for cooking have a 2.0(1.2-3.2) or 3.8(2.1-7.1) times increased odds compared to collected firewood.
7	Gambia	Howie *et al* 2016 [67]	Urban/peri-urban	Case-control	June 2007-september 2010	Primary	<60	Exposure to CO	CO Measurement Questionnaire	1581	Single disease episode	No association was found between pneumonia and individual CO exposure as a measure of household air pollution. Strong evidence was found of an association between bed sharing with someone with a cough and severe pneumonia OR 5.1: 3.2-8.2 and non-severe pneumonia OR 7.3: 4.1-13.1. Undernutrition and pneumonia also had a clear evidence of association OR 8.7: 4.2-17.8
8	Indonesia	Shibabta *et al* 2014 [84]	Urban	Cross-sectional	June 2011-june 2012	Primary	<60	Measured PM2.5 and PM10	PM2.5 Measurement Questionnaire	461	Single disease episode	Hourly sampling showed significant differences in PM2.5 and PM10 concentration between households in which children with pneumonia lived compared with controls.
9	Bangladesh	Ram *et al* 2014 [98]	Urban	Case-control	March 2009-March 2010	Primary	<60	Exposure to PM2.5	PM2.5 Measurement Questionnaire	994	Single disease episode	PM2.5 was not significantly associated with pneumonia. However, crowding, tin roof in living space, low-socioeconomic status and being a male child were associated with pneumonia

10	India	Mahalanabis *et al* 2002 [16]	Urban/peri-urban	Case-control	December 1997-Noverber 1998	Primary	<35	Risk factors	Questionnaire	262	Single disease episode	Solid fuel use OR 3.97: 2-7.88 compared to not using any solid fuel for cooking
11	Nepal	Karki *et al* . 2014 [14]	Peri-urban and Rural	Case-control	June 2012-May 2013	Primary	<60	Risk factors	Questionnaire	200	Single disease episode	Using solid fuel with location within living area (OR 3.76:1.20-11.82)
12	Tanzania	PrayGod *et al* 2016 [22]	Urban/peri-urban	Case-control	May 2013-March 2014	Primary	<60	Behaviour	Questionnaire	117	Single disease episode	Increased risk of severe Pneumonia was associated with cooking indoors OR 5.5: 1.4-22.1 compared to cooking outdoors

2.4 General risk factors associated with childhood pneumonia

General risk factors included, undernutrition, cooking location, bed sharing, number of people sleeping in a room, number of siblings, cross-ventilation and season. From all the general risk factors investigated within each study, Howie found clear evidence of association between undernutrition and pneumonia (OR 8.7: 4.2-17.8). Karki *et al* (2014) from Nepal, found that cooking inside the house increased the risk of pneumonia almost 4 times (OR 3.76: 1.20-11.82).

Mahalanbis *et al* (2002) from India, described a strong association between bed sharing and severe pneumonia (OR 5.1: 3.2-8.2) and non-severe pneumonia (OR 7.3: 4.1-13.1). Howie *et al* (2016) from Gambia found strong evidence was found of an association between bed sharing with someone with a cough and severe pneumonia (OR 5.1: 3.2-8.2) and non-severe pneumonia (OR 7.3: 4.1-13.1). Ram *et al* (2014) from Bangladesh reported four or more people sleeping in a room was significantly associated with pneumonia (OR 1.60: 1.18-2.18). However, PrayGod *et al* (2016) from Tanzania reported no significant association between the number of people sleeping in a room and pneumonia (OR 1.1: 0.7-1.7). Furthermore, Mahalanbis *et al* (2002) from India didn't find any association between numbers of siblings and increase in disease episodes. However, Broor *et al* (2001) and Bassani *et al* (2010) both from India reported having 4 or more siblings was significantly associated with all-cause mortality both for boys (PR 1.44: 1.18-1.76) and girls (PR 1.76: 1.43-2.10).

Ram *et al* (2014) from Bangladesh reported that having a cross ventilated living area would be protective (OR 0.72: 0.53-0.98). The living space in case households was 28% less likely than in control households to be cross-ventilated.

Bassani *et al* (2010) from India, Dionosio *et al* (2012) from Gambia, Howie *et al* (2016) from Gambia, Sharma *et al* (1998) from India and Shibata *et al* (2014) from Indonesia considered seasons in their study. Out of the five studies that took season into account, Bassani *et al* (2010) from India reported solid fuel use to be higher in children that died compared to living children between ages one to four in the same geographical area in winter months. Dionosio *et al* (2012) from Gambia also reported that cooking with biomass fuel indoors or an enclosed cook house rose to 84% during the rainy season compared to dry season. However, Howie *et al* (2016) from Gambia only matched participants based on season to account for the influence it might have on the study. Finally, Sharma *et al* (1998) from India and Shibata *et al* (2014) from Indonesia only took measurements during the winter and dry seasons respectively accepting that the complete seasonal influence within these studies is unknown.

Table 3: Overview of included studies and summary of variables adjusted for within each study

	Study			*Adjusted For*								
No	Country	Name/ Year of study	Definition of air pollution	Pneumonia measurement	Access to care	Immunization	undernutrition	Exclusive breastfeeding	LBW	No of siblings	Marital status	Occupation SES
1	India	Broor *et al* . 2001	Use of solid fuel	Syndromic	✔	✔	✔	✔		✔		✔
2	Botswana	Kelly *et al* 2015	Use of wood as fuel	Syndromic	✔		✔		✔			✔
3	India	Sharma *et al* 1998	Types of fuel used at home	Syndromic	✔	✔	✔					✔
4	Nepal	Karkis *et al* . 2014	Condition of home environment	Presumptive	✔	✔		✔			✔	✔
5	India	Mahalanabis *et al* 2002	Condition of home environment	Presumptive	✔			✔	✔	✔		✔
6	Bangladesh	Ram *et al* 2014	Concentration of PM2.5	Presumptive	✔							✔
7	India	Bassani *et al* 2010	Use of solid fuel							✔		✔
8	Gambia	Dionosio *et al* 2012	Exposure to CO	Presumptive	✔							✔
9	Gambia	Howie *et al* 2016	Exposure to CO	Presumptive	✔	✔	✔	✔	✔			✔
10	Tanzania	PrayGod *et al* 2016	Condition of home environment	Both syndromic and Presumptive	✔	✔	✔				✔	✔
11	Nepal	Dhimal *et al* 2010	Types of fuel used at home	Both syndromic and Presumptive	✔			✔				✔
12	Indonesia	Shibabta *et al* 2014						✔				✔
				Total	(11, 92%)	(5, 42%)	(5, 42%)	(6, 50%)	(3, 25%)	(3, 25%)	(2, 17%)	(12, 100%)

No	*Parents smoke*	*Parents education*	*Religion*	*Kitchen location*	*Cooking fuel type*	*Cook area*	*No sleeps in room*	*ventilation*	*House material*	*Source of drinking water*	*Season*	*Associated variables*
1	✔	✔			✔				✔			Exclusive breastfeeding, undernutrition, fuel type and Immunization
2		✔			✔		✔			✔		Cooking fuel type used and undernutrition
3		✔			✔		✔				✔	Cooking fuel used, parents education and Immunization
4	✔			✔	✔	✔						Kitchen location and cook area
5	✔	✔			✔				✔			Cooking fuel type used and occupation SES
6	✔					✔	✔	✔	✔			Number of people sleeping in a room, occupation SES, house material and ventilation
7		✔	✔		✔	✔			✔	✔	✔	Parents education, number of siblings, house material and cooking fuel type
8	✔				✔	✔					✔	Occupation SES, cooking fuel type and season
9		✔			✔		✔			✔	✔	Undernutrition and Bedsharing
10	✔	✔	✔	✔	✔	✔	✔					Cook area
11	✔				✔							Cooking fuel type
12	✔	✔			✔						✔	Exclusive breastfeeding
	(8, 67%)	(8, 67%)	(2, 17%)	(1, 17%)	(11, 92%)	(5, 42%)	(5, 42%)	(1, 8%)	(4, 33%)	(3, 25%)	(5, 42%)	

2.5 Supporting studies on indoor air pollution and pneumonia

Sonego *et al* 2015; Heather J. Zar and Thomas W. Ferkol 2014 and Rudan *et al* 2008 investigated the risk factors responsible for childhood pneumonia within low and middle income countries, all studies showed that indoor pollution was an important risk factor responsible for increase in childhood pneumonia based on their reported findings. Sonego reported OR of 3.02 (2.11-4.31). Heather and Rudans study also concluded that childhood pneumonia can be prevented by improving nutrition, comprehensive immunisation, better living conditions to prevent crowding, avoidance of tobacco smoke and indoor air pollution exposures and finally, applying measures to prevent and treat HIV in low and middle income countries. Buchner, H and Rehfuess (2015) found that Indoor cooking and season was significantly associated with childhood pneumonia with OR during the rainy season to be 1.80 (1.30-2.50) and OR during the dry season to be 1.51 (1.09-2.10). Bruce *et al* (2013) focused on the type of fuel used and exposure to biomass smoke. Jackson *et al* (2013) reported exposure to indoor air pollution from the use of biomass fuels for cooking was associated with childhood pneumonia OR 1.57 (1.06-2.31). Dhereni *et al* (2008) conducted a meta-analysis using 25 studies reported that fuel used at home, living environment and behaviour could influence the quality of indoor air in low- and middle-income countries. Dhereni *et al* (2008) reported that the use of unprocessed solid fuel was associated with childhood pneumonia OR 1.8 (1.5-2.2) in low- and middle-income countries. Finally, Smith *et al* (2000), confirms a strong association between household biomass fuel and pneumonia episodes in children OR 3.02 (2.11-4.31) in low- and middle-income countries.

Table 4: Reviews focused on the association between indoor air pollution and childhood pneumonia

NO	*Author, year*	*Study design*	*Age in months*	*Exposure*	*Outcome*	*Key findings*
1	Jackson *et al* 2013 [86]	Systematic review	<60	Use of biomass fuel for cooking	Pneumonia	Exposure to indoor air pollution OR 1.57: 1.06-2.31
2	Dhereni *et al* 2008 [11]	Meta-analysis and systematic review	<60	Behaviour and environment (fuel use)	Pneumonia	Indoor air pollution is associated with pneumonia OR 1.8: 1.5-2.2
3	Smith *et al* 2000 [39]	Critical review	<60	Indoor air pollution	Pneumonia	Confirms strong association between indoor air pollution and pneumonia in children. The risk of pneumonia is strong in households using biomass fuels, presumably because of the high daily concentrations of the pollutants found in such setting and the amount of time young children spend with their mothers doing household cooking
4	Sonego *et al* 2015 [88]	Systematic review	<60	Indoor air pollution	Pneumonia	A strong association between indoor air pollution and pneumonia in children OR 3.02: 2.11-4.31
5	Heather J. Zar and Thomas W. Ferkol 2014 [89]	Review	<60	Environmental risk factor, including indoor air pollution	Pneumonia	Childhood pneumonia can be prevented by improving nutrition, comprehensive immunisation, better living conditions to prevent crowding, avoidance of tobacco smoke and indoor air pollution exposures and finally measures to prevent and treat HIV
6	Bruce *et al* 2013 [85]	Systematic review and meta-analysis	<60	Solid fuel used for cooking	Pneumonia	Reducing exposure to household air pollution could substantially reduce the risk of several child survival outcomes, including fatal pneumonia
7	Rudan *et al* 2008 [87]	Systematic review	<60	Indoor air pollution	Pneumonia	A strong association between indoor air pollution and pneumonia in children OR 1.8
8	Buchner, H and Rehfuess 2015 [41]	A Cross-Sectional Multi-Country Analysis	<60	Risk factors (indoor air pollution)	Pneumonia	A strong association between indoor air pollution and pneumonia in children OR 2.17: 1.09-4.33

2.6 Discussion of systematic review findings

Over the past 17 years, an increasing number of studies have investigated the role of indoor air pollution and its effect on childhood pneumonia in children below the age of five. Twelve of these studies have mainly focused on particulate matter ($PM_{2.5}$) [11-16, 22, 23, 39, 41, 57, 58, 67, 84-89, 98], solid fuels and general risk factors within low and middle-income countries. This has led to a greater understanding and better management of the disease over the years. Pneumonia-related deaths are decreasing. In 2000 mortality rates was 1.7 million, but has fallen to 920,000 globally in 2015 [108]. Undeniably, compared to mortality rates in other common paediatric diseases such as measles, HIV and malaria, pneumonia associated mortality rates has had a significantly slower rate of reduction [108].

Results from this review confirm the role exposure to indoor air pollution plays in childhood pneumonia. Ninety percent of all the studies included in this review reported that solid fuel use was significantly associated with increased incidence of childhood pneumonia. However, 10% reported no significant association between solid fuel use and risk of childhood pneumonia. These discrepancies in the results might be due to the different study designs and sample sizes used. Also, when indoor air pollution is measured the association fails to reach statistical significance. However, when solid fuel is used as a proxy a larger more significant association is observed. This could be due to equipment used in the measurement of pollution, study power and also lower quality study designs. Nonetheless, there is evidence suggesting a link between solid fuel use and incidence of pneumonia in children. There is a need to improve the study designs and first investigate the solid fuel meditated pollutant components for each fuel type and then investigate the relationship with pneumonia incidence.

Studies where CO was used as a proxy for pollution, showed no association on childhood pneumonia. Although solid fuel use has been shown to have a strong association with increased child CO exposure, there is no evidence to suggest the link to disease incidence. However, more studies need to be done to elucidate the validity of CO exposure as a metric for pneumonia incidence in children. Especially given the emergence of improved methods of measuring indoor CO exposure [109, 110].

Children with higher exposure to particulate matter were at a higher risk of developing pneumonia compared to children with less exposure. It is important to note that this association of $PM_{2.5}$ and incidence of childhood pneumonia was observed when biomass fuel use was used as a proxy for $PM_{2.5}$ and not when $PM_{2.5}$ was directly measured [14, 23, 87, 88]. $PM_{2.5}$ as an effective exposure metric in health outcome studies has been contested [111]. Furthermore, results from this review showed that cooking and living spaces had higher levels of $PM_{2.5}$ in cases houses compared to controls [14, 22, 84]. Crowding was more common in the houses of cases compared to controls [98]. All these suggest a link between polluted indoor air and pneumonia incidence. However, these studies could not directly link measured $PM_{2.5}$ with childhood pneumonia after multivariate analysis did not reach statistical significance. It is therefore important to look closely at the components of $PM_{2.5}$ that might be better exposure metrics to investigate. For example, Black Carbon, which is produced following the incomplete combustion of solid fuels, has shown higher association with disease incidences in studies where the direct association between $PM_{2.5}$ did not show more association [112, 113]. So far, no study has looked at black carbon (BC) and childhood pneumonia. Therefore studies looking at the influence of indoor air pollution and childhood pneumonia in the future should account for individual components of $PM_{2.5}$ such as PM_1 where possible and BC [72].

Other risk factors that showed possible association with childhood pneumonia were season where there was an increased risk of pneumonia (OR 4.2: 3.1-5.7) in the rainy season compared to the dry season (Kelly *et al*. 2015), bed sharing with someone with a cough increased the risk of severe pneumonia (OR 5.1: 3.2-8.2) and non-severe pneumonia (OR 7.3: 4.1-13.1) (Howie *et al*. 2016). Also, under-nutrition was associated with childhood pneumonia (OR 8.7: 4.2-17.8) (Howie *et al*. 2016). Finally, crowding and building materials showed significant association with childhood pneumonia (Ram *et al*. 2014).

Strengths and limitation

This review looked at the individual constituents of indoor air pollution and how they affect pneumonia in children under five. The search strategy was designed to be extensive and at all stages, minimise chance and bias by excluding studies with fewer than 100 patients. The review was not restricted by language, study design or year of publication and took into account published and unpublished material from nine databases. Studies, where secondary data was used, should be interpreted with care because data from national surveys were collected for other objectives. Studies where caregivers or study personnel followed an outcome definition of pneumonia with at least one precise sign of as described by the WHO were included. There was no standard definition of pneumonia, which could mean some of the impacts of indoor air pollution may remain under or over reported.

A limitation with comparing all of these studies is the lack of standardization of methods used. The air quality measurements could have been influenced by the equipment and study design used in each study. Not all air quality equipment and study design can give a comprehensive overview of the indoor environment, which will often require continuous measurements with detailed activity monitoring.

Seven of the twelve studies based their diagnosis on a qualified personnel's objective assessment of pneumonia, with two looking at symptoms. The risk of disease misclassification bias cannot be ruled out given that none of these studies used radiological confirmation of pneumonia. Probably, this could be the reason for some of the findings of the review with regards to association between exposure to pollutants and childhood pneumonia as an outcome. Methodologically none of these studies was fit to assess causality or dose-effect relationship. Majority of the studies were conducted in rapidly progressing peri-urban areas. Nonetheless, none of them investigated the interaction between outdoor and indoor air quality and their potential combined impacts on childhood pneumonia.
Results from the systematic review conducted proposes an urgent need for direct measurement of BC as an indoor air quality indicator. BC, as suggested by other researchers, could be an important exposure assessment tool for future health studies because currently, researchers might be underestimating the true health effect of indoor air pollution by focusing only on PM [47, 114]. Therefore, in order to address these gaps, this dissertation expands the investigation to include PM_1 and black carbon (BC).

The findings from the systematic literature review helped inform the design of the household questionnaire and variables included in the primary and secondary data collection and analysis. The next chapter expands on and explains the methods used for analysis of the 2013 DHS data. Also, the data collection and analysis of the case control and key informant interviews with healthcare professionals.

3 Research Methods

This chapter presents an overview of the methods used for data collection for the overall study. This includes DHS survey, case-control investigation and key informant interviews. The DHS component was on the national level, whilst the case control was at the household level and key informant interviews with healthcare professionals were conducted at the healthcare facility level.

This chapter describes the study area and study design in depth for all study objectives. A full data management protocol is explained, including collection, storage, analysis and dissemination for the three components (DHS, case-control and key informant interviews with healthcare professionals) of the study. Finally, the chapter ends by describing the ethical and in country clearances obtained from relevant departments before the commencement of the study.

Table 5: Overview of research questions, methods adopted and sample size.

NO	Research question	Method	Sample size
1	To identify areas with a higher incidence of pneumonia and high pollution exposure in Nigeria using the 2013 Demographic Health Survey (DHS) data.	Spatial analysis techniques	757 children under five
2	To investigate the association between specific indoor air pollutants ($PM_{2.5}$, PM_1, CO and BC) and pneumonia episodes in children under five.	Case control study	150 cases and 140 controls
3	To explore health professionals' perspectives on the effect of household air pollution and childhood pneumonia. Exploring, strengths, weaknesses, gaps and opportunities within the healthcare system	Semi structured interviews	19 healthcare professionals

Research Design

DHS data was obtained from the Demographic and Health Surveys Program after approval was granted. For the case-control, air quality monitoring data were collected by the lead researcher and trained research assistants. The lead researcher collected the qualitative data during the interviews of healthcare providers and professionals through semi-structured interviews Figure 4.

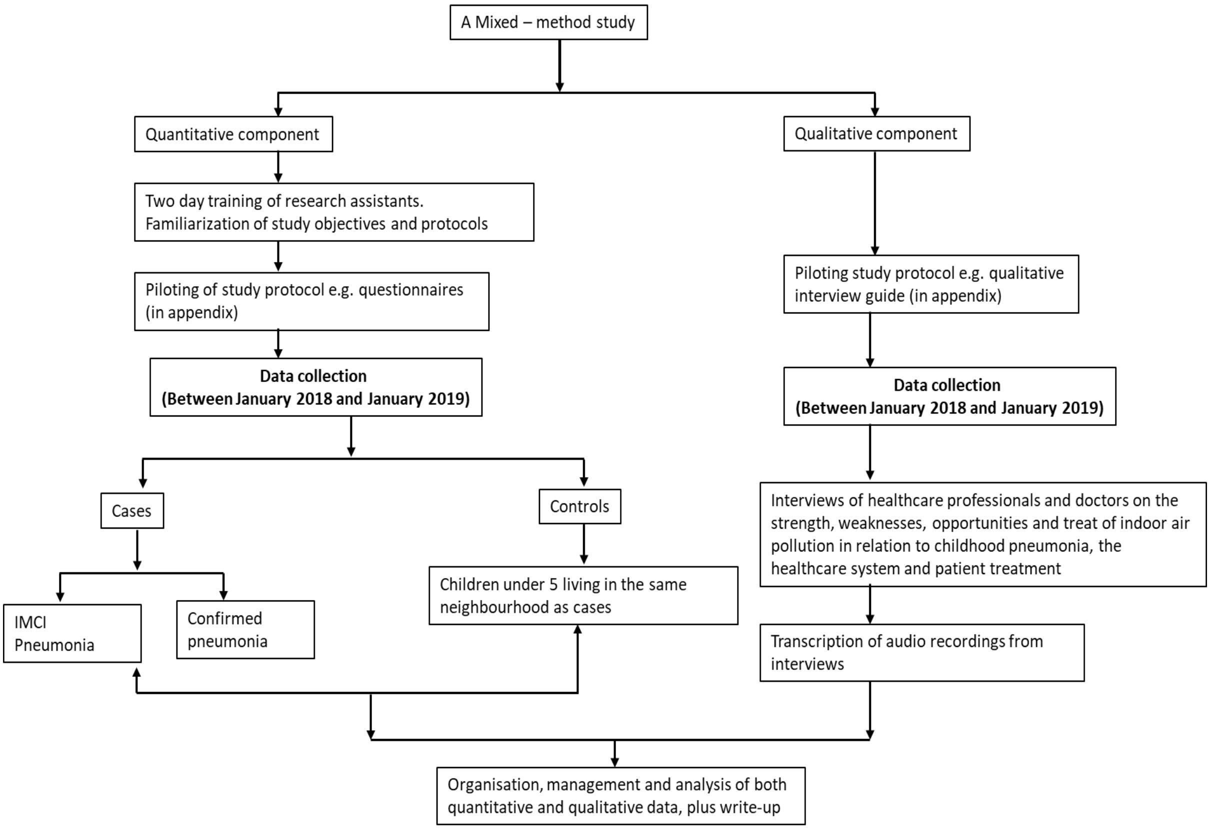

Figure 4**:** Flowchart showing the various research stages for primary data collection.

3.1 2013 Demographic Health Survey (DHS) data

National and subnational representative data from Nigeria were obtained from the 2013 Demographic Health Survey (DHS) [115, 116]. The extracted data included information on age, socio economic status (SES), education, health status of children, and household characteristics. Data also included immunization (BCG, DTP, Polio, and measles) information of children under five years of age. Children were considered to have had ARI in the past two weeks if the mother or caretaker reported all four of the following symptoms: cough event in the last 2 weeks, fever event in the last two weeks; a cough which was accompanied by short rapid breaths; problem in the chest. A child with all four symptoms were flagged as having ARI. Within this cohort, children with ARI were compared with other children without ARI albeit with similar characteristics (i.e. religion, socio economic status, age, education, season, housing, and health seeking behaviour). Using spatial analysis, this study provides a spatial explicit estimation of the effect of biomass cooking fuel and $PM_{2.5}$ exposure to ARI occurrence on a national scale.

Household section of the questionnaire was used to extract information on building materials (floor, roof, and wall), number of rooms, type of settlement (urban or rural) and type of cooking fuel and cooking location. Full description of the questionnaire can be found on the DHS project web site [115]. Geographical positions of sampled locations were also provided but with a displacement of up to 20km to avoid site identification. DHS also provided several environmental and demographic parameters (e.g., vegetation indices, population density, annual precipitation, and annual temperature) information for each geo-located location extracted from several remote sensing sources [117].

Remote sensing data

Global Human Settlement Layer (GHSL) raster with information about percentage of area covered by built-up area was downloaded from the site of the European commission [118]. Map reporting the fraction of houses categorized as 'improved' were obtained from the Malaria Atlas Project's website (https://malariaatlas.org/, Tusting *et al*. 2019 [119]. Tusting *et al*. consider as 'improved' those household having all four of the following characteristics: improved water supply; improved sanitation; less than three people per bedroom; and house built with finished materials (i.e. concrete, brick, tiles).

Aerial information about level of $PM_{2.5}$ was obtained from the SEDAC website [120, 121]. We set a threshold of $10\mu/m^3$ as set by the World Health Organization (WHO) [122, 123]. Data on map of cumulative human pressure on the environment (human foot print) to quantify human disturbance to natural system was reported by Venter *et al*. [124]. Treatment seeking, as percentage of feverish children for whom treatment was sought, were obtained as raster data 2018 by Alegana *et al*. [125]. High resolution data on children population count and percentage of total population living in poverty for the year 2013 were obtained as raster from World Pop's website [126].

Statistical analysis for DHS

Matching procedure was applied to create a homogeneous group of children based on variables used to adjust models performed to assess the impact of biomass fuel on respiratory infection, as listed and reported by Adaji *et al* [47]. Children were matched by gender, religion, mothers´ education and marital status, wealth of their household, and BCG, Polio, DPT, and measles vaccinations [47]. The matching procedures allowed to reduce the number of variables to include in a model by 'matching' individuals by creating groups based on a set of characteristics [127, 128]. The database with matched children was used to build a model to assess the effect of biofuel and $PM_{2.5}$ on the occurrence of ARI.

The modelling approach was based on structural additive regression (STAR) model [129]. This model structure allows including linear and non-linear predictor effects. Each model included a spatial spline to take into account the spatial autocorrelation of the DHS data. Model selection based on the Aikaike Information Criteria (AIC) was performed to select the model formula with the highest performance [130].

Model formula:

$$ARI\ (0,1) = ENVIR + HOUSE + COOKING + SMOKE + PM_{2.5} + CLUSTER_{SPAT}$$

Where, ENVIR represented the environmental characteristics (vegetation and percentage of built areas), HOUSE was the variables describing the household (number of rooms, type of wall, type of floor, type of ceiling), COOKING were the variables linked with cooking habits (the type of fuel, presence of kitchen), SMOKE represented smoking behaviour of household inhabitants, $PM_{2.5}$ was the level of $PM_{2.5}$ of the area, $CLUSTER_{SPAT}$ was a spatial random effect represented by a geospatial spline. All tested models were adjusted by the interview month. The best models were used to investigate the effect of biomass fuel on the risk of ARI and were also used to perform prediction to create maps showing the areas in which biofuel has the greatest impact on ARI. The model was also used to estimate the population attributable risk (PAR) of ARI cases for biofuel and $PM_{2.5}$ per each DHS cluster. The PAR is the proportion of total cases that are associated with the specific risk factor and could have been averted in the absence of exposure [131]. $PM_{2.5}$ was added to the final model as a priori factor having been found to be associated to ARI from previous studies [6, 132-136].

In order to produce a surface map of PAR attributable to biomass fuel and $PM_{2.5}$, we built a second STAR model. The dependent variable of this model was the cluster PAR estimation. The whole model formula was:

$$PAR_{PSU} = IMP\_HOUSE + ELEV + FOOT\_PRINT + POVERTY + ACCESS + EVI + NIGHTLIGHTS + RAINFALL + CLUSTER_{SPAT}$$

where PAR_{PSU} was the PAR of each PSU, IMP_HOUSE was the percentage of improved household, ELEV was the elevation in meters above sea level, FOOT_PRINT was the cumulative human pressure on the environment, POVERTY is the proportion of population with an income below $1.25 a day, ACCESS was the time to reach the first >50,000 people city, EVI was the Enhanced Vegetation Index, NIGHLIGHTS was night time luminosity, RAINFALL was the year total precipitation, and $CLUSTER_{SPAT}$ was a spatial random effect represented by a geospatial spline. The best model was selected using AIC, as described before. The best model was used to create a surface map of PAR for biofuel, $PM_{2.5}$, and combined PAR.

Data management and statistical analyses were performed using R language [137]. Geodata were managed and analysed using QGIS [138]. All remote sensing raster maps were rescaled to 1km resolution.

3.2 Case Control study (air quality, HH questionnaire and MUAC)

A case-control study design was used for the quantitative component of the study. This design was to allow comparison between pollutants exposures between cases and controls. Analysis and results from the DHS component helped validate study area. Due to the nature of the study a case-control study design allowed for the identification of multiple cases at local hospitals. Controls were identified around the neighbourhood where cases lived. A

Study area

The study location was informed by results from the the Demographic Health Survey in Nigeria as well as the security landscape of Nigeria at the time of the research. Following the results acquired from the secondary analysis of the Demographic Health Survey (DHS) the North East and the South West were regions with the highest associations of indoor air pollution and ARI (refer to section 3.1). The North East region experiences high levels of terrorist activities with the average experience of violence at 73% from 2010 to 2017 [139]. Similarly, the South-South is characterized with militant activities and kidnappings which accounts for 87% of the conflict in these communities [139]. However, due to security challenges across the country the researcher couldn’t investigate pollution exposures in those locations. The indoor exposure levels across many parts of the country observed through the DHS study was exceeding the WHO requirements. Hence, the researcher chose

Abuja as a primary location of investigation. Abuja is the fastest growing and most westernized city in Nigeria.

Nigeria has a total population of over 200 million as of August 22, 2020 [140]. Seventeen percent of the Nigerian population are children under five [141]. Abuja is the federal capital territory of Nigeria. Abuja is referred to as the fastest growing and most westernized city in Nigeria [142, 143]. Surrounding states include Kogi, Niger, Kaduna and Nasarawa States. Abuja is located between longitude 7.483333°E and latitude 9.066667°N, has a total area of 1,769 km^2 (683 square miles). Available data from Bwari and Municipal area council, suggests children make up 38% of the of the city's total population [143]. The city comprises of a mixture in socio economic status and infrastructural settlements. Hence, the reason for interest, as it provides an opportunity for a comparison of exposures to indoor pollution and disease outcomes across different settlements. The World Health Organization (WHO) standard for indoor air quality (25 µg/m^3) would be used as a baseline comparator for indoor air pollution [144].

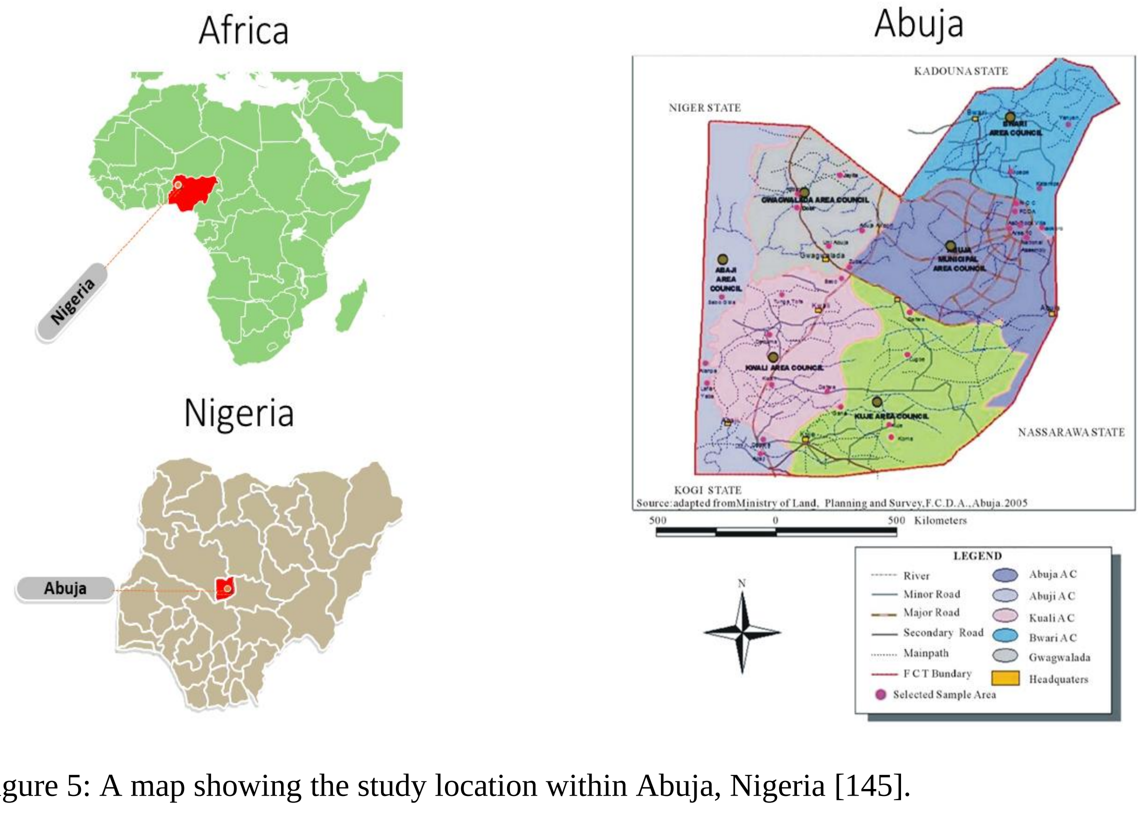

Figure 5: A map showing the study location within Abuja, Nigeria [145].

Recruitment of study participants

At the execution of the project, eleven (11) general hospital were covered in Abuja. All PHC (seven) had primary health workers (PHWs) that provided basic health services both precautionary and curative (i.e. antenatal care, immunisation, child growth monitoring). Common illnesses were treated including diarrhoea, malaria and pneumonia. In some cases, family planning, sanitation and hygiene, and referrals to higher secondary and tertiary hospitals were carried out.

Data was collected on demographic, socioeconomic status, environmental, nutritional and health information. Also, information on the health status of the child from parents and issues relating to pneumonia and undernutrition as defined by the WHO [146].

For inclusion, children were to be aged between zero and five years. They must have lived in Abuja for the last five years and parents must have not moved houses in the last five years. Parents of all children were asked for their informed consent before recruitment into the study.

Diagnosis of pneumonia and recruitment of cases.

Cases were identified either following presumptive diagnosis by healthcare workers or where possible, radiographic confirmation of pneumonia. Cases were referred to our study by medical professionals in the different facilities. And at the end of the month total numbers of cases was collated manually from ward registers.

Diagnosis of pneumonia

Clinically suspected (using IMCI Guidelines) and radiologically confirmed cases of Pneumonia were all included

Cases recruited from general hospitals were diagnosed using chest radiographs (gold standard). Clinically suspected cases were identified as per Integrated Management of Childhood Illness (IMCI) Guidelines. Non-severe pneumonia was defined as the presence of cough or difficulty breathing and fast breathing (60, 50, or 40 breaths per min or higher in those aged <2 months, 2–12 months, and 1–5 years, respectively) [147]. Severe IMCI pneumonia was defined additionally by chest in-drawing, stridor, or any general danger sign (inability to drink or breastfeed, vomiting, convulsions, lethargy, or unconsciousness) [147]. Cases identified from primary health care centres were diagnosed using IMCI guidelines.

The following sampling approach was employed to collect data from a sample representative of the entire population. Applying judgement sampling approach [148, 149], Abuja was selected as the study location. A random sampling approach [150], was used to identify 20 urban and 20 rural enumeration areas within the different council areas. Hospitals and primary healthcare centres from these areas were approached and pneumonia cases recruited into the study. Adopting systemic sampling [150] the addresses of cases recruited from the hospitals were used as the starting point and control houses were identified by knocking every 4^{th} household within the same street where cases lived. If study criteria were not met the process was repeated until a household that met all study eligibility criteria was located. All households with children aged 0-5 were selected and parents were invited to participate.

Control households with children having cough or difficulty breathing, age-specific tachypnea, and auscultatory evidence of crepitation were not included and referred to the hospital for pneumonia tests. For inclusion, they must have lived in Abuja for the last five years and parents must have not moved houses in the last five years. Also, a control must be living in the same areas as a case.

Parents of all children were asked for their informed consent for recruitment into the study. Caregivers for cases, were contacted within one week of identification at participating hospitals and measurements were made within two weeks of identification based on participant availability and consent. Control participants were contacted immediately after consent was obtained from matching cases and measurements were made within two weeks of identification.

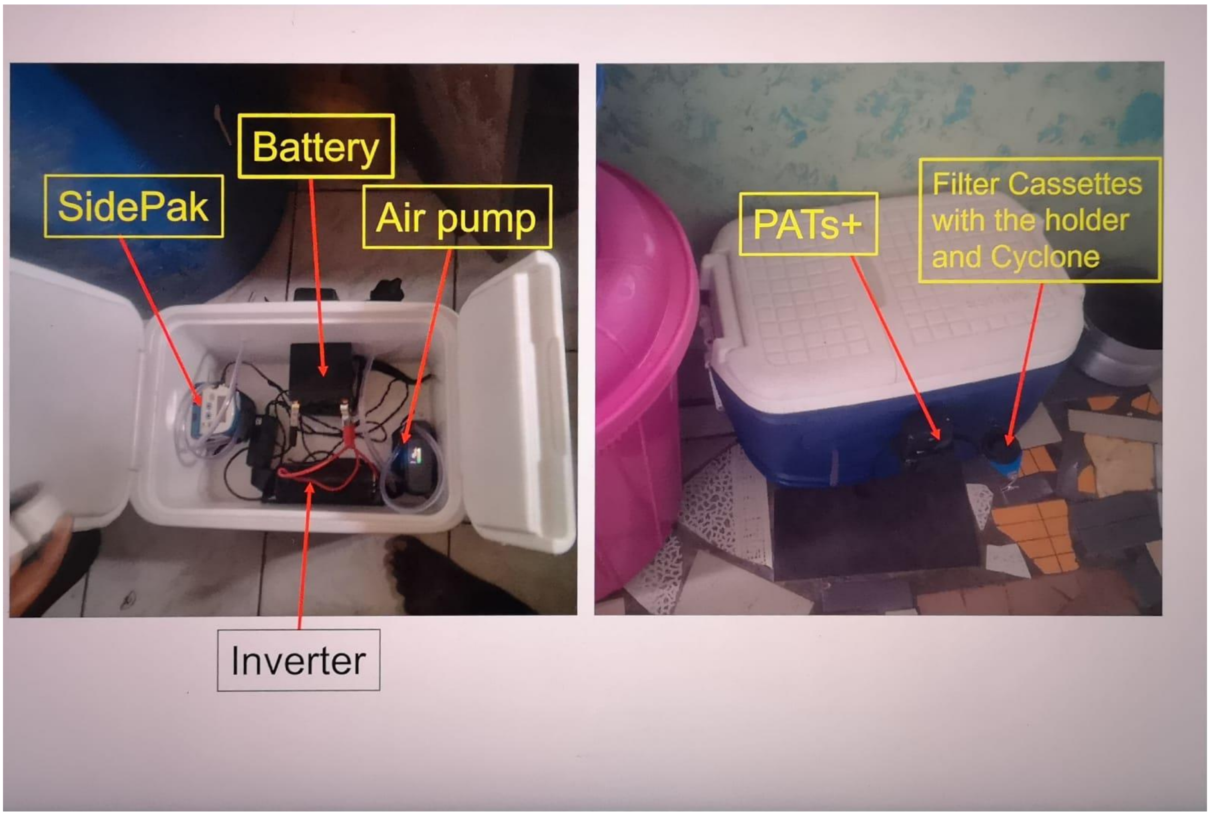

Figure 6: Equipment setup for indoor air measurements (Picture Credit: Author)

Study staff training and piloting research protocol

A two-day training was organized to help the research assistants to fully understand the study. From its rationale to its objectives and finally to its methodology. The training materials included the study protocol, research papers and equipment user manual etc. all these were provided by the lead researcher before the training began. The training ran between 12th – 13th January 2018. On the second day of the training, the research assistants were taught how to go over the questionnaires with both parents and caregivers.

Following training, the study protocol was piloted on the 18th of January 2018. The case was identified from hospital and was contacted for consent to participate in the study; once consent was given a control was identified around the neighbourhood where the case lived. The pilot was crucial to test and validate the study protocols before the commencement of the actual study. After the pilot, the following were identified: The questionnaires were too long and needed to be reduced. The batteries used to support the Sidepak worked perfectly and ran for 24 hours as planned. The equipment was arranged in a cooler in other to minimise noise and avoid tempering. It was difficult to get a perfect time during the week, where the child was at home for measurements. Children were at school when houses were visited this made it hard to carry out physical measurements of the child (height, weight, MUAC). Both families didn't fill the time activity sheet in proper detail and they both ignored the nutrition sheet. The study protocols were then revised based on the findings of the pilot. We tried to make the questionnaire shorter by removing some questions which felt were not relevant. Due to the difficulty around appropriate time for household and hospital visit, the lead researcher could not always be with the research assistants in the field. However, to maintain a stable standard of collected data the lead researcher had to turn up unannounced to supervise their work and data collected to ensure the quality of the data. And to make sure that they adhere to study protocols.

Air quality measurements

Concentrations of carbon monoxide (CO), fine particles ($PM_{2.5}$ and PM_1), and black carbon (BC) was measured. Black carbon was measured and monitored using a cell phone based system developed by NEXLEAF ANALYTICS [151-158]. This involves an optical technique where a photograph of the filter is captured with a cell-phone or a camera and transmitted to a server where an algorithm compares the image (the colour of the filter) with a calibrated scale [151-158]. The BC load is estimated by measuring its reflectance in the red wavelength, based on the "blackness" of the photograph. PM_1 concentrations were measured using a battery-operated SidePak Personal Aerosol Monitor AM510 (TSI Inc, MN, USA) fitted with a PM_1 impactor and set to a calibration factor of 0.30. In accordance with manufacturer's instructions, SidePak devices were cleaned, the impactor re-greased, zero calibrated and the flow rate set at 1.7 l/min before each use. PM_1 measurements were logged at one-minute intervals, with each one-minute data point being an average of 60 seconds of sample measurements. $PM_{2.5}$ and CO was monitored and measured using PATS+ which is a small, portable datalogging device that measures real-time particle concentrations. Its specifications include lower particulate matter detection limit of 10 to 20μg/m^3 upper particulate matter detection limit is 30,000 to 50,0000μg/m^3. Before each PATS+ sampling round, the device was zero calibrated in zero-particle environment for 10 minutes and the CO sensor was calibrated as recommended by the manufacturer. These techniques have been validated in laboratory and household-level applications [151-156] (Figure 6). Air quality measurements were made in the cooking environment.

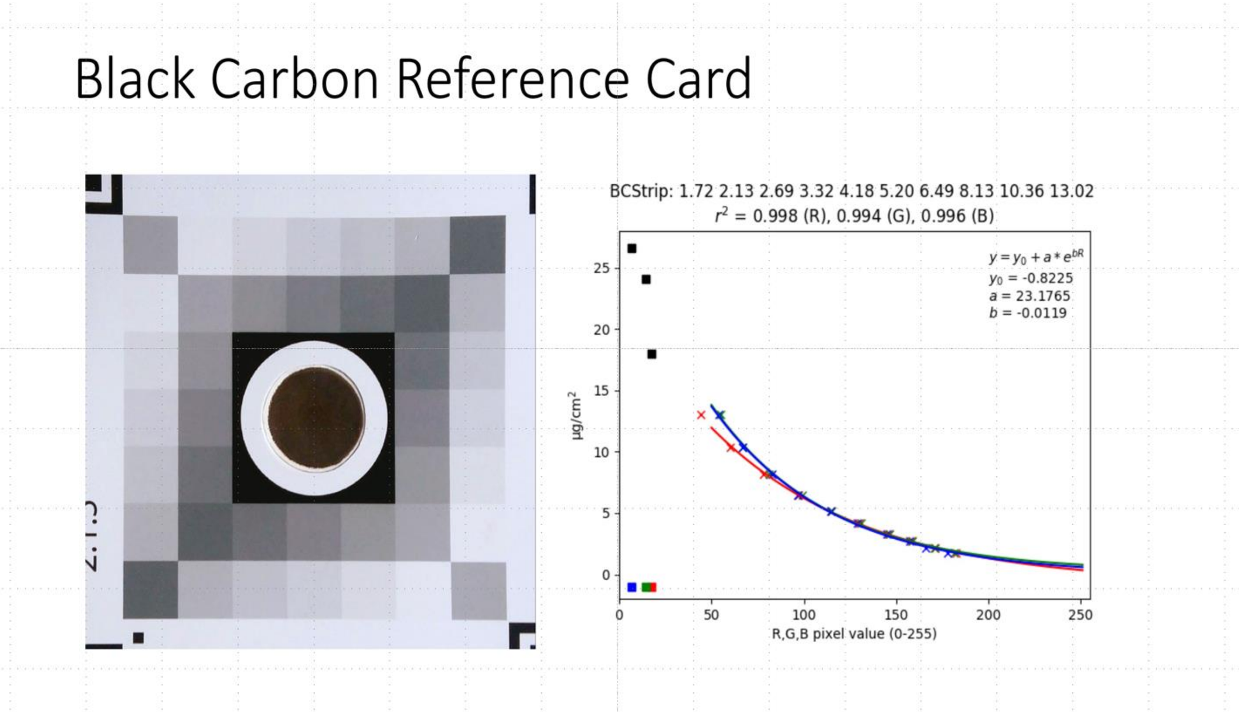

Figure 7: Exposed filter and reference card. Graph showing analytic algorithm with concentration of BC loaded on the filter (NEXLEAF Analytics Black Carbon Portal).

Each set of sampling data was downloaded from their monitors using their manufacturer's software (i.e. Trakpro and Pica software's and NEXLEAF Analytics Black Carbon portal) and transferred to STATA 16 (alongside the unique household ID). Each of the data was measured in a minute-by-minute format, except for PATs+ where the pollutants had measurements second by second, but were then aggregated to minute by minute to compute measures.

Data was matched for control and cases to ensure the same hours were been considered when making comparisons between both groups. For matching, each case was matched to its own control (obtained in the same geographical area). At the stated time points (3 to 24h), both the case and control needed to possess 3h, 15h or 24h measurements to be included in the corresponding analysis at the time point. Data with no matched sample time were discarded, reducing the amount of sampling minutes to compare from 150 cases and 140 controls in total to 112 cases and 112 controls having 3 hours, 112 cases and 112 controls having 10 hours, 112 cases and 112 controls having 15h and 112 cases and 112 controls having 24h measurements. For paired analyses, the percentage change of pollutant (PM_1, $PM_{2.5}$ and CO) concentrations was determined by comparing the mean and median levels overall and in each case and control household. Although data distributions were skewed towards zero, arithmetic mean figures was presented throughout since these are used by the WHO to define their upper guidance limits. To compare differences in exposure to our measures of indoor pollution between cases and controls Wilcoxon signed-rank test was used. This test has been used in similar studies of air quality measurements [159, 160].

Household questionnaires

Information on demographics, socioeconomic status, environmental, structural characteristics of the house and health information of participants was collected using a structured questionnaire. Information on the health status of the child requested from parents on history and issues relating to pneumonia and undernutrition were as defined by the WHO [31, 161, 162]. Although, nutrition was not the main focus of this study. Anthropometry would require training and equipment that would incur more cost. MUAC is an acceptable measure of a rapid status of nutrition [161]. MUAC measuring tapes were used to map the prevalence of undernutrition within the study population. After the pilot study, MUAC was chosen in this study because of measurements could be done quickly increasing participant's willingness to participate [161]. Otherwise, malnutrition would have been measured by the proportion of weight-for-age, height-for-age and weight-for-height below -2 and -3 standard deviations (SDs) (Z-scores). Future studies should use the standard anthropometry measurements for malnutrition.

Data management and analyses

Pre-study power calculations using Epi Info showed that 185 cases and 185 controls would be needed to provide 80% power to detect an odds ratio of 1.8 or greater, assuming the percentage of controls with high exposure is 40%. However, with the available date sample size defined as 100 participating households per group, powered at 83% assuming alpha 0.05 and calculated to detect a 33% difference between pneumonia cases and control households.

First, a comparison of cases and controls based on: age, sex, socioeconomic status, income, immunization, and MUAC, was done using chi-square to assess statistical difference. Also, a comparison of cases and controls in terms of structural characteristics of the house (e.g. number of windows, type of building materials used and type of roofing material used etc.)

and lifestyle factors affecting exposure to pollutants (e.g. time children spent in the cooking environment, fuel type) was done.

We compared cases and controls in terms of mean, range, median, IQR and the proportion of time the $PM_{2.5}$, PM_1 and CO concentration exceeded WHO 24-hour mean $PM_{2.5}$ upper limit of 25μg/ m^3 [144], based on continuous indoor monitoring of 3, 15 and 24 hours each of the specific air pollutant. Finally, to illustrate the sampled $PM_{2.5}$ and BC distribution between pneumonia cases and controls box plots were graphically constructed. All analyses were performed in STATA version 16™ and the confidence level was set to 95% with *p*-values <0.05 considered to be significant.

Given the influence of seasonality on the burden of pneumonia, data were collected throughout a year (January 2018 – January 2019). [163]. Rainy season was designated from April to October 2018, whilst dry season from January to March 2018 and November 2018 to January 2019. As seasonality is important in changing both the composition and concentration of pollutants, a subgroup analysis by season was carried out.

Analysis for quantitative data from case control

Each set of sampling data was downloaded from their monitors using their manufacturer's software (i.e. Trakpro and Pica software's and NEXLEAF Analytics Black Carbon portal) and transferred to STATA 16 (alongside the unique household ID). Each of the data was measured in a minute-by-minute format, except for PATs+ where the pollutants had measurements second by second, but were then aggregated to minute by minute to compute measures.

Data was matched for control and cases to ensure the same hours were been considered when making comparisons between both groups. For matching, each case was matched to its own control (obtained in the same geographical area). At the stated time points (3 to 24h), both the case and control needed to possess 3h, 15h or 24h measurements to be included in the corresponding analysis at the time point. Data with no matched sample time were discarded, reducing the amount of sampling minutes to compare from 150 cases and 140 controls in total to 112 cases and 112 controls having 3 hours, 112 cases and 112 controls having 10 hours, 112 cases and 112 controls having 15h and 112 cases and 112 controls having 24h measurements. For paired analyses, the percentage change of pollutant

(PM_1, $PM_{2.5}$ and CO) concentrations was determined by comparing the mean and median levels overall and in each case and control household. Although data distributions were skewed towards zero, we present arithmetic mean figures throughout since these are used by the WHO to define their upper guidance limits. To compare differences in exposure to our measures of indoor pollution between cases and controls we used the Wilcoxon signed-rank test. This test has been used in similar studies of air quality measurements [159, 160, 164].

3.3 Key informant interviews with healthcare professionals

The aim of the key informant interview component of this study was to understand the knowledge of healthcare providers and professionals in relation to HAP and childhood pneumonia. Also, to capture the current reduction and prevention strategies and explore improvement opportunities within the healthcare system. The philosophical idea behind this study is that the approach of healthcare professionals and providers is largely shaped by their individual perceptions and understanding of guidelines for improving pneumonia outcomes in children. Therefore, these interview gives participants the opportunity to explain and describe events as experienced in their own words, which cannot be achieved through quantitative research alone. The main goal is to understand the approach taken by healthcare providers and professionals in handling cases of pneumonia particularly linked to poor HAP without any preconceived biases or judgement on the accuracy of their responses by the researcher. Both the researcher and healthcare providers and professionals all share a common reality according to social constructionism. Therefore, the researcher has to be open-minded in the meaning generating process as he explores the perceptions of the participants towards HAP and pneumonia.

In qualitative studies, interviews are the most common ways of collecting data. For this study, a face-to-face semi structured interview was the most appropriate that could capture the perception of the healthcare providers and professionals about HAP and pneumonia within the healthcare system. A reflective statement was written before interviews were conducted because interviews are subjective. A reflective statement is a way of acknowledging the different ways bias can be introduced into the study through the researchers' knowledge or background, which may influence their understanding of participants' perceptions. A researcher without a reflective statement can unconsciously impose their beliefs on study participants [165].

The work aimed to gain insights into the perception and experiences of healthcare providers and professionals on HAP and childhood pneumonia also, gaps and opportunities that exist for development within the healthcare system hence why semi-structured interviews with open ended questions were chosen over unstructured interviews. However, if there was little to no qualitative evidence on the perception of HAP and childhood pneumonia in children under five among health care professionals, then unstructured interview would have been best to develop possible questions for imminent studies.

Study participants for the qualitative component

Study participants were healthcare professionals and providers involved with the delivery and management of healthcare in hospitals and primary healthcare centres in Abuja.

For the recruitment of healthcare professionals and providers, a purposive sampling approach was used. A purposive sampling includes participants that meet certain criteria and meets a set of laid out characteristics.

Within our collected sample, the use of purposive sampling allowed us to achieve maximum variability. Healthcare professionals and providers were selected from different professional positions, educational attainment, experience, and training.

As there are no set rules in qualitative research in terms of determining the sample size, Hardon and colleagues [166] recommended realistic criteria to determine the sample size in a qualitative study, bearing in mind the cost and time it takes to interview interviewees and transcribe the interviews. Therefore 10 interviews were the minimum sample size for healthcare professionals and providers in this study considering the factors mentioned above. 20 interviews were the target number for this study, due to the available resources and study timeline, whilst using the technique outlined by Francis and colleagues [167] for identifying saturation. Overall, 19 interviews of healthcare professionals and providers were conducted between January 2018 and January 2019.

Development of interview guides

The researcher developed the interview guides and questions in line with the literature and research questions. To trigger deeper responses, open-ended questions were developed for the healthcare professionals and providers (i.e. medical doctors, nurses, primary health workers, PHC coordinators). The developed research guide was reviewed by two supervisors (RP and MC) and applicable changes were made.

Piloting of study protocol and interview guides

A pilot interview was conducted to test the study materials with two nurses, similar to the main study participants to make sure the questions where clear and could capture the participant's general perception around the questions. The review of the recordings by the researcher led to minor alterations of the initial interview guides. The data from the pilot study was excluded from the main study.

Data collection

The interviews were conducted at the preferred place and time chosen by each participant, as the researcher had to be flexible to suit their convenience. Using the study protocol, the researcher explained the purpose of the study to each participant, but this was brief in order not to influence their answers, thereby introducing bias. It was made clear to healthcare professionals and providers that they were under no obligation to participate in this study and could decline to answer to any question they did not feel comfortable answering. Furthermore, the researcher described confidentiality and anonymity to study participants, with an avenue for questions before interviews commenced.

We received consent from participants to record interviews by the signing of consent forms. If the participant did not understand English, the researcher translated the questions into the more common Pidgin English. A signed copy of the consent form was given to each participant for their record.

Interviews were recorded to give the researcher full concentration during the interview process, and less time writing and jotting. All interviews were uniquely coded 1 – 19 and any linked identifier such as names addresses were removed before analysis commenced.

Analysis for key informant interview data from field study

Thematic analysis

Thematic analysis was used to search, identify, analyse and report themes found within the transcripts of the interviews of healthcare professionals and providers. Before the analysis commenced the researcher had to decide on what approach would be taken to identify themes either inductive or deductive, and the level at which decisions were going to be made either at the semantic or latent level.

For this study, an inductive approach was chosen because unlike the theoretical approach the identified themes are strongly linked to the data itself which eliminates the researchers' biases or use of any prior codes. Furthermore, the thematic analysis on the semantic level was chosen to identify themes at the surface of the data or the literal meaning of participants' responses.

A six-step approach was adopted for the thematic analysis as suggested by Braun and Clarke [168]. This was a fluid process giving the researcher the ability to go back and forth as needed. These six steps are discussed here.

Getting familiar with the data

The researcher began by listening to the audio recordings followed by in-depth transcription of the recording. Transcription was done immediately after interviews in other to cross check against recorded audio files and written filed notes, with the interview fresh in the researcher's mind. This was done a number of times to identify errors when heard until the transcripts reflect the accuracy of the audio files. This process would help the researcher to familiarise himself with the content of each transcript. During meetings, the initial ideas and codes generated were discussed with research supervisors.

Generating initial codes

The initial approaches chosen earlier for thematic analysis were applied in this phase. This involved identifying codes from written transcripts and organising them into different groups. This process was done throughout the entire dataset until all transcripts were coded. Five random transcripts were selected and independently double coded by colleagues to ensure consistency.

Searching for themes

With the use of Nvivo 12 and Microsoft Excel spreadsheet, the codes within the data were sorted into different potential themes and sub-themes and then developed into an initial thematic table from the coded data within the recognised themes and sub-themes.

Review of initial themes

Each theme was further examined for internal and external homogeneity. Internal homogeneity means the data within each theme are related to each other, whilst the existence of clear differences between themes is called external heterogeneity. Therefore, this phase involved reviewing and refining the entire dataset by going through the transcripts over and over again until internal and external homogeneity is reached.

Defining and naming themes

At this stage, the researcher refined and further defined each theme and sub-theme for analysis and where necessary, consulted my supervisors until a consensus was reached. The researcher focused on finding the essential meaning and representation of each theme. At the end of this phase, the researcher had finalised the main themes and sub-themes that emerged from the interviews with healthcare professionals and providers.

Producing the report

Data extracts from the transcripts were used to describe and populate the final themes and sub-themes.

Healthcare professionals and providers were replaced by unique number identifiers (i.e. 1 – 19) when participants were referred to in-text with quotations, and a prefix with the unique number was used to identify which participant was speaking.

3.4 Data confidentiality and storage

Data collected were stored in a secure password protected hard drive and a shared online password-secured study folder created within the University of Nottingham workspace that was only accessible to the lead researcher. The online folder was also used to share collected data with study supervisors during data collection in Nigeria. All hard copies of data including field notes, consent forms, interview guides and questionnaires were stored in a locked filing cabinet in Nigeria.

During the management of both quantitative and qualitative data, participant details were anonymised by dropping personal identifiers (e.g. names, residential addresses, and telephone numbers). After the completion of management and analysis for the study, the database versions were dated for easier identification and transferred to a secure University of Nottingham backup server for storage for a period of seven years as per the University's Code of Research Conduct and Research Ethics.

3.5 Ethics and dissemination plan

Ethics and ethical considerations for study

Prior to data collection, the protocol for both the DHS, case-control and key informant interview components of the study was reviewed and approved by the University of Nottingham Medical School Ethics Committee (Reference number: 134 – 1710) and the National Health research Ethics Committee of Nigeria (Reference number: NHREC/01/01/2007) (Appendix III). All procedures performed in this study were in accordance with the ethical standards of institutional research committees and with the 1964 Helsinki declaration and its amendments.

Dissemination Plan

The work has led to four manuscripts (one published, two under review and one under preparation). One finalised summary results will be provided to the hospitals and PHC especially those participating in the study. Additionally a short workshop for sharing and discussion of findings with health workers and caregivers will also be organised resources permitting.

4 Results

This chapter begins with results from spatial analysis of pneumonia and biomass fuel use in Nigeria using the 2013 Demographic Health Survey (DHS) data. Thereafter the results from the case-control component of continuous air quality monitoring are described and finally the results from the semi-structured interview by key informant are described which helped explain some of the findings from the DHS and case control components.

4.1 Results from the analysis of ARI and biomass fuel use in Nigeria using Demographic Health Survey data

The dataset extracted from 2013 DHS data included 28,950 under five children. A complete description of demographic and household environmental characteristics of the sample population has been already reported by Akinyemi *et al*. [48]. Based on inclusion criteria, 757 (2.6%) children were identified with ARI. The model selection applied to the STAR model and performed after the matching procedures, showed that the best model included the following variables: cooking fuel, $PM_{2.5}$, and type of house. The results of the model are shown in Table 6. Biomass fuel and $PM_{2.5}$ increased the risk of ARI, but only biofuel use was significantly associated with an increase in ARI. Children under five living in household using biofuel had 55% higher odds of developing ARI. The results of the model showed that living in an improved house was associated with a 28% reduction in the odds of ARI.

Table 6: Results from STAR model. The children with ARI symptoms were matched with children without ARI symptoms by religion, marital status of the mother, education, sex, vaccination status, and household wealth index [47]. The model was adjusted by survey month (survey performed from February to March 2013).

Variable	OR (95% C.I.)
Biofuel	1.55 (1.16-2.21)*
$PM_{2.5}$	1.02 (0.96-1.07)
Improved Housing	0.72 (0.54-0.95)**

The PAR calculated at the cluster level identified a strong spatial heterogeneity of the effect of biomass fuel and $PM_{2.5}$ on ARI occurrence (Figure 8). The association of biomass fuel, $PM_{2.5}$, and combined exposure was equal to an increase in odds of ARI of 20.8 % (95% CI 16.1-25.7%), 2.1% (95% CI 1.1-6.4%), and 23.1% (95% CI 13.2-28.3%) respectively. The association between biomass fuel and odds of ARI was higher throughout the country except the clusters in the south-western part of the country including Lagos, Delta and Rivers states close to the coastal area (Figure 8). The effect of $PM_{2.5}$ was higher in the south-central parts of the country in Akwa Ibom, Cross River, Abia, Ebonyi, Imo, Enugu and Anambara states (Figure 8). When the effect of biomass fuel from DHS reports and $PM_{2.5}$ from satellite readings was merged the south-eastern part of the country especially Cross River and Ebonyi states showed the higher PAR.

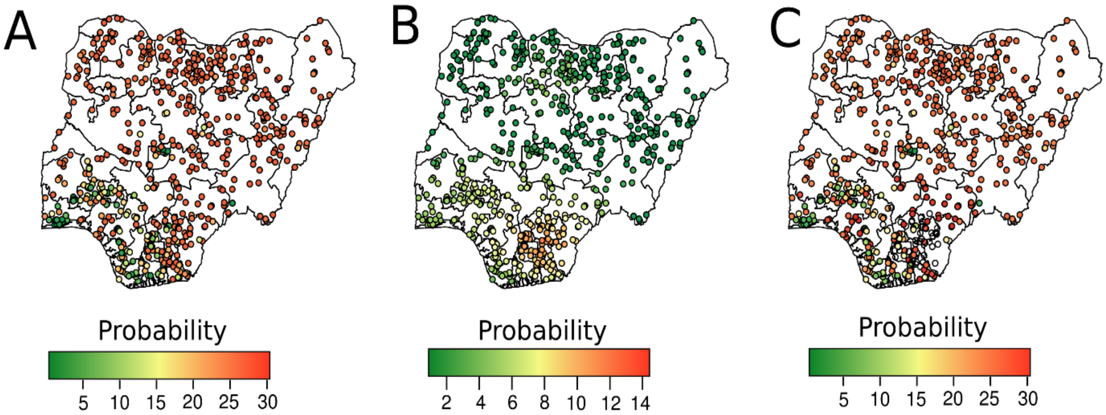

Figure 8: PAR of ARI attributable to indoor and outdoor pollution. The figure shows the PAR attributable to biofuel (A), level of $PM_{2.5}$ (B), and combined pollution (C) across Nigeria.

The country-level map of PAR of ARI attributable to biomass fuel has a higher effect on ARI in regions with low population density (Figure 8). The PAR attributable to biomass fuel, $PM_{2.5}$, and combined effect were equal to 24.7% (95% CI 18.4-28.3%), 1.6% (95% CI 0.8-2.4%), and 25.4% (95% CI 20.1-29.3%) respectively. The low effect of biomass fuel on ARI was recorded in the urban areas of the southern part of Nigeria. However, $PM_{2.5}$ had a great impact on ARI in the south-eastern (Akwa Ibom, Cross River, Abia, Ebonyi, Imo, Enugu and Anambara states) part and north central (Kano, Katsina and Kaduna states) part of Nigeria (Figure 9).

The map of the combined effect of the two air pollution markers highlighted a noticeable increase in the risk of ARI due to air pollution in Akwa Ibom, Cross River, Abia, Ebonyi, Imo, Enugu and Anambara states. Among all Nigerian states, Borno has the greatest PAR of ARI (28.1%, 95% CI 21.3-34.6%) due to biomass fuel, and Lagos the lowest (12.8%, 95% CI 7.2-15.9%) (Figure 9). Imo was the state with the highest PAR of ARI due to $PM_{2.5}$ (9.3%, 95% CI 4.2-12.1%) and Borno with the lowest (0.01%, 95% CI 0.004-0.014%) (Figure 9). When the PARs of the two pollution sources were combined, Cross River showed the highest PAR (30.1%, 95% CI 26.7-36.3%) and Lagos the lowest (15.3%, 95% CI 8.3-18.3%) (Figure 9).

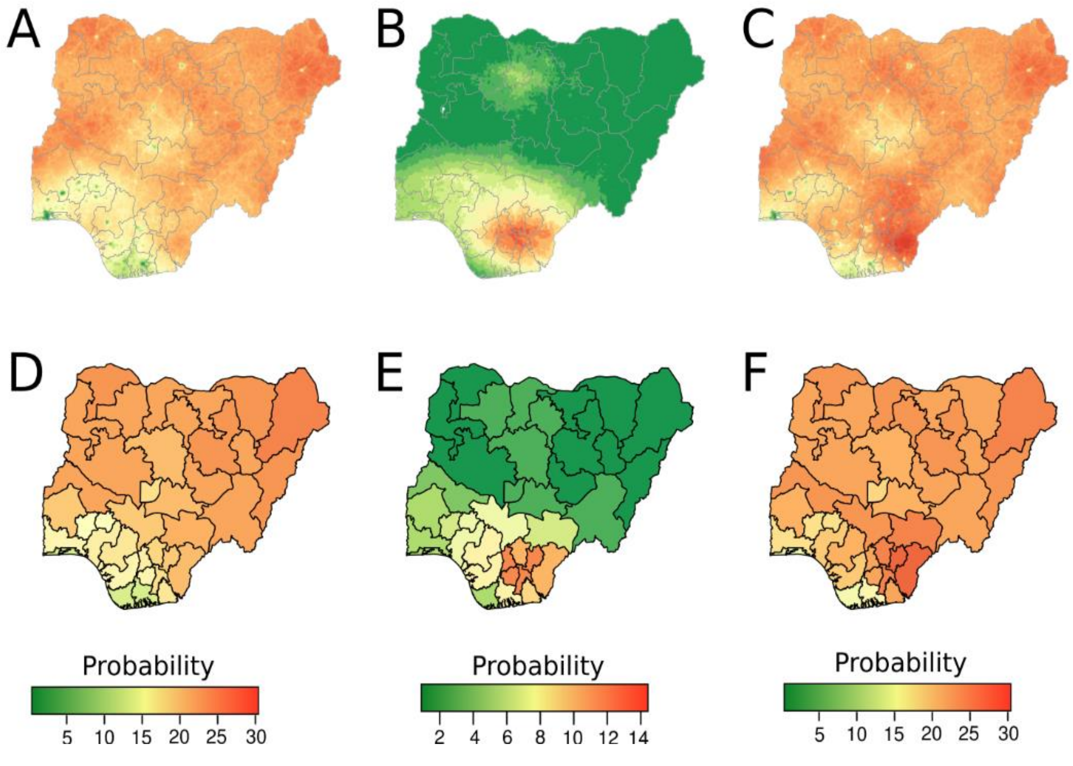

Figure 9: Increased odds of ARI at high resolution (5km) and the state level linked to biofuel cooking (A and D), $PM_{2.5}$ (B and E), and combined (C and F) for 2013.

In Nigeria in 2013, half of the children under five lived in areas with high risk of ARI due to increased concurrent exposure to biomass fuel and $PM_{2.5}$. Half of the population lived in settlements with an increased risk of ARI due to the two pollution sources above 25% (Figure

10, A). Half of children under five resided in areas where $PM_{2.5}$ is above the limit set by WHO guidelines of 10 µg/m^3 annual mean [153] (Figure 10, B).

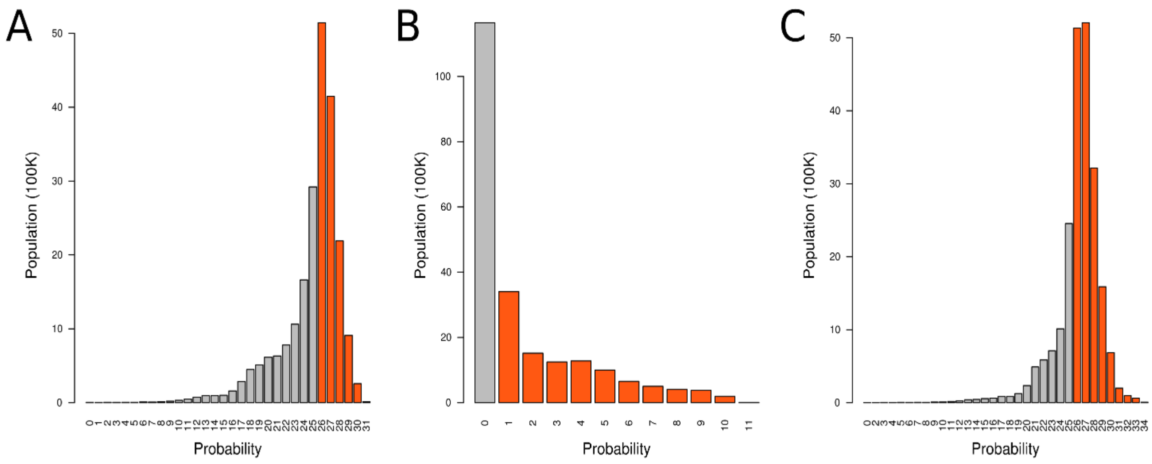

Figure 10: Fraction of Nigeria's under five population subjected at different level of PAR of ARI attributable to air pollution sources. The figure shows the fraction of the under-five population per level of PAR attributable to biomass fuel (A), PM2.5 (B), and the combined effect of both biomass fuel and $PM_{2.5}$ (C). Each colour, red and grey, represents 50% of the under-five population.

Children living in areas where there was a stronger association between biofuel mass and $PM_{2.5}$ and odds of ARI showed a significantly lower percentage of treatment seeking in case of fever (Figure 11) ($p<0.01$). Children living in areas with increased ARI risk due to biofuel and $PM_{2.5}$ above 20% had a treatment seeking level lower than 50%.

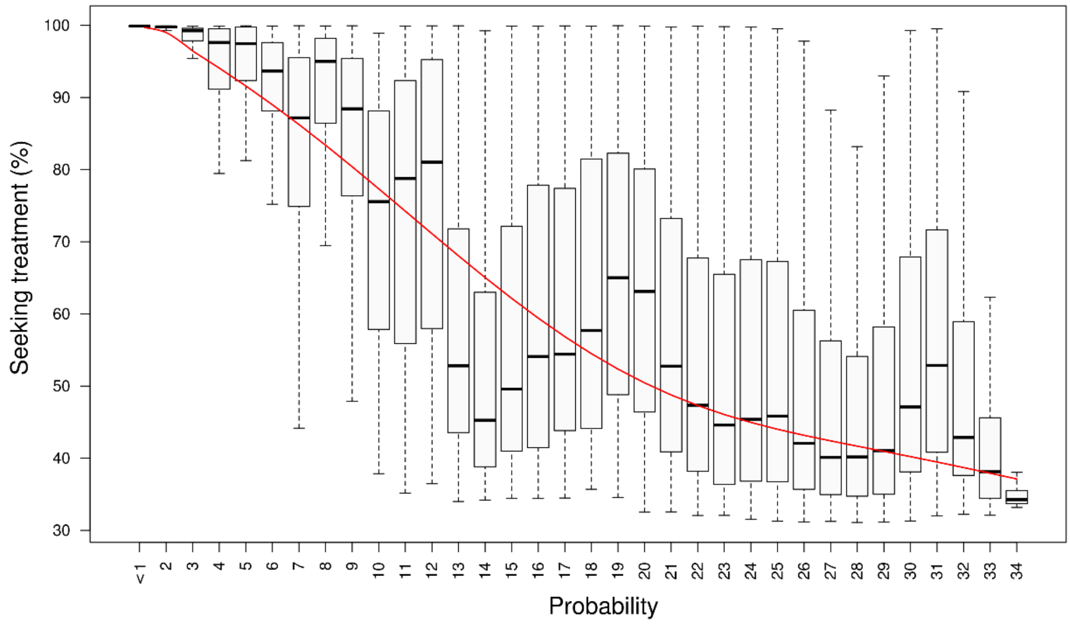

Figure 11: The probability of seeking treatment for fever in under-five children compared with PAR due to the combined effect of biomass fuel and $PM_{2.5}$ increases.

The red line shows the non-linear trend of treatment seeking linked with increased risk of ARI due to the combined effect of biomass fuel and $PM_{2.5}$.

4.2 Results from the case-control study (air quality, HH questionnaire and MUAC)

Household characteristics and study participants

The study population comprised of 290 children. 150 cases (aged 1–59 months) presenting to the study hospitals and PHCs and 140 controls who met all eligibility criteria. Of these 30 households that had measurements less than 3h or more than 24h were discarded with their matched household making 60 in total. Three households had equipment tampering were also discarded with its matched household making six in total. The remaining 112 cases and 112 controls had measures on pollutants that ranged between 3 hours and 24 hours and were included in the analyses. Cases and controls were matched based on time of the day and total time of data observed in order to compute comparable means and medians per household consisting of the same times of the day and same total number of minutes. Table 11 summarises the number of children IMCI or radiographically diagnosed with pneumonia.

Table 7: Sociodemographic characteristics of the study population, Abuja, Nigeria (Cases = 150, Controls = 140) Chi square.

Characteristics	Cases (150)	Controls (140)	*p*-value
Age, Months			
0-6 (%)	17 (11.33)	20 (14.29)	
7-12 (%)	40 (26.67)	19 (13.57)	
13-24 (%)	41 (27.33)	31 (22.14)	
25-59 (%)	51 (34)	64 (45.71)	
			0.079
Sex			
Male (%)	56 (37.33)	87 (62.14)	
Female (%)	94 (62.67)	53 (37.86)	**0.000**
Socio-economic status			
Low	76 (50.67)	54 (38.57)	
Middle	57 (38)	70 (50)	
High	17 (11.33)	16 (11.43)	0.090
Household Income per month (₦)			
0-20,000	4 (2.67)	10 (7.14)	
20,001-100,000	86 (57.33)	105 (75)	
100,001-500,000	53 (35.33)	19 (13.57	
500,001-1,000,000	3 (2)	4 (2.86)	
>1,000,000	0 (0)	1 (0.71)	
Missing	4 (2.67)	1 (0.71)	**0.000**
Immunization			
Yes	141 (94)	138 (98.57)	
No	6 (4)	1 (0.71)	
Missing	3 (2)	1 (0.71)	0.115
MUAC			
Green	88 (58.67)	108 (77.14)	
Red	62 (41.33)	32 (22.86)	**0.001**

Nearly 50% of the population of cases and controls aged between 25 – 59 months, there was no significant difference of age between cases and controls with a *p*-value >0.05, sex was uneven amongst cases and control, with more girls approximately 63% in the case population, compared with 53% of girls making up the control population (Table 7).

Socio economic status was defined as the ownership of certain physical assets as described in study questionnaire (Data collection Instrument). 50% of cases where within the lowest social group, whilst it was roughly 39% of the control group within the lowest social category. However, for the middle group 50% was from the control households and 38% were cases. There was no difference observed within the highest socio-economic group with roughly 11% for both cases and controls.

There was a significant difference in undernutrition (MUAC) between cases and controls. Around, 62 (41%) of case population were malnourished, compared to 32 (23%) of the control population (Table 7).

More cases 113 (75%) were present in the cooking environment with their mothers during cooking, compared to 52 (37%) being present in the control population. This difference was significant with a *P*-value <0.05 (Table 8).

Table 8: Lifestyle factors affecting exposure to pollutants. (Cases = 150, Controls = 140) Chi square.

Characteristics	**Cases (150)**	**Controls (140)**	*P*-value
Child present during cooking			
Yes	113 (75.33)	52 (37.14)	
No	28 (18.66)	83 (59.29)	
Sometimes	3 (2)	0 (0)	
			0.000
Main cooking fuel			
Woods	10 (6.71)	13 (9.35)	
Charcoal	8 (5.37)	3 (2.16)	
Kerosene	18 (12.08)	28 (20.14)	
Electricity	7 (4.70)	4 (2.88)	
Liquid petroleum gas (LPG)	43 (28.86)	31 (22.30)	
Bio-gas	21 (14.09)	24 (17.27)	
Fuel combinations	41 (27.52)	36 (25.90)	
No reply	1 (0.67)	0 (0)	0.268

Roof Materials			
Local sources	1 (0.67)	0 (0)	
Tiles, slate, shingle	17 (11.33)	16 (11.43)	
Zinc, Iron or other metal sheets	126 (84)	121 (86.43)	
Asbestos cement sheets	2 (1.33)	0 (0)	
Other material	0 (0)	2 (1.43)	
Don’t know	3 (2)	0 (0)	0.168
Floor Material			
Mud/dirt	2 (1.33)	2 (1.43)	
Brick, stone & lime	2(1.33)	0 (0)	
Cement	75 (50)	74 (52.86)	
Mosaic/tiles	64 (42.67)	61 (43.57)	
Other materials	2 (1.33)	0 (0)	
Combination	3 (2)	2 (1.43)	
No reply	1 (0.67)	0 (0)	0.552
Wall materials			
Mud/dirt	28 (18.67)	30 (21.43)	
Unburnt bricks	4 (2.67)	8 (5.71)	
Stone	3 (2)	1 (0.71)	
Cement concrete	109 (72.67)	98 (70)	
Combination	1 (0.67)	2 (1.43)	
No reply	3 (2)	0 (0)	0.302
Number of windows and major openings in house			
0-2	69 (46)	50 (35.71)	
3-5	64 (42.67)	64 (45.71)	
6-8	11 (7.33)	15 (10.71)	
9-13	3 (2)	6 (4.29)	0.246
Number of windows in Kitchen			
0	50 (35.46)	9 (7.63)	
1	82 (58.16)	88 (74.58)	
2	5 (3.55)	14 (11.86)	
3	0 (0)	2 (1.69)	
5	0 (0)	1 (0.85)	
No reply	1 (0.71)	4 (3.39)	
Don’t know	2 (1.42)	0 (0)	
Not applicable	1 (0.71)	0 (0)	**0.000**

Within the households of cases approximately 43 (29%) used liquid petroleum gas (LPG) compared to 31 (22%) of controls. Similarly, 18 (12%) of cases used kerosene compared to 28 (20%) controls. However, it was clear that both cases 41 (28%) and controls 36 (26%) used a mixture of fuels for their daily needs.

In cases with lack of electricity, rechargeable electric lamps were the most common alternative source of lighting among study household with 52% cases and 61% controls. The second most common source of alternative lighting was generators with 29 (20%) cases and 14 (10%) controls using them (Table 8).

Over, 105 controls had windows in their kitchens compared to 87 in cases with over 50 (36%) cases reporting no windows in their kitchen (Table 8).

Estimated burden of pneumonia across medical facilities

Table 9 summarises the estimated burden of pneumonia in children under-five who presented to the Hospitals and PHCs assessed over the 12-month study period. The overall highest and lowest estimated burden of pneumonia during the 12-month study period was 14.6% in October and 2.5% in January according to combined IMCI and radiographic diagnosis.

The estimated burden of pneumonia varied significantly across the study location and their respective hospital and PHCs. All healthcare facilities contributed at least one case during the study period.

Table 9: Estimated burden of pneumonia in children under five within study setting (January 2018 – January 2019)

	January	***February***	***March***	***April***	***May***	***June***	***July***	***August***	***September***	***October***	***November***	***December***	***January***
General Hospitals													
1	0	0	0	0	3	4	0	0	2	7	4	0	0
2	1	0	0	0	0	0	2	0	1	8	0	0	0
3	0	1	1	0	0	0	1	1	1	0	1	7	1
4	0	0	0	0	7	0	7	0	0	9	0	1	2
5	0	0	0	0	0	0	0	0	0	0	0	0	1
6	0	0	7	0	0	5	2	0	5	4	5	5	0
7	2	0	0	1	2	0	1	2	2	0	0	2	0
8	0	0	0	0	1	1	2	2	2	3	3	4	1
9	0	0	0	7	0	1	0	3	4	3	0	0	0
10	0	0	0	0	0	0	5	0	7	5	7	1	2
11	0	0	1	1	5	2	3	5	6	7	10	4	0
Public Health Centres (PHC)													
1	0	7	1	0	0	0	2	2	2	6	4	1	0
2	0	0	0	1	1	2	1	6	0	2	7	1	5
3	0	0	0	5	2	7	2	5	6	0	0	3	0
4	0	0	0	0	0	1	0	2	0	1	0	3	1
5	0	5	3	2	2	1	3	7	4	2	3	1	1
6	0	2	3	3	0	2	5	5	3	2	5	4	0
7	7	1	2	3	2	1	0	0	2	0	0	2	0
Total	10	16	18	23	25	27	36	40	47	59	49	39	14
												Total	403

Particulate Matter (PM)

Across the board, mean $PM_{2.5}$ was higher in controls compared to cases (Table 10). The highest mean recorded for controls was 177 µg/m^3. However, there was a statistically significant difference in mean between cases (129.3 µg/m^3) and controls (176.97 µg/m^3) for 10 hour measures (P-value 0.0147), cases (100.2 µg/m^3) and controls (162.3 µg/m^3) for 15 hour measures (P-value 0.0111) and cases (117.4 µg/m^3) and controls (174.4 µg/m^3) for 20-24 hour measures (P-value 0.0296) (Table 10).

Figure 12: Study participants exposed to extreme levels of pollution (Photo Credit: Author)

Table 10: Summary data showing the comparison of the $PM_{2.5}$, CO, PM_1 and BC in matched (N) cases and control at particular time points.

Variables	3 hours (10am – 5pm)			10 hours (3am – 2pm)			15 hours (3am – 5pm)			20 -24 hours		
	Case mean (n)	Control mean (n)	P Value	Case mean (n)	Control mean (n)	P Value	Case mean (n)	Control mean (n)	P Value	Case mean (n)	Control mean (n)	P Value
$PM_{2.5}$ (µg/m3)	51.87 (110)	105.06 (112)	0.0533	129.3 (111)	176.97 (112)	**0.0147**	100.2 (112)	162.3 (112)	**0.0111**	117.4 (112)	174.4 (111)	**0.0296**
CO (µg/m3)	2700 (110)	1730 (112)	0.3527	2270 (111)	2930 (112)	0.3251	2340 (112)	2700 (112)	0.3269	1950 (112)	2810 (111)	0.0729
PM_1 (µg/m3)	50.04 (112)	123.9 (112)	0.0653	62.13 (112)	91.06 (112)	0.3545	65.19 (112)	85.95 (112)	0.6163	61.26 (112)	94.39 (111)	0.1819
BC (µg/m3)										4350.5 (132)	4126.3 (123)	**0.0260**

Note that BC was a single measurement showing the average for a 24h period. **Bold figures show where there was a statistically significant difference between cases and controls.** (Rank sum test, *P* value <0.05).

$PM_{2.5}$ was higher in rainy season than dry season by 11.7% at 3h, 52.7% higher at 10h, 44.4% higher at 15h and 48.7% higher at 20-24h for controls. In cases, $PM_{2.5}$ was higher in rainy season than dry season by 11.9% at 3h, 57% higher at 10h, 45.9% higher at 15h and 52.5% higher at 20-24h. Overall, $PM_{2.5}$ was higher in cases during the rainy season than controls by 0.15% at 3h, 5% higher at 10h, 2% higher at 15h and 4% higher/lower at 20-24h (Table 11).

PM_1 was higher in dry season than rainy season by 10.5% at 3h, 16.5% higher at 10h, 16.5% higher at 15h and 12.5% higher at 20-24h for controls. In cases, PM_1 was higher in dry season than rainy season by 5.4% at 3h, but PM_1 was higher in rainy season than dry season by 4.9% higher at 10h, 6.8% higher at 15h and 9.4% higher at 20-24h. Overall, PM_1 was higher in cases during the rainy season than controls by 4% at 3h, 21.6% higher at 10h, 24.4% higher at 15h and 21.3% higher/lower at 20-24h (Table 11). There was no significant difference in exposure to PM_1 between cases and controls with PM_1 consistently higher in controls compared to cases. With the highest PM_1 mean concentration recorded being 124 $\mu g/m^3$ (Table 10)

Table 11: Summary data showing the comparison of the $PM_{2.5}$, CO, PM_1 and BC in cases and control divided by season and mode of diagnosis.

Variables	3 hours							10 hours						
	Case mean (n)				Control mean (n)		P Value	Case mean (n)				Control mean (n)		P Value
	Dry Season		Rainy Season		Dry Season	Rainy Season		Dry Season		Rainy Season		Dry Season	Rainy Season	
Diagnosis	IMCI	RC	IMCI	RC				IMCI	RC	IMCI	RC			
$PM_{2.5}$ (μg/m3)	43.18	52.03	83.65	37.25	91.01	114.85	0.0533	43.57	47.77	42.26	289.62	85.82	240.50	**0.0147**
CO (μg/m3)	1420	1250	5950	3090	1740	1730	0.3527	1990	1000	2260	3920	2140	3480	0.3251
PM_1 (μg/m3)	23.32	64.81	33.41	45.70	144.61	109.48	0.0653	24.18	71.20	30.31	74.80	135.30	60.22	0.3545
BC (μg/m3)														

IMCI – IMCI diagnosed clinically suspected pneumonia RC – Radiologically Confirmed pneumonia. Rainy season was from April to October 2018, whilst dry season was from January to March 2018 and November 2018 to January 2019 [169]. **Bold figures show where there was a statistically significant difference between cases and controls.** (Rank sum test, *p*-value <0.05).

Variables	15 hours							20 -24 hours						
	Case mean (n)				Control mean (n)		P Value	Case mean (n)				Control mean (n)		P Value
	Dry Season		Rainy Season		Dry Season	Rainy Season		Dry Season		Rainy Season		Dry Season	Rainy Season	
Diagnosis	IP	RC	IP	RC				IP	RC	IP	RC			
$PM_{2.5}$ (μg/m3)	43.13	50.36	56.50	195.72	86.478	215.22	**0.0111**	46.60 (8)	49.25 (47)	64.49 (19)	243.13 (38)	90.12 (45)	231.88 (66)	**0.0296**
CO (μg/m3)	1760	1090	3570	3410	1960	3230	0.3269	1350 (8)	720 (47)	2220 (19)	3460 (38)	1590 (45)	3650 (66)	0.0729
PM_1 (μg/m3)	25.77	73.00	33.46	79.68	131.96	53.89	0.6163	19.37 (8)	66.87 (47)	20.49 (19)	83.54 (38)	133.39 (46)	66.79 (65)	0.1819
BC (μg/m3)								4274.67 (9)	3481.02 (53)	4376.71 (19)	5257.65 (51)	3217.41 (45)	4650.61 (78)	**0.0260**

IP – IMCI Pneumonia RC – Radiologically Confirmed pneumonia. Rainy season was from April to October 2018, whilst dry season was from January to March 2018 and November 2018 to January 2019 [169]. **Bold figures show where there was a statistically significant difference between cases and controls.** (Rank sum test, *p*-value <0.05).

Black Carbon

There was a significant difference (*p*-value 0.0260) in exposure to Black Carbon between cases and controls. With the average mean for cases 4350 $\mu g/m^3$ and controls 4126 $\mu g/m^3$.

In all the cases identified in the study, 24.11% of measurements were from IMCI diagnosed pneumonia and 75.89% were from pneumonia confirmed by chest radiographs in hospital. BC was higher in rainy season than dry season by 13% at 20-24h. In cases, BC was higher in rainy season than dry season by 10.80% at 20-24h (Table 11).

Figure 13: Representative images of participants cooking environment. Women did most of the cooking in nearly all households (Photo Credit: Author).

Carbon monoxide

For controls CO was higher in rainy season than dry season by 41.9% at 3h, 30.6% higher at 10h, 36% higher at 15h and 43.7% higher at 20-24h. In cases, CO was higher in rainy season than dry season by 54.4% at 3h, 34.8% higher at 10h, 42% higher at 15h and 46.6% higher at 20-24h. Overall, CO was higher in cases during the rainy season than controls by 27% at 3h, 5.5% higher at 10h, 9% higher at 15h and 4% higher/lower at 20-24h (Table 11). There was no significant difference in CO concentration between cases and controls. With the highest CO mean concentration recorded being 2930 $\mu g/m^3$.

Overall, concentrations of pollutants were higher during the rainy season compared to dry season. The highest reported mean concentration (289.62 μg/m3) was observed when cases and controls where compared after a 10-hour period. Overall concentrations of PM_1 were higher in most cases during the dry season.

Distribution of $PM_{2.5}$ and BC concentrations was measured between houses of cases and controls. When outside (Figure 14) values were excluded $PM_{2.5}$ was higher in controls during the dry season compared to cases, with the highest mean value over 150 µg/m^3. However, in contrast BC was higher in cases compared to controls both during the rainy and dry season, the highest mean of over 11,000 µg/m^3.

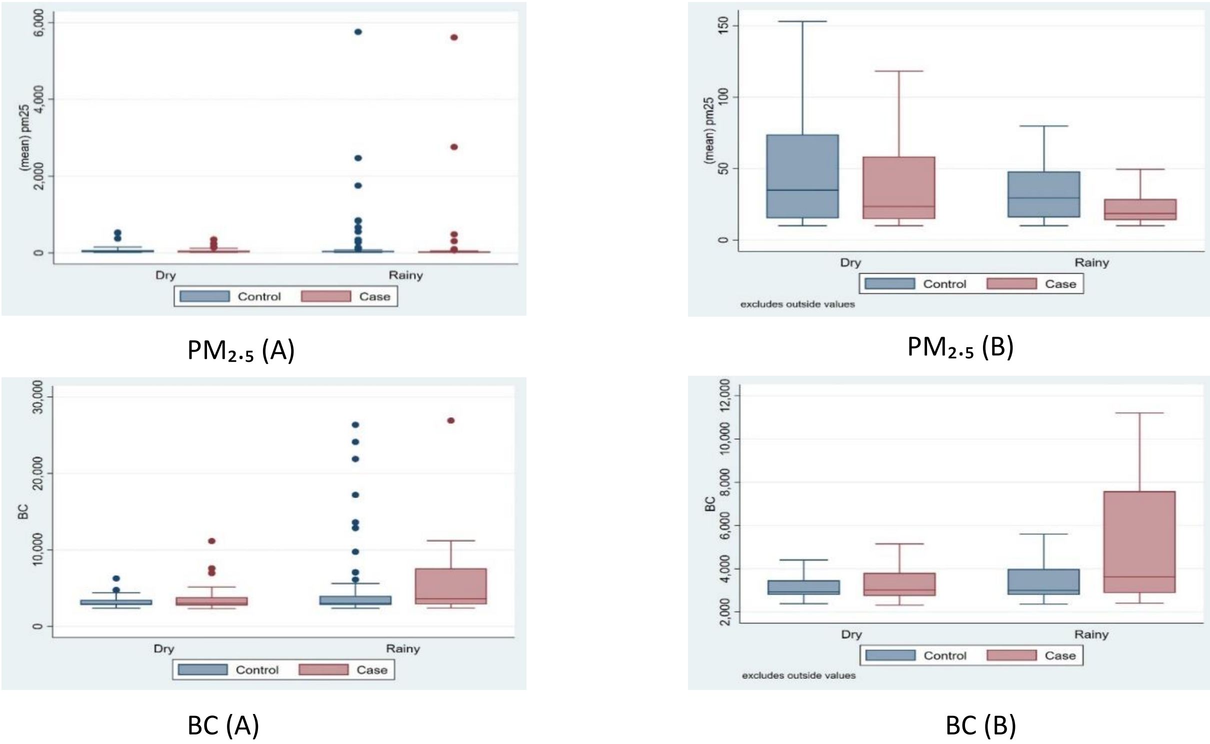

Figure 14: Box plots of $PM_{2.5}$ and Black carbon (BC) distributions over 20 to 24 hours. The horizontal line in each box represents the median value and the top and bottom of the box represent the 25th and 75th percentile, with the lines extending from the top and bottom of the boxes widening to the 5th and 95th percentile of the distribution. For ease of representation, (B) does not show outside values.

The distribution of seasonal variables during study period, January 2018–January 2019

Figure 15 shows the average monthly temperature (^{o}C), rainfall (mm) and humidity (%) during study period. The highest temperature recorded throughout the study period was in March 2018 (34^{o}C) which corresponded with the dry season in Nigeria. The highest amount of rainfall in 2018 was recorded in August 2018 (188.56 mm). The values recorded for humidity during the study period was similar to the recorded pattern of rainfall. This was such that the highest and lowest values corresponded with the peak of rainy season in 2018.

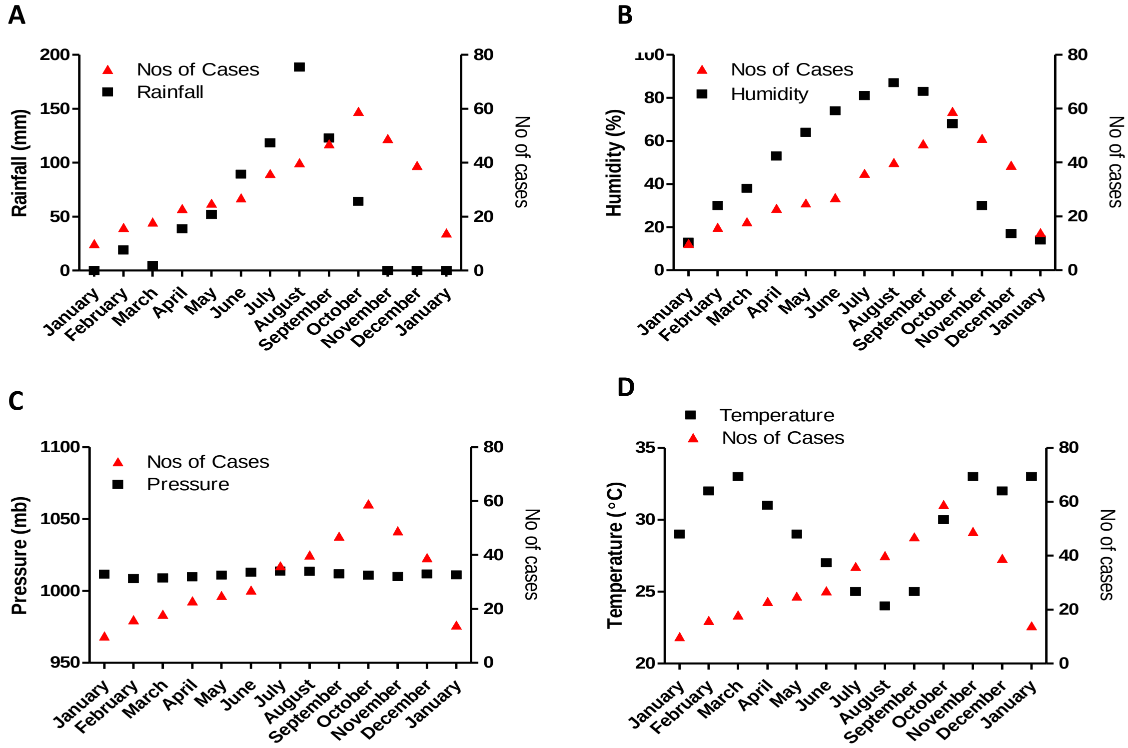

Figure 15: Association between average meteorological parameters and hospital reported pneumonia cases in Abuja [170].

The estimated burden of pneumonia during study period in relation to seasonal variables

Figure 15, shows the estimated burden of pneumonia in relation to the average monthly rainfall and humidity. Figure 15 (A), shows that there was an increase in the estimated burden of pneumonia diagnosis during high amount of rainfall in 2018 (August).

Figure 15 (B), shows the estimated burden of pneumonia in relation to the average monthly humidity. Like the findings for rainfall, higher cases of pneumonia were recorded in the months with corresponding higher values of humidity.

Figure 15 (C and D), above shows the estimated burden of pneumonia cases in relation to the average monthly temperature and pressure during study period. Moderate monthly temperature values appeared to be associated with higher estimated burden of pneumonia (bottom section of Figure D). Whilst pressure stays stable during the entire study period.

4.3 Results from key informant interviews with healthcare professionals

Of the 34 healthcare professionals and providers approached, six declined to participate, nine agreed to participate but were unavailable during the study period and 19 were interviewed. Most interviews lasted between 30 and 70 minutes. This variation was mostly due to participant's role or their knowledge of the health effects of indoor air pollution in children under five in Nigeria. The participants were nine medical doctors, four nurses, two primary health workers, four PHC coordinators.

Table 12: Background characteristics of health professionals (*n=19*)

HPs' unique code *	**Sex**	**Professional qualification**	**Years of experience**
1-Doc	Female	LGA Medical Officer of Health & Medical doctor	8
1-PHW	Female	Junior community health extension worker	5
2-PHW	Female	Junior community health extension worker	5
2-Doc	Male	Medical doctor	6
1-Nurse	Female	Nurse	22
1-PHC	Male	PHC co-ordinator and Disease surveillance	1
3-Doc	Male	Medical doctor	>11
2-Nurse	Female	Registered nurse mid-wife	6
2-PHC	Female	PHC co-ordinator	9-12
3-Nurse	Female	Director of nurse/matron	25
4-Doc	Male	Medical doctor	>5
5-Doc	Female	Medical doctor	4
6-Doc	Male	PHC co-ordinator & Medical doctor	11
7-Doc	Female	Medical doctor	4
4-Nurse	Male	Nurse	7
8-Doc	Female	LGA Medical Officer of Health & Medical doctor	28
9-Doc	Female	Medical doctor consultant paediatrician	7
3-PHC	Male	PHC co-ordinator	6
4-PHC	Male	PHC co-ordinator	2

Table 13: A summary of the themes and subthemes.

Themes	Sub-themes
Education	Culture Social norms
Rising levels of poverty	High cost Price and affordability
Access and tendency to seek early treatment	Detection Diagnosis
Mass media campaign	Public awareness Enabling factors
Active preventive government policies	Economy Implementation Weak enforcement
The healthcare system	Lack of funding Corruption Bureaucracy Fake drugs Infrastructure and maintenance Job satisfaction and fulfilment
Healthcare research capacity	Lack of support and resources
Knowledge of air pollution and health	Lack of awareness of health risk
Ventilation	

Education

Most of the participants identified education or the lack of it to be influencing the current trends being observed with HAP and its link to childhood pneumonia. The participants reported that most of the parents were ignorant and need to be sensitised about the dangers of burning polluting fuels indoors or in a confined environment with the child present and without adequate ventilation. As well, they stressed the need to inform and convince them about the benefits of switching to cleaner fuels options (resources permitting).

What we do is that whenever we have such cases, we give them health talks on how to handle such things. Following the education, we normally give them, we give corrections and from there we normally start to see changes. Sometimes, we do follow-ups to actually see that they do what they have been told and that they adhere to it. The follow-ups are not frequent though due to the nature of our work here. Ignorance plays a huge part here. Education has to come into play also. When they are educated and they know the hazard that goes with it, and they have the means to do it, people would prefer clean energy. ***Participant 11***

Whilst most healthcare professionals believed, upon diagnosis of pneumonia in children, they inform the parents on strategies to reduce reoccurrence; they also mentioned the lack of structure in providing sensitisation in rural settings, thereby reducing the efficacy of this strategy.

Of course, we educate them on environmental hygiene. Well, when patients come in, we take history to know the cause of the pneumonia and from there we know where to channel the health education while they undergo treatment. There is really no program outlined for that as we are not situated in a rural setting. The case here is such that even some parents know more than one as they are well educated and enlightened. The most we can do is to keep up with the education. We have to keep talking about it and perhaps someday, something will change. ***Participant 12***

Well we give them health talks in that aspect including sources of smoke and its effects as it could cause pneumonia. We give them information on the issue, telling them of the dangers and risks attached to the issue. The mothers are advised about the dangers of exposing their children to harmful fumes that cause serious health problems. The government could educate the people. Also giving them the necessary aids that would reduce and possible halt its continuation. ***Participant 13***

Rising levels of poverty

Almost all participants thought that the increasing levels of poverty in the country had a significant role to play in the high cases of pneumonia and mortality rates amongst those vulnerable. Participants highlighted clean fuels was not a priority for most households, as using firewood or charcoal was economically more feasible and it was easily accessible.

If there is constant electricity or cheaper alternatives, then government can introduce strict regulations. Now even with strict regulations, there is no light or cheaper alternative. Some of the children that die from pneumonia do not even make it to the hospital. Either the parents underestimated the symptoms or do not have the finances to treat the child. If *treatment is free for children under five. Then we would know that the remaining problem to deal with is getting them here.* ***Participant 14***

I think because of the level of poverty and ignorance. It still boils down to the issue of prices and poverty. ***Participant 11***

Access and tendency to seek early treatment

Participants reported generally a poor access to healthcare across the board. Participants report that in some situations, parents do not seek healthcare until the case deteriorates into almost irreversible states which often pushes the cost up.

If children are brought here on time most times, they have a higher chance of cure and survival. ***Participant 17***

Furthermore, the participants reported that the access to early treatment is hampered by lack of accessibility to the hospitals, thereby making it less likely for people to access appropriate care in a timely manner.

It should also not only be available but also accessible. So, the government should decide to make such things essential and accessible in its hospitals. ***Participant 10***

Let it be known that the NHIS in Nigeria is not working. More funding needs to be provided. The drugs should be made more affordable and accessible to everyone. ***Participant 12***

Mass media campaign

All participants mentioned mass media as a key approach for reaching out to the general public but most state that not much has actually been done on this front. Most of the participants identified the opportunity that exists through radios, televisions, school curriculum and existing community structures. Participants also revealed that there are limited resources available for carrying out these public awareness campaigns.

Organise campaigns on awareness and we just have to keep talking about it to these people. ***Participant 10***

Door to door communication in the local communities and radio. ***Participant 17***

Local language, mass media print and television, churches, community meetings. ***Participant 15***

Sometimes, we carry out outreaches to reach them in their homes. And whenever they are here, we educate them. Yes, we do have a plan in place as a source of orientation to those that still indulge in such practices. By empowering the people however, it must be noted that this does not stop them from reverting back to their traditional methods of doing things. ***Participant 11***

We go around sometimes using word of mouth using public address systems to give out the necessary information. ***Participant 13***

Awareness whereby children are not taken for treatment unless the father is present. This hinders early progression. Regulation enforcement of childbirth registration and immunization. ***Participant 1***

We talk to mothers about exposure to smoke as it generally affects their health. Most of them cough and complain of eye problem. We just give them general advice if they come here and present symptoms related to use of firewood for cooking. From my experience I think community outreach. I would suggest community outreach and education of the public to even understand the dangers of using polluted fuels to health. ***Participant 14***

Active preventive government policies

Most of the participants believed that the government has a huge role to play in creating policies that would create a shift in population behaviour. A consistent trend that emerged from conversations with healthcare professionals and providers was that the current policies were quite generic and based on global trends and not locally generated data. Furthermore, most of the participants suggested more policies targeted at promoting cleaner energy use be created but it would be the enforcement and implementation that would make them more effective.

Government should have a medium/low term policy. Electricity policy to enhance socio-economic mobility. ***Participant 1***

> *In terms of the government, if they can do some policy checks like a "no more charcoal" policy. But even when these policies are in place, the government would now have to empower the people accordingly.* ***Participant 11***

> *The government has a serious role to play in this aspect by setting up the necessary infrastructure and policies that would gradually phase out the use of biomass cooking methods.* ***Participant 12***

> *Government effort to make them readily available and cheap for the masses. If there is constant electricity or cheaper alternatives then government can introduce strict regulations. Now even with strict regulations, there is no light or cheaper alternative.* ***Participant 14***

> *Government should subsidise the high entry cost so people can have access to these clean fuels.* ***Participant 17***

> *Government regulations of biomass fuel use, with policies to discourage its use and encourage alternative fuel sources. The multi-faceted approach to solving the problems associated with indoor air pollution is required for effective outcomes. The government needs to provide business incentives for innovative approaches to reducing indoor air pollution in Nigeria. Private organisations need to work with individuals in educating and promoting clean energy use.* ***Participant 18***

> *Government should be able to put policies that will enlighten the communities and implement it also. Improve the economy of the country. Government should be able to implement any policies they have made.* ***Participant 2***

The healthcare system

Almost all respondents thought that the healthcare system was inadequate and needed improvements in x-ray diagnostics and availability of antibiotics in healthcare centers. Participants mentioned lack of funding and how it affected the services provided, this translated into poor equipment with little to no maintenance. Also, participants mentioned the enthusiasm within the profession is dropping as most colleagues would prefer to go abroad than work within the system and there is continuous brain drain.

Currently we have no equipment's. They are just not available. We are also short of staff. For instance, I am the only one in the paediatric clinic which could have been better if were 3 or 4. Also the non-availability of equipment's used for diagnosis and treatment is a problem. We also do not have some of the drugs in the hospital as they are quite expensive for even the hospital pharmacy to stock up on. So, the government could include them as essential drugs that should made available and accessible in the hospital. ***Participant 10***

We have good personnel including doctors and nurses. Also, the equipment's to handle and tackle cases are available especially for when the cases are brought in early enough. More personnel and equipment's would be appreciated in the Paediatric section. As a result of the influx of patients, the facilities and equipment's are overstressed. NB: the question was not specified to childhood pneumonia. The big threat here is the issue of adulterated and fake drugs. Hence sometimes when we treat patients and administer drugs, they do not respond to the treatment. Also, the issue of patients not adhering to our treatment instructions and general education is an issue. ***Participant 11***

The success rate on treatments carried out here is about 85-90%. Also, our equipment's and medical devices work perfectly for us. Let it be known that the NHIS in Nigeria is not working. More funding needs to be available. It is not just a function of the hospital as people report cases very late and, in many cases, indulging in self-medication in the process. ***Participant 12***

Our equipment's need to be upgraded. Also, more qualified doctors should be hired. These being put in place; our strength could rise up to 80% and more. Poor equipment's and not very qualified medical personnel including doctors. ***Participant 13***

Some of the children that die from pneumonia don't even make it to the hospital. Either the parents underestimated the symptoms or don't have the finances to treat the child. If treatment is free for children under five. Then we would know that the remaining problem to deal with is getting them here. We do not have the resources and capacity to deal with high number of cases. Also, the pay before service system practiced in Nigeria as painful as it sounds leads to the death of so many patients. Funding, public education to recognise symptoms early, access and resources. ***Participant 14***

There are not enough staff to treat patients. Doctors and nurses. critical patients we don't have cutting edge lifesaving modern equipment's to help save such children. Lack of funding and equipment's. Healthcare workers satisfaction and brain drain. Doctors and nurses leaving the country for better working conditions, environment and pay. ***Participant 17***

> *Lack of modern diagnostic equipment, poor maintenance culture of hospital equipment. Availability of specialist doctors. Access to healthcare services, when children start to develop symptoms can be improved as numbers are still low.* ***Participant 18***

> *Lack of adequate health care staff. Funding, substandard accessories (oxygen, x-ray anti biotics), lack of staffs, bureaucracy.* ***Participant 3***

> *Lack of funding. Provide funding. Lack of amenities.* ***Participant 4***

> *Lack of equipment to work with. poor staff and staff training. Poor funding of projects. Corruption: the funds diversion that was meant to sponsor programmes on childhood pneumonia.* ***Participant 6***

Healthcare research capacity

Most participants suggested that medical research was a huge challenge. They indicated that there was little to no air pollution and health research and monitoring in Nigeria. Lack of adequate funding and resources were identified by participants as the major barriers to healthcare research. Most of the participants believed that adequate research if available could identify solutions to tackle the pneumonia cases linked to air pollution.

> *I do not have plans to talk about it because the research is not comprehensive enough or conclusive. I cannot just walk up to someone and say "stop doing this or that". But if for instance a child has allergies, or is asthmatic and has been reacting then we know the information to give. So, it is wrong to just tell people to stop using this or that.* ***Participant 10***

> *Technology should be taken to the grass roots.* ***Participant 2***

Knowledge of air pollution and health

Few of the participants acknowledged any knowledge of indoor air pollution and childhood pneumonia. Some confirmed the common myth in Nigeria that it is mostly caused by cold weather. However, they all believed that a shift from polluting fuels would be made possible if the price is subsidised so people can afford it. And finally, it should be readily available on demand so people would know they can have access when they want to.

Pneumonia is not that common all year round as it is mostly experienced during the cold periods. ***Participant 11***

Personally, I use gas cookers in my home. I do have friends who still use kerosene stoves though but I ask them to use it in a well-ventilated kitchen or better still, take it outside because the fumes can be quite terrible at times. ***Participant 12***

Increasing the accessibility to clean stoves may improve its uptake. ***Participant 18***

To solve this problem, the people need to get better cooking equipment's for themselves and also keep the old and traditional ones away from their living areas. ***Participant 13***

No, we have not, they hardly follow our advice because they is no realistic alternative they can switch to. Government effort to make them readily available and cheap for the masses. If there is constant electricity or cheaper alternatives then government can introduce strict regulations. Now even with strict regulations, there is no light or cheaper alternatives. Then rolling out cheaper and cleaner alternatives. ***Participant 14***

subsidise the cost, make it readily available. ***Participant 15***

If the clean fuel is popular like firewood and charcoal. ***Participant 17***

Increasing the accessibility to clean stoves may improve its uptake. ***Participant 1***

Ventilation

Most of the participant were aware and conscious of the effects of poor ventilation on health outcomes. The participants mentioned they mostly gave their patients advice on how to improve the ventilation in the homes to prevent pollution-related diseases. This included advice on the location of generators and opening windows.

It is a matter of preference. For instance, in my 20 years of marriage, my husband and I refused to get a generator set because of the hazardous effects it could have on our children.

> *But now that they are grown, we just recently acquired one 2 months past. And it is kept behind the building. For those who have a compound and building to themselves, it is advisable to have the generator shed away from the main living building, so it poses no health hazards.* ***Participant 12***

> *Provide good ventilation in the room, use of A/C. Proper cleaning and dusting of the rooms.* ***Participant 6***

In summary, findings of the DHS survey indicated that biomass fuel and improved housing were positively associated with ARI. Being exposed to biomass fuel increased the risk of ARI by 55% in children under five. The case control study highlighted that the mean $PM_{2.5}$ was higher in control households compared to cases households. No significant difference in CO concentration was observed between cases and controls. BC was significantly higher in households of cases compared to controls. The semi-structured interviews provided a deeper insight into the perception of household indoor air pollution and childhood pneumonia amongst these stakeholders. Healthcare professionals commented on the lack of funding to the lack of equipment and support needed for the treatment of their patients. Also, lack of awareness regarding health risks from household air pollution, level of education, poverty, treatment-seeking behaviour, lack of research and funding and effective implementation of policies. The next chapter offers an in depth discussion into the study findings.

5 Discussion

This penultimate chapter begins by discussing the findings of the four study specific objectives with respect to the available literature. It then synthesizes the overall findings across the four study objectives using a holistic mixed-methods research. The chapter concludes with strengths and limitations of the study, including the generalizability and transferability of findings.

Pneumonia remains the foremost killer of children under five across the world and Nigeria is a major contributor to the high mortality rate. As highlighted in this research, urgent attention to understanding factors affecting pneumonia amongst Nigerians is required in order to inform strategies to reducing the high mortality rates. Whilst, the link between HAP and pneumonia is beginning to be well characterized across the world [47], it is noteworthy that Nigeria-focused studies are rare.

This study applied a mixed-methods approach to evaluate the effect of HAP on pneumonia episodes in children under the age of five years in Abuja City, Nigeria. It was first informed by analyzing a demographic health survey data showing the spatial distribution of air pollutants and pneumonia hotspots in children under five across Nigeria.

Furthermore, air quality monitoring data was collected between January 2018 and January 2019, to allow the comparison of concentrations of carbon monoxide (CO), fine particles ($PM_{2.5}$ and PM_1), and black carbon (BC) between pneumonia cases and controls in Nigeria. This was then used to assess the effect of these pollutants on episodes of pneumonia in children under five. Whilst, the effects of $PM_{2.5}$, CO and solid fuel proxies have been assessed in relation to pneumonia, to the knowledge of the researcher, this is the first report of direct household PM_1 and BC measurement in relation to pneumonia episodes in children under five.

The qualitative component of the study used semi-structured interviews conducted during the study period to capture the knowledge and perspective of healthcare workers about the effect of HAP and childhood pneumonia. Specifically, the first section of the qualitative study explored the perceptions of HPs, regarding Household Air Pollution (HAP) and childhood pneumonia. This section also sought to explore the strengths, weaknesses, and opportunity for improvement within the healthcare system with regards to tackling childhood pneumonia which might be influenced by constant exposure to high levels of HAP.

5.1 Spatial heterogeneity of cooking fuel and $PM_{2.5}$ contribution to the occurrence of acute respiratory infections in children under-five in Nigeria

Results from this study confirm air pollution as a public health priority by demonstrating a strong association of air pollution on ARI in children under five which shows a strong subnational spatial heterogeneity of ARI incidence in Nigeria. These findings suggest a high proportion of under five children live in areas with high indoor air pollution HAP due to the use of biofuel for cooking was significantly associated with ARI compared to $PM_{2.5}$. Furthermore, places with high fraction of ARI associated with air pollution was linked to lower level of seeking treatment.

As earlier stated, children are affected by ARI mostly because of their underdeveloped lungs and rapid breathing compared to adults [31, 171]. Evidently, there is a great interest in lowering ARI incidence within this population group. Research has been carried out to understand fuel use among Nigerian population. For example, the reason behind their choice and willingness to change to cleaner fuels [132, 133] and the effectiveness of changes to cleaner fuels on health outcomes [132-136]. This led to the emergence and debate around the energy ladder which links people´s fuel preference to household income and socio economic status (SES) [132, 133].

A major challenge facing the development and implementation of targeted strategies across Nigeria, is the lack of a country wide map showing the distribution of pollution and disease incidence. Previous research has measured pollution and disease incidence in particular states [47] or individual geographical zones in Nigeria [172]. Herein, the presentation of spatial analysis of ARI hot spots in Nigeria and associated pollutants.

Results from this study show that biomass fuel such as firewood, charcoal, and agricultural waste, affect the respiratory health of a high proportion of Nigerian's children under five. Moreover, a greater effect was observed in rural settlements compared to urban cities. However, effect of combined air pollution sources, $PM_{2.5}$ and biofuel, on ARI is lower in the urbanized areas in the south-western part of the country. Which may be because the south-western part are coastal regions, where clean air from the ocean dilutes $PM_{2.5}$. Similar trends have also been observed in countries like China and India around coastal cities [173, 174].

Cooking with biomass fuels in Nigeria is common not only in people with low income [175-177]. Especially, during the festivities and large family gathering, the preferred cooking fuel in Nigeria are biomass fuels [175-178]. Taste, culture and convenience have proven to be the main reasons why people with any type of socio-economic background, continue to use traditional methods of cooking involving biomass [175-178]. However, the use of biomass fuels usually requires the availability of open air spaces, so its use in rural areas is greater compared to urban areas [179, 180]. In urban settings, liquefied petroleum gas (LPG) is the preferred choice of fuel [181, 182]. This may be due to their economic buying power amongst urban households, alongside improved housing with proper ventilation, adequate space, open air cooking and the ability to keep children away from cooking areas. This may further explain why the effect of combined air pollution sources, $PM_{2.5}$ and biofuel use, on ARI is lower in the urbanized areas in the south-western part of the country.

The increased use of biomass fuels, the existence of oil refineries in the southern parts of Nigeria, and the proximity to the Sahara desert increase the general exposure to $PM_{2.5}$ [183, 184]. Adopting and enforcing environmental pollution policies in the country have been a huge challenge [183, 184]. In particular, the highest risk of ARI associated with $PM_{2.5}$ was observed in the south-eastern regions of Nigeria. This suggests that the increased levels of $PM_{2.5}$ is possibly compensating for low use of biomass fuels, leading to increased incidence of ARI. Whilst in the south-eastern region the incidence of ARI is intimately associated with atmospheric $PM_{2.5}$, in the northern part of the country, particularly Borno state, ARI incidence is more likely linked to household pollution from biomass fuel use which is known to be high in addition to atmospheric dust [185].

Previous studies have shown that exposure levels and risk of ARI are influenced by the geographical location in Nigeria [185]. Lifestyle and industrial variations exist across the different geographical zones of Nigeria, which may inadvertently affect levels of different pollutant and possibly consequentially ARI incidence. For example, firewood use is greater in the north east and north west than other parts of Nigeria [186]. Furthermore, most major oil refineries are located in southern Nigeria (Warri, Port Harcourt) except one which is in north central (Kaduna) [187]. More so, illegal oil refineries in the Niger-delta regions further exacerbate risk factors for exposure to environmental pollutants such as $PM_{2.5}$ in southern Nigeria [188].

As biomass fuel use and $PM_{2.5}$ is known to be often correlated [47], their combined effect on ARI incidence was used (Figure 9C and Figure 9F). For example, the daily exposure to $PM_{2.5}$ in households with biomass fuels is known to be significantly greater than the WHO recommendations (~1000 $\mu g/m^3$ compared to the recommendation of 35 $\mu g/m^3$) [27]. There was a combined influence of biomass fuel use and $PM_{2.5}$ on ARI incidence (Figure 8C). This observation highlights the complex relationship between the combined exposure to both biomass fuel and $PM_{2.5}$, and other sources in the population under study. Only satellite-obtained measurements and questionnaires are readily available nationally as there are poor household air quality monitoring systems. Therefore, whilst the current data shows an increased association for ARI with combined biomass fuel use and satellite obtained $PM_{2.5}$ across the country, comparable measurements are required to fully understand their combined effect. Studies from The World Bank and Institute for Health Metrics and Evaluation University of Washington (IHME) with similar methodology of combining ground data of biomass fuel use and satellite obtained $PM_{2.5}$ data found similar trends in China, India, Pakistan and Bangladesh [189].

Additionally, our results show that in children living in areas where the effect of biofuel mass and $PM_{2.5}$ are high, the incidence of treatment seeking in case of fever was lower (Figure 11). This is consistent with other findings which suggest that a number of factors such as socio-economic status, access to health care services, cultural dispositions and severity of symptoms are known to influence willingness to seek healthcare treatment among different populations [190, 191]. There is a documented lack for treatment seeking behaviour in Nigeria, with parents acting as doctors, initially diagnosing and administering medication to children prior to assessment by healthcare professionals [192]. Furthermore, there is a link to socio economic status, as the poorest civil servants in Ibadan were more likely to have poor health seeking behaviours [193]. More so, increasing treatment-seeking behaviour in relation to other health indicators such as sexually transmitted diseases has been shown to be beneficial [194]. Increasing the ease of access and quality of health care provisions in under-served areas and disease hotspots are possible interventions to reducing ARI incidence.

Furthermore, results from this study suggest that access to improved housing reduced the risk of ARI in children under five. This could be due to increased ventilation, or less exposure to smoke. Previous studies have shown that building materials are linked to respiratory health of children [100, 195, 196]. Therefore, this suggests that housing quality could potentially affect ARI incidence in Nigeria. Behavioral changes like window opening and cooking outdoors could help improve the air quality of the home [8].

ARI in children is characterized by high mortality rate in children under five in Nigeria. Improving the capability of healthcare workers for timely diagnosis and early treatment through the Integrated Management of Childhood Illness (IMCI) guidelines, would improve disease outcomes. This management tool has been adopted across the healthcare system of Nigeria [192, 197].

5.2 The effect of individual pollutants on pneumonia episodes in children under-five in Abuja, Nigeria

This is the first study to measure and compare the association between indoor air quality in terms of specific component pollutants ($PM_{2.5}$, PM_1, CO and BC) and pneumonia episodes in children under five in Abuja, Nigeria. Previous studies have measured single pollutants or used proxies measurements in the absence of observed primary data [11-16, 22, 41, 57, 58, 67, 84-86, 88, 89, 98, 136]. We have previously reported that when directly measuring pollutants, there was no association with pneumonia incidence, but when using biomass fuel as a proxy, there was an association [47]. This highlights the need for targeted approaches for measuring indoor pollutant levels. Studies directly measuring BC levels in association with pneumonia episode are scarce. Herein, a report of the importance of behaviourally modifiable and unmodifiable factors during the study period on pneumonia episode in children was reported. Unmodifiable factors include increasing the number of windows and doors in the kitchen and the entire house whilst behaviourally modifiable factors, such as behavioural changes that might arise from consultation with healthcare professionals such as: cooking with cleaner fuels, keeping children away from the cooking environment and opening windows more to allow the flow of fresh air.

Indoor air pollutants and pneumonia episodes

In this study, most participants were exposed to levels of pollution that vastly exceed WHO guidelines (Figure 12). Whilst it might be expected to find higher levels of household air pollution in households where there had been a reported case of childhood pneumonia, in this study, both cases and controls were exposed to extreme levels of household air pollution (Figure 13). In some cases the levels were ten times higher than the WHO guidelines, which confirms published reports from the WHO reporting extreme levels of exposure in households using biomass fuels for cooking [77, 79]. For individual pollutants, the mean $PM_{2.5}$ was higher in controls compared to cases (Table 10). There was no significant difference in CO concentration between cases and controls. There was no significant difference in PM_1 between cases and controls (*P*-value >0.05). However, there was a significant difference (*P*-value 0.0260) in exposure to Black Carbon between cases and controls. BC was higher in households of cases compared to controls.

The finding that $PM_{2.5}$ was higher in controls than cases was initially perplexing, however, it is important to note that the study design was such that measurements were made following a lag time from when cases presented to hospital and consent was given to take measurements. The presence of a sick child and visit to health care centres presents the possibilities of behavioural changes following medical advice [198]. Awareness on pollution levels and practical actions to reducing indoor pollution such as opening of windows is part of the care given to parents and caregivers when treatment is sought [199]. This could have led to modifications in habits that could have led to reduction in $PM_{2.5}$ levels prior to our measurements among cases. Transcript from the qualitative interviews conducted for this study confirms that parents of some cases were given exposure and lifestyle advice by healthcare professionals. Therefore, changes may have been implemented between hospital care and time of air monitoring.

> *"What we do is that whenever we have such cases, we give them health talks on how to handle such things. Following the education, we normally give them, we give corrections*

*and from there we normally start to see changes. Sometimes, we do follow-ups to actually see that they do what they have been told and that they adhere to it. The follow-ups are not frequent though due to the nature of our work here. Ignorance plays a huge part here. Education has to come into play also. When they are educated and they know the hazard that goes with it, and they have the means to do it, people would prefer clean energy". **Participant 11***

Future studies should adopt a study design that follows a representative sample within a prolonged timeframe where periodic indoor air quality measurements are observed and respiratory symptoms are continuously monitored by a healthcare professional to give a wholistic view of exposure to pollutants and pneumonia association. I return to the effect of unmodifiable factors later in this discussion.

Nonetheless, there was higher BC levels in houses with a pneumonia episode. Furthermore, within matched time frames, the average BC load was higher in cases compared to controls (Figure 2). This result is in line with results from in vitro studies conducted by Hussey *et al* [40] that reported that BC significantly affect the behaviour of *S. pneumoniae* by altering the structure and proteolytic degradation of the biofilm, therefore promoting its tolerance to multiple antibiotics. Furthermore, BC promotes the spread of bacteria to the lungs and consequently exacerbates the disease occurrence [40, 72].

In recent times, there has been increased interest into the role of black carbon in climate change, air quality and health [200]. Epidemiological studies have shown that BC is a better indicator for short-term health effects compared to undifferentiated PM mass [201]. Furthermore, pneumococcal bacteria which causes pneumonia has been shown to be more associated with BC than with $PM_{2.5}$ [202], suggesting that BC is a better indicator of harmful particulate substances from combustion sources than undifferentiated PM mass. Whilst $PM_{2.5}$ has been widely used in the literature as an indicator of indoor air pollution [21, 203], new research is showing that it in itself contains PM_1 and BC in different proportions depending on the source [21, 203]. This finding highlights the importance to measure each pollutant and not depend on proxies or surrogate markers of the pollutants. This is therefore the first case-control study to investigate and report an association between BC and childhood pneumonia at the household level in Abuja, Nigeria. Furthermore, this is the first population-based study to report this association; previous studies investigating the influence of BC have been done mostly in controlled settings.

Furthermore, there was an association of seasonality on pollutant levels. We found that households were exposed to higher concentration of $PM_{2.5}$, CO and BC during rainy season compared to dry season. This could be due to increased cooking activities indoors during the rainy season. This reinforces previous findings where higher exposure during the rainy season compared to the dry season has been observed [74-76]. However, PM_1 was higher during the dry (i.e. November to March) season compared to rainy season (i.e. April to October).

Seasonality is implicated in changing both the composition and concentration of pollutants. For example, in a study conducted in Italy, $PM_{2.5}$ analysed in the winter months was made up of organic species and products of combustion from heating however, in the spring and summer months, $PM_{2.5}$ obtained in identical environments was characterised by soil-related organic components and secondary inorganic components [204]. As lifestyle is significantly affected by season, it is not inconceivable that the compositions of PM between seasons in Nigeria is likely to also vary and requires careful evaluation. However, it is important to note that a longer study of at least two years is required to understand fully the effect of seasonality on pollutants and disease episode.

Undernutrition and pneumonia episode

Furthermore, the results presented in this thesis indicate that cases were more likely to be undernourished (p-value <0.05). This result agrees with existing research; most healthy children can fight the infection with their natural defences, children whose immune systems are compromised are at higher risk of developing pneumonia, although it is difficult to ascertain if undernutrition in this case, was present before pneumonia episode or was a consequence of the disease. A child's immune system may be weakened by undernutrition, especially in infants who are not exclusively breastfed [205, 206]. Childhood undernutrition, especially wasting (children who have a weight too low for their height) is a risk factor for pneumonia in children [207]. It contributed to 53% of pneumonia deaths in 2017 in children under five in Nigeria. Without sufficient energy intake, the body cannot cope with increased energy demands required to fight off the infection. A literature review of pneumonia in malnourished children by Chisti and colleagues found that undernourished children are between two and four times more likely to be admitted to hospital due to pneumonia and up to 15 times more likely to die from it in developing countries [9].

Other factors affecting pneumonia episodes in children under five

Factors affecting pneumonia may be grouped into behaviourally modifiable and unmodifiable factors. Behaviourally modifiable factors may have affected the observations and interpretation of the pneumonia episodes. The problem is that results could have been different if behaviour is been affected after the hospital/health care advice.

Alongside pollution levels, a higher proportion of cases were within the lowest socioeconomic group compared to controls. Poverty is known to affect early treatment seeking behavior by caregivers predominantly due to barriers to financial access [208]. Treatment seeking behavior is associated with high disease incidence usually in low-income countries [208].

In general, more cases (75%) were present for cases who accompanied their mothers during cooking, compared to 37% of the control group. A study assessing cooking fuel choice in Lagos, Nigeria, reports the choice of cooking fuels was predominantly kerosene, followed by charcoal. Liquified petroleum gas was the least used [209]. Cooking fuels such as kerosene and firewood are known to increase household pollution levels, which increase the risk of health damaging effects [209]. In this study, 12% of cases used kerosene compared to 20% of controls. Furthermore, 12% of cases used biomass fuel while 11.5 % of control. Overall, a high percentage of the study population used a combination of these fuel choices. This therefore suggests, time children spent with their mothers during cooking is a more important factor to consider in reducing pollution-induced pneumonia episode than fuel choice. Time spent in cooking-environment is a behaviourally modifiable factor, which following empowerment of caregivers may have beneficial effects in reducing pneumonia episodes.

Interestingly, it was noted that, of the cases present with mothers during cooking, 63% of them were females compared to 37% males. This gender difference was also significant with a p-value <0.05. This is consistent with the literature that women and children, especially female children are often with their parents during cooking [210-213]. This gender bias means that women and female children are more frequently exposed to the dangers of indoor air pollution [210-213]. This can be due to the observation that culturally, women are responsible for cooking, cleaning and childcare which could contribute to this observation (Figure 13). Although sex is an unmodifiable construct in this setting, both genders could biologically respond differently to the exposure to pollutants [213]. Therefore, more research is required to fully understand this observation.

Bruce *et al*. found that windows did not have an independent association with indoor air pollution exposure of children. Contrary to Bruce *et al.*'s [214] findings, cases had lower number of windows in the kitchen which suggests that there can be an association between less ventilation, BC levels and a pneumonia episode in the studied population. Our finding that a reduced number of windows and ventilation holes have a positive association with the likelihood of a recent pneumonia episode in children under five may not only be due to differences in size of these structures, location, and frequency of keeping windows open as observed by Jing Chang *et al* [8]. It is likely that in some households, though there is an active chimney, owing to poor house construction (lack of concrete material), smoke removed from the chimney may be circulating back into the house owing to porous walls. This echoes Langbien's [215] finding which suggests the need to study pollutant exposure and its impact on human health under various ventilation conditions and cooking locations.

In summary, observations from this study showed that unmodifiable factors such as reduced number of windows showed a statistically significant difference between those who had a pneumonia episode and those who did not, whereas behaviorally modifiable factors such as opening of windows could potentially have a positive effect on reducing pollution levels but not enough to reach WHO "safe" levels.

5.3 The perceptions of healthcare professionals on the understanding of indoor air pollution and pneumonia in children under-five in Abuja, Nigeria

Interviews with healthcare professionals offered deeper insight into their perception of household indoor air pollution and childhood pneumonia. There was an overall sense of confidence that if well supported with education and equipment, healthcare professionals would be able to face the challenge of pneumonia in children under five. However, there was a consistent degree of frustration within the healthcare system that stems from lack of funding to the lack of equipment and support needed for the treatment of patients. Lack of health education, poverty, treatment-seeking behavior, lack of research and funding and a lack of effective policies were amongst the themes that emerged from the interviews with frontline healthcare experts.

Perceptions on education

The importance of educating and empowering the public about the link of HAP cannot be over emphasized, because currently lack of awareness plays a partial role in the behaviors observed today. Furthermore, even where the knowledge exists, households may not be empowered to implement changes. Therefore, implementation of health education programs for both caregivers and parents at the household and community level to share knowledge on how to prevent childhood pneumonia, identifying the danger signs and symptoms and immediate treatment seeking procedure. Findings from this study are in agreement with previous research highlighting the importance of health education, and its role in the fight against childhood pneumonia [216-219].

Perception on early access to treatment

In Nigeria, there is a common misconception that pneumonia is caused by exposure to cold; either through consuming cold food or experiencing cold weather [192]. This common behavior is in part to blame for treatment seeking behavior of parents because the disease etiology and preventive measures are not widely known [219, 220]. Poverty also influence early treatment seeking behavior by parents because PHC and hospitals often seem too expensive and inaccessible to them [220]. This is reflected from the qualitative interviews conducted for this study.

Also, treatment is mostly hampered by lack of accessibility to the hospitals, thereby making it less likely for people to access appropriate care.

This agrees with results obtained from the DHS component, where, children living in areas where the effect of biomass fuel and $PM_{2.5}$ was high showed a significantly lower treatment seeking behaviour when presenting with a fever (Figure 11). Children living in areas with increased ARI risk due to air pollution sources above 20% had a treatment-seeking level lower than 50%. This finding agrees with the literature there is a link between poverty and late presentation of children with pneumonia symptoms to a treatment facility. Most times, if these children were brought in for treatment earlier they would have had a better chance of recovery and there would be lesser reported mortalities because pneumonia can be treated and cured if managed properly [216, 217, 219].

Perception on health research capacity in Nigeria

One of the emerging themes obtained from the qualitative research was the lack of research on the subject matter in Nigeria. There was little to no air pollution and health research and monitoring in Nigeria. Lack of adequate funding and resources were identified by participants as the major barriers to healthcare research. Most of the participants believed that adequate research if available could identify solutions to tackle the pneumonia cases linked to air pollution.

> *"I do not have plans to talk about it because the research is not comprehensive enough or conclusive. I cannot just walk up to someone and say "stop doing this or that". But if for instance a child has allergies, or is asthmatic and has been reacting then we know the information to give. So, it is wrong to just tell people to stop using this or that".* ***Participant 10***

No doubt there is a need for transformative research in Africa. The previous lack of research investment in the continent has led to the rise of so-called neglected diseases. If cutting edge research is funded and encouraged the high mortality rate currently experienced across the continent in children under five especially in Nigeria could be substantially reduced [221, 222].

Perception on indoor air pollution in Nigeria

Indoor air pollution in Nigeria is often seen as unavoidable for rural dwellers. However, for higher income earners, smoke from cooking with biomass is often experienced during larger gatherings or celebrations (i.e. birthdays, religious celebrations, weddings) where clean cooking methods are not able to meet the large cooking demands [223]. These behaviours lead to fuel stacking by people who often use different fuel types for different occasions [223].

Certain families are aware of the health dangers associated with HAP. However, some households are not aware of these risk, whilst others do not feel empowered to deviate from the norm as burning biomass fuels is their only means of cooking and people must cook [224]. A study conducted by Isara and Aigbokhaode in Nigeria discovered that not only did household know the health implications of exposure to biomass smoke, they also had some knowledge on smoke interventions [225].

The definition of indoor pollution amongst the population is not very clear. Certain people believe it is the presence of smoke from burning biomass, meaning that a kerosene stove is perceived as cleaner. Others believe that any source of fuel other than electricity and LPG is polluting the indoor environment [224-226].

Also, in Nigeria there is a lack of knowledge that links pollution to pneumonia. When asked most responders did not think smoke was a risk factor that could be linked with childhood pneumonia and accordingly did not think that avoiding smoke in their homes could prevent pneumonia in their children [226].

5.4 Synthesis of main findings from all three components of the study

This section aims to provide an in-depth synergy of the distinct quantitative components (DHS and Indoor air monitoring) and qualitative findings.

Most participants are routinely exposed to levels of pollution that exceeds WHO guidelines.

A high number of both cases and control were exposed to extreme levels of pollution across all measured pollutants. This agrees with the DHS study and other published work which report that a significant part of the population are exposed to dangerous levels of pollution [79]. This could explain the fact that Nigeria is ranked highly in countries most affected by pneumonia mortality in the worlds [1]. Furthermore, the high levels of atmospheric pollution across the country meant that it was important to assess other factors that could promote disease outcomes such as lifestyle, building structure and treatment seeking behavior. From our analysis, the exposure of the control population was significantly higher than cases, this could due to the fact that healthcare professionals had advised parents of children with pneumonia on how to reduce the risk of the child by subtle lifestyle changes such as opening the windows of the living area more often or using less smoky fuel types.

Undernutrition

More children with pneumonia were observed to also be undernourished. Undernourishment and pollution are a dangerous combination because an immunocompromised child finds it very difficult to fight infection. Most healthy children can fight the infection with their natural defences, whilst children whose immune systems are weak are at higher risk of developing pneumonia. A child's immune system may be weakened by undernutrition or undernourishment, especially in infants who are not exclusively breastfed [205, 206].

Improved housing

Our finding from DHS study showed that improved housing could protect children from respiratory infection. Similarly, it has been previously reported that cement floors have a protective effect on child health (respiratory infection) [227]. This is consistent with the urban planning and public health literature on housing improvements being critical to health [228], housing improvements such as cemented floors to improve child health, is a key policy recommendation.

Our finding that cooking indoors, relative to outdoor cooking, significantly increases children's likelihood of experiencing indoor air pollution of households related illnesses, is similar to results from Langbien's [215] study that outdoor cooking significantly reduces respiratory diseases among children aged 0–4 years, in 30 developing countries. A second policy recommendation would be to promote outdoor (full or partial) cooking, during favorable seasons, in alignment with households' existing cooking practices.

Contrary to Bruce *et al* 's [214] findings, in this study we found that the number of windows has a significant association with respiratory infection. Our finding that number of windows and ventilation holes have opposing associations with the likelihood of children experiencing health symptoms may be due to differences in size of these structures, and frequency of keeping windows open. It is likely that in some households, though there is an active chimney, owing to poor house construction (lack of concrete material), smoke removed from the chimney may be circulating back into the house owing to porous walls, echoing Langbien's [215] finding which suggests the need to study pollutant exposure and its impact on human health under various ventilation conditions and cooking locations.

Black carbon was significantly higher in cases compared to controls

This is an interesting finding because although PM is lower in cases compared to controls, black carbon was significantly higher, possibly due to the composition of the particulate matter. Pneumococcal bacteria which causes pneumonia has been shown to have associations with BC rather than with $PM_{2.5}$ [202], suggesting that BC is a better indicator of harmful particulate substances from combustion sources than undifferentiated PM mass. This is the first population-based study to report this association; scientific studies investigating the influence of BC are mostly in controlled settings. Pollutants such as BC can alter human functioning in multiple ways.

Firstly, there is growing evidence that pollutants such as PM and BC triggers immune response in experimental conditions. For example, both diesel and ambient particulate matter samples which ae established sources of BC induce pro-inflammatory responses in both macrophages [229, 230] and human bronchial epithelial cells [231-234]. Furthermore, brake abrasion dust (BAD) at non-lethal dosages emits BC and induces pro-inflammatory responses in A549 and Calu-3 epithelial cells [235, 236]. Similar responses have been reported in primary bronchial epithelial cells challenged with metal-rich PM collected from an underground railway station [237]. Conceivably, an overdrive in immune response due to exposure to pollution will only exacerbate the occurrence of ARIs such as pneumonia.

Secondly, pollutants may also be able to alter innate human response to fighting pathogens. Phagocytosis is an important protective mechanism employed by lungs against foreign materials such as bacteria. However, one effect of these pollutants such as BC is to hamper the normal phagocytic ability of these specialised cells, increasing the susceptibility of the lungs to infections [238]. For example, ambient $PM_{2.5}$ and diesel exhaust particle (DEP) have been shown to reduce the capacity for macrophages to engulf and process respiratory pathogens [239-242]. Furthermore, in both experimental and clinical studies, the ability of pollution to increase susceptibility has been demonstrated, with urban air pollution and household air pollution [243] as well as exposure to electronic cigarette smoke disrupting essential immunological responses, therefore increasing predisposition to infections and complications such as pneumonia [244, 245]. Importantly, these essential phagocytic responses could be reversed in-vitro when these pollutants were removed [246]. Therefore, this could mean the health effects of pollution are generally reversible. However more research is needed to establish this.

Thirdly, pollution may also alter the biology of the pneumonia-causing pathogens, making them less susceptible to available treatments. For example, BC has been shown to alter Streptococcus pneumoniae colonization of the respiratory tract [40]. exposure to BC was shown to promote thicker and more complex Streptococcus pneumoniae biofilms as well promoting antibiotic resistance in these bacteria [40].

5.5 Potential solutions for reducing HAP to improve health outcomes

Electricity

Electricity has been shown to produce less local pollution when used as a fuel during cooking in low- and middle-income countries. This in turn would have favourable health outcomes [247, 248].

Electricity is regarded as a standard cooking fuel rated high on the energy ladder because of its high performance and heat transmission characteristics together with little particulate emissions. Electricity is being subsidised in Nigeria as part of a Government initiative to stimulate the manufacturing sector. National energy policy does not encourage heating and cooking by using electricity [249]. Overall, most households generally use electricity for lighting and powering appliances, especially in the dark. Studies have reported that there are several problems in relation to energy infrastructure and also identified systemic malpractice, like overestimation of bills and unauthorised connection to the power grid so as to get access to free electricity [223]. Also, insecurity of supply makes it an uncommon cooking option.

These reports also indicated that the distribution companies take advantage of the estimated billing scheme and would not be willing to provide energy metres available to consumers. Households in rural and semi-urban sites which don't have electricity metres indicated that prevented them from officially paying for electricity used. Across urban areas, some electrical metres are placed on power poles, making it easy for households to form unauthorised connections anywhere they please.

Given these illicit ties and also the discounts available for energy, supply problems remains a serious problem in Nigeria. Households not connected to the national grid and people with varying views on the supply of power were asked about the employment of electrical stoves for cooking. Most stated that they are not going to connect electricity to their households within the near future and therefore do not plan to use electricity for cooking: While most households understood the importance of electricity, within our study population only 5% cases and 3% controls used it for cooking purposes. Ayodeji *et al's* study reported using Nigeria DHS study, where the quantity of households use energy for cooking is little (less than one per cent) relative to those using firewood [250].

Liquid Petroleum Gas (LPG)

LPG is a fuel mostly used for cooking in developing countries. It has been shown to emit less pollution when used in place of solid biomass fuels [26].

Cost of LPG

While the national approach to energy use aims to encourage LPG as a household cooking fuel, it is not subsidised. LPG is primarily supplied to customers in cylinders and there is a marginal demand for LPG in industrial and semi-urban areas within Nigeria. The cylinders are calibrated in kilogrammes (kg) and a ten kg cylinder was priced at N3500 (£7.17) during data collection. Usually a 10kg cylinder usually lasted a family of four for a month, and the cost of LPG was relatively stable as compared with other fuels like charcoal and fuelwood which have prices that fluctuate seasonally.

Access to LPG

Participants that use LPG in semi-urban and rural areas indicated that refuelling stations are situated outside their towns, which also raises the question of cost of travel for customers, causing problems when refuelling cylinders. Many rural participants who don't use LPG posed questions regarding connectivity, suggesting that various income classes, even rural households could have access, but fuel usage was still a general problem for semi-urban and rural households.

The results show that participants score LPG high in terms of cooking speed, cleanliness of cooking pots and kitchen cleanliness. Interestingly, cooking pace was the attribute most users enjoyed regarding LPG, with few noting that LPG stoves don't emit smoke. Cecelski and Matinga's research on gas cooking in developed countries, reveals that individuals want LPG because it saves time and domestic drudgery [251]. Studies looking at fuel uptake in Nigeria showed that continuous usage of LPG wasn't feasible in Nigeria because of a number of factors, including family size and finance.

Some household participants, who had abandoned gas stoves outside their houses, identified the following problem. Responses indicate that there are many explanations for dumping LPG stoves. Similar results were reported during a qualitative study conducted in Abia, Nigeria, which checked out obstacles to LPG uptake in urban households [252], Respondents say that there are many explanations for dumping LPG stoves, several of which are linked to health and safety and others were personal experience. Different results were identified during the analysis conducted in Abia, Nigeria, which investigated obstacles to the use of LPG in urban households [252].

In this study, no participants expressed reservations regarding the usage of LPG stoves while cooking with children. However, the results of a qualitative study conducted in Peru [253], most children favoured cooking with LPG because they did not consider LPG stoves to be dangerous, while adults were worried about using this fuel because of the chance of LPG explosion.

It can thus be summarised that the lack of stable electricity, lack of availability of low-cost clean fuels and unclear health benefits have acted as primary obstacles to the energy transition. The development of infrastructure to promote modern fuels and lift safety consciousness is highly desirable.

Improved cook stoves

This research wanted to understand where improved cook stove (ICS) fall into household spending schedules, since most studies identified finance as a major barrier to uptake. It was not surprising that ICSs was listed low on participants expense charts, indicating that they'd spend on other things before spending on ICS. Such responses agree with the findings of a study in Kenya [254] on energy deprivation limits, which focused on supporting ICS and indicated that economic conditions influence how households distribute their capital.

This finding is partially backed by the qualitative research carried out in India [255] on the effect of a rise in economic well-being on the choices taken by the disadvantaged in terms of fuel use and environmental factors. The lists was largely informed by different priorities, household provisions and items, house renovation and, specifically children's schooling had higher priorities in these cultures. The general belief within these communities was that if you trained your children, they are more likely to have a prosperous life in the future and can then purchase ICS.

Ruiz-Mercado and Masera's [256] reported that fuel-device stacking analysis in Mexico, The study reported that the social position of households has an impact on the energy transition. Researchers have also found that households assign preference to their fuel cooking option, which depends on cooking activity depending on the circumstances.

Jane Trac [257] expressed an analogous opinion during her research performed in China, which revealed that, following 30 years of electrification, wood-burning had taken a huge place within household traditional cooking techniques, and therefore the consequence was the limited use of electricity. Which means, the energy ladder model has oversimplified the complicated complexities of energy transformations, and the related theories and models must include those cultural, behavioural and technical interactions that influence the use of ICS and observe its benefits through sustained use.

Households from rural and semi-urban dwellers expressed specific concerns regarding ICS. Their responses suggest that the measurable advantages of ICS are challenging to grasp, Similar findings were made during a study conducted in Bangladesh by Miller and Mobarak [258] on intra-house externalities and low demand for brand new technology; the research showed that there was a low demand for new technologies. These was correlated with a lack of trust. It was reported that some participants chose conventional stoves over ICS due to their underlying socio-economic and cultural background, even being mindful that utilising ICS could also be cost-effective.

The second point indicates that, in certain cases, the households are not using ICS due to inadequate access to refuelling sources, despite being aware of the benefits these stoves provide. This contradicts the recommendations of Rehfuess *et al* [259] study, which suggests that households would tend to use better stoves thanks to the benefits. Therefore, it is assumed that several variables, including belief and trust, jointly affect end-user expectations of ICS usage. Constant knowledge building and confidence-building among ICS users could promote continued usage.

Biomass fuels are valuable to society as the simplest way of providing fuel to cook for social events and for agricultural practises. We should note that, clean fuels and cooking technology are mainly inaccessible in rural areas thanks to lack of infrastructure, and therefore the trends of usage indicate that the energy change is unlikely to occur without significant intervention.

When commenting on the problems arising in the literature and trends of fuel and stove use, it was observed that these are affected by fuel supply, costs, family size, ICS measurable advantages, community and various goals. Significant results indicate that the choice of fuel and cooking technology is seen as “a women's duty” thanks to their crucial role in collecting fuel and preparing food in Nigeria and most developing countries.

The usage of ICS was discarded by women having several stoves at any given point in time when ICS and regular stoves did not function optimally. In particular, fuel and stove stacking has become a typical occurrence in both high and low-income families and has been due to different variables, like family size. There is a custom where people choose big stoves to prepare food for visitors or parties. As a consequence, they still keep these stoves that are suitable for various occasions which indirectly facilitates stacking.

The cooking approach is concentrated on the wants of the household and the knowledge of the standard stove, because it provides versatile facilities, thereby complicating the energy transfer cycle. The culinary habits in these families have social and environmental consequences; it is therefore essential to grasp their understanding of biomass smoke, additionally because of the inhibitors and facilitators of ICS in Nigeria.

Other studies reported that households were worried about smoke generated while cooking [7, 260-263]. Studies found that certain households designed inefficient kitchens, indicating their lack of awareness of indoor air pollution of households.

An interesting limitation to the energy ladder model, is to note that households have conflicting needs and are likely to channel their financial capital to other, more pressing needs. However, the literature showed that these households prioritised their requirements on the premise of neighbourhood preferences and failed to favour renewable fuel and cooking technology as compared to the recommendations of the energy ladder model. It is, therefore, necessary for the theoretical model to spot user-related input for the research and production of energy programmes.

Difficulty, failures and reason for low uptake

LPG, kerosene charcoal, and electricity were available, but most fuels were not used exclusively. Households revealed that a complete move to cleaner/safer cooking is impossible because a single stove / fuel fails to meet all of their cooking needs and desires.

Households were found to stack kerosene at both the upper and lower rungs of the energy ladder. They also showed a transparent preference for using firewood on conventional stoves because it satisfied much of their cooking needs, while many also used ICS. The selection of cooking methods observed within households was influenced by many concerns, including expense, availability, standard of operation, functional factors and cultural impacts. Conventional wood-fired stoves were widely considered to be the best to meet household cooking preferences. In comparison to the energy ladder paradigm [264-266], the socio-economic position didn't seem to have a big effect on household fuel preferences, as even households categorised as high-income with access to modern fuels still depend on biomass fuels.

The free acquisition of firewood hindered a switch to alternative fuels like charcoal, kerosene or modern fuels. Also, many households in urban and semi-urban areas prefer to buy firewood, event when the cost surpassed that of other fuels. Nonetheless, household energy preferences were found to be influenced by a stove's fuel price, including the degree to which they compared with other household prices, and even how they differed between locations.

Discussions on household investment preferences have shown that buying an ICS is ranked much lower than paying child school fees, creating business-related livelihood prospects or investing in property. Certain households gained income from the acquisition and selling of firewood and charcoal and regarded it as convenient to use them for his or her own cooking needs.

The higher cost of charcoal within the urban region relative to the semi-urban area, however, served as a deterrent to the use of charcoal, whereas with the case of kerosene, high cost and limited availability – especially in rural areas – restricted its use as a cooking fuel. Firewood, on the other hand, was commonly favoured, since households could quickly and reliably access it.

In the case of clean fuels, results from our research mirrored studies showing that concerns about the initial cost of stoves and ongoing fuel bills especially among low-income consumers were an obstacle to the adoption of electrical or LPG-based cooking systems [267]. In the case of energy, reservations over recurring costs and inaccurate or overestimated bills combined with a scarcity of ability are described as primary obstacles to the use of clean fuels as a long-term cooking option. In the case of gas, however, the initial expense of stoves and cylinder re-filling charges is listed as disincentives for the adoption and sustained usage of LPG and access to gas re-filling facilities was low in rural areas.

5.6 Challenges of doing research in Nigeria

Often the research conducted in Nigeria are cross sectional studies collecting data using questionnaires or analysis of secondary data. It was a huge challenge getting the required equipment needed for research in Nigeria, as most rental companies declined to supply equipment for use in Africa.

Whilst in the field, I was faced with numerous challenges. Conducting this type of research is not the norm in Nigeria hence sometimes my reception was met with mixed feelings. Also, unexpected events like, strikes or regime change can interrupt data collection.

At the government level, I got all the support I needed. Ethical application was approved at no cost within a month. However, one approval from the federal government (National Health Research Ethics Committee) was not enough. I had to apply for additional approval whenever I entered a new hospital or council.

In addition, the public are not used to participating in these types of research. There is a huge issue with regards to trust in developing countries, in Nigeria letting a stranger into your home is not common practice and would raise security concerns and suspicion. During my field work I had a close call when security operatives were called because my air quality monitors were mistaken for a bomb. This lack of trust meant an increase in equipment tampering which meant some observations where discarded and could not be included in the study analysis

Repeatedly I had to explain to participants when asking for their consent, the concept of conducting research and the benefits it could provide to the public. However, it was unclear to them the bigger picture and benefits of conducting such research.

Furthermore, the lack of constant reliable electricity meant that external batteries were deployed which meant additional logistics and cost. Logistical difficulties due to poor transport infrastructures like bad roads to hospitals or participants households were also apparent.

5.7 Strength and limitations of the study

One of the core strengths of this research is its novelty. This is the first study to simultaneously measure exposure of pneumonia cases to PM_1 $PM_{2.5}$, CO and BC in Abuja, Nigeria. This piece of research adds to the growing knowledge of the health effects of indoor air pollution in households, further understanding the pollutants that are crucial to the mechanism of transmission from pollution source to host.

The use of a mixed methods approach addressed the overarching study aims more comprehensively than by using either quantitative or qualitative method alone. By adopting a mixed methods approach, quantitative study which is limited by the ability to explain the ‘how’ or ‘why’ of research findings was compensated by the qualitative study. Also, the quantitative component of the study counterbalanced a common limitation of qualitative study, which is the limited applicability of findings due to the small sample sizes required for an in-depth exploration of a research question.

A case control study design was employed to compare exposures to different indoor pollutants between cases and controls with the assumption that they would have similar exposures. However, a limitation to this approach was that cases where recruited from hospitals, which might influence the post diagnosed exposure of the child.

Measurements were taken over 24 hours. In 33 households, equipment was tampered with (e.g. by blocking the air inlet or batteries running out due to electricity issues) or experienced interruption in device power supply leading to a break in the continuous measurements over the 24h period. Second, measurements for less than 24 hours were recorded, whilst WHO guidelines are based on 24-hour measurements. We cannot rule out selection bias within the cases population as only a certain group of people choose to, and can afford to, go to the hospital. Also, in the absence of radiologically diagnosed cases, DHS program remains an important source of health information to facilitate research, which would otherwise be impossible.

Furthermore, given the sample size restriction in spite of collecting data for a year, there was a need to alter air quality analysis. Whilst Wilcoxon rank sum test tests provides an opportunity to analyze two independent samples without assuming the population is normally distributed (a concern which arose following the smaller sample size), logistic regression would have provided the opportunity for adjustment for potential confounding factors like sex, household income and MUAC. Therefore, this is a limitation of the study.

Nonetheless, collecting data across the entire year meant that the researcher was able to quantify seasonal effects on pollution and pneumonia. Despite these difficulties, across the entire year, out of a total of 403 cases from 11 hospitals and 7 primary healthcare centers, 290 (72%) agreed to participate in our study. A number of issues during the year delayed data collection; on one occasion there were hospital strikes across the country. In addition, the limited time and security constraints faced in the field influenced my movement and working hours.

Study limitations relating to the use of SidePak and PATs+ monitors for example, battery life limits the number of hours the equipment can run for. I had to prolong running time by using external batteries and an inverter to make sure they ran for more than 24 hours.

Another limitation of this study is the lack of subgroup geospatial analysis comparing urban vs rural areas within the DHS database. Further research is required to see if the associations observed between solid fuel use and pollution in children under 5 shows any differences in urban vs rural areas.

A major strength of this study is that it measures for the first time the association of multiple component exposures of household air pollution (PM_1 $PM_{2.5}$, CO and BC) and pneumonia in Abuja, Nigeria. This works strengthens available primary data evidence on the effects of indoor air pollution on pneumonia episodes in children under five. The use of secondary symptomatic data for the diagnosis of ARI was a limitation to the current study, however in the absence of feasible medically or radiologically confirmed diagnosis this is best possible option and perhaps closest to reality.

Furthermore, the use of satellite obtained $PM_{2.5}$ rather than physical measurement of $PM_{2.5}$ in household to study the combined effects of biomass fuel use and $PM_{2.5}$ exposure is a limitation of the study. However, the combination used herein, provides nationally representative and robust data. A strength of this study is that it provides a country-wide visual map of the pollution levels and disease prevalence, which helps put the pollution problem in a country-wide perspective.

5.8 Generalizability and transferability of findings

As earlier stated, due to the security concerns, this study could not be carried out in the most affected areas identified from the DHS study, nonetheless the findings of this current study could still be generalised to the whole of Nigeria nonetheless with some caution that the results from the case-control study may be more exaggerated in certain parts of Nigeria. Furthermore, it may not be appropriate to generalise findings in this study as most patients who present to healthcare centres (e.g. PHCs, secondary and tertiary hospitals) in Nigeria tend to be of higher socioeconomic class [268, 269]. Nonetheless, the study contributes to the literature especially regarding the association of individual pollutants to childhood pneumonia.

Findings in the qualitative study may be transferable across the healthcare system as there seemed to be a fair representation of health workers, because the study explored the perspectives of healthcare professionals with diverse backgrounds (e.g. PHC coordinators, nurses, surveillance officer, medical doctors etc.) involved with the running of primary healthcare system in Nigeria.

The views expressed by the interviewed mothers in the qualitative component of study may not be applicable to those of fathers. Fathers are known to significantly influence the decision making and health seeking behaviours of mothers and ultimately the health of the child [270]. It would have been interesting to explore fathers’ perceptions and knowledge of indoor air pollution and child health.

6 Recommendation and Conclusions

Recommendations for public health practice and future research

Health Education and Promotion including behaviour change

The reduction of pneumonia incidence in children under five in Nigeria is urgently needed and this requires a multifaceted approach from the government, caregivers, including healthcare providers and other stakeholders. Educational and health promotion campaigns to prevent exposure of children under five to pollutants from cooking fuel is essential because we observed that the understanding of the health consequences of indoor pollution amongst the studied population varies considerably. Caregivers are unaware of the potential consequences of the exposure to household air pollutants and the health effects arising from this. Therefore, to achieve this much needed reduction in disease burden a targeted approach to empowering caregivers is required. We propose a grassroot system of health education provision for caregivers during antenatal classes and routing immunization visits on the importance of ventilation and cleaner fuel uses as interventions to reduce their exposure to pollutants. Furthermore, as there is some longstanding preference for biomass fuel use, guidance on its use whilst minimizing detrimental health effects needs to also be provided via these platforms. For example, behavioral changes such as not having children close to biomass fuel stations whilst cooking could provide favorable health outcomes.

Reducing Exposure

Furthermore, active prevention actions such as cleaner fuel choices, household behavioural modifications such as reducing child presence in the cooking environment and encouraging the opening of windows for optimal ventilation is recommended [8]. Firstly, it can thus be summarised that the lack of stable electricity, lack of access to affordable clean fuels and a lack of clear health benefits of using clean fuels have acted as primary obstacles to energy transition [271]. The development of infrastructure to facilitate access to clean fuels and promotion of safety consciousness should be considered. Second, children should be kept away from cooking areas to help reduce their exposure to pollutants emitted during cooking. This is crucial because children in homes that uses good quality chimney stoves and exclusive use of gas cookers, still show high exposure levels [271]. This information needs to be reiterated in schools, hospitals and through the media for parents to be well informed.

Influencing Health Seeking Behaviours and health service provision

Furthermore, factors affecting the health seeking behavior can be very complex nonetheless, understanding this is critical to the overall reduction in the health burden from pneumonia in children under 5. Providing free or subsidized health care services will eradicate the economic reasons that deter caregivers from assessing health care promptly. Furthermore, culturally, caregivers often seek to provide treatment at home before seeking professional health care [192]. Therefore, informing caregivers on the etiology and severity of pneumonia is necessary to improve promote health seeking behavior.

Most healthcare facilities currently work with proxy indicators, which makes a definite pneumonia diagnosis difficult in these settings. Improving radiographic diagnostics would give healthcare professionals enough time to detect and adequately manage the disease [197]. Existing health systems lack the capacity for proper diagnosis and early treatment. In other to improve early home diagnosis and treatment implementation the adoption of the WHO IMCI across the country is crucial [192].

Policy Review and improving access to data for decision making

Pneumonia was widely referred to as the silent killer due to the lack of targeted resources to reducing its burden in Nigeria [197]. However, in recent years the ministry of health has evaluated strategies to combating pneumonia in Nigeria [197]. Of these interventions, reduction of household air pollution as well as other factors such as promoting immunization, improving nutrition and availability of oral antibiotics have been proposed [197]. This present study strongly supports the implementation of these strategies as a means of reducing the disease burden in Nigeria. A more targeted research approach and effective monitoring of the implementation of current and new policies is needed particularly in high population areas. In addition, researchers should try an understand the interaction between indoor and outdoor pollution. Also, with global rising temperatures researchers need to understand the effect these would have on pneumonia episodes.

As stated, in this report [197], the Nigerian government is duly aware of the problem of pollution and the associated high mortality and morbidity from pneumonia and other ARI in children under 5. Various policies and landmarks interventions have been proposed, all without fruition until now. This current study further reiterates a need for urgent action. Whilst there is the economic means and health knowledge of dealing with this problem, interventions need to go beyond isolated policies to working in sync with researchers, caregivers and families to ensure change is elicited.

Furthermore, policies are often proposed in isolation, ignoring the fact that problems such as climate change, the environment, deforestation, gender and health cannot be dealt with in isolation, because they are often connected. Therefore, a policy that would have a united front to tackle climate change, the environment, deforestation, gender and health would directly help the reduction of pollution exposure of mothers and children and the resulting diseases like pneumonia.

One aspect of the problem so far is the lack of household air quality monitoring in Nigeria. This study provides a representation of the household air quality factors associated with pneumonia episodes in children under five in Nigeria. Therefore, results reported in this study can help guide the government and public health practitioners in developing appropriate household and treatment seeking behaviour interventions and a review of the policy around air quality and childhood respiratory illnesses in Nigeria. There needs to be concerted effort towards improving routine information systems which captures environmental and health data so that reliance on secondary imperfect data such as the DHS for investigations in the future is reduced.

Conclusion

The problem remains that pollution is widely investigated using proxy indicators for pollutants particularly in developing countries. Furthermore, pollutants such as $PM_{2.5}$, PM_1, BC and CO are often investigated in isolation. Therefore, the gap still exists for the simultaneous measurement of key pollutants in association with pneumonia. Also, it is unclear what the individual effects of the emitted pollutant to health is, especially in children.

Findings from the initial review conducted in this study indicated that measurements and definitions of exposures and outcomes are unclear and so is the current evidence of HAP and pneumonia in children. Use of proxy indicators such as solid fuel suggested an association with pneumonia, however, when CO and $PM_{2.5}$ were measured, no association was observed this may be as a result of methods used. Therefore, direct measurements of all pollutants simultaneously is urgently required to fully understand the role of pollution in pneumonia incidence in children under five. Preferably, factors influencing pneumonia incidence and disease onset needs to be ascertained in children under age five. This review also identified the need to understand how season, under-nutrition, crowding and building materials can influence the risk of childhood pneumonia as this may help inform more targeted strategies to reducing the burden of pneumonia in this age group.

In this current study these gaps were addressed. Firstly, the analysis of DHS data showed that across Nigeria, the entire population is exposed to very high levels of pollution with the worst hit areas also linked to low levels of treatment seeking behavior. Furthermore, this study reports the association between BC and childhood pneumonia episodes in a case-control study setting. Also, this study confirms the association between undernutrition and childhood pneumonia. Finally, this study reports the importance of non-modifiable factors such as number of windows, and building materials but also behaviourally modifiable factors such as time spent in the cooking environment during the study period. In general, the entire population were exposed to pollutant levels that far exceeded WHO guidelines both assessed via satellite data in DHS component and in the case-control component when primary air quality measurements were made. Nonetheless, easy lifestyle factors such as promoting air circulation by increased number of windows, removing children from cooking environment and early treatment seeking were seen to be important in disease episodes.

The interviews with healthcare professionals revealed the dissatisfaction within the healthcare system caused by lack of support needed for the treatment of their patients, funding, and the lack of equipment. Furthermore, the themes that emerged from the key informant interviews were, lack of awareness, education, poverty, treatment-seeking behavior, lack of research and funding and a lack of effective policies. Also, these interviews helped us understand that the lack of trust within the healthcare system in high impact areas may explain the low care seeking behavior observed in these communities.

This work recommends a multifaceted approach that combines educational and health promotion campaigns to prevent childhood pneumonia. This includes, promoting improved housing and behaviour changes that support exposure reduction and adequate ventilation, early treatment seeking behaviour and targeted implementation of the integrated management of childhood illness particularly in high pollution areas is an important step in reducing the pneumonia burden in children under five in Nigeria.

Also, health care providers need to have a robust approach to early pneumonia diagnoses in the identified hotspot areas alongside public health education campaigns to reduce exposures and encourage behaviour change. Furthermore, the visual map hotspots of ARI in Nigeria presented in this study can aid decision making by policy makers, to reallocate resources to these hotspots in high transmission periods in order to achieve higher impact.

This research is particularly important since the vast majority of affected countries like Nigeria with high childhood pneumonia mortality and morbidity have difficulty implementing their laws or policies needed to tackle childhood pneumonia. Evidence presented in this research revealed the context of this, from the Nigerian perspective and provides a starting point for policy review to include PM_1 and BC in public health questions. Although focused on only one country, the findings such as the effect of high BC exposure and pneumonia episodes have a broader relevance as HAP and childhood pneumonia challenges inevitably contribute to similar health and social challenges worldwide.

7 Appendix

7.1 Appendix 1: Systematic Review search strategy

Pubmed

Indoor Air Pollution:

((("Air Pollution, Indoor/adverse effects"[Mesh] OR "Air Pollution, Indoor/analysis"[Mesh] OR "Air Pollution, Indoor/statistics and numerical data"[Mesh])) OR "Pollution"[Mesh] "Tobacco Smoke Pollution"[Mesh]) OR "Air Pollution, Indoor"[Mesh]

Pneumonia:

"Pneumonia"[Mesh] OR "Pneumonia, Ventilator-Associated"[Mesh] OR "Pneumonia, Bacterial"[Mesh] OR "Pneumonia, Viral"[Mesh] OR "Pneumonia, Staphylococcal"[Mesh] OR "Pneumonia, Rickettsial"[Mesh] OR "Pneumonia, Mycoplasma"[Mesh] OR "Pneumonia, Pneumococcal"[Mesh] OR "Pneumonia, Aspiration"[Mesh] OR "Pulmonary Eosinophilia"[Mesh] OR "Idiopathic Interstitial Pneumonias"[Mesh] OR "Idiopathic Pulmonary Fibrosis"[Mesh] OR "Lung Diseases, Interstitial"[Mesh] OR "Bronchopneumonia"[Mesh]

Children:

("Child, Preschool"[Mesh]) AND "Child"[Mesh]

(((("Air Pollution, Indoor/adverse effects"[Mesh] OR "Pollution"[Mesh] OR "Air Pollution, Indoor/analysis"[Mesh] OR "Air Pollution, Indoor/statistics and numerical data"[Mesh])) OR "Tobacco Smoke Pollution"[Mesh]) OR "Black carbon"[Mesh] OR "Air Pollution, Indoor"[Mesh] AND "Pneumonia"[Mesh] OR "Pneumonia, Ventilator-Associated"[Mesh] OR "Pneumonia, Bacterial"[Mesh] OR "Pneumonia, Viral"[Mesh] OR "Pneumonia, Staphylococcal"[Mesh] OR "Pneumonia, Rickettsial"[Mesh] OR "Pneumonia, Mycoplasma"[Mesh] OR "Pneumonia, Pneumococcal"[Mesh] OR "Pneumonia, Aspiration"[Mesh] OR "Pulmonary Eosinophilia"[Mesh] OR "Idiopathic Interstitial Pneumonias"[Mesh] OR "Idiopathic Pulmonary Fibrosis"[Mesh] OR "Lung Diseases, Interstitial"[Mesh] OR "Bronchopneumonia"[Mesh] AND ("humans"[MeSH Terms] AND (("infant"[MeSH Terms] OR "child"[MeSH Terms] OR "adolescent"[MeSH Terms]) OR "children nder 5"[Mesh] OR "infant, newborn"[MeSH Terms] OR "infant"[MeSH Terms] OR "infant"[MeSH Terms:noexp] OR "child, preschool"[MeSH Terms])))

Emabse search:

exp Infant/ or infant$.mp. or infancy.mp. or newborn$.mp. or baby$.mp. or babies.mp. or neonat$.mp. or exp Child/ or child$.mp. or kid.mp. or kids.mp. or toddler$.mp. or exp Adolescent/ or adoles$.mp. or teen$.mp. or boy$.mp. or girl$.mp. or exp Pediatrics/ or pediatric$.mp. or paediatric$.mp. or paediatric$.mp. or young people.mp.

And

Pneu$.mp. or exp Pneumonia

And

Air pollution/ or indoor air pollution/ or indoor air quality.mp

Web of Knowledge

Infant or infant or infancy or newborn or baby or babies or neonat or child or child or kid or kids or toddler or adolescent or adolesc or teen or boy or girl or pediatrics or pediatric or paediatric or paediatric or young people

AND

pneu or pneumonia

AND

Air pollution or indoor air pollution or carbon monoxide or carbon mono or carbon dioxide or carbon diox or nitrogen monoxide or nitrogen dioxide or particulate matter or sulphur dioxide or ozone or volatile organic compounds or black carbon

CINAHL

"(indoor air quality OR indoor air pollution) AND pneumonia AND (children under five OR children under five OR children)"

Scopus:

Pneumonia AND indoor air pollution AND children under five

Appendix 2: Pico Table screening criteria for titles and abstracts

Criterion	Guidance notes	Decision
1. Year	No restriction on date	
2. Study Design	To include: Cross sectional studies, case control studies, longitudinal observation studies (prospective and retrospective cohort and longitudinal studies) and systematic reviews (meta-analysis/reviews/reviews of reviews)	
3. Type of participants	Studies involved children aged 0 – 5 years old	
4. Health Outcomes	The study focused on pneumonia as the primary health outcome	

5. Exposure	Does the study look at indoor air pollution as primary exposure	

Appendix 3: NEWCASTLE - OTTAWA QUALITY ASSESSMENT SCALE CASE CONTROL STUDIES

Note: A study can be awarded a maximum of one star for each numbered item within the Selection and Exposure categories. A maximum of two stars can be given for Comparability.

Selection

1) Is the case definition adequate?

a) Yes, with independent validation

b) Yes, e.g. record linkage or based on self-reports

c) No description

2) Representativeness of the cases

a) Consecutive or obviously representative series of cases

b) Potential for selection biases or not stated

3) Selection of Controls

a) Community controls

b) Hospital controls

c) No description

4) Definition of Controls

a) No history of disease (endpoint)

b) No description of source

Comparability

1) Comparability of cases and controls on the basis of the design or analysis

a) Study controls for _______________ (Select the most important factor.)

b) Study controls for any additional factor (This criteria could be modified to indicate specific control for a second important factor.)

Exposure

1) Ascertainment of exposure

a) Secure record (e.g. surgical records)

b) structured interview where blind to case/control status

c) Interview not blinded to case/control status

d) Written self-report or medical record only

e) No description

2) Same method of ascertainment for cases and controls

a) Yes

b) No

3) Non-Response rate

a) Same rate for both groups

b) Non respondents described

c) Rate different and no designation

APPENDIX 4: Risk of bias assessment tool (Newcastle-Ottawa scale)

Domain (source of bias)	Assessment	Risk of bias
Selection (representativeness of the sample)	Adequate case definition with independent validation (A)	Low
	Consecutive or obviously representativeness (B)	Moderate
	Selection of community participants (C)	High
	No description of sampling strategy (D)	Unclear/High
Selection (sample size)	Justified and satisfactory (A)	Low
	Not justified (B)	High
Detection (exposure)	Validated measurement tool (A)	Low
	Tool described but non-validated (B)	High
	Tool not described (C)	Unclear/High
Confounding	Adjusted for confounders (A)	Low
	No adjustment for confounders (B)	High
(Detection) Outcome assessment	Syndromic (A)	-
	Presumptive (B)	-
	Both (C)	-
	No description (D)	-

Appendix 5: Risk of bias assessment for each study

No	Country	Name/ Year of study	Selection (sampling)	Selection (sample size)	Detection (exposure)	Control confounders	Detection (outcome assessment)
1	India	Broor *et al* . 2001	A	A	B	A	A
2	Botswana	Kelly *et al* 2015	A	A	B	A	A
3	India	Sharma *et al* 1998	A	A	A	A	A
4	Nepal	Karkis *et al* . 2014	A	A	A	A	B
5	India	Mahalanabis *et al* 2002	A	A	A	A	B
6	Bangladesh	Ram *et al* 2014	A	A	A	A	B
7	India	Bassani *et al* 2010	A	A	A	A	B
8	Gambia	Dionosio *et al* 2012	A	A	B	A	B
9	Gambia	Howie *et al* 2016	A	A	A	A	B
10	Tanzania	PrayGod *et al* 2016	A	A	A	A	B
11	Nepal	Dhimal *et al* 2010	A	B	A	A	C
12	Indonesia	Shibabta *et al* 2014	A	A	B	A	C

7.2 Ethical Approval

Faculty of Medicine & Health Sciences
Research Ethics Committee
c/o Faculty PVC Office
School of Medicine Education Centre
B Floor, Medical School
Queen's Medical Centre Campus
Nottingham University Hospitals
Nottingham, NG7 2UH

University of Nottingham
UK | CHINA | MALAYSIA

Email: FMHS-ResearchEthics@nottingham.ac.uk

31st October 2017

Enemona Emmanuel Adaji
PhD Student, Epidemiology and Public Health
c/o Dr Ravai Phalkey
Assistant Professor in Public Health
Division of Epidemiology and Public Health
Room B126 Clinical Sciences Building 2
City Hospital Campus
Nottingham University Hospitals
Hucknall Road, Nottingham
NG5 1PB

Dear Mr Adaji

Ethics Reference No: 134-1710 – **please always quote**	
Study Title: Investigating the effect of indoor air pollution on pneumonia in children under 5 in Abuja, Nigeria.	
Chief Investigator/Supervisor: Dr Revati Phalkey, Assistant Professor in Public Health, Division of Epidemiology and Public Health	
Lead Investigators/student: Enemona Emmanuel Adaji BSc MPH PhD Student, Epidemiology and Public Health	
Other Key Investigators: Dr Mike Clifford, Associate Professor, Faculty of Engineering	
Type of Study: PhD Overseas mixed quantitative/qualitative	
Proposed Start Date: 01/11/2017	**Proposed End Date:** 01/11/2018 12mths
No of Subjects: 500	**Age:** 18+years
School: Medicine	

Thank you for submitting the above application which has been considered by the Committee at its meeting on 20th October 2017and the following documents were received:

- FMHS REC Application form and supporting documents version 1.0: 09.10.2017

These have been reviewed and are satisfactory and the study has been given a favourable opinion.

A favourable opinion is given on the understanding that:

1. All appropriate ethical and regulatory permissions are respected and followed in accordance with all local laws of the country in which the study is being conducted and those required by the host organisation/s involved.
2. Approval letters from the The healthcare facility Director and the Ministry of Health, Nigeria (National Health Research Ethics Committee, Nigeria) are submitted via e-mail when these are available for the records.
3. The protocol agreed is followed and the Committee is informed of any changes using a notice of amendment form (please request a form).

HHID [__ | __ | __ | __ | __ | __]

4. The Chair is notified of any serious or unexpected event.

5. An End of Project Progress Report is completed and returned when the study has finished (Please request a form).

Yours sincerely

Professor Ravi Mahajan
Chair, Faculty of Medicine & Health Sciences Research Ethics Committee

HHID [__ | __ | __ | __ | __ | __]

National Health Research Ethics Committee of Nigeria (NHREC)

Promoting Highest Ethical and Scientific Standards for Health Research in Nigeria

Federal Ministry of Health

NHREC Protocol Number NHREC/01/01/2007-25/09/2017
NHREC Approval Number NHREC/01/01/2007-26/10/2017
Date: 27 October 2017

<u>Re: Investigating the Effect of Indoor Air Pollution on Pneumonia in Children under five in Abuja, Nigeria</u>

Health Research Committee assigned number: NHREC/01/01/2007

Name of Student Investigator:	Enemona Emmanuel Adaji
Address of Student Investigator:	University of Nottingham school of Medicine Division of Epidemiology Email: Emmanuel.Adaji@nottingham.ac.uk

Date of receipt of valid application: **25/09/2017**
Date when final determination of research was made: 27-10-2017

<u>Notice of Expedited Committee Review and Approval</u>

This is to inform you that the research described in the submitted protocol, the consent forms, advertisements and other participant information materials have been reviewed and *given expedited committee approval by the National Health Research Ethics Committee.*

This approval dates from 27/10/2017 to 26/10/2018. If there is delay in starting the research, please inform the HREC so that the dates of approval can be adjusted accordingly. Note that no participant accrual or activity related to this research may be conducted outside of these dates. *All informed consent forms used in this study must carry the HREC assigned number and duration of HREC approval of the study.* In multiyear research, endeavour to submit your annual report to the HREC early in order to obtain renewal of your approval and avoid disruption of your research.

The National Code for Health Research Ethics requires you to comply with all institutional guidelines, rules and regulations and with the tenets of the Code including ensuring that all adverse events are reported promptly to the HREC. No changes are permitted in the research without prior approval by the HREC except in circumstances outlined in the Code. The HREC reserves the right to conduct compliance visit your research site without previous notification.

Signed

Professor Zubairu Iliyasu MBBS (UniMaid), MPH (Glasg.), PhD (Shef.), FWACP, FMCPH
Chairman, National Health Research Ethics Committee of Nigeria (NHREC)

Department of Health Planning, Research & Statistics
Federal Ministry of Health
11th Floor, Federal Secretariat Complex Phase III
Ahmadu Bello Way, Abuja

Tel: +234-09-523-8367
E-mail: chairman@nhrec.net, secretary@nhrec.net, deskofficer@nhrec.net,
URL: http://www.nhrec.net,

RESEARCH ETHICS COMMITTEE

KUBWA GENERAL HOSPITAL

HEALTH AND HUMAN SERVICES SECRETARIAT, FCTA
ABUJA FCT

20th February, 2018.

PRINCIPAL INVESTIGATOR : Enemona Emmanuel Adaji

DATE: 20th December, 2017.

RESEARCH TOPIC: Investigating Indoor air Polution on Pnuemonia in children under- 5 in Abuja, Nigeria.

NOTICE OF RESEARCH APPROVAL

Your letter of application, dated 20th December, 2017 refers. The proposal for the above research has been reviewed by the Research Ethics Committee of the Hospital, we hereby wish to give an approval for your study in Kubwa General Hospital Abuja.

The base of your study shall be in the paediatric Department and the General Out Patient Department of the Hospital.

The commencement Date for the study is 22nd February, 2018 and ends within 12 months from date of approval.

At the end of the study a copy of the study should be submitted to REC Kubwa General Hospital Abuja.

Dr. Collins A. Kalu

Chairman, Research Ethics Committee

Kubwa General Hospital

HHID [__ | __ | __ | __ | __ | __]

UNIVERSITY OF ABUJA TEACHING HOSPITAL

P.M.B. 228, ABUJA - F.C.T. NIGERIA
07040045614, 09-2905535,
www. uath.gov. ng.

Chief Medical Director
Professor Bissallah Ekele
FWACS, FICS, FRCOG

Chairman Medical Advisory Committee
Dr. Nicholas Baamlong
Bm, Bch,FMCF.MBA

Director of Administration
Modupe K. Adebanjo (Mrs)
BA,M.Sc,FCIA,AHAN

Our Ref FCT/UATH/HREC/1085

Date: 25/1/18

UATH HREC Protocol number: UATH/HREC/PR/2018/001/141
UATH HREC Approval Number: UATH/HREC/PR/2018/01/007

Proposed Title: Re: **Investigating the effect of indoor air pollution on pneumonia in children under five in Abuja, Nigeria at University of Abuja Teaching Hospital.**
Name of Principal Investigator: Enemona Emmanuel Adaji
Address of Principal Investigator: University of Nottingham, School of Medicine, Division of Epidemiology
Date of receipt of valid application: 23/1/18
Date when final determination of research was made: 25/1/18
Proposed site: UATH
Sponsor: Principal Investigator

This is to inform you that the activity described in the submitted protocol/documents have been reviewed and the UATH HREC has determined that according to the National Code for Health Research Ethics, the activity described has met the criteria for approval and is thus approved.

The National Code for Health Research Ethics requires you to comply with all institutional guidelines, rules, regulations and the tenets of the code.

The approval is for one year and will lapse on 24/1/19. However, it could be renewed on request by application four weeks before the expiry of the approval.

Accept assurance of our highest regards.

25-01-18

Dr Abubakar M. Jamda
Chairman UATH HREC

HHID [__ | __ | __ | __ | __ | __]

FEDERAL CAPITAL TERRITORY
Health Research Ethics Committee

Research Unit, Room 10, Block A Annex, HHSS, FCTA Secretariat,
No. 1 Kapital Street Area 11, Garki, Abuja - Nigeria

Notice of Research Approval
Approval Number: FHREC/2018/01/01/08-01-18

Study Title: Investigating the Effect of Indoor Air Pollution on Pneumonia in Children Under Five(5) in Abuja, Nigeria.

Principal Investigator: **Enemona Emmanuel Adaji**

Address of Principal Investigator: University of Nottingham School of Medicine, Division of Epidemiology & Public Health.

Date of receipt of valid application: 11/12/2017

This is to confirm that the FCT Health Research Ethics Committee (FCT HREC) has approved the research described in the above stated protocol.

This approval is valid from **08/01/2018** to **09/01/2019**.

Note that no activity related to this research may be conducted outside of these dates. Only the FCT HREC approved informed consent forms may be used when written informed consent is required. They must carry FCT HREC assigned protocol approval number and duration of approval of the study. The FCT HREC reserves the right to conduct compliance visit to your research site without prior notification.

The National Code of Health Research Ethics requires the investigator to comply with all institutional guidelines, rules and regulations regarding health research, and with the tenets of the code.

Modifications: Subsequent changes are not permitted in this research without prior approval by the FCT HREC.

Problems: All adverse events or unexpected side effects arising from this project must be reported promptly to FCT HREC.

Renewal: This approval is valid until the expiration date. If this project is to proceed beyond the expiration date, an annual report must be submitted to FCT HREC early in order to request for a renewal of this approval.

Closure of Study: At the end of the project, a copy of the final report of the research should be forwarded to FCT HREC for record purposes, and to enable us close the project.

For queries and further information contact FCT HREC office. I wish you best of luck with your research.

Desmond Emereonyeokwe
Ag. Secretary, FCT HREC
January 08, 2018.

7.3 Participant information and consent form

University of Nottingham
UK | CHINA | MALAYSIA

Participant Information and Consent Form

The effect of indoor air pollution on pneumonia in children under five in Nigeria

Introduction

You have been invited to participate in a PhD research aimed at assessing the effect of indoor air pollution on pneumonia in children under 5 in Abuja, Nigeria. The social impact of this research would take us a step closer in reducing under five mortality within low and middle-income countries, by informing targeted policies and decisions supported by research. This information will be used to help improve the overall prevention and management of childhood Pneumonia.

What mothers and caregivers would be asked to do

You have been asked to participate in a confidential and anonymous face-to-face interview session, lasting 30 - 60 minutes. The interview will be conducted at your house. You will be asked questions about your household living conditions, household information, health and previous immunization. You will be asked to present evidence based on your responses in some cases for further clarity and information. Air monitors will also be set up to take air sample measurements for 24 hours from our visit.

Your data

To ensure accuracy of the data collected for qualitative analysis, the interview session will be recorded with your consent. Notes and recordings will be anonymised and stored within an encrypted folder, accessible only to the lead researcher, Enemona Emmanuel Adaji. Your responses will not be discussed with other participants in the study and your identity will not be discussed either. Please keep in mind that all responses will be kept confidential.

Your participation in this study is completely voluntary. You may choose not to answer any of the questions asked of you. You may withdraw at any time during or after the interview session up until any potential publication of the findings.

If you agree to take part, your information will not be disclosed to other parties. Your responses to the questions will be used for the purpose of this project only and I will not have access to any of your medical records. You can be assured that if you take part in this project you will remain anonymous. If you do not wish to take part you do not have to give a reason and you will not be contacted again. Similarly, if you do agree to participate you are still free to withdraw at any time.

You may contact the Researcher, Enemona Emmanuel Adaji (PhD Student) of the Division of Epidemiology and Public Health, University of Nottingham. Room B126 Clinical Sciences Building 2, Nottingham City Hospital, Hucknall Road. Nottingham NG5 1PB UK on Emmanuel.Adaji@nottingham.ac.uk or Revati Phalkey on revati.phalkey@nottingham.ac.uk should you have any questions following this interview.

Please sign below once the interviewer has explained fully the aims and procedures of the study to you. Confirm you have been given full explanation of the research, you have understood the information, and have been given an opportunity to ask questions.

HHID [__ | __ | __ | __ | __ | __]

University of Nottingham
UK | CHINA | MALAYSIA

Name: ____

Address/Location: ____

Signature: ____

Date: ____

I confirm that I have fully explained the purpose of the study and what is involved to the above named participant, and also give them a copy of this form together with the information sheet.

Investigator(s) Signature: ____________________________________

Date: ____

Investigator(s) Name: ____

Study Household Number: ____

HHID [__ | __ | __ | __ | __ | __]

HHID [__ | __ | __ | __ | __ | __]

Section 1: DRAFT Form to be completed by Physician

Section 1: patient details

Child's Name (full): ……………………………………......................................

Age: ……………………………………………………………………………………...

D.O.B: ……………………………………………………………………………………..

Height: ………………...cm

Weight: ………………. Kg

Mother's/primary caregiver's name: ………………………………………………….....................

Address: ……………………..................

……………………..................

……………………..................

……………………..................

……………………..................

Telephone number……………………………

Date of examination:…………………………………………………………....

Section 2: presenting signs + symptoms

Respiratory symptoms: ………………………………………………………………..

………………………………………………………………..

………………………………………………………………..

Respiratory rate:

Temperature (oC):

Sub-costal retractions / lower chest wall indrawing (y/n):

3

HHID [__ | __ | __ | __ | __ | __ | __]

HHID [__ | __ | __ | __ | __ | __]

Record any findings on auscultation -

Section 3: Investigation

Chest X-ray ordered (y/n):

Section 4: Diagnosis

Pneumonia non-pneumonia (circle appropriate)

Presence of exclusion criteria

Recurrent wheezing

Chronic cough (more than 10 days)

Already on antibiotic treatment

Recent pneumonia episode within past 10 days

History of congenital heart disease

Symptoms for more than 4 weeks

Previous clinic treatment for this illness episode

What other illness has this child suffered from in the last one to six months ago?

What do you know about the health risks involved with high indoor air pollution and childhood pneumonia?

Do you advise the parents of the children to reduce their exposure Indoor Air Pollution?

HHID [__ | __ | __ | __ | __ | __]

University of Nottingham
UK | CHINA | MALAYSIA

Strength	Weakness
Opportunity	**Treat**

Physician name:……………………………….

Date:……………………………………………

HHID [__ | __ | __ | __ | __ | __]

HHID [__ | __ | __ | __ | __ | __]

7.4 Data collection Instrument

Case/control

Informed consent form

Informed consent form for: health interview of the caregivers of children (1month-5years of age) who present to hospital or health clinic with respiratory symptoms.
Title of research project: The effect of indoor air pollution on pneumonia in children under five in Nigeria

Sponsor: University of Nottingham

Part 1: information

Introduction and purpose of the research:
Health surveys where mothers and other caregivers are asked about the health of their child or about a recent illness episode are carried out by the government in this country. This is done to give information to help improve child health programmes. We are investigating the influence of indoor air pollution associated with childhood pneumonia in Nigeria, in order to develop, improve and promote a site-specific environmental public health intervention.

Reason for selection

Since you live in our study area, and your child is between the ages of 1 month and 5 years, we would like to ask you to be involved in our study.

What is expected of the respondent

If you agree to take part, in 2 or 4 weeks' time a field worker will visit your house and ask you questions about the recent health of your child. The visit will last no longer than 60 minutes. We will then compare your answers with your child's medical records.

Risks and benefits

There is no risk posed to either you or your child because of our study. If any questions make you feel uncomfortable during the interview you do not have to answer them.
There will be no direct or immediate benefit to you or your child from participating in this study. However, the results of this study will help to assess how accurate the pneumonia information from household survey is. This information could be used to improve childhood pneumonia programmes and so help improve the health of the children in your community.

Privacy, anonymity and confidentiality

Privacy, anonymity and confidentiality of any data/information identifying you will be strictly maintained. We will keep all information you provide us with, private and make

HHID [__ | __ | __ | __ | __ | __]

sure it is secure. Members of our research team will do the processing of the data in a secure place. Only people involved in this research will normally have access to this information. Any data that we send to other research groups will not include any of your personal identifiable information.

Please feel free to ask any questions. We are always happy to answer. You can also contact any members of our research team (contact address provided) if you have any questions at a later date. Also, once the study is completed the results will be available for you on well.

Future use of information

The results of our study may be shared with other health or health research organizations, but none of your personal information or your names will ever be shared with anyone. We will always uphold your privacy, anonymity and confidentiality.

Right to refuse participation and withdrawal

You do not need to agree to take part in this study. You alone have the sole choice of whether you wish to take part or not. There will be no difference in the care provided for your child, whether you agree to take part or not. If you do decide to take part, you are free to withdraw at any stage. Also, during the interview, if there are any questions that you do not want to answer then please feel under no obligation to do so.

Principle of compensation

Your participation in this study is completely voluntary, and you will not be paid or receive any incentive for taking part.
If you agree to our proposal, and are willing to take part in our research please indicate this by putting your signature, or left thumbprint impression in the specified place below.

Part 2: certificate of consent

(Instructions to physician: read this statement and explain the consent to the mother or caregiver of the child, and answer any questions she may have.)

I have been asked to give my consent for my child and to be involved in this study, which will involve me being interviewed about my child's recent health. I have been read the information above and understand fully what the study will involve. I have had the opportunity to ask any questions that I have wanted, and any questions that I have asked to have been answered to my satisfaction. I voluntarily consent to myself and my child being involved in this study.

If illiterate: a witness must be present and the mother or caregiver should give her thumb print. (the witness should be selected by the mother if possible and not be a member of the research team.)

HHID [__ | __ | __ | __ | __ | __]

Print name of mother/caregiver………………………………

Signature/left thumbprint of mother/caregiver …………………………………...
Date………………………………………………….
day/month/year

Print name of witness………………………………

Signature/left thumbprint of witness………………………………..

Date………………………………………………….
day/month/year

Statement by the research person taking consent:
I have read out all of this information to the mother and made sure to the best of my ability that she understands that the following will be done:

1. A field worker will interview her 2 or 4 weeks after the child was brought to the clinic.
2. The interview will concern her child's recent health and treatment
3. She is under no obligation to take part in this study, or answer any questions during the interview that she is not comfortable in doing so.
4. All information about her and her child will remain confidential.

I confirm that the mother was given opportunity to ask any questions that she may have had, and that I answered them all correctly and to the best of my ability. I confirm that the mother has not been coerced into giving consent, and that it has been given freely and voluntarily.
A copy of this consent form has been given to the mother or primary caregiver.

Print name of researcher/

Person taking consent…………………………………..

Signature of researcher/person taking consent…………………………………….

Date………………………………………………….
day/month/year

HHID [__ | __ | __ | __ | __ | __]

General information

1. Name of respondent	
2. What are the GPS coordinates of the house?	Lon: Lat:
3. Address / location of household	
4. Household number (HHID)	
5. Date of first visit	
6. Date of second visit (reason for first absence)	
7. Date of third visit (reason for second absence)	
8. Date observation complete	
9. Time (00:00) start	
10. Time (00:00) finish	
11. Were there any disturbances to the monitoring equipment while it was kept in your home?	Yes__________1 No___________2 No reply_______666 Don't know_____777 Not applicable___888 Missing_______999
12. If yes, describe	

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Household information

Name	Relationship to head of household* head	Sex	Age <1 year give age in months	Involved in cooking?	What is the highest grade of education completed by any member of the household Primary school Middle school High school Some college (trade/professional/ Community) Four-year college/university None No reply Don't know Not applicable Missing	Occupation	Marital status	Religion	Is the child usually present in kitchen during cooking?
Name1	Head of hh	Male___1 Female 2		Yes___1 No____2					Yes___1 No____2
Name2		Male___1 Female 2		Yes___1 No____2					Yes___1 No____2
Name3		Male___1 Female 2		Yes___1 No____2					Yes___1 No____2
Name4		Male___1 Female 2		Yes___1 No____2					Yes___1 No____2
Name5		Male___1 Female 2		Yes___1 No____2					Yes___1 No____2
Name6		Male___1 Female 2		Yes___1 No____2					Yes___1 No____2
Name7		Male___1 Female 2		Yes___1 No____2					Yes___1 No____2
Name8		Male___1 Female 2		Yes___1 No____2					Yes___1 No____2
Name9		Male___1 Female 2		Yes___1 No____2					Yes___1 No____2
Name10		Male___1 Female 2		Yes___1 No____2					Yes___1 No____2

HHID [__ | __ | __ | __ | __ | __]

Socio economic questions

Does the household own any of the following?							
	Yes (1)	No (2)	How many (3)	No reply (666)	Don't know (777)	Not applicable (888)	Missing (999)
13. Furniture (3/4-piece sofa set)							
14. Furniture (chairs)							
15. Furniture (table)							
16. Bed							
17. Mat							
18. Sewing machine							
19. Gas cooker							
20. Stove (electric)							
21. Stove gas (table)							
22. Stove (kerosene)							
23. Fridge							
24. Freezer							
25. Air conditioner							
26. Washing machine							
27. Electric clothes dryer							
28. Generator							
29. Fan							
30. Radio							
31. Cassette recorder							
32. Hi-fi (sound system)							
33. Microwave							
34. Iron							
35. TV set							
36. Computer							
37. DVD player							
38. Satellite dish							
39. Musical instrument							
40. Mattress							
41. A bicycle							
42. Livestock							
43. A moped/scooter/motorcycle							
44. A radio/transistor							
45. A car?							
46. Do you have any form of insurance?							
47. Are you part of any microfinance scheme?							
48. Does the household have access to electricity?							
49. If yes, how many hours per day?	1-6 ______________1 6-12______________2 12-18______________3 18-24______________4 No reply ___________666 Don't know _________777 Not applicable _______888 Missing____________999						

HHID [__ | __ | __ | __ | __ | __]

50. Does any member of the household smoke?						
51. Does anyone smoke indoors?						
52. If yes, how often?	Every day____________1 Every week___________2 Every month__________3 No reply_____________666 Don't know___________777 Not applicable _________888 Missing______________999					
53. If yes, how much?	A stick______________1 A pack______________2 No reply_____________666 Don't know___________777 Not applicable ________888 Missing______________999					
54. How will you class your household income per month?	0 – 20,000____________1 20,001 – 100,000___________2 100,001 – 500,000__________3 500,001 – 1,000,000__________4 >1.000.000________________5 No reply ____________666 Don't know __________777 Not applicable _______888 Missing_____________999					
55. What percent of household income do you spend on?	Education___________1 Food_______________2 Clothing ____________3 Cooking fuel_________4 Transport ___________5 Business____________6 Investment___________7					

Health questions

Patient details						
56. Child's name (full):						
57. D.O.B						
58. Age						
59. Height						
60. Weight						
61. Mother's/ 62. Primary caregiver's name						
63. Presenting signs + symptoms						
64. Body temperature (°C):						
65.	Yes (1)	No (2)	No reply (666)	Don't know (777)	Not applicable (888)	Missing (999)
66. Sub-costal retractions / lower chest wall indrawing						
67. Record any findings on auscultation?						

HHID [__ | __ | __ | __ | __ | __]

Diagnosis						
68. Pneumonia						
69. Non-pneumonia						
70. What type of diagnosis test was done?						
71. Is this the first diagnoses or has (name) been diagnosed before?						
72. If yes, how many times?						
73. Has (name) been ill with a fever at any time in the last 2 weeks?						
74. Has (name) had-cough at any time in the last 2 weeks?						
75. If (name) had cough, did he/she breathe faster than usual with short, rapid breaths or have difficulty breathing?						
76. Was the fast or difficult breathing due to a problem in the chest or to a blocked or runny nose?	Chest only____________1 Nose only ____________2 Both____________3 Other ________ (specify)________4 No reply ____________666 Don't know ____________777 Not applicable ____________888 Missing____________999					
77. Has (name) had fever time in the last 2 weeks?						
78. Did you seek advice or treatment for the illness from any source?						
79. If yes, where did you seek advice or treatment?	Public sector ____________1 Govt hospital ____________2 Govt health centre ____________3 Govt health post____________4 Mobile clinic ____________5 Fieldworker ____________6 Other public________ (specify)________7 Private medical sector ____________8 Private hospital/clinic____________9 Pharmacy____________10 Private doctor____________11 Mobile clinic____________12 Fieldworker____________13 Other private med.________ (specify)________14 Other source____________15 Pharmacy/shop____________16 Traditional practitioner____________17 Other________ (specify)________18 No reply____________666 Don't know____________777 Not applicable____________888 Missing____________999					
80. If anywhere else, where?						

HHID [__ | __ | __ | __ | __ | __]

81. At any time during the illness, did (name) take any drugs for the illness?	
82. What drugs did (name) take? Any other drugs? Record all mentioned	Antimalarial drugs_____1 SP/fansidar _____2 Chloroquine_____3 Amodiaquine_____4 Quinine _____5 Combination with artemisinin _____6 Country spec. CBD antimalarial _____7 Other antimalarial_____ (specify)_____8 Antibiotic drugs _____9 Pill/syrup_____10 Injection_____11 Other drugs_____12 Aspirin _____13 Acetaminophen_____14 Ibuprofen_____15 Other _____ (specify)_____16 No reply _____666 Don't know _____777 Not applicable_____888 Missing_____999
83. When did you first seek treatment? 84. How many days after the illness began did you first seek advice or treatment for (name)? If the same day, record '00'.	
85. Does the child have?	Recurrent wheezing_____1 Chronic cough (more than 10 days)_____2 Already on antibiotic treatment_____3 Recent pneumonia episode within past 10 days_____4 History of congenital heart disease _____5 Symptoms for more than 4 weeks_____6 Previous clinic treatment for this illness episode_____7 No reply_____666 Don't know_____777 Not applicable_____888 Missing_____999
86. Has (name) received the PCV vaccine before?	
87. Is there a vaccination card for (name)?	Yes, seen_____1 Yes, not seen _____2 No _____3 No reply_____666 Don't know_____777 Not applicable_____888 Missing_____999
88. How are you feeding (name)?	Breastfeeding exclusively_____1 Both breastfeeding and feeding breast-milk substitutes_____2 Feeding my baby breast-milk substitutes (not breastfeeding at all) _____3 Other: (please describe): _____ (specify)_____4 No reply_____666 Don't know_____777 Not applicable_____888 Missing_____999

89. How much drink (including breastmilk) was given to (name) during the illness (fever/cough)?	Much less__________1 Somewhat less__________2 About the same__________3 More __________4 Nothing to drink__________5 No reply __________666 Don't know__________777 Not applicable__________888 Missing__________999
90. Was he/she given less than usual to drink, about the same amount, more than usual to drink? 91. If less, probe: was he/she given much less than usual to drink or somewhat less?	
92. How much was (name) given to eat,	Much less__________1 Somewhat less__________2 About the same__________3 More __________4 Nothing to drink__________5 No reply __________666 Don't know__________777 Not applicable__________888 Missing__________999
93. About the same amount, more than usual, or nothing to eat? 94. If less, probe: was he/she given much less than usual to eat or somewhat less?	
95. Has your child been cured?	
96. How many other siblings does (name) have? ________________ (specify)	

Knowledge, attitude and practice

Knowledge of child's parents	
97. Do you know about pneumonia in children?	Yes__________1 No__________2 No reply ______666 Don't know_____777 Not applicable___888 Missing_______999
98. From which sources do you get information on childhood pneumonia?	From health workers ________________1 TV and radio ________________2 Newspapers, publications and journals __3 Other sources (please write)___________4
99. Do you know that air pollution affects pneumonia in children?	Yes __________1 No __________2 No reply ______666 Don't know_____777 Not applicable___888 Missing_______999
100. What do you think, how do people get pneumonia infection?	Air ____________1 Contact __________2

HHID [__ | __ | __ | __ | __ | __]

	Dirty hands _______3 Other ways _______4
101. What do you think are the causes of respiratory diseases among the children?	Getting cold __________1 From infected person ___2 Air pollution __________3 From dust ____________4 Other (please write) ____5
102. In your opinion does air pollution have an effect on respiratory diseases?	Yes__________1 No___________2 No reply ______666 Don't know ____777 Not applicable__888 Missing_______999
103. In your opinion do indoor temperature, humidity and air movement have an effect on respiratory diseases?	Yes__________1 No___________2 No reply ______666 Don't know_____777 Not applicable___888 Missing_______999
104. Do you know some sources of indoor air pollutants?	Yes__________1 (Skip to 9) No___________2 (Skip to 10) No reply ______666 Don't know_____777 Not applicable___888 Missing_______999
105. Mention sources of air pollution (can be many answers)	Sources of incomplete combustion of coal and wood ____1 Occurrence ash and dust ____________________________2 Outdoor air pollution /vehicles/ ___________________________3 Natural impact (wind) ________________________________4 Tobacco smoking ____________________________________5 Others (please write)_________________________________6
106. Do indoor smoke ash and dust affect the occurrence of disease in your opinion?	Yes__________1 No___________2 No reply ______666 Don't know_____777 Not applicable___888 Missing_______999
107. Does smoke of vehicles affect indoor air quality?	Yes__________1 No___________2 No reply ______666 Don't know_____777 Not applicable___888 Missing_______999
108. What is the street movement like around your home?	Very busy __________1 Middle ______________2 Low ________________3 Quite ________________4 No reply ___________666 Don't know__________777 Not applicable________888 Missing____________999
Practice of parents on prevention of respiratory diseases	
109. How often do you keep the house ventilated by opening windows and doors?	Always ____________________1 Sometimes __________________2 Never use ___________________3 Don't have any equipment _____4 No reply____________________666 Don't know __________________777 Not applicable_______________888 Missing_____________________999

HHID [__ | __ | __ | __ | __ | __]

110. Do you have any ventilation system to remove smoke and steam?	Yes__________1 No___________2 No reply ______666 Don't know_____777 Not applicable___888 Missing_______999
111. Do you use a fan to remove smoke and steam during cooking?	Always ______________________1 Sometimes ___________________2 Never use ___________________3 Don't have any equipment _____4 No reply_____________________666 Don't know ___________________777 Not applicable_________________888 Missing______________________999
Attitude of child's parents	
112. Do you care about reducing indoor smoke and dust?	Yes__________1 No___________2 No reply ______666 Don't know_____777 Not applicable___888 Missing_______999
113. Do you take care to stabilize indoor heating during raining and cold season?	Yes__________1 No___________2 No reply ______666 Don't know_____777 Not applicable___888 Missing_______999
114. If yes, what actions do you take? /can be many answers	Continuous burning ____________________________1 Isolation from the cold in winter season ___________2 Prepare sufficient coal and wood for burning _ _______3 Use electric heating ____________________________4 Others / please write ___________________________5 No reply _____________________________________666 Don't know ___________________________________777 Not applicable _________________________________888 Missing______________________________________999
115. Do you care about improving your child's immune system?	
116. Please tell us what you do to improve the immunity of your child?	

Household Characteristics

117. How many rooms are there in your household?	
118. Wall height (in feet/inch)	Highest point___1 Lowest point___2 Average height_3 No reply ______666 Don't know ____777 Not applicable__888 Missing_______999
119. Is there a gap between the wall and roof?	Yes__________1 No___________2

	No reply ______666 Don't know_____777 Not applicable___888 Missing_______999
120.If yes, record the size of the gap in feet	
121.Number of doors in the kitchen	
122.Number of doors in the entire house	
123.Number of windows / major openings	
Kitchen characteristics	
124.Length, width and height in feet/inch	Longest wall___1 Shortest wall___2 Average length _3 Not applicable __4 Missing _______999
125.Number of windows / openings in kitchen	
126.For each window / opening in kitchen, rate size:	Small (23.6inch/23.6inch)__1 medium (1.2h/1.2l) ___2 large (1.2-1.8h)____3 Window #1 small medium large Window #2 small medium large Window #3 small medium large Window #4 small medium large Window #5 small medium large Not applicable___4 Missing ________999
127.Do you think your ventilation is adequate?	Yes ___________1 No ____________2 No reply ______666 Don't know_____777 Not applicable___888 Missing_______999
128.Can you say why?	
For households with kitchen partition	
129.Do you have a separate room that is used as a kitchen?	Yes___________1 No____________2 No reply ______666 Don't know_____777 Not applicable___888 Missing_______999
130.Does partition extend to the ceiling?	Yes____________1 No_____________2 Not applicable___888 Missing _______999
131.If no, record height of partition in feet (ft)	
132.For households with open air kitchen outside the house: is the stove located under any shed roof or canopy?	Yes___________1 No____________2 No reply ______666 Don't know_____777 Not applicable___888 Missing_________999
133.If yes, what is this shed roof or canopy made of? (check all that apply)	Bricks or bamboo _______________________1 Tiles, slate, shingle ____________________2 Corrugated iron, zinc or other metal sheets___3 Asbestos cement sheets _________________4

	Brick stone and lime ____________________5 Stone ________________________________6 Concrete _____________________________7 Record all other materials not stated ________8 No reply ______________________________666 Don't know____________________________777 Not applicable__________________________888 Missing_______________________________999
134. If yes, record height of shed roof/canopy in (ft) highest point: lowest point: average height:	
135. How many sides of the outdoor kitchen are enclosed? (i.e. By walls, make-shift partitions, etc.	
Sanitation	
136. How do you dispose your household waste?	
137. Do you burn your household waste?	Yes__________1 No___________2 No reply ______666 Don't know_____777 Not applicable___888 Missing________999
138. How close are you to the garbage dump site?	
Household characteristics	
139. Roof materials	Grass leaves, reeds, thatch, wood, mud, unburnt bricks or bamboo ____1 Tiles, slate, shingle ____2 Corrugated iron, zinc or other metal sheets ____________________3 Asbestos cement sheets _____________________________________4 Brick stone and lime ____5 Stone ____6 Concrete ____7 All other materials not stated ____________________________8 No reply ____666 Don't know ____777 Not applicable 888

140. Wall materials	Check all that apply: Grass, leaves, reeds, bamboo or thatch ________1 Mud / dirt ________________________________2 Unburnt bricks ____________________________3 Wood ____________________________________4 Burnt bricks ______________________________5 Metal sheets ______________________________6 Stone ____________________________________7 Cement concrete ___________________________8 Other materials not stated _________________9 No reply __________________________________666 Don't know ______________________________777 Not applicable _____________________________888 Missing____________________________________999
141. Floor	Check all that apply: Mud / dirt ________________________________1 Wood/planks ______________________________2 Bamboo or logs ____________________________3 Brick, stone & lime _________________________4 Cement ___________________________________5 Mosaic/tiles _______________________________6 Other materials not stated _________________7 No reply __________________________________666 Don't know ________________________________777 Not applicable______________________________888 Missing____________________________________999
142. What type of fuel does your household mainly use for cooking?	Wood (logs) ____________1 Crop residues ___________2 Coal/coke/lignite _________3 Charcoal _______________4 Kerosene _______________ 5 Electricity ______________6 Liquid petroleum gas (LPG) _7 Bio-gas ________________8 Other (specify) ___________9 No reply________________666 Don't know______________777 Not applicable____________888 Missing _________________999
143. Why have you chosen this cooking method(s)?	
144. If you use fire. What is the total time that the cooking fire was on (hours)	
145. Where is the source of your households drinking/cooking water?	
146. In the last 6 months has your household ever changed its cooking area?	Yes __________1 No ___________2 No reply_______666 Don't know_____777 Not applicable___888 Missing_______999
147. If yes, describe changes. 148. (Probe: when they occurred, where, and reasons for change)	

HHID [__ | __ | __ | __ | __ | __]

149. What type of fuel does your household mainly use for boiling / heating water?	Wood (logs) _____________1 Crop residues ___________2 Coal/coke/lignite __________3 Charcoal _______________4 Kerosene ______________ 5 Electricity ________________6 Liquid petroleum gas (LPG) _7 Bio-gas _______________8 Other (specify)___________9 No reply_______________666 Don't know______________777 Not applicable_____________888 Missing _________________999
150. What type of fuel does your household commonly used for space heating indoors? (for keeping the house hot)	Wood (logs) _____________1 Crop residues ___________2 Coal/coke/lignite __________3 Charcoal _______________4 Kerosene ______________ 5 Electricity ________________6 Liquid petroleum gas (LPG) _7 Bio-gas _______________8 Other (specify)___________9 No reply_______________666 Don't know______________777 Not applicable_____________888 Missing _________________999
151. What is the main source of lighting for your household in the dark?	Wood (logs) _________________1 Crop residues _______________2 Coal/coke/lignite lamps __________3 Charcoal lamps ______________4 Glass kerosene lamps ___________ 5 Local kerosene lamps___________6 Electricity lamps _______________7 Liquid petroleum gas (LPG) lamp _8 Bio-gas lamp ________________9 Other (specify)___________10 No reply_______________666 Don't know______________777 Not applicable_____________888 Missing _________________999
152. If yes except electricity, how long does it burn on an average time period?	
153. How many do you use at any given time? (allow for mixtures)	
154. Why have you chosen this lighting method?	
155. Did you light any lamps within the household?	
156. Does the household's cooking pattern change seasonally?	Yes__________1 No___________2 No reply ______666 Don't know_____777 Not applicable___888 Missing________999
157. If yes, describe changes and reasons for change?	

HHID [__ | __ | __ | __ | __ | __]

158. Does anyone burn mosquito coils?	Yes__________1 No___________2 No reply ______666 Don't know_____777 Not applicable___888 Missing_______999
159. If yes, how many on an average day?	
160. How long? (record appropriate)	
161. In the last 6 months has your household ever changed its fuel use pattern?	Yes__________1 No___________2 No reply ______666 Don't know_____777 Not applicable___888 Missing________999
162. If yes, describe changes, when they occurred, and reasons for change.	
Stoves	
163. Do you use stove?	Yes__________1 No___________2
164. Type of stove	Traditional biomass stoves (no chimney) __________1 Improved biomass stoves ______________________2 Kerosene stove ______________________________3 LPG stove __________________________________4 Biogas stove ________________________________5 No reply ___________________________________666 Don't know__________________________________777 Not applicable _______________________________888 Missing_____________________________________999
165. Traditional biomass stoves (no chimney)	
166. Type of traditional stove	3 stone or brick _____1 Simple mud stove ____2 Modified mud stove ___3 (ridges at pot hole ____4 No reply ___________666 Don't know__________777 Not applicable _______888 Missing_____________999
167. If traditional stove is a modified mud stove (#3 above), was this stove constructed as an improved cook stove?	Yes___1 No____2
168. Height of the traditional stove in ft/inch	
169. traditional Stove material	Mud __________________1 Brick _________________2 Other (specify) _________3
170. Does the traditional stove have a hood?	Yes___1 No____2
171. If yes, describe the hood:	

HHID [__ | __ | __ | __ | __ | __]

172. Is the traditional stove ever used for space heating indoors?	Yes___1 No____2
173. When is the traditional stove used?	Check all that apply For cooking __________________1 When making tea ______________2 When heating/boiling water _______3 Rainy days ____________________4 During shortage of other fuel ______5 Other specify __________________6 No reply ______________________666 Don't know ____________________777 Not applicable__________________888 Missing_________________________999
Improved biomass stoves	
174. Improved biomass stoves are characterized by the presence of a chimney or flue.	
175. Is the Stove fixed or portable	Fixed ____1 Portable __2
176. Does the Improved biomass stove have a chimney (flue)?	Yes___1 No____2 If no skip to question 72
177. If yes, describe chimney material:	
178. Height of chimney in ft/inch	
179. If no, this is not an improved stove—please record stove details in traditional	
180. How long have you had this stove?	Months / years
181. Please rate the overall condition of the chimney:	Poorly maintained /inefficient ________1 Moderately well maintained__________2 Well maintained /efficient
182. Does the stove have a controllable damper?	Yes___1 No____2
183. Height of the stove in ft/inch	
184. Does the stove have a hood?	Yes___1 No____2
185. If yes, describe the hood:	
186. Please rate the overall condition of the stove:	Poorly maintained /inefficient ________1 Moderately well maintained__________2 Well maintained
187. Is the stove ever used for space heating indoors?	Yes___1 No____2
188. When is the improved biomass stove used?	Check all that apply For cooking __________________1 When making tea ______________2 When heating/boiling water _______3 Rainy days ____________________4 During shortage of other fuel ______5 Other specify __________________6 No reply ______________________666 Don't know ____________________777 Not applicable__________________888 Missing______________________999

HHID [__ | __ | __ | __ | __ | __]

Kerosene stove characteristics	
189. Type of kerosene stove?	
190. Height of the kerosene stove in ft/inch	
191. What is the kerosene stove material?	
192. Does the kerosene stove have a hood?	Yes___1 No____2
193. If yes, describe the hood:	
194. Is the kerosene stove ever used for space heating indoors?	Yes___1 No____2
195. When is the kerosene stove used?	Check all that apply For cooking ___________________1 When making tea _______________2 When heating/boiling water _______3 Rainy days _____________________4 During shortage of other fuel ______5 Other specify ___________________6 No reply _______________________666 Don't know ______ _______________777 Not applicable___________________888 Missing________________________999
Biogas stove characteristics	
196. Number of burners	
197. Describe the maintenance of the stove	
198. Type of biogas stove	
199. Height of the biogas stove in ft/inch	
200. What is the biogas stove material?	
201. Does the biogas stove have a hood?	Yes___1 No____2
202. If yes, describe the hood:	
203. Is the biogas stove ever used for space heating indoors?	Yes___1 No____2

HHID [__ | __ | __ | __ | __ | __]

204. When is the biogas stove used?	Check all that apply For cooking ___________________1 When making tea _______________2 When heating/boiling water _______3 Rainy days _____________________4 During shortage of other fuel ______5 Other specify ___________________6 No reply _______________________666 Don't know _____________________777 Not applicable____________________888 Missing_________________________999

HHID [__ | __ | __ | __ | __ | __]

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Air quality monitoring

Household name and location: ______________________________________ Date of monitoring: ______________________

Monitoring conducted by: ______________________

Air temperature: _____________˚C Air pressure: ___________mm Hg Relative humidity: ________%

Sample ID	Location of sampler* (record location on sketch and Height from floor)	Pump No	Battery No	Cyclone No	Filter cassette ID	Pre-sample calibration flow rate	Post-sample calibration flow rate	Sample time (include Programming instruction)	Sample stop time

Field notes: ________

HHID [__ | __ | __ | __ | __ | __]

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Particulates sampling data

1. General information			
2. Sample ID			
3. Date collected			
4. Collected by			
5. Location	❑ kitchen	❑ living	❑ outdoor
6. Height from floor			
7. Pump			
8. Model			
9. Serial no.			
10. Battery			
11. Serial no			
12. Cyclone			
13. Serial no			
14. Filter			
15. Manufacturer/type			
16. Lot no.			
17. Post-weight (mg)			
18. Pre-weight (mg)			
19. Weight of dust on filter			
20. Sampling parameters			
21. Flow rate # 1 (l/min)			
22. Flow rate # 2 (l/min)			
23. Average flow rate(l/min)			
24. Start time			
25. Stop time			
26. Elapsed time (min)			
27. Program settings			
28. Total pump time			
29. Volume of air sampled (l)			
30. Result			
31. Concentration ($\mu g/m^3$)*			

NOTE

$$\text{*Concentration C } (mg/m^3) = \frac{\text{Weight of dust on filter (mg)}}{\text{Volume of air sample (l)}} \times 10^3$$

Volume of air sampled = Flowrate (lpm) *Total pump Time(Min)

HHID [__ | __ | __ | __ | __ | __]

Time activity record form (To accompany field monitoring forms)

For the following time of the day, please specify the cooking or any burning activity that took place during these times.

Householder name	Morning				Afternoon				Evening		
	Activity that involved burning	What was burned (fuels, candles, coils)	Duration	Loc	Activity that involved burning	What was burned (fuels, candles, coils)	Duration	Loc	Activity	What was burned (fuels, candles, coils)	Duration

Locations (Loc):
1 = in the kitchen, close to stove
2 = in kitchen, not near stove
3 = indoors at home, but not in kitchen
4 = indoors not at home
5 = outdoo

HHID [__ | __ | __ | __ | __ | __]

Nutrition

In the past 7 days, did members of this household consume any of the following meals or drinks away from home?							
		Yes **(1)**	No **(2)**	No reply **(666)**	Don't know **(777)**	Not applicable **(888)**	Missing **(999)**
Full meals (e.g rice and stew, pounded yam and egusi, etc)	**Breakfast**						
	Lunch						
	Dinner						
Side dishes like pepper soup, nkwobi, suya etc.							
Snacks such as sandwiches, biscuits, meatpies, donuts, pofpof, etc							
Dairy based beverages such as milk, yoghurt etc.							
Vegetables and roasted such as (carrot, pears, roasted corn and plantain, sugar cane)							
Non-alcoholic drinks							
Alcoholic drinks							

HHID [__ | __ | __ | __ | __ | __]

8 References

1. *Stoppneumonia.org. 2020. [online] Available at: <https://stoppneumonia.org/wp-content/uploads/2019/11/GLOBAL-World-Pneumonia-Day_Media-Release.pdf> [Accessed 30 July 2020].*
2. WHO. *Air pollution*. 2020 28/05/2020]; Available from: https://www.who.int/health-topics/air-pollution#tab=tab_1.
3. *Who.int. 2020. Pneumonia. [online] Available at: <https://www.who.int/news-room/fact-sheets/detail/pneumonia> [Accessed 30 July 2020].*
4. Smith, K.R., *Fuel Combustion, Air Pollution Exposure, and Health: The Situation in Developing Countries.* Annual Review of Energy and the Environment, 1993. **18**(1): p. 529-566.
5. Fullerton, D.G., N. Bruce, and S.B. Gordon, *Indoor air pollution from biomass fuel smoke is a major health concern in the developing world.* Transactions of The Royal Society of Tropical Medicine and Hygiene, 2008. **102**(9): p. 843-851.
6. Adaji EE, et al., *Understanding the effect of indoor air pollution on pneumonia in children under 5 in low- and middle-income countries: a systematic review of evidence.* Environmental science and pollution research international., 2019. **26**(4): p. 3208–25.
7. KR, S. and P. A, *Household Air Pollution from Solid Cookfuels and Its Effects on Health. In: Mock CN, Nugent R, Kobusingye O, et al:.* The International Bank for Reconstruction and Development / The World Bank. Chapter 7, ed. I.P.a.E. Health. 2017, Washington (DC).
8. Chang, J., W. Liu, and C. Huang, *Residential Ambient Traffic in Relation to Childhood Pneumonia among Urban Children in Shandong, China: A Cross-Sectional Study.* International journal of environmental research and public health, 2018. **15**(6): p. 1076.
9. Chisti, M.J., et al., *Pneumonia in severely malnourished children in developing countries - mortality risk, aetiology and validity of WHO clinical signs: a systematic review.* Trop Med Int Health, 2009. **14**(10): p. 1173-89.
10. Chopra, M., et al., *Ending of preventable deaths from pneumonia and diarrhoea: An achievable goal.* Lancet (London, England), 2013. **381**(9876): p. 1499–1506.
11. Dherani, M., et al., *Indoor air pollution from unprocessed solid fuel use and pneumonia risk in children aged under five years: a systematic review and meta-analysis.* Bulletin of the World Health Organization, 2008. **86**(5): p. 390-398C.
12. Dhimal, M., et al., *Environmental burden of acute respiratory infection and pneumonia due to indoor smoke in Dhading.* Journal of Nepal Health Research Council, 2010. **8**(1): p. 1–4.
13. Dionisio, K.L., et al., *The exposure of infants and children to carbon monoxide from biomass fuels in The Gambia: a measurement and modeling study.* J Expo Sci Environ Epidemiol, 2012. **22**(2): p. 173-81.
14. Karki, S., A.L. Fitzpatrick, and S. Shrestha, *Risk Factors for Pneumonia in Children under 5 Years in a Teaching Hospital in Nepal.* Kathmandu University medical journal (KUMJ), 2014. **12**(48): p. 247–252.
15. Kelly, M.S., et al., *The effect of exposure to wood smoke on outcomes of childhood pneumonia in Botswana.* The international journal of tuberculosis and lung disease

: the official journal of the International Union against Tuberculosis and Lung Disease, 2015. **19**(3): p. 349–355.

16. Mahalanabis, D., et al., *Risk factors for pneumonia in infants and young children and the role of solid fuel for cooking: A case-control study*. Epidemiology and infection, 2002. **129**(1): p. 65–71.

17. *Who.int. 2021. Household Air Pollution And Health. [online] Available at: <https://www.who.int/news-room/fact-sheets/detail/household-air-pollution-and-health> [Accessed 8 January 2021].*

18. Chen, G., et al., *Effects of ambient PM1 air pollution on daily emergency hospital visits in China: an epidemiological study.* The Lancet Planetary Health, 2017. **1**(6): p. e221-e229.

19. Zwozdziak, A., et al., *Influence of PM(1) and PM(2.5) on lung function parameters in healthy schoolchildren-a panel study*. Environmental science and pollution research international, 2016. **23**(23): p. 23892-23901.

20. Chen, G., et al., *Effects of ambient PM1 air pollution on daily emergency hospital visits in China: an epidemiological study.* The Lancet. Planetary health, 2017. **1**(6): p. e221-e229.

21. Zajusz-Zubek, E., T. Radko, and A. Mainka, *Fractionation of trace elements and human health risk of submicron particulate matter (PM1) collected in the surroundings of coking plants.* Environmental Monitoring and Assessment, 2017. **189**(8): p. 389.

22. PrayGod, G., et al., *Indoor Air Pollution and Delayed Measles Vaccination Increase the Risk of Severe Pneumonia in Children: Results from a Case-Control Study in Mwanza, Tanzania.* PloS one, 2016. **11**(8): p. e0160804.

23. Sharma, S., et al., *Indoor air quality and acute lower respiratory infection in Indian urban slums.* Environmental health perspectives, 1998. **106**(5): p. 291–297.

24. Walker, C.L.F., et al., *Global burden of childhood pneumonia and diarrhoea.* Lancet (London, England), 2013. **381**(9875): p. 1405–1416.

25. CDC., *Help Prevent Pneumonia [Internet].* Centers for Disease Control and Prevention. , 2016.

26. Albalak, R., et al., *Indoor respirable particulate matter concentrations from an open fire, improved cookstove, and LPG/open fire combination in a rural Guatemalan community.* Environ Sci Technol, 2001. **35**(13): p. 2650-5.

27. Bruce, N., R. Perez-Padilla, and R. Albalak, *Indoor air pollution in developing countries: a major environmental and public health challenge.* Bulletin of the World Health Organization, 2000. **78**(9): p. 1078–1092.

28. N, B., *Indoor air pollution from unprocessed solid fuel use and pneumonia risk in children aged under five years: a systematic review and meta-analysis.* . Bulletin of the World Health Organization, 2008. **86**(5): p. 390-4.

29. *Who.int. 2019. Children: Reducing Mortality. [online] Available at: <https://www.who.int/news-room/fact-sheets/detail/children-reducing-mortality> [Accessed 30 July 2020].*

30. McCollum, E.D., et al., *Predictors of treatment failure for non-severe childhood pneumonia in developing countries – systematic literature review and expert survey – the first step towards a community focused mHealth risk-assessment tool?* BMC Pediatrics, 2015. **15**(1): p. 547.

31. UNICEF, *One is too many: ending child deaths from pneumonia and diarrhoea.* 2016.

32. Liu, L., et al., *Global, regional, and national causes of child mortality in 2000–13, with projections to inform post-2015 priorities: an updated systematic analysis.* The Lancet, 2015. **385**(9966): p. 430-440.
33. *Bernadeta Dadonaite (2018) - "Pneumonia". Published online at OurWorldInData.org. Retrieved from: 'https://ourworldindata.org/pneumonia' [Online Resource].*
34. UNICEF, *UNICEF analysis based on WHO and Maternal and Child Epidemiology Estimation Group interim estimates produced in September 2019, applying cause fractions for the year 2017 to United Nations Inter-Agency Group for Child Mortality Estimation estimates for the year 2018; Convention on the Rights of the Child*. 2019.
35. *The Project., 2020. World's Air Pollution: Real-Time Air Quality Index. [online] waqi.info. Available at: <https://waqi.info/#/c/8.345/26.137/4.3z> [Accessed 25 July 2020].*
36. *World Health Organization. 2020. Ambient Air Pollution: Pollutants. [online] Available at: <https://www.who.int/airpollution/ambient/pollutants/en/> [Accessed 30 July 2020].*
37. Martelletti, L. and P. Martelletti, *Air Pollution and the Novel Covid-19 Disease: a Putative Disease Risk Factor.* SN comprehensive clinical medicine, 2020: p. 1-5.
38. Ciencewicki, J. and I. Jaspers, *Air pollution and respiratory viral infection.* Inhal Toxicol, 2007. **19**(14): p. 1135-46.
39. Smith, K.R., et al., *Indoor air pollution in developing countries and acute lower respiratory infections in children.* Thorax, 2000. **55**(6): p. 518–532.
40. Hussey, S.J.K., et al., *Air pollution alters Staphylococcus aureus and Streptococcus pneumoniae biofilms, antibiotic tolerance and colonisation.* Environmental microbiology, 2017. **19**(5): p. 1868-1880.
41. Buchner, H. and E.A. Rehfuess, *Cooking and season as risk factors for acute lower respiratory infections in African children: a cross-sectional multi-country analysis.* PloS one, 2015. **10**(6): p. e0128933.
42. Mustapha, A., D. Briggs, and A. Hansell, *Air Pollution and Risk Factors Related to Respiratory Illness in Schoolchildren in the Niger-Delta.* Epidemiology, 2009. **20**: p. S183.
43. Mustapha, A., D. Briggs, and A. Hansell, *Burden of Childhood Respiratory Illness and Indoor Air Pollution in the Niger Delta, Southern Nigeria.* Epidemiology, 2011. **22**: p. S151.
44. Moya J, B.C., Etzel RA, *Children's Behavior and Physiology and How It Affects Exposure to Environmental Contaminants.* Pediatrics, 2004. **113**: p. 996-1006.
45. Epa.gov. *Overview of Particle Air Pollution (PM2.5 and PM10)*. 2012; 2014-05]. Available from: www.epa.gov/sites/production/files/2014-05/documents/huff-particle.pd.
46. Fagbeja, M.A., Chatterton, T. J., Longhurst, J. W. S., *Air pollution and management in the Niger Delta—Emerging issues, Conference Information.* 16th International Conference on Modelling, Monitoring and Management of Air Pollution, 2008. **WessexInstTechnolSkiathos GREECE. Air Pollution, XVI**(116, 207–216): p. 207–216.
47. Adaji, E.E., et al., *Understanding the effect of indoor air pollution on pneumonia in children under 5 in low- and middle-income countries: a systematic review of evidence.* Environmental science and pollution research international, 2019. **26**(4): p. 3208–3225.

48. Akinyemi, J.O. and O.M. Morakinyo, *Household environment and symptoms of childhood acute respiratory tract infections in Nigeria, 2003-2013: a decade of progress and stagnation.* BMC infectious diseases, 2018. **18**(1): p. 296.
49. Habre, R., et al., *The effects of PM2.5 and its components from indoor and outdoor sources on cough and wheeze symptoms in asthmatic children.* Journal of Exposure Science & Environmental Epidemiology, 2014. **24**(4): p. 380-387.
50. Jacobson, L.d.S.V., et al., *Association between fine particulate matter and the peak expiratory flow of schoolchildren in the Brazilian subequatorial Amazon: A panel study.* Environmental Research, 2012. **117**: p. 27-35.
51. Wu, S., et al., *Chemical constituents of fine particulate air pollution and pulmonary function in healthy adults: The Healthy Volunteer Natural Relocation study.* Journal of Hazardous Materials, 2013. **260**: p. 183-191.
52. Duan, Z., et al., *[Effects of PM2.5 exposure on Klebsiella pneumoniae clearance in the lungs of rats].* Zhonghua jie he he hu xi za zhi = Zhonghua jiehe he huxi zazhi = Chinese journal of tuberculosis and respiratory diseases, 2013. **36**(11): p. 836-840.
53. Wang, G., et al., *Rat lung response to ozone and fine particulate matter (PM2.5) exposures.* Environmental Toxicology, 2015. **30**(3): p. 343-356.
54. Davel, A.P., et al., *Endothelial dysfunction in the pulmonary artery induced by concentrated fine particulate matter exposure is associated with local but not systemic inflammation.* Toxicology, 2012. **295**(1-3): p. 39-46.
55. Thaller, E.I., et al., *Moderate increases in ambient PM2.5 and ozone are associated with lung function decreases in beach lifeguards.* J Occup Environ Med, 2008. **50**(2): p. 202-11.
56. Ogino, K., et al., *Allergic Airway Inflammation by Nasal Inoculation of Particulate Matter (PM2.5) in NC/Nga Mice.* PLOS ONE, 2014. **9**(3): p. e92710.
57. Bassani, D.G., et al., *Child mortality from solid-fuel use in India: A nationally-representative case-control study.* BMC public health, 2010. **10**(1): p. 279.
58. Broor, S., et al., *Risk factors for severe acute lower respiratory tract infection in under-five children.* Indian pediatrics, 2001. **38**(12): p. 1361–1369.
59. Agudelo-Castañeda, D.M., et al., *Exposure to polycyclic aromatic hydrocarbons in atmospheric PM1.0 of urban environments: Carcinogenic and mutagenic respiratory health risk by age groups.* Environmental Pollution, 2017. **224**: p. 158-170.
60. Yang, B.-Y., et al., *Long-term exposure to ambient air pollution (including PM1) and metabolic syndrome: The 33 Communities Chinese Health Study (33CCHS).* Environmental Research, 2018. **164**: p. 204-211.
61. Yang, M., et al., *Is smaller worse? New insights about associations of PM1 and respiratory health in children and adolescents.* Environment International, 2018. **120**: p. 516-524.
62. Darrow, L.A., et al., *Air Pollution and Acute Respiratory Infections Among Children 0–4 Years of Age: An 18-Year Time-Series Study.* American Journal of Epidemiology, 2014. **180**(10): p. 968-977.
63. Jung, K.H., et al., *Childhood exposure to fine particulate matter and black carbon and the development of new wheeze between ages 5 and 7 in an urban prospective cohort.* Environment international, 2012. **45**: p. 44-50.
64. Gleason, J.A., L. Bielory, and J.A. Fagliano, *Associations between ozone, PM2.5, and four pollen types on emergency department pediatric asthma events during the warm season in New Jersey: a case-crossover study.* Environ Res, 2014. **132**: p. 421-9.

65. Nachman, K.E. and J.D. Parker, *Exposures to fine particulate air pollution and respiratory outcomes in adults using two national datasets: a cross-sectional study*. Environmental health : a global access science source, 2012. **11**: p. 25.
66. Tsai, S.-S., C.-C. Chang, and C.-Y. Yang, *Fine particulate air pollution and hospital admissions for chronic obstructive pulmonary disease: a case-crossover study in Taipei*. International journal of environmental research and public health, 2013. **10**(11): p. 6015-6026.
67. Howie, S.R.C., et al., *Childhood pneumonia and crowding, bed-sharing and nutrition: A case-control study from The Gambia*. The International Journal of Tuberculosis and Lung Disease, 2016. **20**(10): p. 1405–1415.
68. Lin, M., et al., *Gaseous Air Pollutants and Asthma Hospitalization of Children with Low Household Income in Vancouver, British Columbia, Canada*. American Journal of Epidemiology, 2004. **159**(3): p. 294-303.
69. *US EPA. 2020. Volatile Organic Compounds' Impact On Indoor Air Quality | US EPA. [online] Available at: <https://www.epa.gov/indoor-air-quality-iaq/volatile-organic-compounds-impact-indoor-air-quality> [Accessed 26 July 2020].*
70. Shuai, J., et al., *Health risk assessment of volatile organic compounds exposure near Daegu dyeing industrial complex in South Korea*. BMC Public Health, 2018. **18**(1): p. 528.
71. Kwon, J.-W., et al., *Exposure to volatile organic compounds and airway inflammation*. Environmental Health, 2018. **17**(1): p. 65.
72. Baumgartner, J., et al., *Highway proximity and black carbon from cookstoves as a risk factor for higher blood pressure in rural China*. Proceedings of the National Academy of Sciences of the United States of America, 2014. **111**(36): p. 13229–13234.
73. Agency, U.S.E.P. *Indoor Air Quality (IAQ)*. 2016; Available from: https://www.epa.gov/indoor-air-quality-iaq/indoor-particulate-matter.
74. Massey, D., et al., *Seasonal trends of PM10, PM5.0, PM2.5 & PM1.0 in indoor and outdoor environments of residential homes located in North-Central India*. Building and Environment, 2012. **47**: p. 223-231.
75. Ni, K., et al., *Seasonal variation in outdoor, indoor, and personal air pollution exposures of women using wood stoves in the Tibetan Plateau: Baseline assessment for an energy intervention study*. Environment International, 2016. **94**: p. 449-457.
76. Carter, E., et al., *Seasonal and Diurnal Air Pollution from Residential Cooking and Space Heating in the Eastern Tibetan Plateau*. Environmental Science & Technology, 2016. **50**(15): p. 8353-8361.
77. WHO. *Air pollution levels rising in many of the world's poorest cities*. 2016; Available from: https://www.who.int/en/news-room/detail/12-05-2016-air-pollution-levels-rising-in-many-of-the-world-s-poorest-cities.
78. Bank, W. *Nigeria Economic Update: Accelerating Economic Expansion, Creating New Job Opportunities*. 2019; Available from: https://www.worldbank.org/en/country/nigeria/publication/nigeria-economic-update-accelerating-economic-expansion-creating-new-job-opportunities.
79. Bank, W. *A Plea for Action against Pollution in Nigeria*. 2015; Available from: https://www.worldbank.org/en/news/feature/2015/06/16/in-lagos-nigeria-a-plea-for-action-against-pollution.
80. Salje, H., et al., *Impact of neighborhood biomass cooking patterns on episodic high indoor particulate matter concentrations in clean fuel homes in Dhaka, Bangladesh*. Indoor Air, 2015. **24**: p. 213-220.

81. Siddiqui, A.R., et al., *Indoor carbon monoxide and PM2.5 concentrations by cooking fuels in Pakistan.* Indoor Air, 2009. **19**(1): p. 75-82.
82. Hulin, M., D. Caillaud, and I. Annesi-Maesano, *Indoor air pollution and childhood asthma: Variations between urban and rural areas.* Indoor air, 2010. **20**(6): p. 502–514.
83. Mustapha, B.A., et al., *Traffic Air Pollution and Other Risk Factors for Respiratory Illness in Schoolchildren in the Niger-Delta Region of Nigeria.* Environmental Health Perspectives, 2011. **119**(10): p. 1478–1482.
84. Shibata, T., et al., *Childhood Acute Respiratory Infections and Household Environment in an Eastern Indonesian Urban Setting.* International Journal of Environmental Research and Public Health, 2014. **11**(12): p. 12190–12203.
85. Bruce, N.G., et al., *Control of household air pollution for child survival: Estimates for intervention impacts.* BMC public health, 2013. **13 Suppl 3**: p. S8.
86. Jackson, S., et al., *Risk factors for severe acute lower respiratory infections in children: a systematic review and meta-analysis.* Croat Med J, 2013. **54**(2): p. 110-21.
87. Rudan, I., et al., *Epidemiology and etiology of childhood pneumonia.* Bulletin of the World Health Organization, 2008. **86**(5): p. 408–416.
88. Sonego, M., et al., *Risk Factors for Mortality from Acute Lower Respiratory Infections (ALRI) in Children under Five Years of Age in Low and Middle-Income Countries: A Systematic Review and Meta-Analysis of Observational Studies.* PLOS ONE, 2015. **10**(1): p. e0116380.
89. Zar, H.J. and T.W. Ferkol, *The global burden of respiratory disease-impact on child health.* Pediatr Pulmonol, 2014. **49**(5): p. 430-4.
90. Jung, K.H., et al., *Childhood exposure to fine particulate matter and black carbon and the development of new wheeze between ages 5 and 7 in an urban prospective cohort.* Environment international, 2012. **45**: p. 44–50.
91. Rumchev, K., et al., *Association of domestic exposure to volatile organic compounds with asthma in young children.* Thorax, 2004. **59**(9): p. 746–751.
92. Berglund M, B.C., Bylin G, Ewetz L, Gustafsson L, Moldeus P, et al, *HEALTH RISK-EVALUATION OF NITROGEN-OXIDES.* SCANDINAVIAN JOURNAL OF WORK ENVIRONMENT & HEALTH, 1993. **19**: p. 1-72.
93. Clements, A.L., et al., *Low-Cost Air Quality Monitoring Tools: From Research to Practice (A Workshop Summary).* Sensors (Basel, Switzerland), 2017. **17**(11): p. 2478.
94. Gall, E.T., et al., *Indoor air pollution in developing countries: research and implementation needs for improvements in global public health.* American journal of public health, 2013. **103**(4): p. e67-e72.
95. Ezzati, M. and D.M. Kammen, *Household Energy, Indoor Air Pollution, and Health in Developing Countries: Knowledge Base for Effective Interventions.* Annual Review of Energy and the Environment, 2002. **27**(1): p. 233-270.
96. Smith KR and P. A., *Household Air Pollution from Solid Cookfuels and Its Effects on Health. In: Mock CN, Nugent R, Kobusingye O, et al., editors. Injury Prevention and Environmental Health. 3rd edition. Washington (DC): The International Bank for Reconstruction and Development*. 2017: The World Bank.
97. Chatzidiakou, L., D. Mumovic, and A. Summerfield, *Is CO2 a good proxy for indoor air quality in classrooms? Part 1: The interrelationships between thermal conditions, CO2 levels, ventilation rates and selected indoor pollutants.* Building Services Engineering Research and Technology, 2015. **36**(2): p. 129-161.

98. Ram, P.K., et al., *Household air quality risk factors associated with childhood pneumonia in urban Dhaka, Bangladesh.* The American journal of tropical medicine and hygiene, 2014. **90**(5): p. 968–975.
99. Schwartz J, N.L., *Fine Particles Are More Strongly Associated Than Coarse Particles with Acute Respiratory Health Effects in Schoolchildren.* 2000. **6**.
100. Adekunle Fakunle, et al., *Housing Quality and Risk Factors Associated with Respiratory Health Conditions in Nigeria.* Intech Open, 2018.
101. Aung, T.W., et al., *Health and Climate-Relevant Pollutant Concentrations from a Carbon-Finance Approved Cookstove Intervention in Rural India.* Environmental Science & Technology, 2016. **50**(13): p. 7228–7238.
102. Kar, A., et al., *Real-Time Assessment of Black Carbon Pollution in Indian Households Due to Traditional and Improved Biomass Cookstoves.* Environmental Science & Technology, 2012. **46**(5): p. 2993–3000.
103. Preble, C.V., et al., *Emissions and Climate-Relevant Optical Properties of Pollutants Emitted from a Three-Stone Fire and the Berkeley-Darfur Stove Tested under Laboratory Conditions.* Environmental Science & Technology, 2014. **48**(11): p. 6484–6491.
104. *The World Bank (2017) World Bank Country and Lending Groups—World Bank Data Help Desk, Datahelpdesk.worldbank.org.*
105. Stang, A., *Critical evaluation of the Newcastle-Ottawa scale for the assessment of the quality of nonrandomized studies in meta-analyses.* Eur J Epidemiol, 2010. **25**(9): p. 603-5.
106. Margulis, A.V., et al., *Quality assessment of observational studies in a drug-safety systematic review, comparison of two tools: the Newcastle-Ottawa Scale and the RTI item bank.* Clinical epidemiology, 2014. **6**: p. 359-368.
107. Samuel, G.O., et al., *Guidance on assessing the methodological and reporting quality of toxicologically relevant studies: A scoping review.* Environment International, 2016. **92-93**: p. 630-646.
108. UNICEF, *One is Too Many: Ending Child Deaths from Pneumonia and Diarrhoea.* UNICEF DATA [Internet]. UNICEF DATA. , 2016.
109. Klasen, E.M., et al., *Low correlation between household carbon monoxide and particulate matter concentrations from biomass-related pollution in three resource-poor settings.* Environmental Research, 2015. **142**: p. 424-431.
110. Zhang, Q., et al., *Exhaled carbon monoxide and its associations with smoking, indoor household air pollution and chronic respiratory diseases among 512 000 Chinese adults.* International Journal of Epidemiology, 2013. **42**(5): p. 1464-1475.
111. Patange, O.S., et al., *Reductions in indoor black carbon concentrations from improved biomass stoves in rural India.* Environ Sci Technol, 2015. **49**(7): p. 4749-56.
112. Geng, F., et al., *Differentiating the associations of black carbon and fine particle with daily mortality in a Chinese city.* Environmental Research, 2013. **120**: p. 27-32.
113. Wang, X., et al., *Associations between fine particle, coarse particle, black carbon and hospital visits in a Chinese city.* Science of The Total Environment, 2013. **458**: p. 1-6.
114. Shen, G., et al., *Impacts of air pollutants from rural Chinese households under the rapid residential energy transition.* Nature Communications, 2019. **10**(1): p. 3405.

115. NPC/Nigeria, N.a.I., I. *Nigeria Demographic and Health Survey*. 2013; Available from: https://dhsprogram.com/publications/publication-fr293-dhs-final-reports.cfm.
116. Surveys, D.a.H. *[Internet]. Dhsprogram.com. 2020 [cited 7 August 2020]. Available from: https://dhsprogram.com/what-we-do/survey-Types/dHs.cfm*. 2020; Available from: https://dhsprogram.com/what-we-do/survey-Types/dHs.cfm.
117. Dontamsetti, T., et al., *A primer on the Demographic and Health Surveys Program spatial covariate data and their applications*. DHS spatial analysis reports. 2018, Rockville, Maryland, USA: ICF. 1 online resource (xi, 39.
118. Settlement, G.H. *GHS BUILT-UP GRID - European Commission*. 2015; Available from: https://ghsl.jrc.ec.europa.eu/ghs_bu.php
119. Tusting, L.S., et al., *Mapping changes in housing in sub-Saharan Africa from 2000 to 2015.* Nature, 2019. **568**(7752): p. 391-394.
120. Bai, K., et al., *Spatiotemporal trend analysis for fine particulate matter concentrations in China using high-resolution satellite-derived and ground-measured PM2.5 data.* Journal of environmental management, 2019. **233**: p. 530–542.
121. SEDAC. *Socioeconomic Data and Applications Center | SEDAC*. 2019; Available from: https://sedac.ciesin.columbia.edu/.
122. Michal, K. and A. Cohen, *Update of WHO air quality guidelines.* Air Quality, Atmosphere & Health, 2008.
123. WHO, *Air quality guidelines for Europe.* WHO regional publications. European series, 2000(91): p. V-X, 1-273.
124. Venter, O., et al., *Global terrestrial Human Footprint maps for 1993 and 2009.* Scientific data, 2016. **3**: p. 160067.
125. Alegana, V.A., et al., *National and sub-national variation in patterns of febrile case management in sub-Saharan Africa.* Nature communications, 2018. **9**(1): p. 4994.
126. Tatem AJ, et al. *Pilot high resolution poverty maps, University of Southampton/Oxford*. 2013; Available from: https://doi.org/10.5258/SOTON/WP00127.
127. D'Orazio, M., M. Scanu, and M. Di Zio, *Statistical matching: Theory and practice*. 2006, Chichester: John Wiley & Sons. 256.
128. Randolph, J.J. and K. Falbe, *A step-by-step guide to propensity score matching in R. Practical Assessment.* Research & Evaluation, 2014. **19**.
129. Umlauf, N., *Structured additive regression models: An R interface to BayesX*. Working papers in economics and statistics. 2012, Innsbruck: University of Innsbruck. Department of Public Finance. 42 Seiten.
130. Anderson, D.R. and K. Burnham, *Model selection and multi-model inference.* Springer-Verlag, 2004. **2**.
131. Spiegelman, D., E. Hertzmark, and H.C. Wand, *Point and interval estimates of partial population attributable risks in cohort studies: examples and software.* Cancer Causes & Control, 2017. **18**(5): p. 571-579.
132. HANNA, R. and P. OLIVA, *Moving up the Energy Ladder: The Effect of an Increase in Economic Wellbeing on the Fuel Consumption Choices of the Poor in India.* American Economic Review, 2015: p. 242-246.
133. van der Kroon, B., R. Brouwer, and P.J.H. van Beukering, *The energy ladder: Theoretical myth or empirical truth? Results from a meta-analysis.* Renewable and Sustainable Energy Reviews, 2013. **20**: p. 504-513.

134. Castañeda, J.L., et al., *Effect of reductions in biomass fuel exposure on symptoms of sleep apnea in children living in the peruvian andes: a preliminary field study.* Pediatric pulmonology, 2013. **48**(10): p. 996-999.
135. Chapman, R.S., et al., *Improvement in household stoves and risk of chronic obstructive pulmonary disease in Xuanwei, China: retrospective cohort study*. BMJ, 2005. **331**(7524): p. 1050.
136. Mortimer, K., et al., *A cleaner burning biomass-fuelled cookstove intervention to prevent pneumonia in children under 5 years old in rural Malawi (the Cooking and Pneumonia Study): a cluster randomised controlled trial.* The Lancet, 2017. **389**(10065): p. 167-175.
137. The R Foundation, *The R Project. (Version 3.6.0).* 2019.
138. QGIS, *QGS. (Version 3.6.1)*. 2019.
139. Azad, M.A.K., E.E. Crawford, and H.K. Kaila, *Conflict and Violence in Nigeria : Results from the North East, North Central, and South South Zones (English).* Washington, D.C. : World Bank Group, 2018.
140. worldometers. *worldometers. Nigeria Population (LIVE)*. 2018; Available from: http://www.worldometers.info/world-population/nigeria-population/.
141. Agency, C.I. *Cia.gov. The World Factbook — Central Intelligence Agency*. 2017; Available from: https://www.cia.gov/library/publications/the-world-factbook/geos/ni.html.
142. O, D., *A predominance of hypertensive heart failure in the Abuja Heart Study cohort of urban Nigerians: a prospective clinical registry of 1515 de novo cases.* European journal of heart failure, 2013. **15**(8): p. 835-42.
143. *Nigerian Urban Reproductive Health Initiative, (NURHI). Building a Thriving City that Contributes to Nigeria's Development Success*. 2013.
144. WHO. *WHO indoor air quality guidelines: household fuel combustion: WHO*. 2017; Available from: http://www.who.int/indoorair/guidelines/hhfc/recommendation_1/en/.
145. Awodugba, A., et al., *Basement Data of the Terrestrial Radionuclide Level of Abuja Federal Capital Territory,(FCT), Nigeria.* Journal of Environmental Protection, 2011. **2**.
146. UNICEF, *One is Too Many: Ending Child Deaths from Pneumonia and Diarrhoea*. 2016.
147. Mortimer, K., et al., *A cleaner burning biomass-fuelled cookstove intervention to prevent pneumonia in children under 5 years old in rural Malawi (the Cooking and Pneumonia Study): a cluster randomised controlled trial.* The Lancet, 2017. **389**(10065): p. 167-175.
148. J, R. and O. R, *Qualitative research practice : a guide for social science students and researchers*. The Application of Qualitative Methods to Social Research. In: Ritchie, J and Lewis J (ed). 2013, London: Sage Publications. 27–46.
149. B, Z., *Focus Group. In: Social research methods*. 2010, Oxford: Oxford University Press. 500–520.
150. Tyrer, S. and B. Heyman, *Sampling in epidemiological research: issues, hazards and pitfalls.* BJPsych Bulletin, 2018. **40**(2): p. 57-60.
151. Chowdhury Z ER, et al., *An inexpensive light-scattering particle monitor: chamber and field validations with woodsmoke.* Journal of Environmental Monitoring, 2007. **9**(10): p. 1099-106.

HHID [__ | __ | __ | __ | __ | __]

152. Belanger, K., et al., *Association of indoor nitrogen dioxide exposure with respiratory symptoms in children with asthma.* American journal of respiratory and critical care medicine, 2006. **173**(3): p. 297–303.
153. Organization, W.H., *Occupational and Environmental Health Team (2006). WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide : global update 2005 : summary of risk assessment. World Health Organization.* . 2005.
154. Ramanathan N, et al., *Comparison Between Elemental Carbon Measured Using Thermal-Optical Analysis and Black Carbon Measurements Using a Novel Cellphone-Based System.* American Geophysical Union San Francisco, CA, 2011.
155. CD, L., et al., *Combined optical and ionization measurement techniques for inexpensive characterization of micrometer and submicrometer aerosols.* Aerosol Science and Technology, 2004. **38**: p. 1054-62.
156. Ramanathan N, et al., *A cellphone based system for large scale monitoring of black carbon.* Atmospheric Environment, 2011. **45**: p. 4481-7.
157. Pillarisetti, A., et al., *Small, Smart, Fast, and Cheap: Microchip-Based Sensors to Estimate Air Pollution Exposures in Rural Households.* Sensors (Basel, Switzerland), 2017. **17**(8): p. 1879.
158. Semple, S., et al., *Using a new, low-cost air quality sensor to quantify second-hand smoke (SHS) levels in homes.* Tobacco Control, 2015. **24**(2): p. 153.
159. Woolson, R.F., *Wilcoxon Signed-Rank Test. In Wiley Encyclopedia of Clinical Trials.* 2008.
160. Wittkowski, K.M. and T. Song, *Nonparametric methods for molecular biology. Methods in molecular biology.* 2010: p. 105–153.
161. Fund, W.H.O.a.t.U.N.C.s., *WHO child growth standards and the identification of severe acute malnutrition in infants and children A Joint Statement by the World Health Organization and the United Nations Children's Fund* 2009.
162. Chance, G.W., *Environmental contaminants and children's health: Cause for concern, time for action.* Paediatrics & Child Health, 2001. **6**(10): p. 731–743.
163. Oluleye A, et al., *Malaria and pneumonia occurrence in Lagos, Nigeria: Role of temperature and rainfall.* Academic Journals, 2010.
164. Jayes, L.R., et al., *Smoke-free prisons in England: indoor air quality before and after implementation of a comprehensive smoke-free policy.* BMJ Open, 2019. **9**(6): p. e025782.
165. Bradshaw, C., S. Atkinson, and O. Doody, *Employing a Qualitative Description Approach in Health Care Research.* Global qualitative nursing research, 2017. **4**: p. 2333393617742282-2333393617742282.
166. Hardon A, Hodgkin C, and F. D, *How to investigate the use of medicines by consumers.* 2004.
167. JJ, F., et al., *What is an adequate sample size? Operationalising data saturation for theory- based interview studies.* Psychology & health, 2010. **25**: p. 1229–45.
168. Braun, V. and V. Clarke, *Using thematic analysis in psychology, Qualitative Research in Psychology.* 3, 2006. **2**: p. 77-101.
169. PG, O., et al., *Analysis of spatial and temporal patterns in onset, cessation and length of growing season in Nigeria.* Agricultural and Forest Meteorology, 2014. **194**: p. 77–87.
170. *Abuja Monthly Climate Averages [Internet]. WorldWeatherOnline.com. 2020 [cited 22 August 2020]. Available from: https://www.worldweatheronline.com/abuja-weather-averages/federal-capital-territory/ng.aspx.*

171. WHO. *Pneumonia*. 2016; Available from: https://www.who.int/news-room/fact-sheets/detail/pneumonia.
172. Ana, G.R., *Air Pollution in the Niger Delta Area: Scope, Challenges and Remedies, The Impact of Air Pollution on Health, Economy, Environment and Agricultural Sources, Mohamed K. Khallaf, IntechOpen, DOI: 10.5772/16817*. 2011: p. - Ch. 9.
173. Chen, Y., et al., *Local characteristics of and exposure to fine particulate matter (PM2.5) in four indian megacities.* Atmospheric Environment: X, 2020. **5**: p. 100052.
174. Liu, W., et al., *Oxidative potential of ambient PM2.5 in the coastal cities of the Bohai Sea, northern China: Seasonal variation and source apportionment.* Environmental Pollution, 2018. **236**: p. 514-528.
175. Ozoh O, et al., *Cooking Fuels in Lagos, Nigeria: Factors Associated with Household Choice of Kerosene or Liquefied Petroleum Gas (LPG).* International Journal of Environmental Research and Public Health, 2018. **15**(4): p. 641.
176. Bisu D, Kuhe A, and I. H., *Urban household cooking energy choice: an example of Bauchi metropolis, Nigeria.* Energy, Sustainability and Society, 2016. **6**(1).
177. Ado, A., I.R. Darazo, and M.d.A. Babayo, *Determinants of fuels stacking behaviour among households in Bauchi Metropolis* The Business and Management Review, 2016. **7**(3).
178. Atagher, P.T., *We Can't Stop Cooking Investigating the Enablers for the uptake of Improved Cookstoves in Benue State, Nigeria*, in *Department of Engineering*. 2019: University of Nottingham.
179. Rehfuess, E., S. Mehta, and A. Prüss-Üstün, *Assessing Household Solid Fuel Use: Multiple Implications for the Millennium Development Goals.* Environmental Health Perspectives, 2006. **114**(3): p. 373-378.
180. Ofori, S., J. Fobil, and O. Odia, *Household biomass fuel use, blood pressure and carotid intima media thickness; a cross sectional study of rural dwelling women in Southern Nigeria.* Environmental Pollution, 2018. **242**: p. 390-397.
181. Pope, D., et al., *Household Determinants of Liquified Petroleum Gas (LPG) as a Cooking Fuel in SW Cameroon.* EcoHealth, 2018. **15**(4): p. 729-743.
182. Goodwin, N.J., et al., *Use of Behavior Change Techniques in Clean Cooking Interventions: A Review of the Evidence and Scorecard of Effectiveness.* Journal of Health Communication, 2015. **20**(sup1): p. 43-54.
183. Africa, Q. *Nigeria has some of the world's most polluted cities—and that isn't about to change*. 2018; Available from: https://qz.com/africa/1433597/nigeria-has-some-of-the-worlds-most-polluted-cities-and-that-isnt-about-to-change/.
184. Odekanle, E., et al., *Personal exposures to particulate matter in various modes of transport in Lagos city, Nigeria.* Cogent Environmental Science, 2016. **2**(1).
185. Adesanya, O.A. and C. Chiao, *A multilevel analysis of lifestyle variations in symptoms of acute respiratory infection among young children under five in Nigeria.* BMC public health, 2016. **16**(1): p. 880-880.
186. Saad, S.T. and I.M. Bugaje, *Biomass Consumption in Nigeria: Trends and Policy Issues.* Journal of Agriculture and Sustainability, 2016. **9**.
187. E., O.T., et al., *Environmental Impact Analysis of the Emission from Petroleum Refineries in Nigeria* Energy and Environment Research, 2015. **5**(1): p. 33-41.
188. Nwokocha, J.C., *Geospatial Distribution of Air Pollutants along Selected Traffic Routes Within Portharcourt Metropolis.* 2018.

189. The World Bank and Institute for Health Metrics and Evaluation University of Washington, S., *The Cost of Air Pollution Strengthening the Economic Case for Action*, I.B.f.R.a.D.T.W. Bank, Editor. 2016.
190. Adam, V. and A. Aigbokhaode, *Sociodemographic factors associated with the healthcare-seeking behavior of heads of households in a rural community in Southern Nigeria.* Sahel Medical Journal, 2018. **21**(1): p. 31.
191. Latunji, O.O. and O.O. Akinyemi, *FACTORS INFLUENCING HEALTH-SEEKING BEHAVIOUR AMONG CIVIL SERVANTS IN IBADAN, NIGERIA.* Annals of Ibadan Postgraduate Medicine, 2018. **16**(1).
192. Elimian, K.O., et al., *'Everybody in Nigeria is a doctor…': a qualitative study of stakeholder perspectives on lay diagnosis of malaria and pneumonia in Nigeria.* J Public Health (Oxf), 2020. **42**(2): p. 353-361.
193. Latunji, O.O. and O.O. Akinyemi, *FACTORS INFLUENCING HEALTH-SEEKING BEHAVIOUR AMONG CIVIL SERVANTS IN IBADAN, NIGERIA.* Ann Ib Postgrad Med, 2018. **16**(1): p. 52-60.
194. Okonofua, F.E., et al., *Impact of an intervention to improve treatment-seeking behavior and prevent sexually transmitted diseases among Nigerian youths.* Int J Infect Dis, 2003. **7**(1): p. 61-73.
195. Sumal Nandasena, Ananda Rajitha Wickremasinghe, and N. Sathiakumar, *Indoor air pollution and respiratory health of children in the developing world.* World J Clin Pediatr, 2013. **2**(2): p. 6–15.
196. Virginia Fuentes-Leonarte, Ferran Ballester, and J.M. Tenías, *Sources of Indoor Air Pollution and Respiratory Health in Preschool Children.* J Environ Public Health. , 2009.
197. Health, N.F.M.o., *National Integrated Pneumonia Control Strategy & Implementation Plan*. 2019.
198. Institute of Medicine (US) Committee on Health and Behavior: Research, P., and Policy, *Health and Behavior: The Interplay of Biological, Behavioral, and Societal Influences*. Individuals and Families: Models and Interventions Vol. 5. 2001, Washington (DC): Washington (DC): National Academies Press (US).
199. Institute of Medicine (US) Committee on Health and Behavior: Research, P., and Policy. , *Individuals and Families: Models and Interventions*, in *Health and Behavior: The Interplay of Biological, Behavioral, and Societal Influences.*, National Academies Press (US): Washington (DC).
200. Bond, T.C., et al., *Bounding the role of black carbon in the climate system: A scientific assessment.* Journal of Geophysical Research: Atmospheres, 2013. **118**(11): p. 5380-5552.
201. WHO, *Ambient air pollution: A global assessment of exposure and burden of disease*. 2016.
202. Shears, R.K., et al., *Exposure to diesel exhaust particles increases susceptibility to invasive pneumococcal disease.* J Allergy Clin Immunol, 2020. **145**(4): p. 1272-1284.e6.
203. Nicole AH Janssen, et al., *Health effects of black carbon.* World Health Organization Regional Office for Europe, 2012.
204. Tofful, L. and C. Perrino, *Chemical Composition of Indoor and Outdoor PM2.5 in Three Schools in the City of Rome.* Atmosphere, 2015. **6**(10).
205. Thörn, L.K.A.M., et al., *Pneumonia and poverty: a prospective population-based study among children in Brazil.* BMC infectious diseases, 2011. **11**: p. 180-180.

206. WHO. *Pneumonia*. 2019; Available from: https://www.who.int/en/news-room/fact-sheets/detail/pneumonia.
207. Troeger, C., et al., *Estimates of the global, regional, and national morbidity, mortality, and aetiologies of lower respiratory infections in 195 countries, 1990–2016: a systematic analysis for the Global Burden of Disease Study 2016.* The Lancet Infectious Diseases, 2018. **18**(11): p. 1191-1210.
208. Alegana, V.A., et al., *Treatment-seeking behaviour in low- and middle-income countries estimated using a Bayesian model.* BMC medical research methodology, 2017. **17**(1): p. 67-67.
209. Ozoh, O.B., et al., *Cooking Fuels in Lagos, Nigeria: Factors Associated with Household Choice of Kerosene or Liquefied Petroleum Gas (LPG).* International journal of environmental research and public health, 2018. **15**(4): p. 641.
210. Dong, G.-H., et al., *Gender differences and effect of air pollution on asthma in children with and without allergic predisposition: northeast Chinese children health study*. PloS one, 2011. **6**(7): p. e22470-e22470.
211. Devakumar, D., et al., *Women's Ideas about the Health Effects of Household Air Pollution, Developed through Focus Group Discussions and Artwork in Southern Nepal.* International journal of environmental research and public health, 2018. **15**(2): p. 248.
212. Dutta, S. and S. Banerjee, *Exposure to Indoor Air Pollution & Women Health: The Situation in Urban India.* Environment and Urbanization ASIA, 2014. **5**(1): p. 131-145.
213. Clougherty, J.E., *A growing role for gender analysis in air pollution epidemiology.* Environmental health perspectives, 2010. **118**(2): p. 167-176.
214. Bruce, N., et al., *Impact of improved stoves, house construction and child location on levels of indoor air pollution exposure in young Guatemalan children.* J Expo Anal Environ Epidemiol, 2004. **14 Suppl 1**: p. S26-33.
215. Langbein, J., *Firewood, smoke and respiratory diseases in developing countries-The neglected role of outdoor cooking.* PLoS One, 2017. **12**(6): p. e0178631.
216. Minz, A., et al., *Care seeking for childhood pneumonia by rural and poor urban communities in Lucknow: A community-based cross-sectional study.* Journal of family medicine and primary care, 2017. **6**(2): p. 211-217.
217. Noordam, A.C., et al., *Care seeking behaviour for children with suspected pneumonia in countries in sub-Saharan Africa with high pneumonia mortality.* PloS one, 2015. **10**(2): p. e0117919-e0117919.
218. Ferdous, F., et al., *Mothers' perception and healthcare seeking behavior of pneumonia children in rural bangladesh.* ISRN Family Med, 2014. **2014**: p. 690315.
219. Ndu, I.K., et al., *Danger Signs of Childhood Pneumonia: Caregiver Awareness and Care Seeking Behavior in a Developing Country.* Int J Pediatr, 2015. **2015**: p. 167261.
220. Ekure, E., et al., *Mothers and childhood pneumonia: What should the focus of public campaigns be?* Nigerian Journal of Paediatrics, 2013. **40**.
221. Joubert, B.R., S.N. Mantooth, and K.A. McAllister, *Environmental Health Research in Africa: Important Progress and Promising Opportunities.* Frontiers in Genetics, 2020. **10**: p. 1166.
222. Dorlo, T.P.C., et al., *Poverty-Related Diseases College: a virtual African-European network to build research capacity.* BMJ Global Health, 2016. **1**(1): p. e000032.

223. Atagher, P.T., *We Can't Stop Cooking Investigating the Enablers for the uptake of Improved Cookstoves in Benue State, Nigeria*, in *Department of Engineering*. 2019, University of Nottingham.
224. Usman, R. and A. Sheu, *Correlates and health on consequences of indoor air pollution among urban households in Ilorin, Nigeria.* Glob J Hum Soc Sci, 2010. **10**(4): p. 80-87.
225. Isara, A.R. and A.Q. Aigbokhaode, *Household Cooking Fuel Use among Residents of a Sub-Urban Community in Nigeria: Implications for Indoor Air Pollution.* The Eurasian journal of medicine, 2014. **46**(3): p. 203-208.
226. Sadoh, A., et al., *Traders' Perception of Cooking Smoke as a Risk Factor for Childhood Pneumonia.* Nigerian Journal of Paediatrics, 2015. **42**(4).
227. Cattaneo MD, et al., *Housing, health, and happiness.* American Economic Journal: Economic Policy, 2009. **1**(1): p. 75-105.
228. ME, N., S. ED, and B. P, *Sorting out the connections between the built environment and health: a conceptual framework for navigating pathways and planning healthy cities.* Journal of Urban Health, 2003. **80**(4): p. 556–568.
229. Guastadisegni, C., et al., *Determinants of the proinflammatory action of ambient particulate matter in immortalized murine macrophages.* Environ Health Perspect, 2010. **118**(12): p. 1728-34.
230. N. Li, S.K., et al., *Use of a stratified oxidative stress model to study the biological effects of ambient concentrated and diesel exhaust particulate matter.* Inhalation Toxicol, 2002. **14**(5): p. 459–486.
231. P. A. Steerenberg, et al., *Diesel exhaust particles induced release of interleukin 6 and 8 by (primed) human bronchial epithelial cells (BEAS 2B) in vitro.* Exp. Lung Res, 1997. **24**(1): p. 85-100.
232. Hawley, B., et al., *Time course of bronchial cell inflammation following exposure to diesel particulate matter using a modified EAVES.* Toxicol In Vitro, 2014. **28**(5): p. 829-837.
233. Behndig, A.F., et al., *Airway antioxidant and inflammatory responses to diesel exhaust exposure in healthy humans.* Eur. Respir. J, 2006. **27**(2): p. 359-365.
234. Samet, J.M., et al., *Concentrated ambient ultrafine particle exposure induces cardiac changes in young healthy volunteers.* Am. J. Respir. Crit. Care Med, 2009. **179**(11): p. 1034–1042.
235. M. Gasser, et al., *Toxic effects of brake wear particles on epithelial lung cells in vitro.* Part. Fibre Toxicol, 2009. **6**(30).
236. C. Puisney, et al., *Brake wear (nano)particle characterization and toxicity on airway epithelial cells in vitro.* Environ. Sci.: Nano, 2018. **5**(4): p. 1036-1044.
237. Loxham, M., et al., *Physicochemical characterization of airborne particulate matter at a mainline underground railway station.* Environ. Sci. Technol, 2013. **47**(8): p. 3614–3622.
238. Brugha, R.E., et al., *Carbon in airway macrophages from children with asthma.* Thorax, 2014. **69**(7): p. 654–659.
239. Braydich-Stolle, L.K., et al., *Nanosized aluminum altered immune function.* ACS Nano, 2010. **4**(7): p. 3661-70.
240. Kodali, V., et al., *Dysregulation of macrophage activation profiles by engineered nanoparticles.* ACS Nano, 2013. **7**(8): p. 6997–7010.
241. Yin, X.J., et al., *Suppression of phagocytic and bactericidal functions of rat alveolar macrophages by the organic component of diesel exhaust particles.* J Toxicol Environ Health A, 2007. **70**(10): p. 820-8.

242. Zhou, H. and L. Kobzik, *Effect of concentrated ambient particles on macrophage phagocytosis and killing of Streptococcus pneumoniae.* Am J Respir Cell Mol Biol, 2007. **36**(4): p. 460-5.
243. Rylance, J., et al., *Household Air Pollution Causes Dose-Dependent Inflammation and Altered Phagocytosis in Human Macrophages.* Am. J. Respir. Cell Mol. Biol, 2015. **52**(5): p. 584–593.
244. Sussan, T.E., et al., *Exposure to Electronic Cigarettes Impairs Pulmonary Anti-Bacterial and Anti-Viral Defenses in a Mouse Model.* ed. D. W. Metzger, PLoS One, 2015. **10**(2).
245. Hwang, J.H., et al., *Electronic cigarette inhalation alters innate immunity and airway cytokines while increasing the virulence of colonizing bacteria.* J. Mol. Med, 2016. **94**(6): p. 667–679.
246. Selley, L., et al., *Brake dust exposure exacerbates inflammation and transiently compromises phagocytosis in macrophages.* Metallomics, 2020. **12**(3): p. 371-386.
247. Luvhimbi, J.H. and H. Jawrek, *Household energy in a recently electrified rural settlement in Mpumalanga, South Africa.* Boiling Point, 1997. **38**: p. 30-31.
248. Hoets, P. *Macro-scale experiment: Social acceptability of low smoke fuels*.
249. NEP. *National Energy Policy; Draft Revised Edition*. 2013; Available from: http://www.energy.gov.ng.
250. Ifegbesan, A.P., I.T. Rampedi, and H.J. Annegarn, *Nigerian households' cooking energy use, determinants of choice, and some implications for human health and environmental sustainability*. Habitat International, 2016. **55**: p. 17-24.
251. Cecelski, E. and M. Matinga, *Cooking with gas: why women in developing countries want LPG and how they can get it*, d.f.t.W.L.G.A.b.E.I.N.o.G.a.S. Energy., Editor. 2014.
252. Oteh, O.U., et al., *Mitigating climate change and determinants of access to liquified petroluem gas (LPG) among urban households in Abia State, Nigeria.* Journal of Earth Science & Climatic Change, 2015. **6**(5).
253. Hollada, J., et al., *Perceptions of improved biomass and liquefied petroleum gas stoves in Puno, Peru: implications for promoting sustained and exclusive adoption of clean cooking technologies.* International journal of environmental research and public health, 2017. **14**: p. 182.
254. Sesan, T., *Navigating the limitations of energy poverty: Lessons from the promotion of improved cooking technologies in Kenya.* Energy Policy, 2012. **47**: p. 202-210.
255. Hanna, R. and P. Oliva, *Moving up the energy ladder: the effect of an increase in economic well-being on the fuel consumption choices of the poor in India.* American Economic Review, 2015. **105**: p. 242-46.
256. Ruiz-Mercado, I. and O. Masera, *Patterns of stove use in the context of fuel–device stacking: rationale and implications.* Ecohealth, 2015. **12**: p. 42-56.
257. Jane Trac, C., *Climbing without the energy ladder: Limitations of rural energy development for forest conservation.* Rural Society, 2011. **20**: p. 308-320.
258. Miller, G. and A.M. Mobarak, *Gender differences in preferences, intra-household externalities, and low demand for improved cookstoves.* National Bureau of Economic Research, 2013.
259. Rehfuess, E.A., et al., *Enablers and barriers to large-scale uptake of improved solid fuel stoves: a systematic review.* Environmental health perspectives, 2014. **122**: p. 120-130.

260. *Who.int. 2020. Household Air Pollution And Health. [online] Available at: <https://www.who.int/news-room/fact-sheets/detail/household-air-pollution-and-health> [Accessed 28 July 2020].*
261. Balmes, J.R., *Household air pollution from domestic combustion of solid fuels and health.* Journal of Allergy and Clinical Immunology, 2019. **143**(6): p. 1979-1987.
262. Mishra, V., *Indoor air pollution from biomass combustion and acute respiratory illness in preschool age children in Zimbabwe.* International Journal of Epidemiology, 2003. **32**(5): p. 847-853.
263. van Gemert, F., et al., *Effects and acceptability of implementing improved cookstoves and heaters to reduce household air pollution: a FRESH AIR study.* npj Primary Care Respiratory Medicine, 2019. **29**(1): p. 32.
264. Barnes, D.F. and L. Qian, *Urban Interfuel Substitution, Energy Use, and Equity in Developing Countries.* 1992.
265. Hosier, R.H. and W. Kipondya, *Urban household energy use in Tanzania: prices, substitutes and poverty.* Energy Policy, 1993. **21**: p. 454-473.
266. Barnes, D.F. and W.M. Floor, *Rural energy in developing countries: A challenge for economic development 1.* Annual Review of Energy and the Environment, 1996. **21**: p. 497-530.
267. Schlag, N. and F. Zuzarte, *Market barriers to clean cooking fuels in sub-Saharan Africa: a review of literature.* Stockholm Environment Institute, Stockholm, 2008.
268. Abodunrin OL, B.J., O.-B. AI, and P. DB, *Preferred choice of health facilities for healthcare among adult residents in Ilorin metropolis, Kwara state, Nigeria.* International Journal of Health Research, 2010. **3**: p. 79–86.
269. BS, U. and O. OE, *Socio-economic differences and health seeking behaviour for the diagnosis and treatment of malaria: a case study of four local government areas operating the Bamako initiative programme in south-east Nigeria.* International Journal for Equity in Health, 2004. **3**(6).
270. Dumbaugh M, et al., *Perceptions of, attitudes towards and barriers to male involvement in newborn care in rural Ghana, West Africa: a qualitative analysis.* BMC pregnancy and childbirth, 2014. **14**: p. 269.
271. Bruce, N., et al., *Impact of improved stoves, house construction and child location on levels of indoor air pollution exposure in young Guatemalan children.* Journal of Exposure Science & Environmental Epidemiology, 2004. **14**(1): p. S26-S33.

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