Air pollution in Mpemba, Malawi: a multidisciplinary exploration of the burden and possible solutions

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Sepeedeh Saleh

Abstract

Introduction

Air pollution is recognised as a leading environmental risk factor, linked to 6.67 million deaths in 2019, especially through effects on the respiratory and cardiovascular systems. In low-income countries, such as Malawi, household air pollution – caused by the burning of solid fuels for cooking, lighting, and heating – continues to constitute a significant proportion of individuals' air pollution exposures.

This thesis explores the issue of household air pollution in a village in Malawi, where existing evidence suggests high levels of household air pollution, but details of source apportionment are not clear. More generally, qualitative data have been limited to investigations of air pollution reduction interventions (mainly improved stoves), leaving significant knowledge gaps in understanding individuals' lived experiences around 'smoke' itself.

The aim was to perform an ethnographic study of air pollution, or 'smoke', in the Malawian village context, incorporating both quantitative and qualitative methodologies, using these insights to co-develop and trial a whole-village cleaner air intervention.

Methods

I performed a systematic review of randomised controlled trials assessing the efficacy of air pollution reduction interventions in low- and middle-income countries. A subsequent ethnography in a rural village in Malawi included participant observations, individual interviews, and participatory workshops. Exposure to airborne particulates and carbon monoxide was assessed in parallel by personal monitoring of researchers and then village residents. We supported the introduction of locally made clay cookstoves across the village, and we repeated both monitoring and participant observation to explore residents' perceptions of the stoves and exposure impacts.

Results

Studies identified through systematic review were dominated by stove interventions, with little evidence of improvement in clinical respiratory diagnoses resulting from these intervention types. In Malawi, we found high levels of personal exposure to airborne particulate matter and carbon monoxide in village residents, with cooking constituting the predominant exposure source. Detailed matched activity records confirmed cooking using biomass on a three-stone fire to be the cause of highest exposure concentrations. A counterintuitive finding of higher exposures during cooking in better ventilated spaces showed the value of first-person participant observation in understanding individuals' daily exposures. Qualitative approaches revealed the complex ways in which scarcity, through limitation, daily hardship, and insecurity, influenced exposures in this setting. The mixed-method intervention evaluation affirmed that, whilst the cookstoves were not able to significantly reduce cooking-related exposures, they were associated with reduced exposures at baseline (during non-cooking periods). Cookstoves were well-received and almost exclusively used across the village as they met residents' immediate needs (relating to fuel savings and shortened cooking times).

Conclusions

Scarcity was a core component of residents' daily lives in rural Malawi, framing and driving individual air pollution exposures. We recommend development of a national strategy for universal domestic clean energy, provided as a utility rather than a marketed product. International support, with an awareness of historical and geographical origins of international inequity, would support this aspiration. Interim steps may include trialling of liquefied petroleum gas distribution or electricity mini-grids. Research methods that seek to provide insights into individuals' lived experiences of using these provisions constitute an important part of evaluation processes.

List of abbreviations

ALRI	acute lower respiratory tract infection
ARI	acute respiratory infection
ANOVA	analysis of variance
CAPS	Cooking and Pneumonia Study
CENTRAL	Cochrane Central Register of Controlled Trials
CF	calibration factor
CI	confidence interval
CINAHL	Cumulative Index to Nursing and Allied Health Literature
CO	carbon monoxide
COMREC	College of Medicine Research and Ethics Committee
CONSORT	Consolidated Standards of Reporting Trials
COPD	chronic obstructive lung disease
COVID-19	coronavirus disease 2019
ERAP	Ebola Response Anthropology Platform
FEV_1	forced expiratory volume in 1 second
FVC	forced vital capacity
GHR	Global Health Research
HIV	human immunodeficiency virus
IMCI	Integrated Management of Childhood Illness
IMPALA	International Multidisciplinary Programme to Address Lung Health and TB in Africa
IQR	interquartile range
LED	light-emitting diode
LMIC	low- and middle-income country
LPG	liquid petroleum gas
LSTM	Liverpool School of Tropical Medicine
MLW	Malawi-Liverpool-Wellcome Trust Clinical Research Programme
NGO	non-governmental organisation
NHS	National Health Service
NIHR	National Institute for Health Research
ODA	Official Development Assistance
OR	odds ratio

PICOS	patient, problem, or population; intervention; comparison, control, or comparator; outcome(s); study design
PM	particulate matter
$PM_{2.5}$	fine particulate matter, particles of diameter <2.5 μm
ppm	parts per million
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
RE-AIM	Reach, Effectiveness, Adoption, Implementation, and Maintenance
RESPIRE	Randomized Exposure Study of Pollution Indoors and Respiratory Effects
RCT	randomised controlled trial
RoB2	Cochrane Risk of Bias 2
RFE	reduced form effect
RR	relative risk
SSHAP	Social Science in Humanitarian Action Platform
TB	tuberculosis
TRUST	Creating and enhancing TRUSTworthy, responsible and equitable partnerships in international research
WHO	World Health Organization

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Chapter 1: Introduction

1.1 Malawi

The research project was set in a single village in southern Malawi (Figure 1.1) – a predominantly rural country in southern Africa – on the outskirts of the city of Blantyre.

Figure 1.1. Map depicting Malawi and location of research project (star). Map data: Google, ©NASA, Terrametrics, 2022.

Much of the population of Malawi are challenged by poverty and subsequent food insecurity, intensified in recent years by severe climactic events – floods and droughts – which are set to worsen with the advance of climate crisis (1). Health indicators for children and adults living in Malawi reflect these challenges with an under-5 mortality rate of 42 per 1,000 live births (2) and a population HIV prevalence of 8%, despite recent reductions (3). Rates of non-communicable diseases, such as cardiovascular disease, diabetes, and chronic respiratory disease in Malawi, while lower than those seen in higher-income countries in the region, are increasing. Global Health Estimates suggest that 40% of deaths in Malawi were caused by non-communicable diseases in 2019, and these illnesses also account for a more than a third of disability-adjusted life years nationally (4-6).

Figures 1.2 & 1.3. Images from fieldwork depicting everyday life in the village (subsistence farming and smoke from cooking in a standalone kitchen building).

In this setting, people experience high levels of individual exposure to air pollution from household sources and, in common with much of the surrounding region, there has been no change in levels of air pollution from solid fuel use over the past 20 years (7).

1.2 Household air pollution in Malawi

In places where populations rely on polluting fuels, household air pollution from the use of solid fuels for cooking, lighting and heating is a major source of ill health, also contributing to ambient air pollution across surrounding areas (8). Household air pollution from the use of solid fuels affects almost half of the global population; population exposures are highest across sub-Saharan Africa. In Malawi in particular, there has been little reduction in reliance on polluting fuels over the past 20 years, in contrast to other global settings (9). Economic and social inequality is a key factor in shaping these risks: the clear inverse relationship between the sociodemographic development index of a country (based on average per person income levels, educational attainment, and fertility rates) and household air pollution levels is becoming stronger over time, indicating increasing levels of inequality (10, 11).

Across most of Malawi, structural and economic constraints to the development of widespread cleaner energy systems, such as those using electricity or even liquid petroleum gas (LPG), accentuate the continuing reliance on biomass as an energy source (12). For cooking, this is usually in the form of wood and crop residues burned on open fires or in local stoves (13). Household air pollution from cooking is an important source of the high concentrations of fine particulate matter (diameter <2.5 μm, $PM_{2.5}$) and carbon monoxide air pollution seen in the Malawian setting (14-16), but other sources of airborne particulate matter exist (17, 18).

1.3 Air pollution: the global picture

Air pollution has been described as the 'biggest single environmental health risk worldwide', claiming 7 million deaths each year, around 94% of which occur in low- and middle- income countries (LMICs) (19). Whilst the respiratory and cardiovascular impacts – including pneumonia, chronic obstructive pulmonary disease (COPD), lung cancer, stroke, and heart disease – are most often cited, air pollution has adverse impacts on most organ systems and can cause fetal and neonatal problems, such as increased risk of preterm birth, low birth weight, and cognitive issues, which can have lifelong health implications (20-25). Modelling has found the global mortality burden attributable to fine particulate matter air pollution to be almost 9 million deaths in 2015 (26).

Beyond their direct health effects, pollutants emitted into the atmosphere also contribute to climate breakdown. Black carbon released from the incomplete combustion of biomass and fossil fuel has been found to be the second most powerful individual climate warming agent, second only to carbon dioxide, with much larger environmental impacts than previously thought (27).

In October 2018, in an open editorial, the World Health Organization (WHO) Director-General, Tedros Adhanom Ghebreyesus, recognised air pollution as representing a 'silent public health emergency' (28). In a subsequent high-level conference, the first WHO Global Conference on Air Pollution and Health, a goal was set to reduce the number of deaths from air pollution by two-thirds by 2030.

Rural areas in low-income countries do not yet experience the very highest levels of air pollution present in regions such as South Asia – related to industrial and vehicle emissions – but do still see significant airborne particulate concentrations (29). In such settings, particularly those in rural sub-Saharan Africa, household air pollution often dominates the air pollution landscape (7).

1.4 Current evidence relating to household air pollution

Observational studies describing household air pollution in sub-Saharan Africa confirm high concentrations, with mean exposures to $PM_{2.5}$ and carbon monoxide exceeding the WHO's Air Quality Guideline level (between 26.3 and 1,574 μg/m^3 in a recent systematic review (30)). Studies tend to report either summary measures (mean or median) of personal particulate or carbon monoxide exposures over a 24–48-hour period or cooking-related emissions exclusively, assessed using stationary monitors placed near cookstoves. A comprehensive understanding of the exposure landscape in a single context can be enhanced by attention to individual trajectories and apportionment of the different sources that contribute to overall daily exposures (31).

Household air pollution reduction interventions in LMIC settings are relatively common, studying different stove and fuel types and focusing on a range of exposure and clinical outcomes, with varying degrees of success (32, 33). In Malawi in particular, a large cluster randomised trial of a highly efficient biomass cookstove incorporating a solar-powered fan, in two regions (CAPS: the Cooking and Pneumonia Study) reported no reduction in the primary outcome of pneumonia in children under 5 years old (34).

Such improved cookstove interventions often achieve reductions in pollutant concentrations, but it is at times unclear how this impacts health (32, 33, 35). This may be partly due to suboptimal emission reductions, with levels remaining above WHO-recommended levels and insufficient to improve health outcomes (33, 35, 36). Exposure reductions are often further compromised by poor uptake, non-exclusive use of intervention technologies, contamination from surrounding air pollution sources, and failure to continue using the technologies beyond the trial period (33, 34, 37).

Qualitative research in this area suggests a range of potential reasons for suboptimal or non-exclusive use of intervention fuels and stoves, which vary by intervention and setting. Key themes here are often cited in terms of barriers and enablers to adoption of new cooking technologies (38, 39). Commonly cited limiting factors include incurred cost (for fuel and for stove maintenance, repair, and replacement) and access: motivators included contextual suitability of technologies, with concerns such as fuel and time saving, and appropriateness for cooking of local dishes raised as important, as well as reduced smoke levels (38-43). This qualitative literature is discussed further in sections 4.3 and 5.2.

In Malawi in particular, qualitative work taking place alongside the CAPS trial found that, while participants valued aspects of the new stoves, access to nutritious food was seen as a priority for communities, and local perceptions of health and well-being departed from researchers' ideas of these concepts (44). Thus, the wider social environments in which exposures and potential interventions exist are important and are likely to be particularly relevant to cooking, in view of its prominent role in communities' social lives (45-47).

Anthropological explorations of public health issues have been valuable in reframing questions of health, illuminating individual and community perspectives on their own health and disease (48), with recent anthropological contributions to specific disease interventions allowing better contextualised and more appropriate responses in the fields of neglected tropical disease, malaria prevention, and Ebola virus disease outbreaks for example (49-52).

In terms of household air pollution, while insights from communities have contributed to evaluations of improved stove or fuel interventions as discussed above (44, 53-56), there has been little to no research thus far eliciting communities' perspectives and priorities on these issues from the outset, before any suggestion of intervention.

Searches of the anthropological literature on lived experiences of smoke or 'air pollution' revealed accounts of pollution in a range of contexts and from various perspectives, including seasonal air pollution linked to commercial agriculture in Northern Thailand, theoretical analysis of narratives around pollution and air purifiers in Delhi, and interviews exploring air pollution experiences of Mexican American children with asthma living in California (57-59).

Perhaps the most relevant piece of ethnographic research found in the literature searches was a study analysing contextual factors underlying indoor air pollution in three urban slums in Bangalore (60). Whilst different in many ways from the more established setting of rural Malawi, with a wide range of cooking modalities used on a contingent basis for example, certain themes were clear here including the effects of low levels of income. Authors cite the need for a "people centric approach" (p.357) to intervention, tailored to specific contextual needs (60). In terms of situated experiences of air pollution in rural African settings, such contextual insights remain elusive.

A recent review of solid fuel users' perceptions of household air pollution and solid fuel use concurred with our observation, commenting that most such research has been done in relation to 'improved cookstove' interventions. Authors highlight the need for research which illuminates the perspectives of community members, and recommend the use of engaged, participatory research approaches, ensuring that communities' experiences can inform acceptable, context-appropriate interventions for the future (61). My PhD addresses this area.

1.5 Overall project aim and individual research questions

Aim: To perform an engaged, multidisciplinary exploration of air pollution, or 'smoke', as situated in the Malawian village context, and to use these insights to co-develop and trial a whole-village cleaner air intervention, in partnership with households.

Research questions:

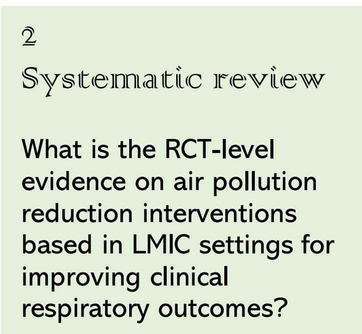
1 What randomised controlled trial (RCT) evidence exists to support the efficacy of air pollution reduction interventions in LMIC settings in producing clinical respiratory benefits?
2 What are the predominant sources of air pollution exposure for individuals living and working in a rural Malawian village, and how do exposure levels vary through the day and by exposure source?
3 How is 'smoke' from various sources perceived and experienced amongst people living in a village in Malawi, and how do these perceptions and experiences fit within their day-to-day concerns?
4 What are the impacts of a co-developed community 'cleaner cooking' intervention from communities' perspectives and in terms of measured air pollution exposures?

1.6 Overview of thesis structure

This thesis is divided into eight chapters. In this introductory chapter, I have presented an overall brief description of the research setting and a review of the issue of air pollution, in particular household air pollution in sub-Saharan Africa. Subsequently, the thesis is composed of four peer-reviewed, standalone manuscripts which reported findings related to air pollution in rural Malawi. I am the primary author on all papers, and statements of authors' contributions are provided for all papers. Each chapter details background, methods, results, and discussion of separate components of the PhD research. Chapter 2 constitutes a systematic review of RCT-level evidence of effectiveness of interventions to reduce particulate matter in LMIC settings in terms of clinical respiratory outcomes (62). Chapter 3 reports baseline air quality monitoring findings in the village, using concurrent personal air quality monitoring and activity reporting to explore individuals' exposures throughout their daily lives, by source (including cooking details) (63). Chapter 4 presents the main qualitative findings of extended participant observation, as well as interviews and participatory workshops, describing how air pollution, or 'smoke', is situated within individuals' daily lives in and around the village (64). Additional material presented alongside this chapter provides further descriptions of these research methods and underlying epistemological approaches. Chapter 5 builds on these observational findings, evaluating a ‘clean air intervention’, implemented across the village, in terms of qualitative and quantitative outcomes (65). Connecting sections root these components in the wider thesis and describe how they flow together. The thesis methods and findings are presented in this way in view of the different methods and approaches which were used, as appropriate, to address each individual question (66).

A further two methodological papers are then presented, discussing elements of the research as they became relevant throughout the fieldwork period. First (chapter 6), a description and discussion of my research approaches and ethical decisions in the context of ‘global health’ research (67), and second (chapter 7), an explanation of my positionality in approaching the research and shifting intersubjectivities in the field, both before and throughout the COVID-19 pandemic period. Finally, in the discussion (chapter 8), I summarise new findings from the individual chapters and their linking narrative (68) before presenting a strategic, theoretically-informed discussion of these findings in the context of existing knowledge. Strengths and limitations of the research are also covered here, along with recommendations for future work.

The six constituent papers of the thesis are illustrated – with chapter numbers and brief statements outlining their key areas of enquiry – in the conceptual diagram below (Figure 1.4). The order presented here represents a logical flow of the question areas, although the methodological ‘backbone’ (including overall research approaches) is presented mainly in Chapter 4, with methods in Chapter 3 relating mainly to quantitative elements of the work. In reality, the research practices described were often overlapping. Similarly, while this progression from tightly defined questions and academic/clinical positivist perspectives towards more inductive interpretivist approaches appears to be linear, it reflects a pragmatic research perspective overall (66), with different approaches taken as appropriate, as described and explained in the relevant chapters.



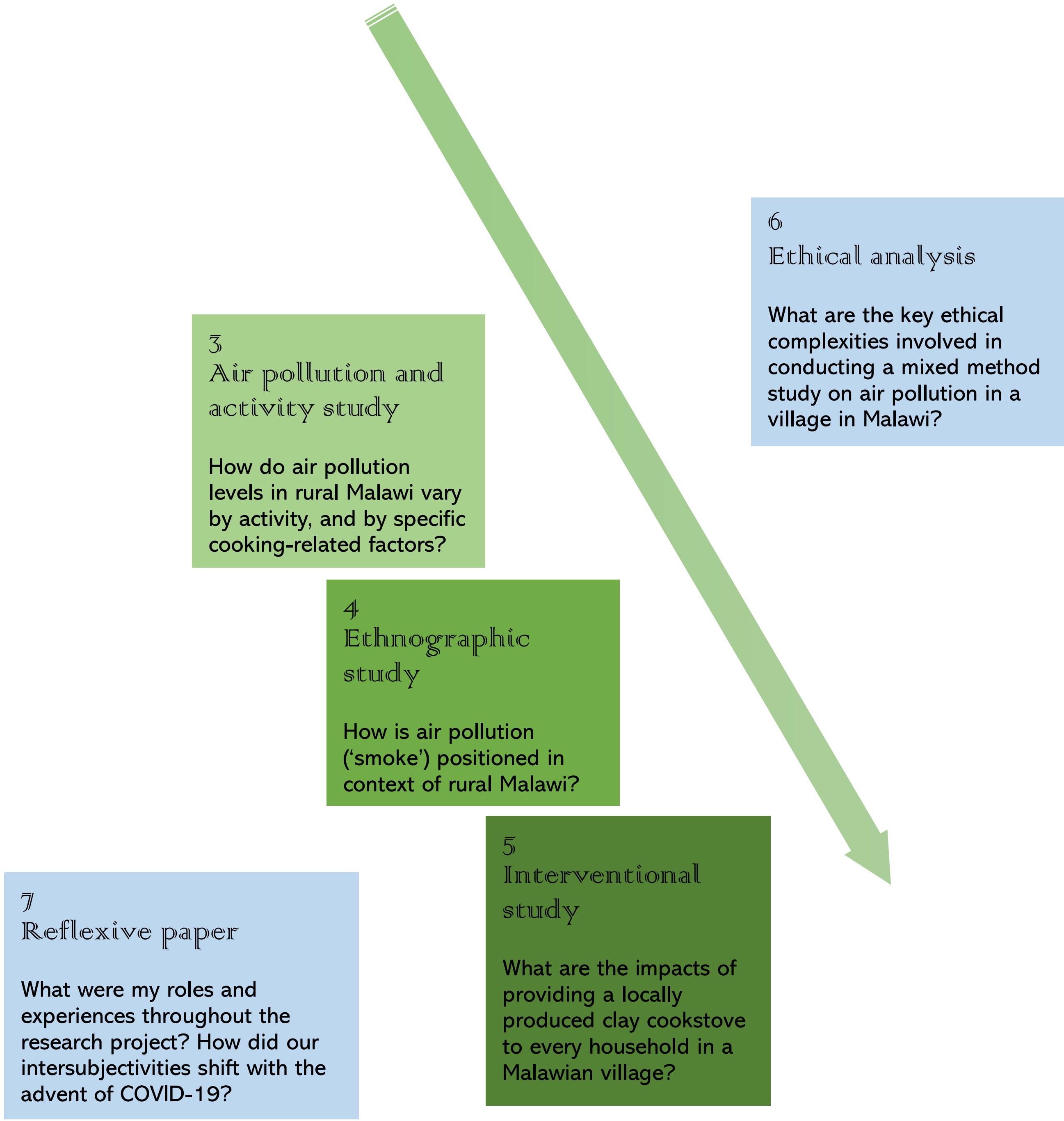


Figure 1.4. Conceptual diagram depicting flow of papers in the thesis and their research questions. RCT = randomised controlled trial; LMIC = low- and middle-income country; $PM_{2.5}$ = fine particulate matter, particles of diameter <2.5 µm; CO = carbon monoxide

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Chapter 2: Systematic review of randomised controlled trials examining the effects of air pollution interventions on respiratory health in low- and middle-income countries

I start with systematically evaluating the existing randomised controlled trial (RCT)-level evidence for air pollution reduction interventions in improving clinical respiratory outcomes in low- and middle-income country settings such as Malawi.

Air pollution interventions and respiratory health in low- and middle-income countries: a systematic review

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2.1 Abstract

Background: Indoor and ambient air pollution exposure is a major risk to respiratory health worldwide, particularly in low- and middle-income countries (LMICs). Interventional trials have mainly focused on alternative cookstove interventions, with mixed results. Beyond cooking, additional sources of particulate matter also contribute to the burden of air pollution exposure. This review explores evidence from current randomised controlled trials (RCTs) on the clinical effectiveness of interventions to reduce particulate matter in LMICs.

Methods: Twelve databases and the grey literature were searched. Eligible studies were RCTs conducted in LMICs aiming to reduce particulate exposure from any source and reporting on at least one clinical respiratory outcome (respiratory symptoms, lung function, clinical diagnoses). Data from relevant studies were systematically extracted, risk of bias assessed, and narrative synthesis provided.

Results: Of the 14 included studies, 12 tested 'improved' cookstoves, most using biomass, but solar and bioethanol cookers were also included. One trialled solar lamps, and the last was an integrated intervention incorporating behavioural and environmental components for treating and preventing chronic obstructive pulmonary disease. Of the six studies reporting childhood pneumonia outcomes, none demonstrated significant benefits in intention-to-treat analysis. Ten studies reported respiratory symptom outcomes with some improvements seen: self-report made these outcomes highly vulnerable to bias. Substantial inter-study clinical and methodological heterogeneity precluded calculation of pooled effect estimates.

Conclusion: Evidence from the RCTs performed to date suggests that individual household-level interventions for air pollution exposure reduction have limited benefits for respiratory health. More comprehensive approaches to air pollution exposure reduction must be developed and evaluated for their potential health benefits.

Keywords: particulate matter; cookstove; pneumonia; lung function; respiratory symptoms

2.2 Background

Air pollution is a major environmental risk factor for a range of respiratory and other diseases (1-3). Airborne particulate matter (PM) plays an important part in the pathophysiology of the development of non-communicable lung disease (3, 4) and has a proposed role in the mechanisms behind susceptibility to acute lower respiratory tract infection (ALRI), a leading cause of mortality worldwide in children under 5 years old (5-7). The great majority of these disease burdens fall on low- and middle-income country (LMIC) populations (8), exacerbating existing health and socio-economic inequalities. Household air pollution from inefficient burning of biomass fuels and kerosene for cooking, heating, and lighting is widespread in LMIC settings, and reinforces gendered inequality, as women and children tend to spend the most time engaged in household tasks.

Systematic reviews of air pollution interventions and health to date have largely focused on household air pollution from cooking with biomass, predominantly confined to trials of improved cookstove interventions (9-11). Cooking sources, however, do not constitute the entirety of PM exposure in LMIC settings: other sources of airborne PM, such as the burning of waste, motor vehicle and engine exhaust, and burning of solid or liquid fuels for heating or lighting, can also contribute to exposure.

One possible explanation for the limited clinical benefits seen in improved cookstove studies is that the particulate and other emission exposure reductions brought about by these interventions alone are insufficient to make a substantial impact on the severity or incidence of clinical outcomes. Two recent systematic reviews have reported the effects of such interventions on airborne PM and carbon monoxide (CO) exposures (9, 12). While various cooking interventions, including improved solid fuel stoves and cleaner fuels, were found to achieve reductions in personal and kitchen levels of PM <2.5 µm ($PM_{2.5}$) and CO, both reviews reported that most interventions resulted in post-intervention $PM_{2.5}$ levels that still greatly exceeded World Health Organization (WHO) air quality guideline limit values (13). Given evidence on elevated morbidity and mortality risks even at PM levels below these limits, it is plausible that the smaller reductions in exposure associated with cookstove interventions may not be sufficient for reductions in clinically significant health effects (14).

Alternative or additional explanations include the continuing impact on health of PM exposures occurring outside the trial households, either in other households or from outdoor sources. A further possibility is that the postulated pathogenic links between air pollution and the clinical outcomes in question (pneumonia, for example) are not as strong as previously thought (15).

This systematic review assesses the available evidence based on randomised controlled trials (RCTs) for efficacy of interventions aimed at reducing respiratory morbidity and/or mortality in adults and children living in LMICs through reduction in exposure to air pollution.

In limiting this review to RCTs, we aimed to constrain methodological heterogeneity, improving the potential for clarity and validity of the overall outcome assessment. We recognise, however, the potential shortcomings of RCTs (16), particularly for often complex air pollution interventions embedded in a wide range of social contexts. Acknowledging this, we present this review as a starting point from which to propose new work aiming to achieve respiratory health outcomes through air pollution reduction.

2.3 Methods

2.3.1 Search strategy

The systematic review protocol was developed collaboratively and registered on Prospero (CRD42019129482).∗ The review is reported in accordance with PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (17).

The following 10 databases were searched, from inception until March 2019: MEDLINE, Embase, CINAHL, Web of Science, GlobalHealth, PsycInfo, Trip, PubMed, WHO International Clinical Trials Registry Platform, and CENTRAL. Google Scholar was also searched from inception, and the first 40 pages reviewed for relevant content (18). ClinicalTrials.gov was searched for additional relevant trials, with authors of ongoing trials contacted to improve coverage of recent trial results. In addition to the formal database searches and protocol identification, reference lists of key articles and related reviews were searched for additional relevant trials.

Provided they met inclusion criteria, trials evaluating results of LMIC-based RCTs with aims which included improvement in one or more clinical respiratory measures to be achieved through reduced air pollution exposure were included.

In terms of search limits, the validated filter, 'Cochrane Highly Sensitive Search Strategy for identifying randomized trials in MEDLINE: sensitivity-maximizing version (2008 revision)' was used as appropriate (in an adapted form as necessary for different databases) to identify randomised interventional trials with optimum sensitivity (19). Another published filter from Cochrane was used (20), adapted to 2019 World Bank country classifications, and in relevant variations for different databases, to identify

∗ Available at: http://www.crd.york.ac.uk/PROSPERO/display_record.php?ID=CRD42019129482 trials taking place in LMICs, as defined by the World Bank for the fiscal period 2019 (i.e., those with gross national income per capita of ≤12,055 US dollars, as calculated by the World Bank Atlas method from 2018) (21).

An example of the full electronic search strategy (for the OVID MEDLINE search) is available as Supplementary Data. Adapted versions of this were used to search other databases, with appropriate alterations to account for differences in search syntax and controlled vocabularies.

2.3.2 Study selection

Studies were selected in accordance with the eligibility criteria (Table 2.1). There were no limitations on the basis of length of follow-up, language, or publication status. In terms of participants, eligible studies included adults and/or children living in LMICs.

Table 2.1. PICOS search criteria

Population
Adults and children living in low- and middle-income countries (as defined by the World Bank, 2019 (21)
Intervention(s)
Any household-level intervention with the primary aim of reducing respiratory morbidity or mortality through reduction in exposure to air pollution, as determined by particulate matter exposure of any size classification. These may include interventions aimed at altering technology, behaviour, educational or other intervention types, or multi-component interventions. Interventions that aimed to mitigate the effects of existing exposure were not considered.
Control(s)
No air pollution intervention or respiratory-related intervention (either no intervention or an intervention unrelated to air pollution or lung health).
Main outcome(s)
The main outcomes of interest are clinical respiratory outcomes including, but not restricted to, clinical diagnoses (such as asthma, pneumonia, tuberculosis, obstructive lung disease, and lung cancer), clinical respiratory symptoms, and lung function.
Study design
Randomised controlled trials only: participants randomly allocated to contemporaneous intervention or control groups

Eligible interventions were those aiming to improve respiratory health through reduction in air pollution exposure. Interventions aimed at altering technology, behaviour, educational or other types of intervention, as well as multi-component interventions, were all eligible. Interventions (e.g., masks) aiming to mitigate effects of existing exposure were not included. Control groups included any in which participants had no exposure to an air pollution- or respiratory-related intervention, either with no intervention or with 'control' interventions unrelated to air pollution or respiratory health.

Eligible outcomes were clinical respiratory measures, including clinical diagnoses (such as pneumonia), symptoms of respiratory illness, and lung function (measured by spirometry). In contrast to recent reviews that considered intermediate outcomes, such as airborne PM levels, the aim of this review is to elucidate whether any PM exposure interventions can bring about measurable improvements in respiratory health. All RCT designs, including individually randomised, cluster randomised, stepped-wedge, and cross-over trials, were eligible.

Titles, and abstracts where necessary, of search results were screened for relevance in accordance with the PICOS criteria outlined above. Full texts of the resulting potentially relevant papers were assessed independently by two reviewers (SS and WS) against the same criteria. Those clearly not meeting the inclusion criteria were excluded at this stage. Where there were areas of uncertainty or disagreement, these were resolved independently by a third reviewer (KM).

2.3.3 Data extraction and quality assessment

A specifically designed and piloted data extraction tool was developed for the review. Two reviewers independently extracted data using the tool. Results were cross-checked in detail and any areas of discrepancy discussed. The third reviewer was consulted in cases of unresolved issues. Authors of original research were contacted where there were important outstanding data points. The key areas in which data were extracted are outlined in Table 2.2; the data extraction tool is provided in the Supplementary Data.

Table 2.2. PICOS search criteria.

Citation information
Study design
Setting
Information on aspects of study duration and follow-up
Participant information
Details of intervention(s) and their implementation
Details of comparator (control group)
Outcomes: definitions, measurement, and classification by study authors (primary/secondary/other)
Type of analysis
Data on study power and statistical considerations
Risk of bias assessment outcome

A hierarchy of outcomes was constructed by the review authors on the basis of clinical importance and potential for objective assessment. Individual outcome-level quality assessments, primarily considering the highest included outcome from the developed hierarchy, were then carried out for all included studies.

Quality assessment involved two authors (SS and WS) independently assessing risk of bias for each study using the Cochrane Risk of Bias 2 (RoB2) tool (22), with any points of discrepancy addressed through discussion. The RoB2 Excel tool (Microsoft, Redmond, WA, USA) was used to collate and process the scores for each study and to tabulate the final results (Figure 2.1). Elements of review-level risk of bias were considered separately.

Figure 2.1. Risk of bias outcomes for included studies based on the Cochrane Risk of Bias 2 (RoB2) tool

2.3.4 Summary measures and statistical analysis

Estimates of relative risks or odds ratios were the principal summary measures extracted from papers (where available) to compare outcomes in the intervention and control groups. These were used for the following main outcomes: incidence of ALRI in children; symptom prevalence (including cough and wheeze) in adults; and difference in mean percentage changes in forced expiratory volume in 1 second (FEV_1) and FEV_1/FVC (forced vital capacity). These are presented with 95% confidence intervals or *P* values as available. Unadjusted estimates are reported, where available, to optimise comparability. Where these were not available, we report the least-adjusted estimates. To reflect levels of baseline comparability between the studies, details of settings and populations are provided in Table 2.3, using the primary study paper for reference. Results for individual outcomes were pooled where appropriate. The online software 'DistillerSR Forest Plot Generator' was used to generate the forest plot (23). For each outcome, a summary measure, confidence interval, and study weighting are presented on a forest plot. Aspects of clinical and methodological heterogeneity between the studies are discussed qualitatively.

Table 2.3. Key features of studies included in analysis

Study	Setting	Population	Intervention	Comparison	Respiratory outcomes	Follow up
Romieu, 2009	Rural highland Mexico	552 women (with child <5 years) throughout follow-up, analysis of ALRI outcome in children under 4 years	Patsari wood cookstove	Traditional open fire	ALRI in past 15 days, in children <4 years, and respiratory symptoms in women (including cough, wheeze)—all results by stove use (intention-to-treat not reported)	10 months
Zhou, 2010	Guangzhou City, China	1,062 adults aged ≥40 years ± COPD (allocated): 872 received; 819 at 4-year follow-up	Integrated intervention (including health education, smoking cessation, participatory clean air project to relocate factory) and COPD management advice	Usual care	Annual rate of FEV_1/FVC ratio decline (adjusted)	4 years
Smith, 2011	Guatemala	534 households (pregnant women/children <4 m)	Locally developed chimney stove	Open wood fires	Pneumonia, severe pneumonia, and numerous other subcategories of pneumonia in children under 18 months. Lung function in children and adult women, respiratory symptoms (including cough, wheeze) in women	26 months

Table 2.3. Key features of studies included in analysis *continued*

Study	Setting	Population	Intervention	Comparison	Respiratory outcomes	Follow up
Burwen & Levine, 2012	Sissala West District, (rural) Ghana	768 women (1 from each household)	Self-constructed (guided) improved cookstove with chimney and ventilation hole	Primary traditional stove	Prevalence of respiratory symptoms including 'bad cough outside cooking' in previous week (self-reported)—average across group, where 0 is no and 1 is yes, and number of symptoms (of 5) in previous week in household members	3–5 weeks
Beltramo & Levine, 2013	Senegal	790 women	'HotPot' panel solar cooker	Existing cooking methods (wood)	Self-reported: number of respiratory symptoms (of seven) in last 7 days	6 months
Hanna, 2016	Orissa, India	2,575 households in total 1,679 initial FEV_1/FVC 2,511 cough symptoms	Improved stove (enclosed flame and chimney)	Existing wood stove	Self-reported 'cough or cold', 'any illness' in last 30 days in primary cooks, lung function (including FEV_1, FEV_1/FVC) in primary cooks. Cough, fever, 'any illness' in children aged ≤13 years	4 years
Jary, 2014	Ntcheu District, Malawi	51 women	*Chitetezo* stove (locally produced, more efficient burning)	Traditional open wood fire	Self-reported respiratory symptoms (cough, wheeze) in women	7 days

Table 2.3. Key features of studies included in analysis *continued*

Study	Setting	Population	Intervention	Comparison	Respiratory outcomes	Follow up
Bensch & Peters, 2015	Senegal	253 households, women cooks	' Jambaar' improved cookstove—more efficient woodstove	Open fire (bag of rice also given)	Any respiratory symptoms in household cook in last 6 months—group mean, where 0 is no and 1 is yes	12 months
Dhamsani a, 2015	Ibadan, Nigeria	303 pregnant women (97 Follow-up spirometry)	' CleanCook' bioethanol stove	Continued use of kerosene/firewood stove	Lung function (spirometry, including FVC, FEV_1, FEV_1/FVC)	6.5 months
Hartinger, 2016	Peru	534 children under 3 (50 communities)	Improved ventilated solid fuel stove (part of integrated programme of interventions)	Unventilated stoves/open fires + early child development intervention	Episodes of acute respiratory infection, acute lower respiratory infection, prevalence of cough or difficulty breathing, and of cough or difficulty breathing and fever	11 months
Tielsch, 2016	Rural district, southern Nepal	5,254 children from 3,376 households with women (15–30 years) or child <3 years; stepped-wedge design	Two burner biomass stove with chimney for ventilation	Traditional open burning cookstoves	Pneumonia incidence in children (maternal report of 2 or more days of fast/difficult breathing and fever'), incidence of respiratory symptoms including cough, wheeze	6 months run in: 12 months rollout; 6 months follow-up

Table 2.3. Key features of studies included in analysis *continued*

Study	Setting	Population	Intervention	Comparison	Respiratory outcomes	Follow up
Mortimer, 2017	2 sites, rural Malawi	10,750 children under 5 (8,626 households)	Biomass force-draft cookstove	Open fire	Incidence of IMCI pneumonia in under 5s (and other pneumonia outcomes: all pneumonia, severe pneumonia, O_2 saturations <90%, death), lung function (spirometry)	24 months
Aiden, 2018	Uganda	230 people (50 households)	Solar LED lamp	Kerosene lamps	Self-reported respiratory symptoms including cough, wheeze	3 months
Kirby, 2019	Western Province, Rwanda	2,440 children (1,582 households)	Portable high-efficiency biomass-burning 'rocket' cookstove (and advanced water filter—combined intervention)	Traditional biomass-burning stoves (no program activities)	ARIs in the preceding 7 days (carer-reported), healthcare visits for ARI, current IMCI pneumonia, severe pneumonia	12 months

ALRI = acute lower respiratory tract infection; COPD = chronic obstructive pulmonary disease; FEV_1 = forced expiratory volume in 1 s; FVC = forced vital capacity; IMCI = Integrated Management of Childhood Illness; LED = light-emitting diode; ARI = acute respiratory infection

2.4 Results

We found 7,956 papers through our database searches and an additional four papers were identified through other sources. After screening the titles and abstracts, 250 papers remained for more detailed review of the full texts. Fifteen studies met our a priori inclusion criteria and were included in the final review. The main reasons for study exclusion were 1) air pollution studies which had no clinical respiratory outcome (e.g., studies which used PM exposure endpoints, or studies which examined the effects of air pollution on other systems); 2) studies which did not use random allocation, or which had no control group for comparison; and 3) protocols or preliminary reports of studies which were still incomplete, or which had not yet reported on clinical respiratory outcomes.

Of the 14 trials included, five were cluster RCTs (including one stepped-wedge design) (24) and the others used individual randomisation. Most of these 14 overarching studies had results available in multiple formats, including working papers and reports, peer-reviewed papers, and presentations available online. While the nominated 'key study paper' for each study is used for reference in Table 2.3, other sources are cited for different outcomes, populations groups, and time points as discussed throughout the paper, and cross-referenced in subsequent summary tables. Twelve studies tested improved cookstoves (with more efficient combustion, chimneys for ventilation, etc.). Of the remaining two studies, one trialled a solar lamp for reducing use of kerosene, and the other used an integrated chronic obstructive pulmonary disease (COPD) management/prevention intervention (in seniors with and without COPD). The complex multimodal intervention used in the latter study differed in a few ways from the other studies included in this review. The constituent components of this intervention are described explicitly in the 'Lung function' section, and the nature of its effects analysed accordingly (25). To note, none of the interventions involved gaseous fuels, and the only study to involve electricity was a trial of solar "light-emitting diode" (LED) lamps.

Follow-up periods ranged from 7 days (for a cookstove pilot) to 4 years in the case of a large improved stove trial and the integrated COPD intervention. The trials were set in countries across Africa, Latin and South America, and Asia. Six trials included estimates of impact on pneumonia incidence in children (of various ages), 10 evaluated estimates of impact on cough and wheeze in adults, and the other key clinical respiratory outcome group was lung function, as assessed using spirometry.

Twelve of the trials had results of clinical respiratory outcomes published in at least one peer-reviewed journal. One trial of a solar lantern intervention in Uganda was only published as a preprint on the BioRxiv platform (26), and the remaining two, both improved stove trials, had associated peer-reviewed publications of other outcomes but reported clinical respiratory outcomes only in the abstracts (24, 27). Many of the trials were incompletely reported and often had missing key steps from the CONSORT (Consolidated Standards of Reporting Trials) reporting guidelines (28), such as participant eligibility criteria, data on sample size calculation, and participant flow.

There were no cases of serious divergence between the RoB2 scores awarded by the two assessors, although in a few selected instances the domain outcomes automatically generated by the RoB2 Excel tool did not match the reviewers' individual judgements. Where this was the case, the reviewer's judgement superseded RoB2. Two studies were judged using the Cochrane RoB2 tool to be at 'low risk' of bias. A further four scored as 'high risk' of bias, and the remaining eight studies were categorised as having 'some concerns' (Figure 2.1). Common features of papers with moderate to high risk of bias included failure to report details of randomisation or blinding, lack of clarity around primary and secondary outcomes, and a related selectivity around outcomes reported in final papers, with incomplete reporting commonly occurring.

2.4.1 Childhood pneumonia outcomes

Six papers included pneumonia outcomes in children (Table 2.4) (24, 29-33). None of these studies evidenced a statistically significant reduction in childhood pneumonia incidence in the intention-to-treat analysis, although other significant results were separately reported. These included a reduction in ALRI-prevalent days in the stepped-wedge trial of improved biomass cookstoves in Nepal (24), reduction in caregiver-reported acute respiratory infection in a combined cookstove and water filtration intervention trial (33), and significant reductions in three severe pneumonia outcomes in a chimney cookstove trial (30).

Table 2.4. Comparison of childhood pneumonia outcomes across the relevant studies

Study	Upper age limit	Outcome definition	Assessor	Intention-to-treat?	Effect estimate† (95% CI)	*P* value
Smith, 2011	18 months	Incidence IMCI-defined* pneumonia episodes (on weekly visits)	Physician	Yes	RR 0.84 (95% CI 0.63–1.13)	0.26
Tielsch, 2014	3 years	Incidence ALRI (fast or difficult breathing and fever, for ≥2 days)	Mother	Yes	Adjusted OR 0.87 (0.67–1.13)	
Schilmann, 2015; further data from 34	4 years	Fast breathing + difficult breathing/cough episode in past 15 days, per child-year	Mother + fieldworker	No	RR 0.78 (95% CI 0.59–1.06)	
Hartinger, 2016	3 years	ALRI (cough or difficulty breathing, with raised respiratory rate) on 2 consecutive measurements (7	Mother + fieldworker (with referral to physician as necessary)	Yes	RR 2.45 (95% CI 0.82–7.39)	0.11
Mortimer, 2017	5 years	Incidence IMCI-defined* pneumonia episodes reporting to health facility	Physician (fieldworker referral)	Yes	Incidence rate ratio 1.01 (95% CI 0.91–1.13)	0.8
Kirby, 2019	5 years (infants <2 months excluded)	'Current' IMCI-defined* pneumonia	Enumerators	Yes	Prevalence ratio 0.87 (95% CI 0.58–1.30)	0.49

* World Health Organization's ICMI pneumonia in children is defined as the presence of cough or difficulty breathing and fast breathing.47
† Unadjusted unless otherwise specified.
CI = confidence interval; IMCI = Integrated Management of Childhood Illness; RR = relative risk; ALRI = acute lower respiratory tract infection; OR = odds ratio

One of the six studies that reported on childhood pneumonia outcomes (a trial of Patsari cookstoves) presented results by reported stove use (a per-protocol analysis), rather than by allocation group (intention-to-treat analysis) (34). This was the only study of the six with a high risk of bias, as judged by the Cochrane RoB2 tool. While no protective effect was found on childhood pneumonia incidence in either analysis, some benefits associated with intervention were reported for children, including reduction in duration of respiratory infections (31). Uptake and sustained use of the intervention stoves were variable in this study population, with approximately half of the intervention households reporting continued use of their original stoves during the study period.

Regarding risk of bias, two of the remaining five studies were found to have low risk of bias (30, 32). These were large studies: the first an RCT testing locally developed chimney stoves, and the second a cluster RCT of force-draft biomass cookstoves using solar-powered fans. Although the first of these found non-significant reductions in pneumonia rates in the intervention group, neither evidenced significant benefits in terms of childhood pneumonia outcomes.

As can be seen in Table 2.4, there was methodological heterogeneity across the studies, with clinical heterogeneity encompassing differences in participant inclusion criteria (in particular, relating to age limits) and outcomes, among other factors. Outcome heterogeneity included differences in diagnostic criteria for pneumonia, and complications around clinical assessment. In one study, for example (29), where respiratory rate was part of the diagnostic criteria, respiratory rate assessments were only made in, respectively, 68% and 63% of intervention and control group participants, with medical treatment given prior to respiratory rate assessment in the remaining cases. In a further study (31), the authors cited physician-diagnosed pneumonia rates as an outcome, but only 71% and 65% of fieldworker-diagnosed pneumonia cases in intervention and control groups, respectively, were subsequently seen by physicians, with the physician-diagnosis data for the other cases estimated using multiple imputation techniques.

Methodological heterogeneity stemmed from the presence of cluster RCTs (29, 32, 33) and a stepped-wedge trial (24), as well as individually randomised trials, variability in study implementation, and differing risks of bias (Figure 2.1). Finally, there were differences in measure of association estimates reported. While most of the studies reported relative risks or equivalent, there were alternatives. Prevalence ratio was the reported outcome in a paper which measured the pneumonia outcome as 'current pneumonia' at the time of the assessor's weekly visit (33), and the stepped-wedge study by Tielsch et al. used odds ratios (24). Furthermore, although all studies reported pneumonia incidence, only one reported 'per child-year' data (35), with the others providing data based on individual children. These differences precluded the intended pooling of outcomes. Instead, we present the childhood pneumonia results in a forest plot (Figure 2.2) accompanied by a qualitative commentary.

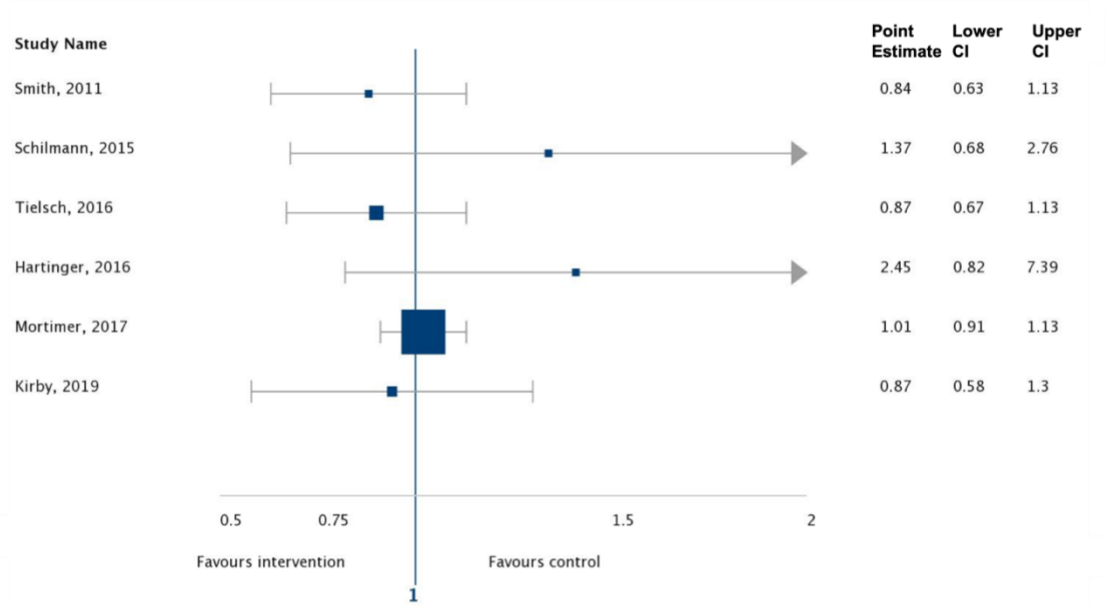

Figure 2.2. Forest plot depicting child ALRI incidence. CI = confidence interval; ALRI = acute lower respiratory tract infection

The forest plot shows relative risk estimates with upper and lower confidence intervals from a total of six RCTs; their relative weights are indicated by box sizes. For the cluster RCTs, the estimates used were adjusted for clustering to maximise the comparability of the results (29, 32, 33). Because of heterogeneity, particularly in terms of clinical diversity, no summary estimate was included.

The confidence intervals of all studies cross one, indicating no statistically significant benefits for any of the interventions, and while some of the confidence intervals are quite wide, effect estimates do not predominantly favour either intervention or control. One study (a large cluster RCT of improved cookstoves) dominated in terms of study size (10,750 children enrolled) (32). The second largest of the studies was a stepped-wedge trial of chimney stoves in Nepal, which enrolled 5,254 children but also encompassed a shorter follow-up period (24).

In terms of exposure to airborne PM – an important intermediate endpoint on the causal pathway to clinical benefit – closer interrogation of the data provided by study authors goes some way to clarifying the picture. Perhaps the clearest evidence of improvement in exposures was seen in the RESPIRE trial, which reported significant reductions of approximately 50% in personal CO exposures in children (with greater reductions in maternal exposures and kitchen measurements) (36). Even this improvement was insufficient, however, to produce a reduction in the main clinical outcome – childhood pneumonia – perhaps due to a plateau effect described by the authors, whereby decreases in exposure at high levels are associated with little reduction in outcome (30).

The failure of interventions to achieve exposure reductions sufficient to impact key clinical respiratory outcomes is a hypothesis supported by available data from the remaining five studies. Evidence from three studies indicated no significant reduction in measured exposure (33, 37, 38), one of which found reductions of, respectively, 27% and 45% in personal CO and $PM_{2.5}$ measurements among females; however, these were statistically non-significant (38). Schilmann et al. quoted reductions of almost 80% in kitchen $PM_{2.5}$ levels in a subset of participants when using Patsari intervention stoves but gave no indication of statistical significance or intention-to-treat data (31). Finally, preliminary data from a stepped-wedge study of biomass chimney stoves indicated reductions in kitchen levels of $PM_{2.5}$ and CO, although data on statistical significance were again lacking (24). It is worth noting that, even for studies which demonstrated reductions in exposure, $PM_{2.5}$ levels remained well above the lower limit suggested in air quality guidelines (24, 37-39).

2.4.2 Respiratory symptoms

Ten papers provided data on respiratory symptoms, with the most frequently cited being cough and wheeze (24, 26, 29, 34, 39-44). All but one of these studies tested cleaner cookstoves of various types, the exception being a study using solar-powered lamps to replace kerosene lamps (26). This increases the methodological heterogeneity in the study set, but the paper remains within the stated inclusion criteria of the current review, since the authors aimed to reduce respiratory morbidity through the reduction of airborne PM levels. This solar lamp intervention was in fact one of six studies reporting improvements in symptoms of respiratory disease (in this case, cough). The authors of this paper also described a significantly greater reduction in the average levels of elemental carbon (soot) in intervention homes compared with control homes, although no differences in organic carbon or $PM_{2.5}$ were reported.

While six of the 10 studies were able to evidence some form of improvement in respiratory symptoms (24, 26, 34, 39, 40, 43), the nature of the outcomes varied. Five of the six studies describing the protective effects of interventions referred to cough and/or wheeze symptoms (an effect which, in one case, was restricted to the intention-to-treat analysis) (34). The fifth of these described the effects on symptoms of a respiratory system disease in the last 6 months (39). Other studies, none of which evidenced significant differences between control and intervention group symptoms, used endpoints, including respiratory symptoms in the last 30 days and counts of symptoms from pre-defined lists. This and other forms of heterogeneity made pooling of these results impossible, and the multiple differing outcomes measured and reported by individual studies raise the question of outcome reporting bias.

With regard to the populations in which outcomes were measured, there was considerable heterogeneity again: papers describing combinations of self-reported symptoms in women (or 'primary household cook'), symptoms in children, and in 'household members'.

Nine of the 10 papers which reported respiratory symptoms included results from intention-to-treat analyses, although one of these reported a combination of intention-to-treat and 'average treatment effect on the treated' results for different outcomes (39). Incomplete reporting of data was seen in many of the studies with data from selected outcomes reported, particularly for outcomes reaching statistical significance. Key features of the relevant papers and results are given in Table 2.5.

Table 2.5. Comparison of papers reporting respiratory symptom outcomes

Study	Population for which respiratory symptoms reported	Reported symptom(s) and definition	Follow-up	Intention-to-treat?	Effect estimate* (95% CI)	*P* value
Romieu, 2009	552 women cooks	Respiratory symptoms in last 15 days (survey) symptoms including cough, wheeze, breathing difficulty, phlegm, chest tightness	12 months	No (no difference in intention-to-treat analysis)	For cough: age-adjusted RR 0.74 (95% CI 0.59–0.92) in 'mainly Patsari' users For wheeze: age-adjusted RR 0.28 (95% CI 0.11–0.76) in 'mainly Patsari' users	
Smith-Sivertsen, 2009	504 women (subset of total RESPIRE households) (30)	Range of symptoms (cough, phlegm, wheeze or chest tightness) in past 6 months, assessed by survey (standardised tools) and interview at 6, 12, 18 months	Multiple follow-up points including 6, 12 and 18 months	Yes	Reduction in RR across all symptoms, but only statistically significant reduction for wheeze: RR 0.42 (95% CI 0.25–0.70)	
Burwen & Levine, 2012	498 participants followed up; inclusion criteria for respiratory outcomes outside of cooking unclear	Prevalence of named symptoms outside of cooking (and count out of 5): sore throat, bad cough, difficulty breathing excessive mucus, chest pain	8 weeks	Yes	Mean difference for 'cough' : 0.11	<0.01
Hanna, 2016	3,569 'primary cooks' (for wheeze and tight chest outcomes)	Respiratory symptoms in the last 30 days (wheeze, tight chest, phlegm)	48 months	Yes	For wheeze, reduced form effect (RFE) of stove = –0.001 (RFE approx. 0 for all variables)	

Table 2.5. Comparison of papers reporting respiratory symptom outcomes *continued*

Study	Population for which respiratory symptoms reported	Reported symptom(s) and definition	Follow-up	Intention-to-treat?	Effect estimate* (95% CI)	*P* value
Beltramo & Levine, 2013	744 women at follow up (also data for men and children available)	Number of respiratory symptoms (of pre-defined list of 7) reported in the last 7 days	6 months	Yes	Difference: treatment minus control group as a percentage of control mean = 3%, SE = –0.12	
Jary, 2014	50 women analysed	Women reporting cough or wheeze at follow up	7 days	Yes	No significant difference between two groups for either symptom	1.000 for both
Bensch & Peters, 2015	Household cooks: 229 analysed (household-level analysis also carried out)	Symptoms of a respiratory system disease in the last 6 months in household cook	12 months	Yes	Difference in means between two groups: 7.1	0.01

Table 2.5. Comparison of papers reporting respiratory symptom outcomes *continued*

Study	Population for which respiratory symptoms reported	Reported symptom(s) and definition	Follow-up	Intention-to-treat?	Effect estimate* (95% CI)	*P* value
Hartinger, 2016	499 children under 3 years analysed	Prevalence of cough or difficulty breathing	11 months	Yes	OR 0.97 (95% CI 0.79–1.19)	0.8
Tielsch, 2016	5,254 children enrolled	Incidence of reported respiratory symptoms in children including persistent cough, wheeze	Complex (stepped-wedge design), 6 months run in, 12 months rollout, 6 months follow-up	Yes	Adjusted OR for persistent cough, 0.91 (95% CI 0.85–0.97) For wheeze, 0.87 (95% CI 0.78–0.97)	
Aiden, 2018	230 people randomised	Reduction in rates of respiratory symptoms including cough, wheezing, difficulty breathing	3 months	Yes	Significant reduction in cough symptom only: RR 7.1 (95% CI 0.57–0.90)	0.03

* Unadjusted unless otherwise specified.
CI = confidence interval; RR = relative risk; OR = odds ratio

2.4.3 Lung function outcomes

FEV_1 and FEV_1/FVC were the most frequently cited outcomes for lung function and were reported by six papers. This included five papers describing improved cookstove interventions (27, 37, 42, 45, 46), two of which reported results on different subsets of the same intervention (Table 2.6), and a 4-year study (one of the longest timescales among the trials included in this analysis) examining the impact of a complex COPD management/prevention programme (25).

Table 2.6. Comparison of papers reporting lung function outcomes

Study	Population for which lung function reported	Follow-up period	Intention-to-treat?	Effect estimate† (95% CI+)	*P* value
Zhou, 2010	872 adults with and without COPD aged 40–89 years	48 months	Yes	Adjusted difference in annual rate of decline FEV_1: 19 ml/year (95% CI 3–36) Adjusted difference in annual rate of decline FEV_1/FVC ratio: 0.6% (95% CI 0.1–1.2)	0.023 0.029
Hanna, 2012	Women who regularly cook in household	48 months	Yes	For FEV_1, reduced form effect (RFE) of stove = 0.003 For FEV_1/FVC x100, reduced form effect (RFE) of stove = –0.005	Not statistically significant
Dhamsania, 2015	303 pregnant women at baseline, 206, and 96 women at subsequent follow up periods	6.5 months (follow-up time points: 26 weeks gestational age, 6 weeks postpartum)	Yes	'No significant differences in pulmonary function between the two control groups at the two follow-up time points'. No further data available	

Table 2.6. Comparison of papers reporting lung function outcomes *continued*

Study	Population for which lung function reported	Follow-up period	Intention-to-treat?	Effect estimate† (95% CI+)	*P* value
Guarnieri, 2015	Subset of 265 women involved in previous study (30)	Variable, following original RCT, mean follow-up 5.6 years	Yes	β-Co-efficient FEV_1 adjusted annual change in control group (stove after 18 months) compared with intervention group (stove from start): –44 ml/year (95% CI –91 to 4)	0.07
				β-Co-efficient FEV_1/FVC adjusted annual change in control group compared with intervention: –39 ml/year (95% CI –93 to 16)	0.16
Heinzerling, 2016	Subset of 355 children involved in previous study (30)	Variable, following original RCT, mean follow-up 1.3 years	Yes	β-Co-efficient† (adjusted) FEV_1 between two groups: −13.0 ml (95% CI −41.1 to 15.4)	
				β-Co-efficient† (adjusted) FEV_1/FVC between two groups: −0.058% –13.0 (95% CI −0.74 to 0.62)	
Nightingale, 2019	Subset of 424 adults (male and female) involved in the previous cookstove RCT (32)	Undefined period of time following 24-month follow-up period of original study	Yes	Intervention vs control coefficient estimate for median FEV_1: 0.08 (IQR −0.06 to 0.22)	0.26
				Intervention vs control coefficient estimate for median FVC: 0.04 (IQR −0.13 to 0.21)	0.62

+ Or IQR, where specified.

† Change in lung function for each 1-unit increase in ln-transformed CO (1 ppm).

CI = confidence interval; COPD = chronic obstructive pulmonary disease; FEV_1 = forced expiratory volume in 1 s; FVC = forced vital capacity; RCT = randomised controlled trial; RFE = reduced form effect; IQR = interquartile range; ppm = parts per million

Of these studies, only the integrated COPD management/prevention programme demonstrated statistically significant lung function benefits (in terms of an annual rate of decline in FEV_1 and FEV_1/FVC) between control and intervention groups (25). This difference was maintained in the subgroup of participants without COPD.

Interventions in this study included health education relating to COPD, smoking, other unspecified health-related 'habits and behaviours', and improvements in air quality. A subset of participants with COPD, and those deemed to be at 'high risk', received additional intensive interventions, including COPD treatment optimisation and support with smoking cessation. This resulted in an almost doubling of the smoking cessation rate in the intervention group compared with that of the control group (21% vs 8%, $P<0.004$), and reports of reduced exposure to environmental tobacco in the intervention group alone, which are likely to have contributed substantially to the differences in lung function decline.

Finally, there was a wider environmental aspect of the intervention that incorporated advice on environmental factors (with stoves, kitchen ventilation, and living and working environment given as examples) and a successful campaign to relocate and upgrade a local cement factory. Among other differences, this achieved statistically significant improvements in sulphur dioxide and dust concentrations in the intervention group compared with the controls.

In terms of the remaining five studies addressing lung function as an outcome – although length of follow-up was variable – only one study had a follow-up period in excess of 2 years (45). These periods are arguably insufficient for improvements in lung function to become apparent. The lung function results came from subsets of larger trials not adequately powered to detect substantial changes in these outcomes. There was great variation in reported outcome measures and in the quality of reporting of these outcomes, particularly in papers reporting continued follow-up of participant subsets after initial trials had ended, further hampering assessment of the impacts of exposure reductions on this outcome.

2.5 Discussion

This review identified 14 RCTs testing air pollution reduction interventions and reporting clinical respiratory outcomes. Of these, 12 were trials of improved cookstoves and one was a trial of solar lamps. The remaining study, set in China, tested an integrated COPD prevention/management intervention (25). Although pooling of the results was not possible due to heterogeneity in study populations and in outcome measures of association, the outcomes for the most commonly assessed primary clinical respiratory diagnosis – childhood pneumonia – consistently indicated no statistically significant associations across the six studies that included this endpoint (Figure 2.2).

Childhood pneumonia is an important outcome, as its diagnosis is more objective than self-reported symptoms and is less vulnerable to bias, particularly if the diagnosis is made by trained staff who are blinded to intervention status. The lack of evidence of improvement in this outcome across the RCTs to date is, therefore, an important finding.

One specific qualification relating to this outcome measure is the fact that the existing criteria used to define pneumonia may be said to lack specificity (47). In terms of alternative outcome definitions, three of the above studies also considered WHO-defined severe pneumonia, but none found significant evidence of intervention benefit (24, 32, 33). One chimney stove intervention, however, was associated with significant reductions in the outcome of physician-diagnosed severe pneumonia with hypoxaemia, arguably a more clinically relevant finding (30).

A number of explanations have been proposed for the apparent resistance of respiratory outcomes to improvement through improved cookstove interventions. First, the degree of exposure reduction required for children to achieve meaningful health improvements may be greater than that achievable through improved cookstoves alone (30, 37). The available evidence on exposure assessment within the childhood pneumonia studies included in the current review went some way to supporting this hypothesis, with post-intervention exposure levels generally remaining well above international standards. In terms of the clinical impact specifically (in this case, reduction in cases of childhood pneumonia), the plateau effect seen in the exposure-response data from the RESPIRE study emphasises the need for further reductions in exposure (36). Exposure reduction as an outcome in itself was not explored in detail in this review in view of the recent systematic reviews on the subject (9, 10, 12). These reviews describe findings of variably reduced $PM_{2.5}$ and CO exposures across studies (with the numbers of studies using each intervention type being too small for firm conclusions to be drawn on differences between intervention stove types). All three reviews included conclusions supporting the hypothesis of insufficient exposure reduction for clinical impact.

In view of these findings, additional considerations for further reducing PM exposure, and/or by addressing additional exposure sources may be useful. Examples could include behavioural interventions relating to the drying of fuels (drier fuels cause less smoke), improving the combustion efficiency of stoves, improving ventilation in cooking areas and mitigating other household sources of PM exposure (48). Ideally, greater accessibility to electricity and electric cookstoves, particularly induction stoves, would form a permanent solution for many.

A second explanation relating to the lack of intervention impacts on respiratory health is that of the credibility of the proposed causal relationship between household air pollution and respiratory diagnoses, which has recently been questioned (49, 50). Furthermore, any such relationship between exposure and pathology is likely to be complex, with adverse effects of exposure possibly starting in the antenatal period (51). This could help explain the comparative lack of impact of such relatively short-term interventions as those considered in this review. A possible exception was the 4-year integrated COPD management/prevention intervention, which was associated with spirometric improvements in the intervention group (25). Even this intervention did not lead to significant reductions in cumulative COPD incidence or mortality rates, suggesting that even longer timescales may be required to detect the impact on such long-term clinical outcomes.

Another factor impacting on real-world effectiveness, while less important in the context of RCTs, is the extent of intervention uptake and sustained use (42). Poor uptake was not commonly seen within the studies in this review, partly perhaps due to the nature of the studies, all of which were RCTs, which tend to reflect experimental rather than real-world conditions. In the large chimney stove trial in Guatemala, for example, a weekly check and repair service was in place for the intervention stoves, and the recent cluster RCT in Malawi reported their repair and replacement service to be 'heavily used' (30, 32). Many of the trials involved regular visits by study teams throughout – for example, weekly 'spot check' visits in a combined community study in Peru (29) – potentially affecting intervention use in ways that would not be seen in real life.

One trial which did report poor uptake and use of the interventions reported improvements in the per-protocol analysis, which were not seen under the intention-to-treat model (34). These implementation factors are complex and context-informed; for example, results of one study suggest that participants spent more time in their less-smoky kitchens post-intervention (29). Further analysis of these factors requires broader research methods, including both qualitative and quantitative approaches.

Results of some studies indicated improvements in respiratory symptoms, but substantial heterogeneity in outcomes reported precluded pooling of these results (24, 26, 34, 39, 40, 43). The nature of these outcomes – especially where self-reported – has implications for their validity as health indicators.

In a context where participants are given (or asked to buy) a technology to improve their health, factors such as courtesy bias and demand effect are likely to play a role in symptom reporting patterns. This was explicitly discussed by authors of an improved cookstove trial (43), who noted that there were no associations between either self-reported intervention use or measured CO levels and self-reported health.

Another salient issue relating to self-reported outcomes is that questionnaires, surveys, and interviews almost always relied on translation, which is complex, incorporating temporal, regional, cultural, and other contextual elements that may subtly change meaning. Validated questionnaires can be useful in navigating some of these difficulties, but such tools are not currently available for all settings and languages (52). Authors of one large study discussed difficulties in developing terminology for symptoms, such as 'wheeze', and described a need for different questions at baseline and follow-up time points to clarify timescales for participants (40, 53).

While six studies reported spirometric outcomes, these outcomes were again reported with so much heterogeneity that we judged calculation of a pooled effect estimate to be inappropriate. Only one of these studies reported significant intervention-related improvement in lung function (25), although data from the RESPIRE study evidenced a statistically significant association between exhaled CO and FEV_1 (54). The one study evidencing spirometric benefits in the intervention group included both COPD patients and those without COPD and involved numerous intervention components (25). Interestingly, this intervention bundle was associated with a significantly reduced all-cause mortality rate compared with controls, although there was no significant difference in cumulative COPD incidence or mortality rate between the two groups (25). The authors of this paper note that their results point to the value of integrated interventions targeting multiple factors in managing and preventing such pathogenically complex diseases. This is a case also made by researchers involved in a recent integrated water filter–cookstove intervention in Rwanda, who cite movement of cooking from indoors to outside, and even reductions in diarrhoea, as potential contributors to respiratory improvements seen in their study (33).

The main limitations of this review concern the amount of between-study heterogeneity – clinical, methodological, and statistical – as well as the small sizes of most of the studies. Notably, this was the case even within the subgroup of studies using similar intervention types (improved cookstoves) and similar outcomes (pneumonia in children). This is, to some extent, unavoidable in such a diverse and applied area of research, although introduction of standardised criteria for the reporting of results from these studies could help to clarify study methods and findings and facilitate future cross-study comparisons (55). We used unadjusted effect estimates to overcome differences in reporting; however, this introduces the potential limitation of uncontrolled confounding. Despite the heterogeneity, we were able to recognise relative consistency in a clinically important respiratory outcome in the field – childhood pneumonia – in the sense that there was little evidence of benefit across the relevant RCTs to date.

In limiting the scope of this review to RCTs only, we excluded potential assessments of wider interventional types that may take different approaches to the reduction of air pollution from various sources. Such wide-ranging studies – analysed in a recent Cochrane review (56) – will be important in reflecting on the next steps for the field. While none were identified in the current review, trials of interventions using alternative (non-biomass) fuel types in settings where this is feasible also offer potential benefits (57, 58).

2.6 Conclusions

Evidence from the RCTs performed to date suggests that cleaner-burning, biomass-fuelled cookstoves and other household-level interventions have limited benefits in terms of clinical respiratory outcomes. We suggest that more comprehensive approaches to air pollution exposure reduction need to be developed and evaluated in large RCTs for their potential health benefits. Greater consistency in measured outcomes for these studies would also help to build the evidence base in this important field.

2.7 Supplementary information

OVID MEDLINE search strategy, data extraction tool, and PRISMA checklist available on Harvard Dataverse: https://doi.org/10.7910/DVN/UICCPB.

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2.9 Conflicts of interest

None declared

2.10 Authors' contributions

SS and KM conceived the work.

SS designed the protocol and search strategies and ran the searches.

SS and WS independently assessed full texts of the retrieved papers, with areas of uncertainty resolved by KM.

SS and WS independently assessed risk of bias for the studies.

SS analysed the data and drafted the manuscript.

KM supported the analysis.

CJ supported with statistical elements.

NLM, JB, MNB, PSL, CAO, MC, WS, and KM contributed to manuscript editing.

All authors read and approved the final manuscript.

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Chapter 3: Air pollution exposure source apportionment in the Malawian village

As identified in the systematic review (chapter 2), individual interventions, such as improved cookstoves, might not sufficiently lower individuals' air pollution exposures in contexts where multiple exposure sources exist. In some cases, there may be a possibility of such interventions being paired with additional measures, such as cooking in more ventilated spaces, for added efficacy.

These considerations led us to perform an in-depth baseline analysis of individuals' exposure landscapes, through a normal day in and around the village in which our research was based. Carried out alongside in-person participant observation, this would describe the existing sources contributing to individuals' overall daily exposures in this setting. We collected detailed activity data – around cooking in particular – to provide further insights into the impacts of cooking-related factors, such as cookstove, fuel, and cooking place, on individuals' exposures.

In methodological terms, this work constitutes most of the quantitative component of the wider ethnographic work presented subsequently. I, along with my research assistant and fieldworker, spent periods during the in-person participant-observation wearing both fine particulate ($PM_{2.5}$) monitors and carbon monoxide (CO) monitors and noting our activities and potential exposures in the field throughout these periods, constituting a form of proxy exposure monitoring. These findings were taken forward to inform the planning and execution of the direct participant monitoring study presented here.

Personal exposures to fine particulate matter and carbon monoxide in relation to cooking activities in rural Malawi

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3.1 Abstract

Background: Air pollution is a major environmental risk factor for cardiorespiratory disease. It is closely linked with climate change, which has further adverse consequences for human health and well-being. People living in low-income countries have particularly high levels of exposure to air pollution from household cooking and other local sources of combustion. Following an extended period of participant observation in a village in Malawi, we aimed to assess individuals' exposures to fine particulate matter ($PM_{2.5}$) and carbon monoxide (CO) and to investigate the different sources of exposure, including different cooking methods.

Methods: We invited adult residents of a village in Malawi to wear personal $PM_{2.5}$ and CO monitors throughout 1 or 2 days, sampling every 1 (CO) or 2 minutes ($PM_{2.5}$). In-person interviews recorded details of potential exposures after every 24-hour period. We present means and interquartile ranges for overall exposures and summaries stratified by time and activity, including cooking characteristics. We used multivariate regression to further explore these characteristics, and Spearman rank correlation to examine the relationship between paired $PM_{2.5}$ and CO exposures.

Results: Twenty participants (17 female; median age 40 years, IQR: 37–56) provided 831 hours of paired $PM_{2.5}$ and CO data. Peak $PM_{2.5}$ concentrations during combustion activity, usually cooking, far exceeded baseline (no combustion activity): 97.9 µg/m^3 (IQR: 22.9–482.0), vs 7.6 µg/m^3, IQR: 2.5–20.6 respectively. Baseline $PM_{2.5}$ concentrations were higher during daytime hours (11.7 µg/m^3 [IQR: 5.2–30.0] vs 3.3 µg/m^3 at night [IQR: 0.7–8.2]). Highest exposures were influenced by cooking location but associated with charcoal use (for CO) and firewood on a three-stone fire (for $PM_{2.5}$). Personal exposures whilst cooking were higher in more ventilated places, such as outside the household or on a walled veranda, than during cooking indoors.

Conclusions: The study demonstrates the value of combining personal $PM_{2.5}$ exposure data with detailed contextual information for providing deeper insights into air pollution sources and influences. The finding of similar or lower exposures during cooking in seemingly less-ventilated places compared with outside cooking should prompt a re-evaluation of proposed clean air interventions in these settings.

Keywords: air pollution; particulate matter; carbon monoxide; exposure; monitoring; cooking

3.2 Background

Air pollution is the fourth leading risk factor for premature mortality worldwide (1). It is estimated to have contributed to 6.67 million deaths in 2019, largely through respiratory and cardiovascular pathology, with the highest risks occurring in low- and middle-income countries (LMICs) (1, 2). Across sub-Saharan Africa particularly, poor air quality is a persisting issue, with little of the improvements sometimes seen in more affluent regions (2, 3). Household air pollution, from cooking, heating, and lighting, accounts for a large proportion of the deaths attributable to air pollution, particularly in low-income countries in sub-Saharan Africa (1); it also contributes to ambient air pollution. In Malawi, where air pollution remains a leading risk factor for morbidity and mortality (4), exposure to fine particulate matter ($PM_{2.5}$), defined as particles of diameter <2.5 μm, from household sources, was responsible for an estimated 12,400 deaths in 2019 (5). Other common air pollution sources in Malawi include pollution from vehicles and burning of farmland and brick ovens (6-8).

In Malawi and similar settings, $PM_{2.5}$ and carbon monoxide (CO) exposures relate strongly to cooking (9-11) and far exceed internationally agreed cut-offs (12). This suggests that cleaner cooking devices might be beneficial (13-17), although provision of these in intervention trials have not significantly improved health endpoints (18, 19). Data on additional non–cooking-related sources of air pollution are available, but specific source apportionment in the context of overall daily exposures is uncommon (14, 20, 21).

In a recent report from Malawi, we drew insights from in-depth participant observation to inform the design of a monitoring study, providing contextual observational data of cooking behaviour (8). Participants' mobility around the household area, even during cooking episodes, means that stationary monitoring inaccurately reflects personal exposure (17). Importantly, individuals within a household use varying sites for cooking, and different fuels and stoves, even within a 24-hour period. More detailed data on cooking-related and additional exposure sources are required to better understand where and to what extent exposures are happening and, therefore, the potential effects of exposure-reduction interventions (22). We set out to fill this evidence gap through concurrent personal $PM_{2.5}$ and CO exposure monitoring, coupled with detailed time-activity data to explore the influence of cooking and of individual cooking characteristics, such place, fuel, and device use. This allows us to develop a more granular model of air pollution exposures. We also examined the relationship between paired $PM_{2.5}$ and CO exposures, adding to the existing evidence on correlates of air quality in this context.

3.3 Methods

3.3.1 Study design

This study was nested within a larger ethnographic study which incorporated extended participant observation with concurrent personal $PM_{2.5}$ and CO exposure measurement in a Malawian village (8). Household-based participant observations in and around the village took place between July 2019 and January 2020 (during the hot season and part of the cooler rainy season in Malawi), with observations and preliminary quantitative data collected from researchers through proxy exposure sampling informing the sampling design.

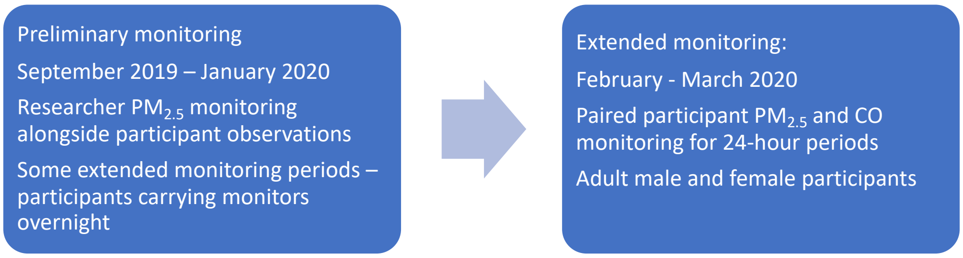


Figure 3.1. Phases of air quality monitoring

Summary measures from the preliminary phase have been reported separately (8). Definitive exposure data reported in this paper reflect results of 48-hour personal monitoring in a cohort of village participants between January and March 2020 ('extended' dataset).

3.3.2 Study setting

Participants lived in a rural village of approximately 840, comprising 722 adults: 380 men and 342 women (population data from local health surveillance assistant, personal communication, 30 September 2021). During daylight hours, the adult population present in the village was largely female, as many men travelled to neighbouring areas seeking employment. The village was 12 km from Blantyre, the commercial capital of Malawi, and approximately 2 km from nearest tarmac single-carriageway road. Much of the area was not accessible by any type of road. Village life focussed around subsistence farming, reflecting the lifestyle seen across most rural communities in the country (23). Prior participant observation of cooking patterns in the village demonstrated that three-stone fires were habitually used in almost all households, with some individuals also using charcoal and firewood stoves. Individuals' stove and fuel use and place of cooking often varied by weather, food cooked (or other stove activity, such as bathwater warming), and occasion.

3.3.3 Participants

Adult male and female residents (>18 years of age) spending at least 6 days of the week in and around the village were invited to participate. Only participants giving informed consent were included. People aged 18 or under, or unable to provide informed consent, were excluded.

3.3.4 Data collection

3.3.4.1 $PM_{2.5}$ and CO measurement

Participants each spent 48 hours carrying two personal air quality monitors in waist bags specifically designed for this study. PurpleAir PA-II-SD laser particle counting devices (PurpleAir, Draper, UT, USA) with 20-Ah portable power banks (Anker Innovations, Changsha, China), previously employed in a number of African settings (24, 25), logged $PM_{2.5}$ concentrations at 2-minute intervals. LASCAR EL-USB-CO devices (Lascar Electronics, Erie, PA, USA) logged CO concentrations every minute. Each PurpleAir monitor was positioned on a large hole in the base of the bag, and the CO data logger protruded from a zip pocket.

3.3.4.2 Activity data

At the end of each 24-hour monitoring period, potential exposures were identified through an in-person review of $PM_{2.5}$ traces created from PurpleAir data using a line graph in Excel (Microsoft, Redmond, WA, USA) (26), viewed on a laptop screen by the participant and a researcher together. Information on potential exposures were gathered at this point, guided by participant recall (around cooking periods each day, for instance), together with visible peaks on traces. Data on potential exposures covered the following key areas, informed by observations during the preceding fieldwork period and preliminary monitoring:

1 Combustion source, including:

- Cooking/bathwater warming/other household fires
- Farming-related exposures
- Traffic exposure
- Other

2 For cooking-related exposures, additional data were gathered on:

a) Place of cooking:

    - 'Indoors' – either inside the household or in an enclosed kitchen
    - Kitchen with no roof
    - Walled *khonde* (veranda)

- *Khonde* with no walls
- Outdoors (in yard area)

b) Device used for cooking:
- Three-stone fire
- Charcoal cookstove
- Firewood cookstove

c) Fuel used for cooking:
- Firewood
- Charcoal
- Other

3.3.5 Statistical analysis

Matching time-activity data generated through interviews were used to indicate which periods on each trace represented 'activity' (when there was an identified exposure source present), with the remainder of the time points constituting a 'baseline' (no identified source of combustion present). For $PM_{2.5}$, 'CF=1' values were selected, on expert advice, in view of key environmental features. After checks that readings from the two sensors were in agreement throughout, an average of the two values was used. Times for these devices were set through connection to the internet, with regular reconnection ensuring no significant drift. Each 2-minute $PM_{2.5}$ concentration was paired with activity data to allow analysis by activity (and by device, fuel, and place for cooking exposures).

Medians and interquartile ranges (IQRs) for $PM_{2.5}$ and CO during 'activity' periods were calculated and compared with those during 'baseline' periods across the full dataset. Medians and IQRs were also calculated for daytime baseline periods (5AM to 10PM) and compared with baseline through the night (10PM to 5AM). Selection of these time categories was informed by the previous ethnographic work in the village. Medians and IQRs were preferred over means throughout the analysis in view of the skewed nature of the exposure data and in line with other work in the area (11, 21, 27).

The medians and IQRs of all datapoints across the dataset during cooking were compared with those associated with 'no activity', and summary measures were similarly used to compare various cooking characteristics (cooking device, fuel, and place of cooking). For boxplots, CO +1 values were used before log transformation to allow for transformation of zero values. Multivariate regression models were employed to explore the effects of these cooking characteristics in greater detail, while also acknowledging autocorrelation between datapoints from the same participant over time (hence the use of mixed models).

Correlation between paired $PM_{2.5}$ and CO exposures was analysed both visually using a scatter plot and through the calculation of a Spearman rank correlation coefficient. All data were analysed using R (R Foundation for Statistical Computing, 2020, Vienna, Austria) (28), and figures were created using the package ggplot2 (29). Linear regression was done using the lme4 package (30) and outputs created using the Stargazer package (31).

3.4 Results

The extended dataset included a total of 831 hours of paired $PM_{2.5}$ and CO exposure data from 20 participants (Figure 3.2). Eleven of these 20 participants had two full contiguous 24-hour traces amounting to more than 48 hours of monitoring. Shorter samples were due to battery faults.

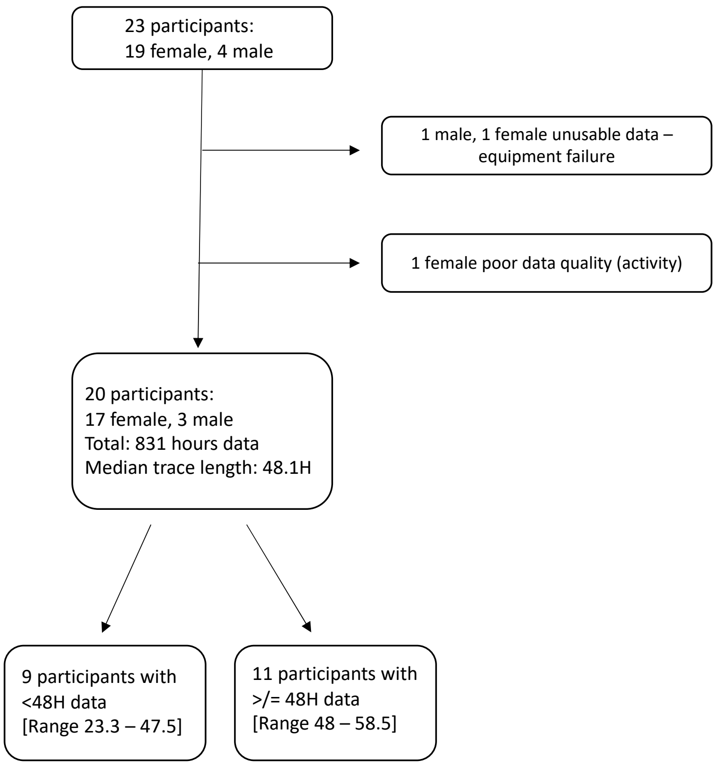


Figure 3.2. Flow chart depicting participants included and excluded, with data on duration of monitoring

Both $PM_{2.5}$ and CO traces showed a 'baseline + peak' pattern, with echoing patterns in paired traces (Figure 3.3).

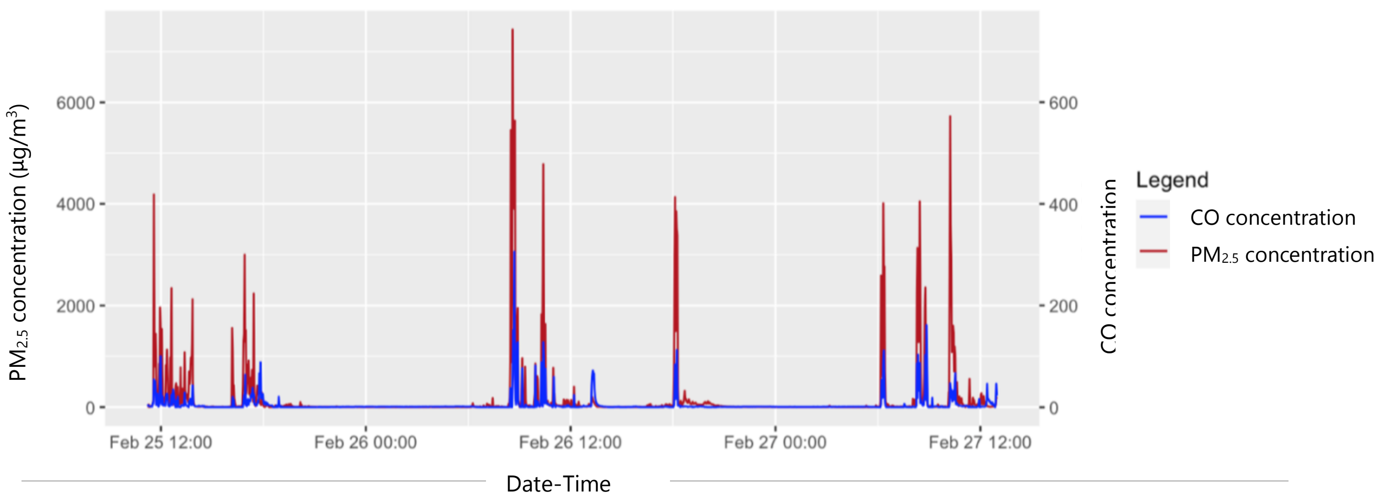


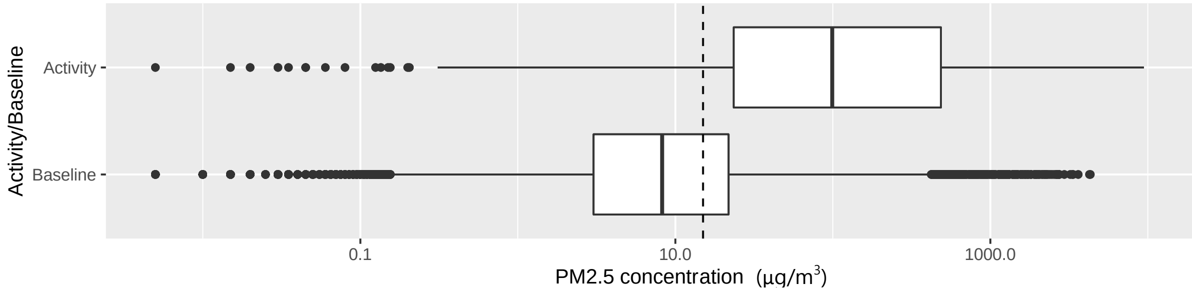
Figure 3.3. Variation in $PM_{2.5}$ and CO concentrations over a 48-hour time-period in a sample participant

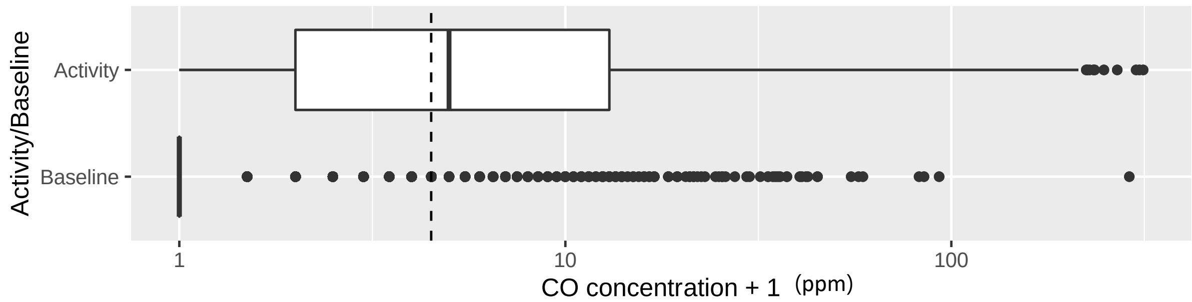
Testing for normality using the Shapiro-Wilks test revealed the data to be highly skewed, with a left skew representing lower $PM_{2.5}$ concentrations (in the absence of combustion activity), and a long tail representing $PM_{2.5}$ concentrations reaching >1,000 µg/m^3 during cooking activity.

3.4.1 Activity-related and baseline exposures

'Peaks', or periods of 'activity' (where there was an identified source of combustion) represented 23% of the overall recording period. Median $PM_{2.5}$ exposure during these activity periods was 97.9 µg/m^3 (IQR: 22.9–482.0), whereas median $PM_{2.5}$ baselines (at times of no identified combustion sources) were 7.6 µg/m^3 (IQR: 2.5–20.6). This comparison is shown in the box plots (Figure 3.4a), which also depict the wide dispersal of values, which often reached above 1,000 µg/m^3 during periods of 'activity'. Median carbon monoxide exposure during periods of identified activity was 4 ppm (IQR: 1–12), compared with 0 ppm at 'baseline' (Figure 3.4b).

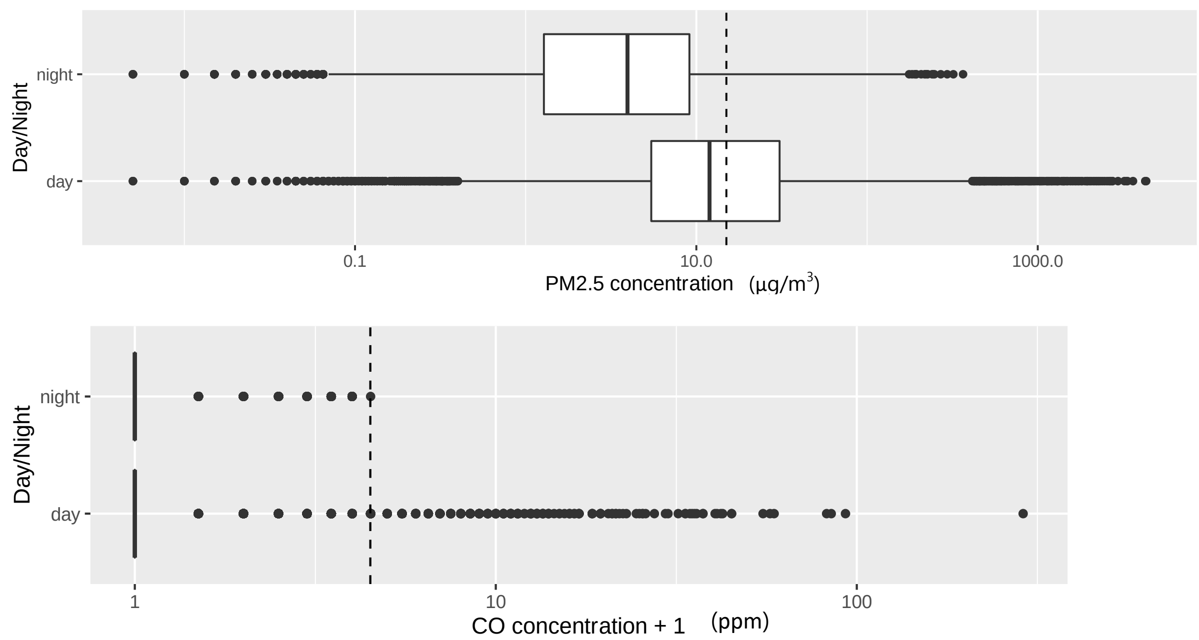
Of the total 'activity' time period, 86% represented cooking or a related activity in the household (including starting a cooking fire and use of this fire – or cookstove – for warming bathwater and warming oneself). Other exposure sources captured in the dataset included burning grass at the farm, proximity to a minibus, soldering of a radio, and an identified cooking fire in a neighbouring household.





Figures 3.4a & b. Box plots depicting median $PM_{2.5}$ and CO exposures during periods of combustion activity and at baseline across the dataset, with $PM_{2.5}$/CO concentrations plotted on a log scale. Dotted lines indicate WHO-recommended 24-hour upper limits ($PM_{2.5}$ concentration 15 µg/m^3; CO concentration 4 mg/m^3 = 3.492 ppm) (12)

When 'no activity' periods were stratified by diurnal period, there were 399 hours of 'no activity' data during the day, compared with 237 hours at night. Median ambient $PM_{2.5}$ exposures were higher in the day than the night (Figure 3.4c): 11.7 µg/m^3 [IQR: 5.2–30.0] and 3.3 µg/m^3 [IQR: 0.7–8.2] respectively.



Figures 3.4c & d. Box plot depicting median $PM_{2.5}$ and CO exposures at baseline (no identified combustion activity), during daytime and night-time hours, with $PM_{2.5}$/CO concentrations plotted on a log scale. Dotted lines indicate WHO-recommended 24-hour upper limits ($PM_{2.5}$ concentration 15 µg/m^3; CO concentration 4 mg/m^3 = 3.492 ppm) (12)

Male and female exposures were not compared because of the small number of male participants involved in this study.

3.4.2 Cooking characteristics

Of all identified cooking time, 80% involved the use of a three-stone fire. The remainder of the cooking time involved either charcoal or firewood cookstoves (10% and 9%, respectively). Indoor cooking was most common (60% of total cooking time, of which 82% was in a closed kitchen, and the remainder in a house). Less commonly, cooking was done on walled verandas (24% of all cooking time), outside (11%), or on open verandas (no walls). Only one participant cooked in a kitchen with no roof (2% of total cooking time).

Univariate analysis suggested that use of firewood was associated with higher $PM_{2.5}$ exposures than charcoal (median 115.0 µg/m^3 [IQR: 26.7–506.0] vs median 25.7 µg/m^3 [IQR: 11.0–65.0] for charcoal). In contrast, CO exposures were slightly lower during cooking periods using firewood compared with charcoal (median 3.5 ppm [IQR: 1.0–10.0] vs median 5.0 ppm [IQR: 1.5–14.0]). These differences are shown in figures 3.5a & b.

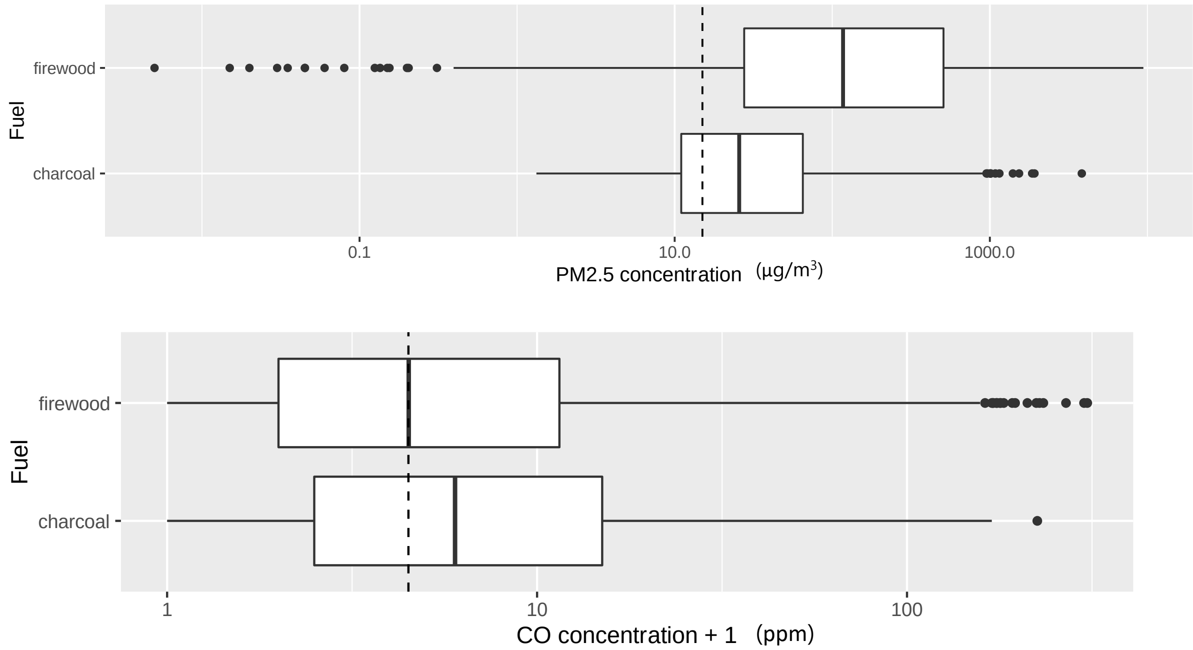


Figure 3.5a & b. Box plot depicting median cooking related $PM_{2.5}$ and CO exposures during cooking episodes using firewood compared with those using charcoal, with $PM_{2.5}$/CO concentrations plotted on a log scale. Dotted lines indicate WHO-recommended 24-hour upper limits ($PM_{2.5}$ concentration 15 µg/m^3; CO concentration 4 mg/m^3 = 3.492 ppm) (12)

Use of three-stone fires was associated with higher $PM_{2.5}$ exposures than either firewood or charcoal cookstoves (median 127.0 µg/m^3 [IQR: 30.7–535.0]; median 39.5 µg/m^3 [IQR: 9.8–221.0]; median 26.7 µg/m^3 [IQR: 11.3–68.0], respectively). This again contrasted with CO concentrations, which were lower during cooking episodes using firewood stoves than with either three-stone fires or charcoal stoves (median 1.0 ppm [IQR: 0.0–3.0]; median 4.0 ppm [IQR: 1.5–11.5]; median 5.0 ppm [IQR: 1.5–14.0], respectively).

All cooking episodes could be represented by one of three combinations:

1. Firewood on a three-stone fire
2. Firewood on a firewood cookstove
3. Charcoal on a charcoal cookstove

Fuel and stove were, therefore, combined into a single 'fuel_stove' categorical variable for the purposes of the regression model. The full model thus includes 'fuel_stove' and 'place of cooking' as fixed effects and participant number as a random effect (in recognition of the likely individual/household-level determinants involved). The dependent variable was log normalised using ($\log_{10}(1+[PM_{2.5}])$) to allow treatment of zero values. Results of regression analyses presented here only relate to the $PM_{2.5}$ outcome. Results of the regression model using CO as a dependent variable have been included in the supplementary materials.

($\log_{10}(1+[PM_{2.5}])$) ~ 'place' + 'fuel_stove' + (1|'participant'))

An initial mixed model examining fuel_stove alone (with 'participant' as a random effect) indicated that use of firewood – either on a three-stone fire, or on a firewood cookstove – predicted higher $PM_{2.5}$ exposure compared with use of charcoal on a charcoal stove. The increase in exposure was greater for firewood on a three-stone fire (estimate = 1.25, error = 0.095, $P<0.01$) than for firewood on a firewood cookstove (estimate = 0.25, error = 0.14, $P<0.1$).

A similar mixed model using 'place of cooking' alone indicated that – compared with cooking indoors – cooking in a kitchen with no roof, walled veranda, or outside the household were all significantly associated with higher exposures ($P<0.01$ in all three cases). Cooking in an unwalled veranda in this model appeared to be associated with higher exposures ($P<0.01$). Both models indicated that inter-participant variation was less than variation due to other factors.

Compared with the fuel_stove–only model, adding place of cooking (to give the full model) significantly improved the prediction of $PM_{2.5}$ exposures ($X^2(4) = 23.7$, ANOVA $P=0.001$). This model affirmed the significance of fuel_stove in shaping exposures, with wood on a three-stone fire significantly associated with higher exposures than charcoal used on a charcoal stove (estimate = 1.12, error = 0.11, $P<0.01$); firewood on a firewood stove was, in this model, not associated with significantly different exposures than charcoal. In the full model, compared with cooking indoors, cooking in a walled veranda or outside the household were associated with significantly higher personal exposures (supplementary materials, Table 3.11). Cooking taking place in a kitchen with no roof and in an unwalled veranda were not associated with any significant differences.

3.4.3 Correlation between $PM_{2.5}$ and CO concentrations

On visual inspection of a contour plot with an overlaid line of best fit (Figure 3.6a), there appeared to be a correlation between $PM_{2.5}$ and CO concentrations across the whole dataset. The Spearman rank correlation coefficient (r_s) was 0.50 ($P<0.001$), indicating a moderate correlation between $PM_{2.5}$ and CO concentrations overall.

The apparent clustering in this graphic was explored using separate plots for 'cooking' and 'baseline' periods (figures 3.6b & c). Analysis of correlation in these subgroups found a stronger relationship during cooking activity ($r^2=0.42$) compared with baseline periods ($r^2=0.22$).

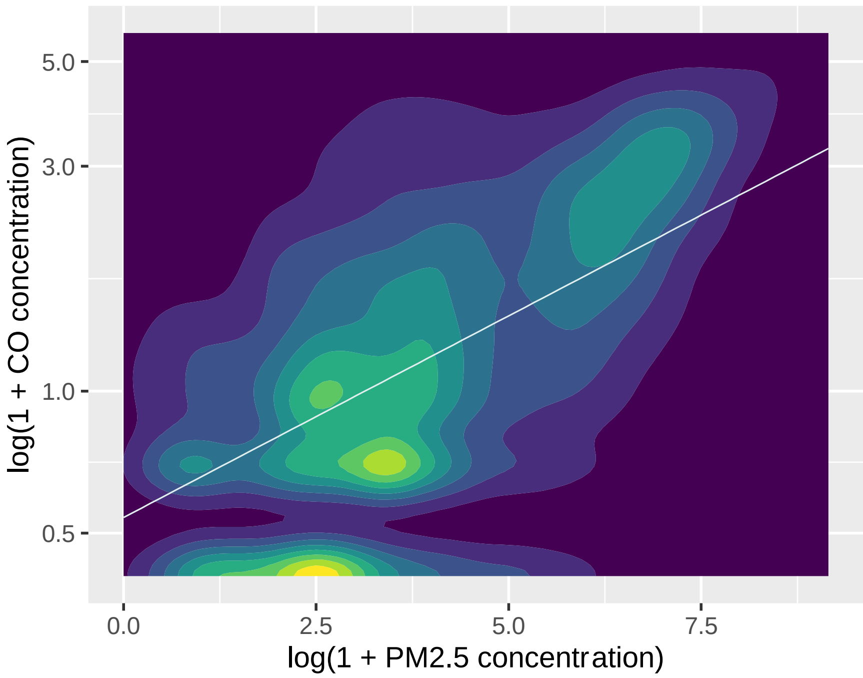
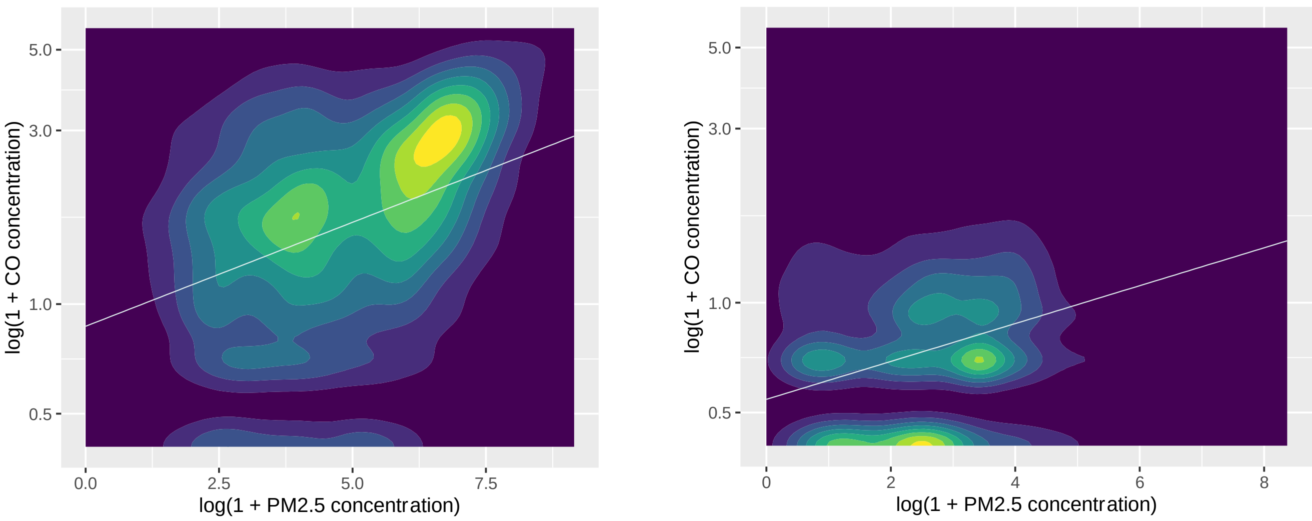


Figure 3.6a. Contour plot illustrating the relationship between $PM_{2.5}$ and CO across the complete dataset, using log(1+CO) and log(1+ $PM_{2.5}$)



Figures 3.6b & c. Contour plots illustrating the relationship between $PM_{2.5}$ and CO during cooking activity, and at baseline (no identified combustion activity), using log(1+CO) and log(1+ $PM_{2.5}$)

3.5 Discussion

Our personal monitoring results, coupled with in-depth data around daily exposures, demonstrated the primacy of cooking in individuals' exposure landscapes in Malawi. Median $PM_{2.5}$ and CO exposures were significantly higher during activity (usually representing cooking) than at baseline, in the absence of identified combustion activity. Analysis of paired cooking data revealed the use of wood on a three-stone fire to be significantly associated with higher exposures than cooking using charcoal or firewood stoves, and cooking in a walled veranda or outside the household were associated with significantly higher personal exposures than cooking outdoors.

The data indicated that at baseline, median $PM_{2.5}$ and CO concentrations – 7.6 µg/m^3 and 0 ppm for $PM_{2.5}$ and CO, respectively – were below WHO-recommended 24-hour levels (12) but that cooking episodes frequently exposed participants to extremely high pollutant concentrations ($PM_{2.5}$ often >1,000 µg/m^3). High pollutant concentrations have been previously reported in this setting (9, 32), but using personal monitoring with paired activity data, we were able to separately analyse baseline and peak $PM_{2.5}$ concentrations, framing cooking as a key exposure source. This echoes findings from Uganda, Ethiopia, and Ghana

(14, 17), with further analysis exploring specific factors which shape cooking-related exposures.

The diurnal difference in baseline $PM_{2.5}$ concentrations reveals the contribution of daily activity across the village to ambient levels. This contrasts with data from more urban LMIC settings, which describe higher pollutant concentrations at night, likely driven by atmospheric changes related to cooling (33). While our observations in and around the village revealed a variety of potential contributors to air pollution (e.g., burning farmland, environmental dust), cooking clearly constituted the primary source of exposure for participants in the village environment (8). The shared nature of air pollution here demands interventions which can be near-universally adopted in a given geographical area (34, 35).

Following an initial period of ethnographic observation for better understanding of the context, personal monitoring paired with fine-grain data on individual cooking episodes, collected after each monitoring period, allowed for analysis of personal cooking exposures by fuel, device, and place of cooking. The association of lower $PM_{2.5}$ concentrations with charcoal cooking reflected community members' own understandings and echoed findings in the literature (36). Small reductions in $PM_{2.5}$ concentrations with use of firewood cookstoves compared with three-stone fires supports the use of these low-cost local stoves, although the health impacts of such modest reductions are unclear (37, 38).

Personal $PM_{2.5}$ exposures associated with cooking indoors were found to be lower than exposures associated with cooking outdoors or on walled verandas and no different from exposures encountered while cooking in other structures. While the idea that cooking in apparently better-ventilated places might be associated with similar or higher exposures than cooking in more enclosed spaces initially seems counterintuitive – and counter to the mainstream discourse (39-42) – cooking patterns regularly witnessed in the village help explain these effects. We frequently noted that women cooking in smoky kitchens spent time sitting outside or away from the kitchen between visits to tend the fire or the pot, whereas cooking done in a more 'social' space, such as a veranda, involved the cook, as well as family and friends, spending extended periods by the fire. In view of the high $PM_{2.5}$ concentrations produced during any cooking activity, periods of physical distancing from the site may plausibly produce similar or more marked reductions in personal exposures than continuous cooking in spaces with a degree of ventilation. Awareness-raising interventions around the harms of 'smoke' and support for women to spend less time close to cooking devices could constitute a first step to reducing exposures in the village setting, although structural changes to overcome contextual limitations will be required to achieve sustainable improvements (43).

Concurrent measurements revealed a strong association between individual $PM_{2.5}$ and CO exposures at peak concentrations but an absence of this association during baseline periods. This builds on review-level evidence from a range of global settings indicating inconsistencies in the correlation (44, 45). In view of the clinical significance of baseline levels of pollutants, even where peak concentrations are reduced (12, 46, 47), our findings indicate weaknesses in the use of CO measurement as a proxy for $PM_{2.5}$ exposure. Our successful use of small, soundless, portable $PM_{2.5}$ monitors establishes their utility in personal exposure monitoring and – in view of the similarities in costs of the two monitors – favours their use for direct $PM_{2.5}$ monitoring, superseding use of proxies.

The current study involved a relatively small number of participants, preventing detailed regression analyses and more precise models. Residual variation in cooking exposures, possibly related to firewood type or moisture content, type of food cooked, or daily weather conditions, was unexplained by the current models. Observations in the village suggested a role for these factors in influencing cooking-related $PM_{2.5}$ concentrations, in keeping with evidence from other studies (48-50), but difficulties in quantification and sample size limitations precluded their incorporation in the analysis.

The retrospective reviewing, with participants, of traces on laptop screens to determine exposure periods could potentially have introduced recall bias in exposure categorisation. Combustion activities tended to create clear exposure peaks (Figure 3.3), but timing inaccuracies could lead to misclassification of datapoints around the start and end of activities. This system was used because while village residents tended to split their days broadly into 'morning'/'afternoon'/'evening' (with lunch usually consumed at around 12 o'clock), they were otherwise generally unaware of the time and did not use watches or clocks at all. Together with the predominance of spoken (over written) communication, this precluded the use of self-completed activity diaries, for example.

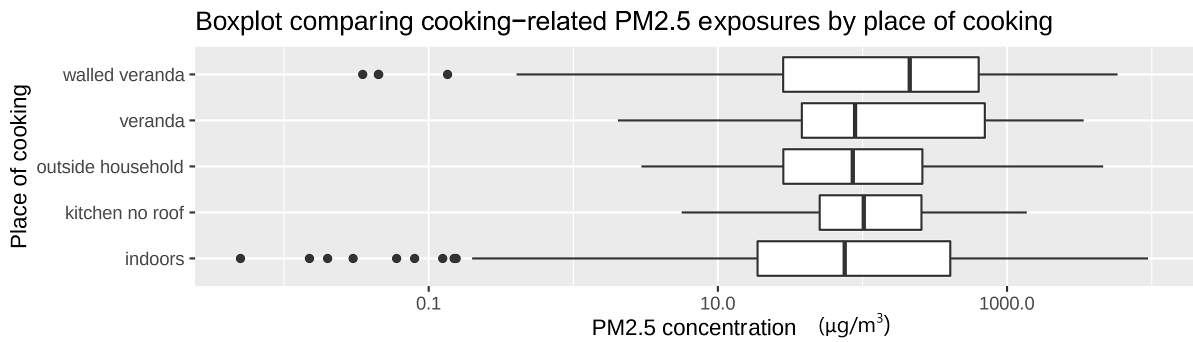
The use of medians rather than means in this study – in keeping with other similar studies (11, 21, 51) – reduced the effects of potential exposure misclassification, and whilst still constituting an inherent risk in the study design, this is unlikely to have significantly impacted the key study findings around diurnal variation or cooking characteristics for example.

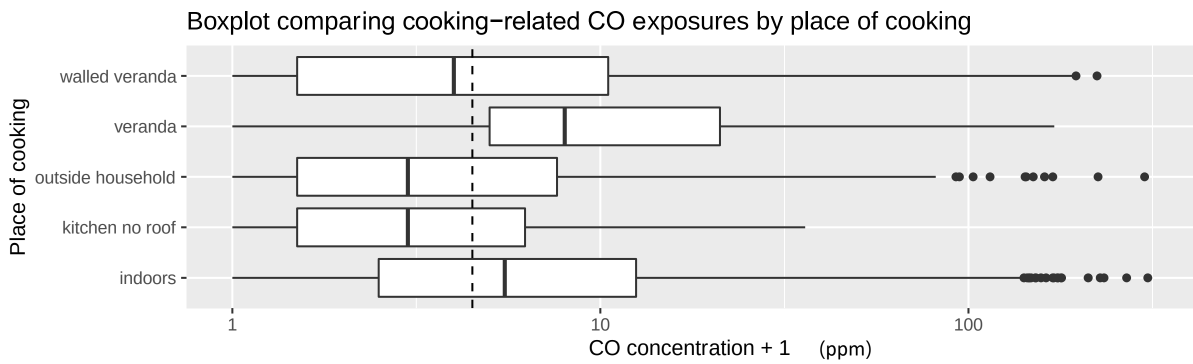
Further study limitations include a relatively short study period (excluding certain seasonal variations, such as changes in fuel use) and the occurrence of very high $PM_{2.5}$ values (>250 μg/m^3) during cooking-related peaks, lying outwith the calibration range of the instruments (24). This highlights the need for gravimetric calibration of the monitors in rural sub-Saharan African settings but does not change the direction of inference of the current results.

3.6 Conclusions

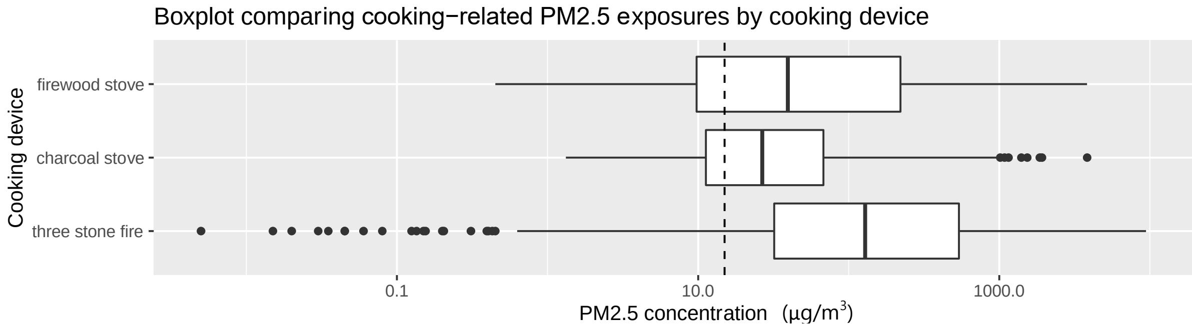
High cooking-related $PM_{2.5}$ and CO concentrations in this study and a raised baseline level during the day compared with night signal the need for accessible, population-wide approaches to achieve clinically meaningful exposure reductions. The study demonstrated the feasibility of direct $PM_{2.5}$ monitoring using personal devices, which is important, given our finding of poor $PM_{2.5}$-CO correlation during baseline (non-activity) periods. The finding of lower or similar exposures during cooking in less-ventilated places outlines the value of our personal, activity-matched monitoring approach, together with detailed participant observations in the setting. This grants added value to exposure assessment and consequent decisions surrounding interventions and their evaluation.

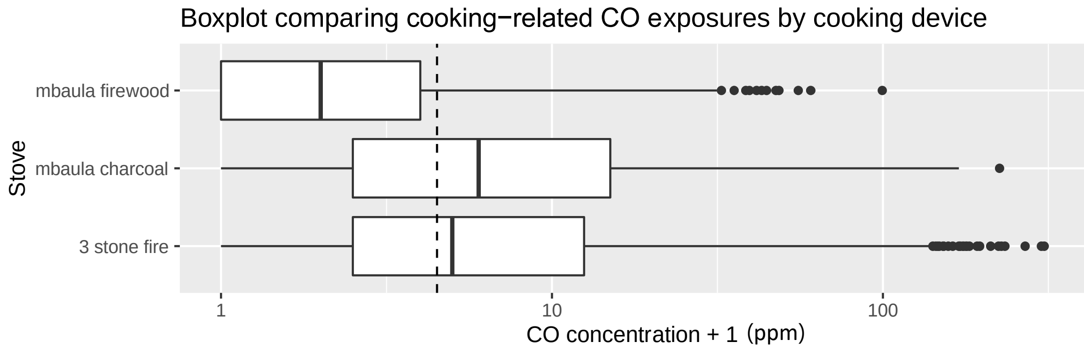
3.7 Paper supplement – 'Personal exposures to fine particulate matter and carbon monoxide in relation to cooking activities in rural Malawi'





Figures 3.7 & 3.8. Box plot depicting median cooking related $PM_{2.5}$ and CO exposures by place of cooking, with $PM_{2.5}$/CO concentrations plotted on a log scale





Figures 3.9 & 3.10. Box plot depicting median cooking related $PM_{2.5}$ and CO exposures by cooking device, with $PM_{2.5}$/CO concentrations plotted on a log scale

Tables 3.1 & 3.2. Output of full regression model using $PM_{2.5}$ and CO as dependent variables

	Dependent variable:
	log(1 + pm_mean)
stoveFuelwoodOnFire	1.118***
	(0.106)
stoveFuelwoodStove	0.106
	(0.152)
Placekitchen no roof	0.529
	(0.326)
Placeoutside household	0.243**
	(0.107)
Placeveranda	-0.110
	(0.219)
Placewalled veranda	0.646***
	(0.136)
Constant	3.548***
	(0.155)
Observations	5,035
Log Likelihood	-9,885.584
Akaike Inf. Crit.	19,789.170
Bayesian Inf. Crit.	19,847.890
Note:	*p **p ***p<0.01

	Dependent variable:
	log(1 + co_pp)
stoveFuelwoodOnFire	-0.304***
	(0.069)
stoveFuelwoodStove	-0.858***
	(0.099)
Placekitchen no roof	0.395*
	(0.215)
Placeoutside household	-0.219***
	(0.070)
Placeveranda	0.228
	(0.143)
Placewalled veranda	-0.031
	(0.090)
Constant	2.042***
	(0.109)
Observations	5,035
Log Likelihood	-7,692.888
Akaike Inf. Crit.	15,403.780
Bayesian Inf. Crit.	15,462.490
Note:	*p **p ***p<0.01

N.B., When carbon monoxide (CO) was used as a dependent variable in the full model, both firewood on a stove and firewood on a three-stone fire were significantly associated with lower exposures than charcoal used on a charcoal stove (estimate = −0.86, error = 0.10, $P<0.01$ for firewood on a stove and estimate = −0.30, error = 0.07, $P<0.01$ for firewood on a fire). In this model, cooking in a walled or unwalled veranda and in a kitchen with no roof were not associated with any significant differences in personal CO exposures compared with cooking indoors, but cooking outside the household was associated with significantly lower exposures (estimate = −0.22, error = 0.07, $P<0.01$).

3.8 Declarations

3.8.1 Ethical considerations

The study was approved and sponsored by the LSTM Research Ethics Committee (19-007). In-country ethical approval was granted by the College of Medicine Research and Ethics Committee (COMREC) in Blantyre (P.02/19/2600). All procedures were followed in accordance with the ethical standards of the Helsinki Declaration (1964, amended in 2008) of the World Medical Association. Participants' written consent was obtained where appropriate.

3.8.2 Availability of data and materials

The quantitative data supporting the conclusions of this chapter are available in the Harvard Dataverse repository (52), available at: https://doi.org/10.7910/DVN/7A0XIS. Results of additional analyses are provided in the supplementary materials.

3.8.3 Competing interests

The authors declare that they have no competing interests.

3.8.4 Funding

This work was supported by a Wellcome Trust Clinical PhD Fellowship awarded to SSa (University of Liverpool, Liverpool, UK, block award 203919/Z/16/Z).

3.8.5 Authors' contributions

SSa conceived and designed the work and was involved with data collection, analysis, and interpretation, as well as drafting of the final paper.

HS was involved with data collection and management.

DM supported data collection.

JC supported the analysis.

SSe contributed to manuscript editing.

KM supported study design and contributed to manuscript editing.

JR supported study design and contributed to manuscript writing and editing.

MC contributed to manuscript editing.

All authors read and approved the final manuscript.

3.8.6 Acknowledgements

Many thanks to James Dodd for the opportunity to discuss approaches to statistical analysis, and to Rachel Burke for her help and support with R.

3.9 Reflexivity statement

The following reflexivity statement details key elements of the research partnership, conduct and reporting of the work presented above, in the hope that transparency with regard to transnational research practices will lay a foundation for more equitable ways of conducting collaborative research across the academic system.

Study conceptualization	**1.**	**How does this study address local research and policy priorities?** Air pollution is a global health priority. Malawi is a low-income country with high levels of air pollution and consequent morbidity. Cooking using solid fuels is thought to be a key contributor to airborne pollutant exposure in rural populations. It is therefore important to know how cooking factors (place, stove, fuel) influence exposure to different pollutants in this setting, to inform any future efforts to reduce these exposures and improve health.
	2.	**How were local researchers involved in study design?** The research assistant (HS) for this study is a local social scientist based in Malawi with previous experience doing research in this area. He was heavily involved with data collection and ensured that approaches and methods were context appropriate. The fieldworker (DM) is a resident of the village in which the study was based and helped to optimise linkages with the community throughout the wider study.
Research management	**3.**	**How has funding been used to support the local research team(s)?** Part of the research funding was used to provide salaries for local researchers – as above – and staff involved in

	the broader research grant, including research governance and grants management.
Data acquisition and analysis	**4. How are research staff who conducted data collection acknowledged?** The research assistant and fieldworker worked with the main researcher on data collection, and the research assistant also supported data management activities. Both are authors of this paper, and their specific contributions are acknowledged in the appropriate section.
	5. How have members of the research partnership been provided with access to study data? Study data are archived at Malawi-Liverpool-Wellcome Trust (MLW). Local researchers have direct access to the data.
	6. How were data used to develop analytical skills within the partnership? The PhD researcher (SSa) supported the research assistant in quantitative data management and analysis, helping to develop these skills further.
Data interpretation	**7. How have research partners collaborated in interpreting study data?** Data interpretation involved discussions around analytical decisions and methods, which incorporated various members of the team (based in Malawi and the UK)
Drafting and revising for intellectual content	**8. How were research partners supported to develop writing skills?** The lead author of this paper is a doctoral candidate. She led in writing the paper, with reflective input and advice from all co-authors.

9. **How will research products be shared to address local needs?**
   Preliminary findings have been shared within the village at dissemination events. Early versions of the quantitative data have been presented at local research dissemination conferences and within the research institution (MLW). This information will be made available to the wider global scientific community for discussion and development of the findings.

Authorship

10. **How is the leadership, contribution, and ownership of this work by LMIC researchers recognised within the authorship?**
    Please refer to the section on authors' contributions. Each author's role is described, including researchers from LMICs who were in the majority.
11. **How have early-career researchers across the partnership been included within the authorship team?**
    Please refer to question 8 above regarding leadership of the project. The study also incorporated a junior researcher in the LMIC setting as research assistant, statistical support from a LMIC-based postdoctoral researcher (JC), and a local fieldworker (DM) who had not previously had any research involvement, all included as authors.
12. **How has gender balance been addressed within the authorship?**
    The research lead (whose doctoral work is represented here) is female, as are 1/3 of the authors, with representation from both local LMIC and HIC settings.

		Contributions to the study are acknowledged in the 'authors' contributions' section.
Training	**13.**	**How has the project contributed to training of LMIC researchers?** The research assistant (HS) was involved in the research process throughout, developing key skills, and he was supported in successfully applying for a Masters' scholarship in global health research. Involvement of the local fieldworker (DM) constituted her first experience of research participation. Both significantly contributed to the project and are recognised accordingly in the authorship. These experiences will lay the foundation for further academic career development.
Infrastructure	**14.**	**How has the project contributed to improvements in local infrastructure?** Whilst this was a small-scale study, the project team strived to support constructive engagement between the village community and the research institution throughout. Work is underway to create a nursery building in the village to express thanks to residents for their involvement and to provide continuity of employment for the local fieldworker. With reference to question 3 above, research governance, ethics, and grant management systems of the local implementing partner (MLW) were supported through this grant.
Governance	**15.**	**What safeguarding procedures were used to protect local study participants and researchers?** The local ethics body and the LSTM Research Ethics Committee reviewed and approved the study protocol, ensuring that both participants and researchers were protected throughout the study. Among other

considerations, participants provided informed consent prior to their participation and, specifically, a named safeguarding lead (SSa) was in place throughout, with various avenues of contact for participants to report any concerns, along with structures for appropriate referral of any such reports.

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Chapter 4: Ethnographic account of smoke in the Malawian village setting

Findings from chapter 3 revealed that cooking-related emissions constituted the main driver of daily air pollution exposures for people living in and around the village. Cooking on a three-stone fire using firewood was found to be the commonest arrangement, and was associated with the highest exposures for the cook, although some residents also cooked with charcoal and on cookstoves. The previous chapter also lends initial insights into the potential benefits of in-person observation, with suggestions of how individuals' exposures to emissions while cooking in less-ventilated spaces might actually be lower, due to small behavioural adjustments.

In this chapter we report the main qualitative findings from the ethnography, incorporating extended participant observation, individual interviews, and participatory workshops, which led to deeper understandings of the social aspects of cooking and of the wider determinants of cooking practices in this setting. The paper is presented first, followed by supplementary material providing further detail on epistemological approaches and individual methods used.

Exploring smoke: an ethnographic study of air pollution in rural Malawi

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4.1 Abstract

Air pollution adversely affects human health, and the climate crisis intensifies the global imperative for action. Low- and middle-income countries (LMICs) suffer particularly high attributable disease burdens. In rural low-resource settings, these are linked to cooking using biomass. Proposed biomedical solutions to air pollution typically involve 'improved cooking technologies', often introduced by research teams from high-income countries.

This ethnography, set in a rural Malawian village, aimed to understand air pollution within its social and environmental context. The results provide a multifaceted account through immersive participant observations with concurrent air quality monitoring, interviews, and participatory workshops. Data included quantitative measures of individuals' air pollution exposures paired with activity, qualitative insights into how smoke is experienced in daily life throughout the village, and participants' reflections on potential cleaner air solutions.

Individual air quality monitoring demonstrated that particulate levels frequently exceeded upper limits recommended by the World Health Organization, even in the absence of identified sources of biomass burning. Ethnographic findings revealed the overwhelming impact of economic scarcity on individual air pollution exposures. Scarcity affected air pollution exposures through three pathways: daily hardship, limitation, and precarity. We use the theory of structural violence, as described by Paul Farmer, and the concept of slow violence to interrogate the origins of this scarcity and global inequality. We draw on the

ethnographic findings to critically consider sustainable approaches to cleaner air, without re-enacting existing systemic inequities.

4.2 Key questions

What is already known?

Air pollution is a leading cause of global morbidity and mortality, and an important driver of health inequalities. Traditional global health approaches typically use individualised 'cleaner cooking' interventions, with limited successes in reducing cooking-related emissions in low- and middle-income countries. Sustainable, clinically important improvements in health outcomes have been more challenging to achieve.

What are the new findings?

Air pollution exposures in rural Malawi exceeded internationally recommended maximum levels even in the absence of identified sources of burning. Compounding this high background, intense exposures were identified during cooking, which constituted the greatest single identifiable contributor to poor air quality.

Ethnographic findings demonstrate the striking impacts of economic scarcity on air pollution and on communities' capacities to avert their exposures.

What do the new findings imply?

Air pollution does not exist in isolation; it is part of a wider environment which structurally compromises respiratory health. Effective interventions to improve lung health must be context-informed and engage with communities' lived experiences. A 'geographically broad' and 'historically deep' analysis of health determinants is invaluable to global health enquiry.

4.3 Introduction

Evidence of the direct and indirect health effects of air pollution is overwhelming, as is recognition of its role in the escalating climate crisis (1-4). In Malawi, studies have demonstrated high domestic levels of harmful airborne particulates (5, 6). Acute respiratory infection and chronic lung disease are common in this population. These are associated with poor air quality and share other causative factors, such as poverty and malnutrition (7-9). Cooking using biomass (organic matter used as fuel) is known to be important, although other sources of air pollution are also present (10-14).

With over 3 billion people worldwide relying on polluting fuels and technologies for cooking, these issues are key to global health (15). Evidence for the effectiveness of improved cooking technologies and clean fuels is mixed. Many interventions are insufficient to reduce particulate levels to below internationally recommended thresholds or to improve health outcomes (16-18). In Malawi, a well-powered trial of efficient fan-assisted biomass stoves did not significantly reduce pneumonia in children (19). The exact relationship between exposure reduction and clinical outcomes is unclear, particularly for modest reductions in particulates. Nevertheless, there is widespread promotion of more basic biomass stoves. Advocates cite their wider benefits to the environment, and potential to support livelihoods through local manufacture (20).

Suboptimal reductions in exposure in interventional trials have been linked to behavioural factors, such as non-exclusive and poorly sustained use of the new technologies and fuels (21-23). Additional pollution sources include concurrent use of traditional cooking methods ('stacking'), or non–cooking-related biomass combustion (13, 24). Combining a quantitative assessment of air quality with an understanding of individuals' cooking related concerns and motivations could contribute to improving outcomes.

Research on enablers and barriers to the adoption and sustained use of cleaner cooking fuels and technologies reveals various interacting factors (25-28). A lack of affordability and access prevent the uptake of new cooking technologies and fuels in many settings (29-34). Some studies suggest that health concerns can motivate transition to cleaner cooking technologies, but knowledge of the health harms of smoke does not necessarily lead to improved stove uptake and sustained use (29, 35). Both enabling and limiting factors are shaped by structural context (e.g., clean energy availability), as well as cultural and social aspects (24, 27, 28, 31, 36, 37). A study of four neighbouring southern African countries (South Africa, Mozambique, Malawi, and Zambia) revealed differing priorities, despite similarities in how individuals valued fuel and cost savings (38).

Cookstove development approaches have changed over time. Analysis by Sesan (39) regards this as transition from an 'expert-based' position through to 'market-based' approaches, noting that agendas are framed by high-income country actors throughout, often in response to their shifting priorities (initially health and subsequently climate). Whilst analyses tend to focus on interventions, the author cites evidence of basic, more immediate needs competing for very limited resources in many settings. It is suggested that the 'local' population be engaged as active agents in the process, choosing priorities rather than acting as passive recipients (39).

We used ethnography – including immersive participant observation in the village context – to bring alternative perspectives. We sought to understand individuals' daily realities (rather than starting with proposed solutions) and to bring together participants' own knowledge, developed through lived experience, with our knowledge as clinicians and academics. The anthropologist João Biehl articulates this as, "rejecting the division between those who know the world and those who must simply struggle to survive it" (40, p135).

The aim was to provide an account of air pollution in the context of the wider hardships, risks, and limitations inherent to life in this setting. Our theoretical analysis incorporates the concept of structural violence, which describes how structures, such as political, legal, and economic systems, can limit individuals, preventing them from reaching their full potential (41). This can include limiting of access to basic needs, such as water, food, and agency, as well as education and healthcare (42). Our critical analysis demonstrates how the context of global economic inequity can dominate individual lives and air pollution exposures in rural Malawi (43, 44). This informs recommendations on meaningful and equitable approaches to air quality and broader environmental issues.

4.4 Methods

4.4.1 Study setting

The study, starting in June 2020, focused on a village of approximately 300 households (1,800 individuals) on the outskirts of Blantyre – Malawi's commercial capital. The village itself is rural, which describes the residences of 83% of the country's population (45). Residents speak mainly Chichewa, the most widely spoken language nationally, with limited levels of spoken English. Households include men and women of all ages, with extended families frequently living in household clusters. There are many female-headed households, as men seek employment in urban areas or neighbouring countries. Economic insecurity is common, with income predominantly derived from ad hoc piecework or self-employment (46, 47). The widespread use of solid fuel – mostly wood – for cooking, and a communal pump for water in the village reflect ways of life typical across rural Malawi (48). Deforestation is increasing nationally, related predominantly to wood use for cooking and to farmland clearing (49).

4.4.2 Historical and global context informing the ethnography

Malawi's current economic situation, and related wider transnational inequities, stem from five key global dynamics (Box 4.1) (50).

1	Colonial processes
2	Colonial influences on postcolonial regimes in newly independent nations
3	Structural adjustment programmes
4	Recent international systems of trade
5	Global climate inequity

Box 4.1. Five key points of origin of global inequity

Malawi, as Nyasaland, was under British control from 1891 until independence in 1964. This period was characterised by extractive agricultural practices in which colonially appropriated land was distributed to European settlers for growing export crops. Resident Malawians were exploited for agricultural labour (the *thangata* system), and hut and poll taxes were introduced to move Malawians into the labour market (51). After independence, Malawi was reliant on crop exports and labour emigration, firmly establishing structural poverty (52). Today, Malawi remains dependent on extractive modes of trade through exportation of raw materials for processing and manufacturing elsewhere (53).

Structural adjustment in 1981, precipitated by the oil crisis of the 1970s, brought financial assistance from the World Bank, conditional on extensive policy reforms (54, 55). Trade liberalisation and deregulation opened countries, such as Malawi, to aggressive foreign markets with highly subsidised agriculture (56). Enforced privatisation of national assets undermined democracy, harmed health, and removed social protection systems, particularly impacting vulnerable groups (54, 56-58). In Malawi, for example, forced economic restructuring to repay high-interest loans precipitated a famine which caused hundreds of deaths in 2001-2002 (59, 60).

Recent droughts and floods, intensified by the climate crisis, add to the daily challenges of rural life. Widespread deforestation amplifies the damage in flood-hit areas. These situations are characterised by large-scale inequity. Globally, the richest 10% of the population are responsible for 52% of recent carbon emissions, whilst the poorest half generate only 7% (61, 62). Food and economic insecurity are dominant issues in a population where smallholder farming accounts for 80% of food needs and where 38% live below the poverty line (63, 64).

4.4.3 Study design and approaches

The research was devised and led by a doctoral researcher of British background (SS), based at a UK institution. The core study team also included a Malawian research assistant and a Malawian fieldworker who was resident in the village. Supervisory staff were of southern African and British backgrounds.

The study used a basis of in-person participant observation around the village over 7 months, with additional research methods superimposed throughout this period. Data were brought together at the analysis stage. This allowed for a more rounded understanding of the issue than could be gained through air quality monitoring, interviews, or participant observation research alone. Multiple methods allowed assessment of the consistency of the findings across different methods ('triangulation'), contributing to the credibility dimension of 'trustworthiness' in qualitative research (65, 66). Related discussions of research approaches, participant contributions, and ownership of the research product may be found in the supplementary materials.

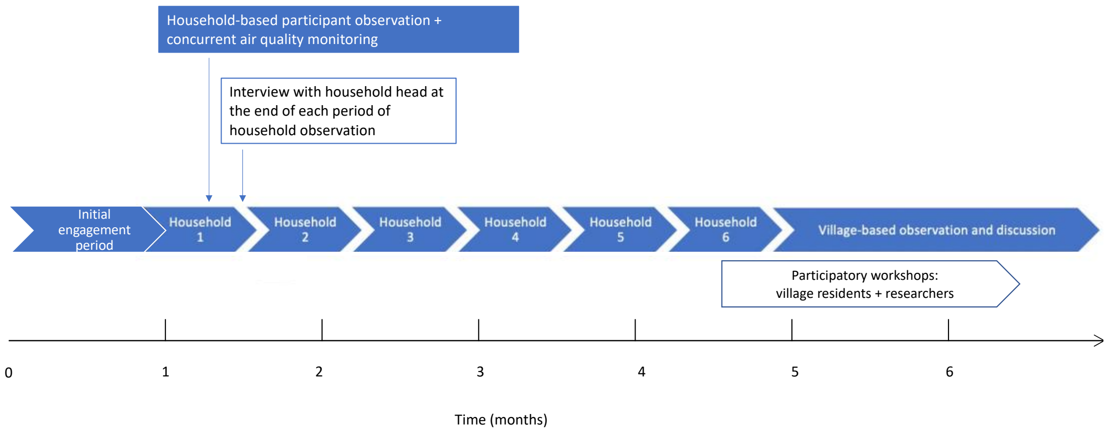

Figure 4.1. Combination of methods over the 7-month ethnographic period (further detail provided in supplementary materials)

4.4.3.1 Quantitative methods

Individual air quality monitoring was conducted during a sample of focused household participant observation periods (described below), measuring levels of inhaled fine particulate matter ($PM_{2.5}$) at 2-minute intervals. Monitoring in each household started only after a period of routine participant observation; monitoring periods were based on participants' convenience and acceptability, with purposive sampling approaches ensuring that a variety of household types, cooking factors, and additional combustion sources were included.

Researchers wore the monitors while taking part in cooking and other activities alongside key household members. A subgroup of participants continued carrying monitors overnight after researchers left the household and were asked the following morning to identify key potential exposures. Extended monitoring incorporating a larger, more representative sample; repeated 24-hour monitoring periods; and spanning multiple seasons was also carried out (chapter 3).

PurpleAir PA-II laser particle counting devices (PurpleAir, Draper, UT, USA), were used for $PM_{2.5}$ monitoring, connected to 20,000-mAh portable power banks (Anker Innovations, Changsha, China). These low-cost monitors show excellent correlation with reference standard gravimetric analysis (GRIMM reference method; R^2=0.98), with field use in various African settings (67, 68). Monitors and power banks were carried in specially designed waist bags which held the device but did not cover any the intake (sampling) port.

Each trace was partitioned into 'activity' (usually cooking) and 'baseline' periods using paired activity data (from ethnographic records and participant reports). These data were analysed using Stata 15.1 (StataCorp, College Station, TX, USA), calculating time-weighted median exposures at baseline and during identified activity periods. We assessed the association of cooking features and location against $PM_{2.5}$ using multi-level mixed-effects linear regression analysis. The fixed effect was the mean $PM_{2.5}$ level and the random effect was participant number (data and code available online: https://doi.org/10.7910/DVN/YPGUEH). Extended analyses from a broader dataset are presented in chapter 3 of this thesis.

4.4.3.2 Qualitative methods

Following gradual community introduction and consent processes, we undertook six periods of focused household participant observation, each lasting 3-4 weeks. This was followed by participant observation in various sites around the village, allowing access to a wider range of residents, sites, and activities. Researchers (SS, accompanied by the research assistant and/or local fieldworker) carried out routine activities alongside residents, including cooking, farming, and visits to the local market, with ad hoc conversations providing opportunities for deeper exploration of specific issues. Notes around smoke exposure and wider aspects of daily life were taken contemporaneously. During later conversations with village members, early themes were raised for discussion, bringing participants' perspectives into the analysis.

Individual interviews were held with household heads at the end of each household observation period, helping to confirm and clarify key findings. Finally, six once-weekly participatory workshops took place alongside the final weeks of participant observation, involving existing and new participants from the village alongside researchers. These workshops, led in Chichewa by an external facilitator, used theatre-based participatory methods to challenge traditional power dynamics often inherent in transnational research projects (69, 70). These methods are explained in further detail in the supplementary materials. Early workshops explored the roles of ‘smoke’ in residents’ lives, and later sessions encouraged participants to collectively consider ways of reducing exposure.

Interviews and most workshops were audio-recorded, translated, and transcribed throughout the fieldwork. Transcripts and field notes were entered into NVivo 12 (QSR International, Hawthorne East, Australia) and independently coded by SS and HS, who then worked together on developing and refining themes from the data. This integration of different perspectives added to the credibility of the analysis (65, 71). Early findings were used to iteratively focus the ongoing fieldwork (72). The theories we cite were arrived at through our findings in the village and were not predetermined (73).

4.4.4 Ethical considerations

The study was approved and sponsored by the LSTM Research Ethics Committee (19-007). In-country ethical approval was granted by the College of Medicine Research and Ethics Committee (COMREC) in Blantyre (P.02/19/2600). Ethical enquiry, running through the project, was characterised by the ‘relational ethics’ approach (74), as previously described (75).

4.4.5 Patient and public involvement

The local community guided methodological decisions throughout the ethnography. The involvement of a resident ‘village fieldworker’ enhanced the integration of community perspectives into the study. We discussed developing findings with residents throughout, particularly during individual and small group discussions. Participants’ contributions to the analysis are discussed further in the supplementary materials. At the end of the participant observation period, key results were disseminated across the village using simple leaflets and at a meeting with a group of key stakeholders from the village.

4.5 Results

4.5.1 Air pollution: levels and sources

Air quality data incorporated 203 monitoring hours and over 6,100 datapoints (76), including 31 female and 14 male participants. $PM_{2.5}$ concentration demonstrated a 'baseline and peaks' pattern, with spikes corresponding to specific exposure sources, such as cooking when analysed in parallel with observational data (see representative trace in Figure 4.3 in the supplementary materials). Air quality monitoring results, coupled with information from interviews and workshops, revealed cooking to be the most important source of airborne particulate exposure, both in terms of frequency and magnitude.

Approximately 31% of the pooled traces were composed of 'activity' (mainly cooking). In the other 69% of the time, with no identified biomass burning, the median $PM_{2.5}$ was 35.2 $\mu g/m^3$ (World Health Organization recommendation: 24-hour average <25 $\mu g/m^3$) (4, 77). Intense peaks of particulate matter exposure were predominantly related to cooking, with the highest levels associated with open fire cooking and cooking in poorly ventilated areas, such as kitchens (Table 4.2 in the supplementary materials). Levels peaked >1,000 $\mu g/m^3$ in 29 of the 31 female traces (all cooking-related). These activities typically took place three times a day, lasting 45-60 minutes. The median cooking activity–related exposure level across the study was 386 $\mu g/m^3$. Cooking was exclusively done by women, often assisted by children (mainly female), frequently while carrying infants on their backs. Additional exposures for women included the warming of bathwater and occasional home-based business ventures, such as roasting nuts or distilling alcohol.

More distant exposure sources were noted during observations, including fires in neighbouring compounds or village brick ovens, although concurrent personal exposure monitoring did not reveal perceptible peaks during these periods. Other particulate sources are summarised in Table 4.1.

Table 4.1. Non–cooking-related sources of exposure to airborne fine particulate matter ($PM_{2.5}$) in and around the village

Activity	Population group exposed	Frequency/duration
Brick ovens: stacks of clay bricks fired in the open using wood combustion	Mainly men, who gained income from brick making	Twice per year on average, burning continuing for approximately 48 hours
Burning of farmland	Any residents close to sites of burning (although individuals rarely continued working on the farm after burning was started, so these exposures were not captured on traces)	Sporadic through the dry season. Observations and participant accounts noted fires typically burning for short periods of time – often <10 minutes – although 'smouldering' may have continued after this time
Visits to the roadside market (roads lined with idling motor vehicles)	Village residents attending the local market (usually women and children, although men often work at markets or as roadside traders)	Once per week on average for individuals attending market, generally lasting under an hour

4.5.2 Wider influences on air pollution exposure levels

In addition to the quantitative findings, qualitative data demonstrated how scarcity shaped individuals' smoke exposures throughout the village. These data could be summarised in three themes, described below: daily hardship, precarity, and limitation.

4.5.2.1 Daily hardship

Village life for women involved daily physical and mental burdens. Women engendered the archetypal identity of a Malawian woman in this social setting through a daily resilience to these hardships. The difficulty of tending the fire and cooking *nsima* (thick maize meal, the staple food in Malawi) went beyond the smoky environment of the fire. Cooking involved a constant balancing of the heavy pot on the three support stones *(mafuwa)*, whilst vigorously stirring the thick mixture, avoiding burns from spillages or extinguishing of the fire. We witnessed how proficiency in this important act was developed from childhood, with children helping their mothers and independently playing cooking games (*masanje*) involving real fires.

In addition to cooking activities, water was pumped from the local well and carried home in large buckets, clothes were washed at the stream by pounding on rocks, and cooking pots were vigorously rubbed *(kukwecha)* with sand and grit with the palm of the hand to remove black soot. These and other tasks – long walks to the market or maize mill for instance – were made more strenuous as they frequently took place under a hot sun and were performed throughout pregnancies and while carrying babies in slings. Such daily hardships were recognised but rarely explicitly discussed by women themselves, for whom this just represented part of their normal lives.

Similarly, smoke itself was seen as unavoidable: a 'fact of life', as evidenced by the disbelieving response of, "*utsi*?" ("smoke?") we became used to hearing on introducing the study topic in the village. There was no commonly used term for 'air pollution' in Chichewa, and the concept of air being polluted (in the way that drinking water might be) was not recognised by participants. Women did laughingly acknowledge the shared experiences of stinging eyes and running noses that we felt during cooking, but these were seen only as minor inconveniences. In conversation, attitudes were stoical:

> Facilitator: *[Your eyes] They don't hurt with the smoke?*
> Female Participant: *They do hurt. So long as the* nsima *gets cooked, we just persevere*
> Workshop 3

On sharing knowledge of the longer-term health effects of smoke exposure and our findings on ventilation, for example, some residents seemed concerned. However, we observed that these concerns quickly faded in the face of more immediate priorities. Throughout daily activities, an aggravating aspect was hunger. Residents themselves worked all year round on their farms to grow maize, the staple food source. Money to purchase small amounts of additional ingredients for daily *ndiwo* (stew eaten with *nsima*) was severely restricted. Meals mainly consisted of *nsima*, with small amounts of *ndiwo*, containing green vegetables and sometimes a protein source (beans, eggs, or dried fish). Sufficient food was not always available: at times the main meals constituted black tea and bread, and sometimes were missed entirely.

> *Sometimes we can eat in the morning. Sometimes we don't have food in the morning, so we wait for 12 o'clock, and then we also eat sometimes in the evening. So when we eat three times a day, it depends on the availability of food.*
> Interview – female household head, household 3

Women did their utmost to manage food scarcity, striving to provide a respectable offering at every mealtime. Most women aspired to owning 'kitchens' (small standalone buildings) for cooking. One reason for this, although rarely explicitly mentioned, was the privacy they endowed: although economic scarcity was present throughout the village, participants did not wish this scarcity to be on public display.

> *...by our culture, women need privacy when cooking. That's the reason why I don't like cooking on the veranda. At times we may not have enough foodstuff, like tomatoes, onions, but you can still cook and eat what you can without people noticing.*
> Interview – female household head, household 6

Efforts to manage and safeguard oneself and one's family thus exacerbated the daily physical hardships witnessed in all households.

4.5.2.2 Precarity

Precarity refers to a state of insecurity or a lack of stability. In the village, residents relied heavily on the crop harvest. A poor harvest, accompanied by food price increases, could mean protracted periods of hunger. Regular employment was rare, and reliance on temporary piecework deepened economic insecurity and increased the threat of sudden impoverishment. For women, the need to support a family accentuated this. Payments from male partners employed elsewhere were inconsistent. When initial funds for investment were available, women supplemented household income via micro-business ventures, e.g., roasting peanuts or bagging and reselling charcoal.

Climate factors exacerbated these daily insecurities. We witnessed floods which washed away a participants' newly built kitchen, representing months of investment of time and money, and great disappointment amongst the (female) household head and the researchers. There was a widespread disinclination for longer-term planning or saving amongst residents, which appeared a natural response to this climate of constant uncertainty.

Lack of motivation towards investment in long-term health or environmental improvement were evident. This included dismissive responses (laughter; "we're busy"; "people can't do that") to our suggestions of tree planting, composting to replace burning of fields, or collective action to access cleaner water when the water from the local pumps appeared brown in the mornings.

4.5.2.3 Limitations on 'choice'

Throughout participant observations we saw how scarcity directly restricted individuals' options, although this was at times complicated by gendered and culturally shaped choices. Use of three-stone fires (Figure 4.2a) for cooking, or eating of *nsima* as a daily staple, were often presented as pillars of Malawian culture and as active choices. However, the landscape of these choices was constricted by availability and need. *Nsima* (made using only maize-flour and water) provided the most satiety for the lowest cost of any foodstuff. This was tacitly acknowledged by women who – in conversation about the contrast with typical British diets – stated that they would not be able to work long periods on the farm with 'only bread' in their stomachs.

For household cooking, three-stone fires were the most frequently used by far, representing a 'default' method and often used even where alternative (firewood or charcoal) cookstoves were available. The fire was a traditional mode of cooking, familiar throughout life, to which people would revert when under pressure.

> *In normal circumstances we use firewood, and that's our culture.*
> Interview – female household head, household 2

> Interviewer: *...but why do you still use the three-stone fire most of the time?*
> Respondent: *Because we are used to it.*
> Interview – female household head, household 5

Other motivations for using the three-stone fires included the adaptability of the fires when dry firewood was scarce. At these times, a range of alternative substances were burned as fuel. Maize cobs and husks were used at harvest time, producing large amounts of smoke and burning for short periods; roofing materials were sometimes burned, with residents replacing their roofs when money allowed. When times were particularly hard, bamboo mats and even household litter, including clothes and shoes, were burned for cooking fuel, as described by one participant:

> *I had to use my old reed mat to cook for my husband and child. I lit the fire with the pieces of the reed mat using the firewood stove. The whole house was filled with a huge mass of smoke. But I had no option but to cook for my family.*
> Interview – female household head, household 6

Firewood cookstoves (*chitetezo mbaula*, meaning 'protective stove' in Chichewa – shown in Figure 4.2b) had been provided to some residents by government or non-governmental initiatives but were regularly used in few households. There was a visibly awkward physicality seen in women tending these stoves, with none of the easy expertise we had grown accustomed to seeing when women cooked on the three-stone fire.

Figure 4.2. Three-stone fire (4.2a), firewood cookstove – *chitetezo mbaula* (4.2b), charcoal cookstove (4.2c)

Whilst the influences of custom and habit were apparent, the relatively restrictive fuel requirements for *chitetezo mbaula* were limiting. Charcoal cookstoves (Figure 2c) were more widely owned and particularly useful during the rainy season when firewood was damp. These mobile stoves could be used indoors to limit cooking disruption. Women often acknowledged improvements in smoke-related symptoms when cooking on charcoal:

> *… there is no smoke; there is nothing like you will be failing to breathe, no.*
>
> Interview – female household head, household 1

In these circumstances, however, free fuel – firewood – was the preferred option for most. Charcoal stoves were used sporadically; charcoal was usually bought in small bags and used sparingly. Firewood scarcity was keenly felt by residents, who talked of the loss of trees in and around the village. Participants reported a desperation for fuel, leading some to fell trees around their households which had been important for providing shade, and even certain respected trees with purported medicinal properties. The occasional felling of trees around the village graveyard and breaking traditional taboos showed how immediate need compromised deeply held principles.

The theme of scarcity-related 'limitation', or 'restriction', returned in workshops as participants considered ways of reducing cooking-related smoke exposures. Suggested technological solutions were severely limited in their capacity to bring about real change as only the most basic of these would be financially feasible. Simple parabolic solar cookers, for example, could not be used for cooking *nsima* (due to the high power-output required), which, together with constraints relating to hours of sunlight, rendered them practically useless in this setting. Any stove which required purchased fuel was similarly impractical, as was cooking with electricity, to which residents commonly aspired.

The suggestion of 'business' – described as development of an income-generating venture, allowing access to improved cooking methods – received a lot of support from the group. This highlighted participants' awareness of the role of scarcity in framing smoke exposure in their lives.

4.5.2.4 Combination of factors

The three themes above interacted in complex ways to shape individuals' access to clean air. Even when residents came to know of the health impacts of smoke, limitations in terms of access to clean fuels and technologies and competing priorities – such as physical work, securing an income, and food for the day – precluded any serious, sustained efforts to improve air quality.

4.6 Discussion

This research demonstrated high levels of particulate air pollution throughout the rural Malawian village and the importance of cooking as a prominent source. Most residents were initially unaware of the impacts of smoke on health and, in fact, did not conceptualise smoke in terms of 'pollution' or contamination. Through our time in the village, as residents became used to seeing us and familiar with our project, knowledge of these health effects became more widespread. Even so, our findings reveal how reducing these exposures might require more than health education.

Simple cooking-related factors and gendered cultural norms in the setting contributed to individual exposures – such as those associated with the use of three-stone fires – but these factors, in turn, were powerfully constrained by overwhelming economic scarcity. Scarcity mediated individuals' relationships with smoke through three mechanisms: limitations on choice, day-to-day hardships, and an underlying sense of precarity. These findings lead us to reframe 'air pollution' as one element of a wider system which structurally compromises health and thus cannot be effectively managed in isolation.

Individual exposures to airborne particulate matter breached international standards even without cooking episodes, reinforcing other accounts (6, 78, 79) and reflecting the potential for adverse health effects (4, 77). Cooking and other combustion sources may also contribute to the background or ambient air quality, as could environmental dust in this setting (80). Superimposed cooking-related exposures for women were particularly high in our analysis.

Evidence for the use of improved cooking technologies references themes of technology access and affordability (30-34) and describes clear relationships between socioeconomic status and technology uptake (29, 81). Ethnographic evidence from the present study interrogates this relationship, considering the realities of life on the ground for women in rural Malawi and their global origins.

Daily limitations were felt particularly by women, whose roles included ensuring the smooth running of their households and providing for all household members. We witnessed how 'choices' of cooking devices, fuels, place of cooking, and even daily food were severely restricted by lack of access. This makes the extent of cultural influences on these practices unclear. An example of this was the use of three-stone fires, where charcoal was in any case prohibitively expensive for most. Had there been a range of alternatives – if gas and electric stoves were freely available, for instance – how then would these choices be made, and what would be the role of culture?

Apart from direct limitations on choice, individual experiences of daily hardship and insecurity also shaped air pollution exposures in the village. Even when the health impacts of chronic smoke exposure were recognised, unpredictability and daily hardship left little room for women to consider smoke levels, still less to try to reduce smoke exposure. This echoes empirical observations that scarcity – defined simply as 'having less' – impacts attention and decision-making, typically leading individuals to focus on immediate concerns at the expense of longer-term high-level planning (82, 83). Daniel Nettle proposes that we consider socioeconomic gradients seen in health behaviours across a population from the following presupposition: "to the extent you see unpredictable health outcomes besetting your peers, worry about today rather than tomorrow" (84, p.4). Nettle's models suggest that actions to improve health follow an inverse U-shaped curve: there is an optimum amount of health behaviour, beyond which negative effects become apparent through their impacts on other aspects of life. Changes in levels of extrinsic mortality – that which cannot be mitigated by individuals' health behaviours – affect these optimum amounts. In situations of high extrinsic mortality, such as those in the Malawian village, optimal amounts of health behaviour are low. Addressing extrinsic mortality through reductions in scarcity and insecurity may be a necessary precursor to positive 'health behaviours', such as changes to cooking practices.

Our approach to understanding air pollution in the village incorporates an examination of the origins of current inequities, described as 'geographically broad' and 'historically deep' (85). This implicates colonialism and subsequent extractive models of international relations. The structural adjustment programme and subsequent debt dependence have particularly impacted subsistence-reliant rural communities (56). This ethnography depicts the multiple ways in which systems of global inequity affect the experiences and choices of individuals in the Malawian village, shaping air pollution exposures through their lives.

Extreme climate events, such as droughts and floods, accentuated individuals' precarity in the village setting. Such climate events are exacerbated by emissions of the most affluent global actors (62). Environmental colonialism, hence, leads to additional forms of structural violence (86). We witnessed a population dependent on biomass for cooking bound into complicity with local environmental degradation, thus worsening the negative impacts of serious climate events. On environmental destruction, Nixon's theory of 'slow violence' builds on the structural violence concept, suggesting that the long time frames over which environmental destruction occurs further obscures its origins (87). This makes restitution, redress, or prevention even harder to achieve.

This project combined fine-grain data on air quality with insights into individuals' lived experiences in the rural Malawian setting. Our approaches counter the 'decontextualising' gaze which can be a feature of global health research efforts. Without recognising the powerful structural forces acting on individuals and populations, recommendations relating to education and empowerment can be abstract and limited in their efficacy. Attention to broader contexts can help with considering effective responses to these complex population health issues.

Limitations relating to air quality sampling in our study may affect generalisability across the wider community. We did not capture certain activities – for example, men involved in burning brick ovens – so data on these areas are unavailable. More extensive quantitative data from an extended, standardised dataset are presented in chapter 3. The monitors held in waist bags, although close to the face when cooks were in typical squatting position during cooking, could still underestimate inhaled particulate levels due to their lower positions. If true, this adds gravity to the findings of particulate matter levels exceeding safe thresholds throughout.

Wider limitations include the necessarily context-specific nature of the ethnography and our restriction to individuals present in the village. Community members living elsewhere, particularly men, may have differing perspectives to contribute, the inclusion of which would be important in forming a more comprehensive account.

4.7 Conclusions

This ethnography represents an in-depth, contextualised account of air pollution in a rural setting in southern Africa. The results reveal how structural inequities, rooted in historical transnational relations, shape health concerns. Clean fuels for cooking – critical for bringing air pollution exposures in line with international standards – are currently inaccessible to rural Malawian communities because of the associated costs and required infrastructure, both at the individual and governmental levels (88). Ultimately, complex global health issues, such as air pollution, demand broad, transdisciplinary approaches, placing communities and their experiences at the centre of research efforts. Solutions to these issues extend into the political sphere (89).

4.8 Supplementary materials

4.8.1 Approach

Throughout the project, I (SS) – as a researcher from a British background – maintained an awareness of potential pre-existing power differentials in the field, in terms of economic inequalities and the deeper imperialist contexts, and of their impacts on ethical research conduct and experiences in the field (90). A commitment to countering these imbalances started from a place of continuous reflection, ethical provisions, and a commitment to incorporating contextualised voices and perspectives as a driving force throughout the project (40). This was in keeping with the wider epistemological approach of the project, moving beyond binaries of knowledge and power (that of intervention 'donor' and 'recipient', for instance) (91). The resulting ethnography could thus be likened to 'bricolage': an amalgamation of diverse knowledges around the issue of air pollution in the given context (92). While this approach has been important throughout our fieldwork and beyond, we, as researchers, also recognise the inherent limit to the redistribution of power in the project, given the central role of researchers in project development, implementation, and data assimilation into the final ethnographic product (93). Indeed, even the participatory elements of this project make no claims to true participatory action research.

Our initial introductions within the community were in keeping with the epistemological approaches outlined. Explanations around the rationale for the project involved conveying what we knew about the effects of 'smoke' on health and explaining our desire to understand more about smoke in the village, aiming to work together to explore whether and how it might be possible to reduce smoke exposures in the village context. At all points through the project, we combined this open sharing of our knowledge with an expressed desire to learn from residents. This knowledge-seeking was evident in my continuing efforts to learn the language, which extended through all of my interactions in the village, as well as an eagerness to 'learn through doing' in all aspects of daily life, including farming, bringing water, and cooking activities.

This aspiration for a balanced sharing of knowledges, and a redressing of power imbalances, continued in our analysis. An example relates to our insights – through the extended period of engagement in the field – into the interplay between 'cultural practices' (such as cooking on a three-stone fire) and elements of structural limitation affecting the availability of alternative choices. This apparent conflict relates to a potential critique of 'cultural relativism': broadly, the concept of understanding values and practices of a cultural group on its own terms, rather than judging from external perspectives (94). Farmer describes how cultural relativist approaches can sometimes conceal power differentials and injustice, through the 'othering' of ethnographic subjects (95).

In relation to cooking practices, while most women were accustomed to cooking on three-stone fires, we saw how these practices and preferences were formed within a context of great limitation. Whilst our structural violence lens could be blamed for making disempowered 'victims' of participants in this context, we felt it important to acknowledge the limitations and consider what participants might aspire to in their absence, rather than accepting the current situation as 'culturally normal'. This relates back to our critical approaches (43), interrogating contextual and historical factors underlying power differentials which shape current landscapes. Such approaches bring the possibility of a deeper, more equitable research engagement, representing empowerment and a liberation from limitations rather than their acceptance.

4.8.2 Individual methods

4.8.2.1 Participant observation

The initial participant observation elements of the study began with the researchers (myself, the main researcher, SS, and my research assistant, HS) walking around the village, discussing research plans with interested residents and hearing their views. Community introductions, including discussions with key figures in the community, such as the chief and village health volunteer, were also part of this early work. The main part of the participant observation element – so-called 'focused household participant observation' – involved two researchers spending long days with household members, spending periods of 3 to 4 weeks at one household before moving to the next. In this time, researchers lived, worked, and rested alongside household members, taking part in activities, including water collection, cooking, and farming, as well as accompanying residents on local outings, for example, to the market.

Time spent with household members varied from long days, including the occasional night, to more focused time periods, incorporating meal preparation and eating, or farming activities, for example. This developed into a form of theoretical sampling, taking place iteratively through the fieldwork period in response to changing relationships and findings in the field. Written field notes made during activities included observations around factors directly relating to smoke exposure and wider aspects of daily life which shaped these exposures. Ad hoc conversations in the field helped to probe more deeply into areas of interest.

Initial participant observations were carried out by the myself and my research assistant, HS, but 2 months into the fieldwork period, a local resident joined the study team in the role of fieldworker. For subsequent participant observations, I was accompanied by one or both of my research assistant and fieldworker. This afforded additional ethnographic perspectives, more akin those of an 'insider', given the fieldworker's residence in the village since birth and extensive familial connections within the community.

Village-based participant observation constituted the core of the ethnographic work, chosen in view of the contextualised nature of smoke exposures in the village setting, with the village itself constituting a 'culture-sharing group' (96). The household, in particular, has a central role in shaping the experiences of many people living in a rural setting such as Malawi. Starting at the level of individual households created a sort of graded entry into village life, helping us become better known amongst the wider village community, allowing access to shared community sites and events, and enabling later spontaneous conversations throughout the village. These conversations generated continuing engagement throughout the project between researchers and residents, from early discussion of the research plans and recruitment, throughout subsequent project development.

In the weeks following completion of the six participatory workshops, the discussions with residents of the village, as outlined above, continued, now creating opportunities for wider engagement with the developing intervention ideas. Written field notes from these discussions were analysed together with the participant observation data.

Limitations in the extent of involvement of participants in theme development and 'checking' were inherent in the study, however. Themes were inductively derived from daily experiences with residents and collaboratively developed by research team members, allowing for some triangulation, and key ideas were broached for discussion at various points in the ethnographic period for discussion with residents. The nature of some of the latent themes – 'precarity', for example – informed by 'outsider' perspectives and western academic epistemologies, meant that analytical discussions of these topics with participants were often unproductive.

4.8.2.2 Individual interviews

At the end of each focused household period, an individual interview was arranged with a key member of the household. The purpose of this was to create space to recap some of the key findings and discuss potentially differing perspectives of researchers and household members, as well as to allow for deeper discussion of particular areas or issues where necessary. Interviews, carried out by the research assistant but with the main researcher also contributing, took place in Chichewa, with the research assistant translating responses for the main researcher where necessary. Interviews were audio-recorded and later translated into English and transcribed by the research assistant, with a Malawian transcriber fulfilling this role for a few of the later interviews for reasons of time. In these cases, completed transcripts were reviewed by the researcher and research assistant alongside recordings to ensure quality and consistency of transcription and translation. Although a denaturalised approach to transcription is not relevant where translation is also incorporated, both research assistant and transcriber used adapted denaturalised approaches where possible, to optimally represent the nature of the spoken conversation as it took place (97).

4.8.2.3 Air quality monitoring

During the later stages of household participant observation, personal air quality monitoring was introduced to provide quantitative information on exposures to airborne particulate matter by time, place, person, and activity. This component involved researchers carrying mobile air quality monitors in small waist bags alongside participant observations. At times, a small number of household members were asked to continue carrying monitors (in waist bags) overnight after researchers left the household, with a short 'debrief' the following morning when the monitor was returned, to register key potential exposure points. This quantitative data lies outside the scope of the current report; the outlining of the methods above is provided only for completeness.

4.8.2.4 Participatory work

A series of six once-weekly participatory workshops, conducted in Chichewa and involving approximately 15 participants (members of the local community) and the three field researchers, were arranged alongside the final weeks of participant observation. These workshops aimed to further explore the different sources of smoke in participants' daily lives and to allow people to think together about ways of reducing their levels of smoke exposure. Workshops were led by an external consultant (EM): a community theatre practitioner and researcher who, whilst of British background, has many years of experience working with communities in Malawi and whose approaches fit closely with the epistemologies underlying the project. EM specialises in the use of participatory theatre methods for research purposes, in particular Boal's Theatre of the Oppressed (98), using elements of physicality and the body to break down conventional 'researcher/researched' dynamics, and an action-reflection discourse through the processes to explore realities as they are, and to co-create imagined futures. This action-oriented research approach was well-suited to the current project, creating a community of co-learning and questioning, providing valuable spaces for researchers and participants to exist as individuals together, and opportunities to uncover new knowledges that might otherwise be harder to access (69). The parallel involvement of research team members and residents allowed this to act as an additional component of the ethnography. Five of the six workshops were audio-recorded (the first workshop, being active in nature and involving mainly familiarisation games, was not).

4.8.3 Qualitative data analysis

Participant observation, involving observation and conversations in the field was accompanied by the contemporaneous recording of written field where possible. These field notes covered aspects of my learning (SS) around daily activities such as learning to light a fire and cook meals, and details of accompanying discussions relating to features of these activities and how they were experienced by residents as part of their daily lives.

Daily reflexive discussions with the Malawian research assistant (HS) around elements of observations and conversations. This helped to further explore observations I (SS) had made but perhaps not fully understood, and was particularly useful in terms of subtler elements where I was limited by my basic levels of spoken Chichewa and cultural understandings, and where the contextually grounded perceptions of my research assistant were invaluable. Further conversations with the resident fieldworker (DM) contributed additional insights here (as recounted in chapter 6). Reflexive notes were also taken during these discussions, and these data, together with field notes, were entered into NVIVO 12 for analysis.

Individual interviews with household heads were recorded, as were most of the participatory workshops (see above), and after translation and checking, these were also added to the data in NVIVO along with reflexive notes made during and after the interviews and after participatory workshops.

A form of reflexive thematic analysis was used for the analysis (99). This provided the necessary theoretical flexibility and allowed us to inductively develop themes from the data, iteratively expanding, revising, and refining them as the data developed.

I (SS) first read through the data a number of times, reflecting on their content, discussing key points with my research assistant and fieldworker, and considering key elements that recurred throughout the data, as well as any seemingly conflicting elements. I then began coding, examining all the data in detail a few times and creating specific inductive codes. These were at first more descriptive (eg. 'use of charcoal', 'symptoms due to smoke') but over time, latent elements began to develop.

Iterative examination of the codes then led to my development of key themes, with relevant data (and codes) relating to each. Again, themes were initially more descriptive, before starting to develop latent themes such as limitation and precarity. These descriptive and latent themes were reviewed and refined with reference to the coded data and more newly emerging data: processes which continued in an iterative manner, even as the fieldwork process was continuing. Finally, a number of key themes were confirmed, and the three latent themes, all coming under the category of 'extreme scarcity', were prepared for presentation in a draft 'results' section.

Whilst the analytical process was owned and led by myself (SS) – with repercussions around 'ownership' of the ethnography and findings, as discussed above – in the development of themes I again benefitted from input from the research assistant (HS) throughout. Throughout the analytical process we frequently discussed key themes, how they related to the data, and how best to develop and refine these in view of continually developing observations in the field.

4.8.4 Results

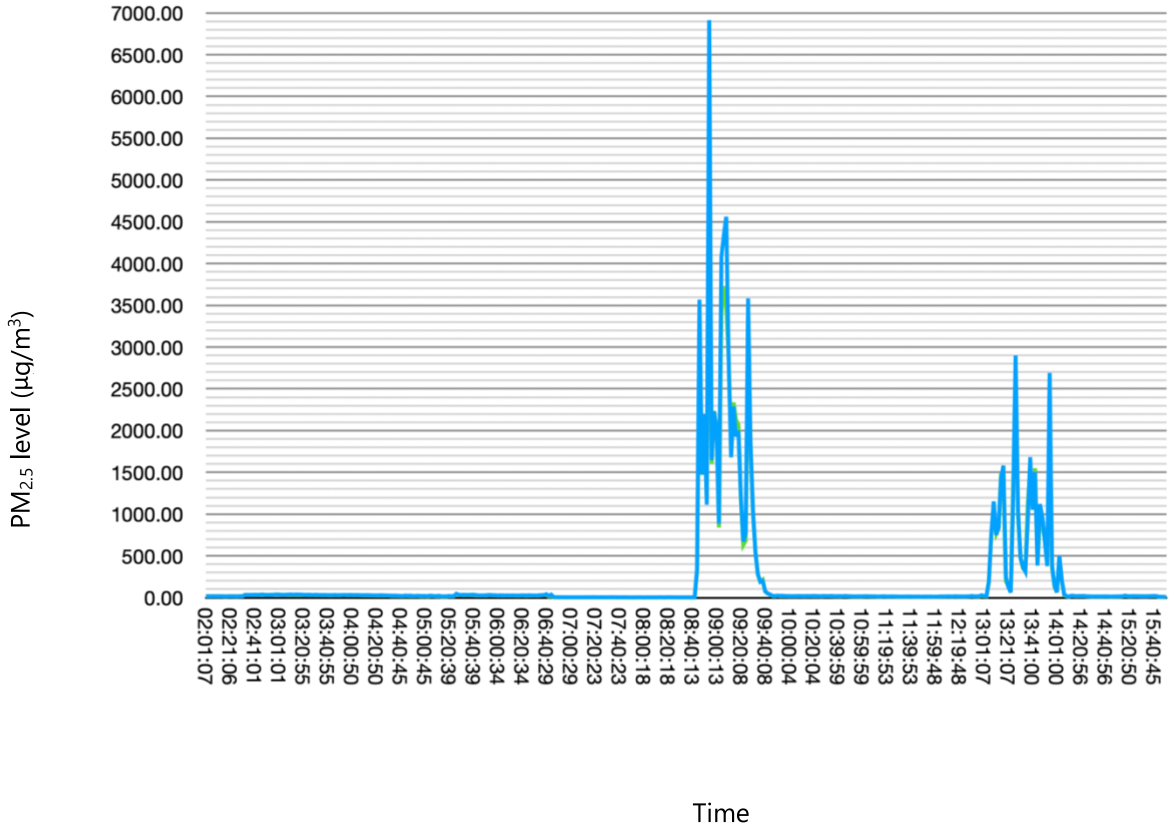

Figure 4.3. Sample $PM_{2.5}$ trace for a female household resident

Table 4.2. Mixed-level regression model to determine the relationship between individual and activity on mean $PM_{2.5}$ exposure. There were 6,091 individual observations with 31 groups. The minimum observations per group were 27 and maximum 596 (average 197). Wald X^2 = 2,904.35

		Coefficient	Standard error	*P* value	95% Confidence interval	
Activity	No activity					
	Cooking	291.7	90.4	0.001	114.5	468.9
	Other	60.0	57.7	0.298	−53.0	173.0
Stove	No activity					
	Three stones	−234.0	233.9	0.317	−692.4	224.4
	Mbaula firewood	−654.2	239.6	0.006	−1,123.7	−184.6
	Mbaula charcoal	210.8	133.5	0.114	−50.8	472.5
Location	No activity					
	Walled veranda	200.8	36.4	<0.001	129.4	272.2
	Unwalled veranda	−164.2	41.1	<0.001	−244.8	−83.6
	Outdoors	−133.5	54.9	0.015	−241.1	−25.9
Fuel	Firewood	639.0	235.6	0.007	177.3	1,100.7
	Constant	104.7	55.1	0.058	-3.3	212.7

Random-effects parameters participant number	Estimate	Standard error	95% Confidence interval	
sd (_cons)	302.4	43.0	228.9	399.6
sd (residual)	443.7	4.0	435.9	451.7

4.8.5 Declarations

4.8.5.1 Acknowledgements

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4.8.5.2 Authors' contributions

SS: conceptualisation, methodology, formal analysis, investigation, resources, data curation, writing (original draft and review), visualisation, funding acquisition

HS: methodology, validation, formal analysis, investigation, data curation, manuscript review, project administration

KM: conceptualisation, manuscript review, supervision

BM: software, data curation, manuscript editing

JR and MK: manuscript review and editing, supervision

MC: conceptualisation, manuscript review and editing, supervision

4.8.5.3 Competing interests

None declared

4.8.5.4 Patient consent for publication

Not required

4.8.5.5 Provenance and peer review

Not commissioned; externally peer reviewed

4.8.5.6 Data availability statement

Data are available upon request. Due to potentially identifiable participant information, even where deanonymised, qualitative data are not publicly available but may be made available on individual request.

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Chapter 5: Village-wide cookstove intervention

In view of the ethnographic findings on the overwhelming influence of extreme scarcity in individuals' lives and cooking experiences, the planning of a context-appropriate intervention for improving air quality became very challenging. In addition, while many residents now understood the long-term health impacts of air pollution, more immediate priorities in their lives clearly took precedence. A further consideration for us as researchers (incorporating the field research team) at this point was the wish to offer a form of locally valued support to the community, as a logical 'next step' to cleaner cooking and in recognition of their welcome and involvement.

The introduction of electricity microgrids and large solar panels, as proposed by a few participants, was outwith the scope of this project, and in any case would not have provided sufficient power to meet domestic cooking needs. Parabolic solar cookers were similarly unsuited to local cooking requirements, being unable to provide sufficient heat to cook the local staple of *nsima*. We, therefore, finally planned – in line with suggestions from some households – to provide locally made clay cookstoves to all households in the village.

These stoves were seen as 'desired objects' by many in the village, and their use in a few households led us to believe in the potential for wider uptake. Procurement and distribution were implemented in partnership with a local non-governmental organisation who provided the stoves at a reasonable price, also offering future trade to residents. The low cost of the stoves was key here – embodying the promise of sustainability beyond the research period. Existing evidence – as reviewed earlier in the thesis – led us to a clear understanding of the limited capacity of these stoves to make sufficient reductions in individual exposures for immediate clinical benefits. A reframing of perspectives throughout this project, however, led us to a dual aspiration: immediate supportive provision to meet residents' felt daily needs, alongside a longer-term aspiration to utility-scale clean energy. The latter represented a realistic path to significantly impacting previously identified high air pollution exposures and their clinical sequelae.

This chapter presents results of our evaluation of this whole-village intervention. Our concurrent use of quantitative and qualitative methods (individual exposure monitoring and participant observation), echoing our earlier approaches, allowed for the integration of multiple perspectives to deliver a rounded account of the intervention.

“We threw away the stones”: a mixed-method evaluation of a simple cookstove intervention in Malawi

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5.1 Abstract

Background: Exposure to air pollution is responsible for a substantial burden of respiratory disease globally. Household air pollution from cooking using biomass is a major contributor to overall exposure in rural, low-income settings. Previous research in Malawi has revealed how precarity and food insecurity shape individuals’ daily experiences, contributing to perceptions of health. Aiming to avoid a mismatch between research intervention and local context, we introduced a simple cookstove intervention in rural Malawi then analysed changes in fine particulate matter ($PM_{2.5}$) exposures and community perceptions.

Methods: Following a period of baseline ethnographic research, we distributed *chitetezo mbaula*, locally made clay cookstoves, to all households (n=300) in a rural Malawian village. Evaluation incorporated village-wide participant observation and concurrent exposure monitoring using portable $PM_{2.5}$ monitors at baseline and follow-up (3 months post-intervention). Qualitative data were thematically analysed. Quantitative analysis of exposure data included pre- vs post-intervention comparisons, with datapoints divided into cooking and non-cooking (‘baseline’) periods. Findings were integrated at the interpretation stage, using a convergent design mode of synthesis.

Results: Individual exposure monitoring pre- and post-cookstove intervention involved a sample of 18 participants (15 female; mean age 43 years). Post-intervention $PM_{2.5}$ exposures (median 9.9 µg/m^3 [interquartile range: 2.2–46.5]) were not significantly different to pre-intervention (11.8 µg/m^3 [3.8–44.4]) exposures (*P*=0.71). On analysis by activity, 'baseline' exposures were found to be reduced post-intervention (from 8.2 µg/m^3 [2.5–22.0] to 4.6 µg/m^3 [1.0–12.6]; *P*=0.01). Stoves were well-liked and widely used by residents as substitutes for previous cooking methods (mainly three-stone fires). Most cited benefits related to fuel saving and shorter cooking times.

Conclusions: The cookstove intervention had no impact on cooking-related $PM_{2.5}$ exposures. A significant reduction in baseline exposures may relate to reduced smouldering emissions. Uptake and continued use of the stoves was high amongst community members, who preferred using the stoves to cooking over open fires.

5.2 Introduction

Air pollution – in particular, fine particulate matter ($PM_{2.5}$) – is a widely recognised risk factor for cardiorespiratory and wider systemic disease, and the interactions between airborne particulates and climate change also have repercussions for health (1-3). In Malawi, which is largely rural, air pollution is a persisting problem, stemming mainly from domestic cooking: Malawian households cook, on average, three times per day, using biomass fuel (usually firewood) on three-stone fires (4).

Recent ethnographic work on 'smoke' in the Malawian setting highlighted the ways in which local experiences and values – often very different from those of western researchers – can shape locally relevant priorities for intervention and contextualised approaches (4). Centring local perspectives in this way, as well as constituting arguably the 'right' approach to global health problems, can optimise the suitability and sustainability of any subsequent solutions (5-7).

In rural Malawi, where experiences of precarity, scarcity, and food insecurity are common, these contextual realities often take precedence over externally proposed agendas such as ours. In a recent study exploring Malawian communities' perceptions of health within a trial of advanced cookstoves (8), participants linked good health primarily to food security (9). Thus, the research imperative in such contexts should be for cleaner air solutions which avoid amplifying existing daily challenges for residents and appropriately address shared concerns. In considering options for cleaner cooking in low- and middle-income countries (LMICs), such as Malawi, economic affordability for the majority is a key consideration (10-13). Whilst initial costs of clean stoves are important here, also relevant are costs of ongoing fuel purchase, as well as maintenance and repair costs of any newly introduced technologies (14-17).

Perceptions of the benefits of new technologies are also context specific. Studies set in various LMICs have cited flexibility, in terms of fuel use or place of cooking (18, 19), and ability to cook quickly or for large numbers of people (12, 20, 21) as important considerations. Whilst cleaner-burning biomass-fuelled cookstoves have been largely rejected by health researchers due to suboptimal emission reductions, features such as more efficient fuel use are themselves highly valued by local populations, with consequent potential environmental impacts conferring additional advantages (22). Thus, while individual household interventions will not be sufficient to achieve clinically impactful reductions in $PM_{2.5}$ (23, 24), there may be benefits to community-level adoption of locally relevant cleaner stove types in low-income settings, such as Malawi. This could represent a useful interim step on the way to the much-needed provision of clean fuels at scale (25).

Following an extended period of ethnographic and monitoring groundwork in a village in Malawi (4), we provided locally made clay stoves to every household. Realist evaluation aimed to assess residents' views of the cookstoves, as well as any changes in personal $PM_{2.5}$ exposures 3 months after cookstove distribution.

5.3 Methods

5.3.1 Study setting and population

The study was set in a rural village of approximately 300 households in southern Malawi, which was the site of previous ethnographic and baseline monitoring work (4). Cooking, mostly carried out by female household members on three-stone fires, constituted the main source of $PM_{2.5}$ exposure in this setting (26). Further contextual details are as previously reported (4). All households in the village were involved in the participant observation work and the intervention, as well as in qualitative elements of the evaluation. For exposure monitoring, consenting adult participants were recruited with an aim of achieving a broadly representative sample of village residents, including both men and women, members of different household sizes and structures, and varied cooking needs. These participants had to be resident in the village and habitually spending 6 or more days per week in the village setting. Children (aged under 18 years) were excluded.

5.3.2 Study design and intervention

This was a before-after study. Following a period of extended participant observation around the village and individual baseline exposure monitoring of a total of 23 residents (between

February and March 2020), all households in the village were given a locally produced firewood cookstove, or *chitetezo mbaula*, meaning 'protecting stove' in Chichewa. These are moulded, natural-draught cookstoves made of clay, promoted by the non-governmental organisation sector in the region (27) and recently piloted in rural Malawi in advance of a large cookstove trial (28).

The cookstoves were introduced to key local representatives (including the chief and a local health surveillance assistant) at a small village meeting, with explanations of their use and some expected benefits, before distribution – without cost – to households. Although they were known about by many in the village, few households already owned one of these firewood cookstoves.

After 3 months, researchers (PhD research candidate, SS, and research assistant, HS) returned to the village for continued participant observations around the village. The originally sampled 23 residents were approached again for involvement in repeat $PM_{2.5}$ exposure monitoring (March–April 2021) during the same evaluation period. These methods are depicted in Figure 5.1 below.

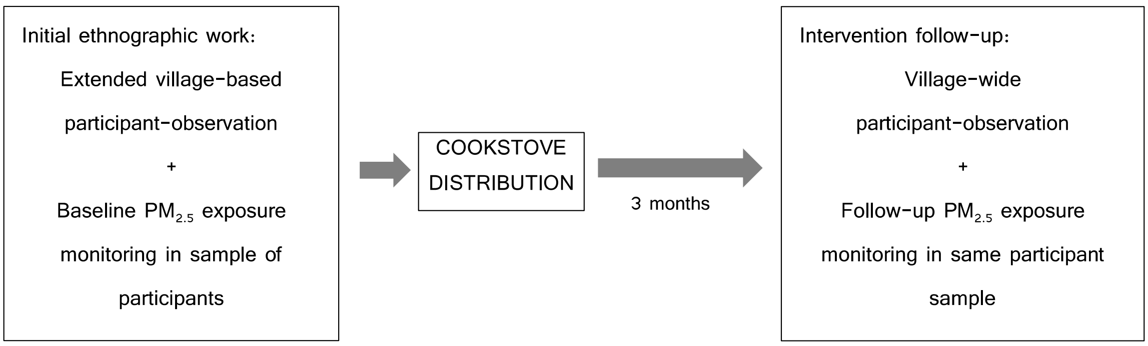

Figure 5.1. Visual depiction of study flow and combination of methods

5.3.3 Data collection

5.3.3.1 Quantitative data collection

The original sample of 23 participants who took part in air pollution exposure monitoring were asked to each spend a further period of 48 hours carrying personal air quality monitors to assess post-intervention $PM_{2.5}$ exposures. PurpleAir PA-II-SD laser particle counting devices (PurpleAir, Draper, UT, USA) were used, as in the pre-intervention phase, again with 20-Ah portable power banks (Anker Innovations, Changsha, China), carried in specially designed waist bags. The devices took $PM_{2.5}$ readings at 2-minute intervals throughout the monitoring period.

As in the baseline study (26), on monitor collection, memory cards were removed, and the data were used to create simple line graphs on a laptop. The graphs were then viewed by the participant and researcher together and used as a basis for activity recall. This technique (developed on the basis of earlier work using monitoring alongside participant observations), allowed for division of all traces into periods of 'baseline' (no identified exposure) and 'activity' (where a specific source of combustion was identified). Further information was gathered around each identified episode of activity (including bathwater warming or fire/stove use for heating), such as place of cooking, stove or device used, and fuel used (29).

5.3.3.2 Qualitative data collection

Participant observations were carried out by the doctoral researcher (SS) and Malawian research assistant (HS), together with a local fieldworker – a village resident – and centred around cooking activity. As the researchers and village residents were familiar with each other, following the initial period of ethnographic participant observation, observations were now spread around the village without the prior focus on a small number of individual households. Researchers visited the village on most days each week over a period of 10 weeks, spending time in all areas of the village over this observation period. Participant observation at this stage involved less active involvement by researchers in daily activities and more passive observation and discussion. Observations were mainly focused around evidence of stoves, fires, food, and fuel use.

Discussions were often based around cooking activities, partly because this was the activity families were most often engaged in when spending time around the household. These discussions were, in reality, more unstructured, participant-led conversations and mainly concerned cooking and stove use, although other related topics were incorporated as was felt relevant by participants and researchers. Ad hoc conversations were held with any willing community members who were present at the time of our visits (although care and attention were always given to ethical issues, including questions of confidentiality). In view of the social nature of the village setting, these conversations, at times, involved several women, either from an extended family group or a group of village residents. At other times, conversations were held with individual men and women. Conversations usually took place at residents' homes, almost always outside houses, in yards or verandas. Contemporaneous field notes were made during this fieldwork, integrating discussion content and observations.

5.3.4 Data analysis

5.3.4.1 Analysis of $PM_{2.5}$ exposure data

Descriptive comparisons of the proportions of recorded time (datapoints) spent cooking and specific cooking features (place, device, and fuel used), before and after stove introduction, were produced. Exposures before and after introduction of the stoves were compared using medians and interquartile ranges (IQRs). Following division of all exposure datapoints into 'activity' or 'baseline' categories using matched time-activity data, medians and IQRs before and after intervention introduction were compared for both 'baseline' and 'activity' subcategories. For boxplots, corrected $PM_{2.5}$ values were used: values were log transformed after adding 0.1 to allow log transformation of zero values. For statistical comparisons of pre- and post-intervention exposures, median exposures for each participant (pre- vs post-intervention) were compared using a Wilcoxon signed-rank test. A non-parametric test was chosen because the data did not consistently show a normal distribution (30). Data were analysed using R (R Foundation for Statistical Computing, Vienna, Austria)(31), and the package ggplot2 (32) was used to create plots.

5.3.4.2 Analysis of participant observation data

Field notes were jointly reviewed and reflected on by SS and HS, with input from the local fieldworker, and tentative themes were iteratively developed through these discussions. Content from field notes was entered onto NVivo 12 (QSR International, Hawthorne East, Australia) for formal coding (SS) and review (HS). The combination of participant observations with personal monitoring allows a number of benefits, including triangulation – avoiding a reliance on 'self-report' by participants – and introducing insights into how interventions work within social contexts (33), particularly important in the case of an intervention centred so firmly in the domestic sphere.

The combination of qualitative and quantitative enquiry, with each applied as appropriate, was used here as it allowed for a fuller exploration of outcomes, particularly important for complex interventions with social elements (34, 35). Rather than separate but parallel applications and analysis, an integrated synthesis was used, allowing for more in-depth findings than when either single methodology is used alone. Qualitative and quantitative data collection were undertaken concurrently by the same research team, with integration happening at the interpretation stage: the so-called 'Convergent Design' model of mixed-method research (36).

5.4 Results post-intervention

Between February 2020 and April 2021, 18 participants (15 female; mean age 43 years, standard deviation 14.2) completed the study with matching pre- and post-intervention traces (February–March 2020 and March–April 2021, respectively). The predominance of women in the sample reflected the female preponderance among cooks in the village. Three participants were lost from the full pre-intervention monitoring set (originally 23 participants) due to participants moving away from village (n=2) and participant death (n=1), and problems with monitors and batteries left only 18 with matching traces. The overall pre- and post-intervention dataset incorporated 1,563 hours of monitoring time (including 788 post-intervention hours). In the pre-intervention dataset, trace lengths ranged from 23.3 to 58.5 hours (median 43.1 [IQR: 39.3–49.2]). Post-intervention traces ranged between 24.1 and 53.9 hours (median 48.6 [IQR: 40.7–49.1]). Traces shorter than 48 hours were due to battery faults.

Of the total recorded period (pre- and post-intervention), 351 hours (22.5%) constituted 'activity', of which 92% was cooking (including bathwater warming) activity. Other non-cooking activities included exposure to others' fires or stoves (such as when socialising at a neighbour's household) and burning grass on farmland. A larger proportion of the total post-intervention monitoring period constituted combustion activity compared with pre-intervention (30% post-intervention vs 23% pre-intervention). Further details are available on Harvard Dataverse (29).

5.4.1.1 Cooking characteristics

In the baseline dataset, most of the cooking time (across the dataset) was spent using three-stone fires, with the remaining time (<20%) spent using charcoal or firewood stoves. After introduction of the firewood cookstoves to all households, >95% of the overall cooking time was spent using the new stoves, with consequent reductions in use of three-stone fires and charcoal stoves, now together constituting <5% of total cooking time (29) (Figure 5.2).

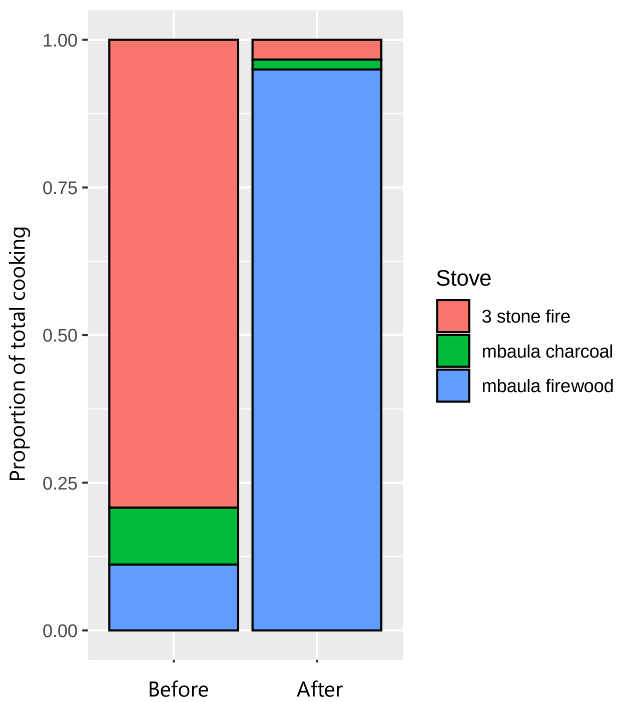

Figure 5.2. Proportion of overall cooking time by stove use, before and after intervention introduction

There were significant differences in fuel use between the pre-intervention and post-intervention phases, with maize cobs widely used (in all but three households) post-intervention (Figure 5.3). This was linked to the timing of the harvest: whilst the pre- and post-intervention periods occurred at a similar time of year, the post-intervention phase coincided with the immediate post-harvest period such that maize cobs were freely available in the village and tended to be preferred as fuel over other available fuel types, such as wood and charcoal (29).

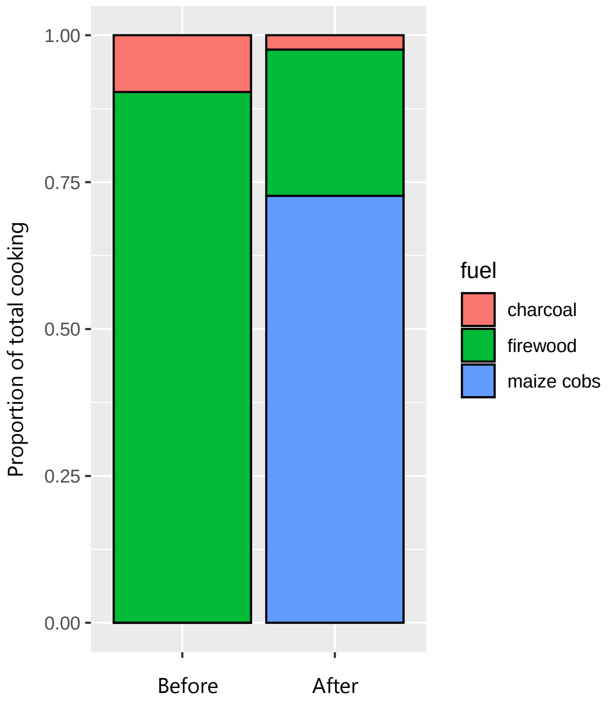

Figure 5.3. Proportion of overall cooking time by fuel use, before and after intervention introduction

5.4.1.2 $PM_{2.5}$ concentrations before and after cookstove introduction

Median overall $PM_{2.5}$ concentrations pre- and post-intervention were not significantly different (medians 11.8 μg/m^3 [IQR: 3.8–44.4] and 9.9 μg/m^3 [IQR: 2.2–46.5], respectively) (corrected data shown in Figure 5.4, with dotted line to denote the World Health Organization (WHO)–recommended 24-hour upper limit [$PM_{2.5}$ concentration 15 μg/m^3]) (37). Comparison of pre- and post- intervention medians grouped by participant number confirmed no significant difference between these concentrations (Wilcoxon V=95; P=0.70).

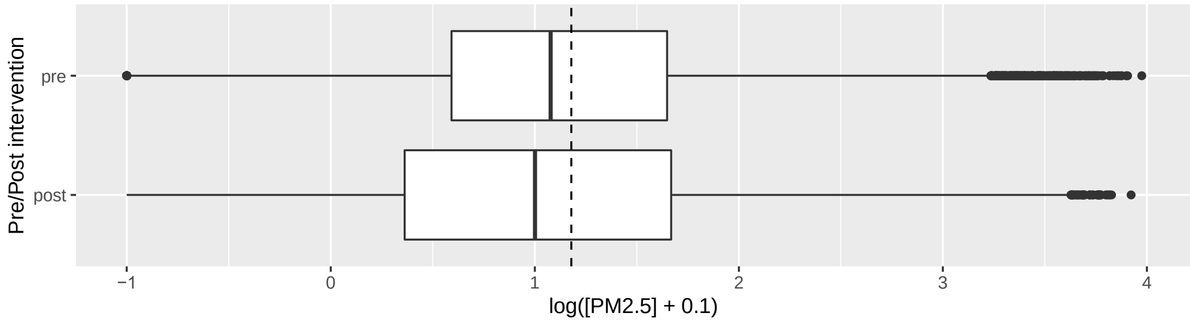

Figure 5.4. Box plot depicting corrected overall median $PM_{2.5}$ exposures before and after cookstove introduction. Dotted line indicates WHO-recommended 24-hour upper limit ($PM_{2.5}$ concentration 15 μg/m^3)

Matching activity data to traces, we found that the medians and IQRs during cooking activity before and after cookstove introduction were not significantly different (medians for cooking-related concentrations pre- and post-intervention 79.4 μg/m^3 [IQR: 21.5–397.0] and 80.6 μg/m^3 [IQR: 36.3–307.4], respectively (V=86; P=1.00). Median and IQR concentrations were above WHO-recommended 24-hour upper limits throughout (corrected data shown in Figure 5.5a).

During 'baseline' periods (no identified combustion activity), there was a statistically significant reduction in median $PM_{2.5}$ concentrations after the introduction of stoves, from 8.5 μg/m^3 (IQR: 3.0–21.4) to 4.6 μg/m^3 (IQR: 1.0–12.7) (V=123; P=0.03). This reduction brought more of the values below the WHO-recommended limits (corrected data shown in Figure 5.5b).

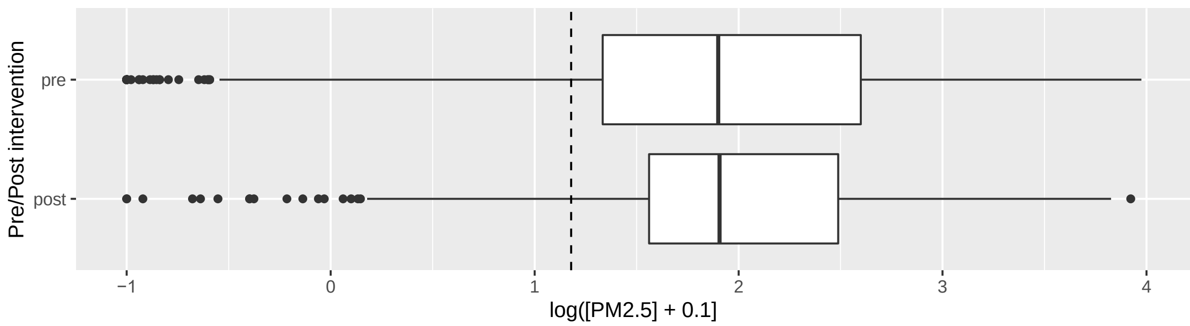

Figure 5.5a. Box plot depicting corrected cooking-related median $PM_{2.5}$ exposures before and after cookstove introduction. Dotted line indicates WHO-recommended 24-hour upper limit ($PM_{2.5}$ concentration 15 μg/m^3)

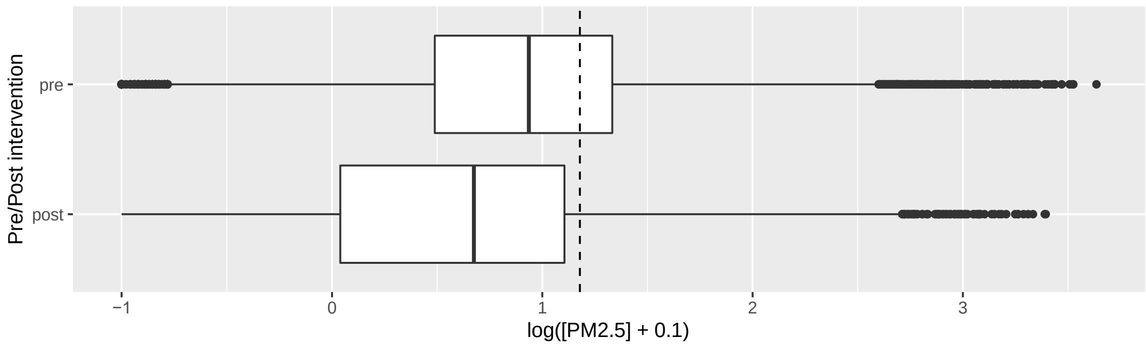

Figure 5.5b. Box plot depicting corrected 'baseline' median $PM_{2.5}$ exposures before and after cookstove introduction. Dotted line indicates WHO-recommended 24-hour upper limit ($PM_{2.5}$ concentration 15 μg/m^3)

5.4.1.3 Qualitative findings

Cookstove use

Observations throughout the village supported the finding from the monitoring sample of high cookstove uptake rates. On walking through the village, we frequently found people cooking on the cookstoves, and there was good evidence of cookstove use at households we passed. Almost all the cookstoves were blackened with cooking smoke, and they were often covered in maize meal, suggesting habitual use. Notably, where previously three stones were to be seen in and around almost every household, these were now much less frequently seen. In some cases, the stones or bricks were seen to be discarded outside the yard. This was confirmed when raised in discussion with female household members who, when asked where their three-stone fires were, responded, "*palibe* (there are none) – we threw them away".

This finding, while frequent, was not universal, however. In discussions, a few residents mentioned using fires concurrently with their stoves if cooking had to be done quickly. In two households, women reported children (who were unused to the new stoves) using fires for cooking, and some women said that the stoves could not be used for very large amounts of food (for example when making *thobwa*, a fermented maize drink, and for cooking during special occasions, such as weddings and funerals), although others' accounts asserted the opposite view, confirming their use of the new stoves for these purposes.

One reason for not using the new stoves, which was raised during several discussions, was that firewood was sometimes in low supply. This related to the season, where there was little firewood to be found on the ground, and this was sometimes damp or wet. In this situation, some residents bought small bags of charcoal, using this on charcoal stoves for the necessary household cooking. Charcoal cooking was infrequently seen, however, and was avoided by most in the village where possible, mainly due to its costs (4).

Perceived benefits of cookstoves

In response to questions around why participants liked and used the new cookstoves, there were a range of responses, of which the most common was that the stoves saved firewood. Participants used the same fuel as they would have used on their three-stone fires – maize cobs (and at times maize stalks) and wood – and many claimed that their stoves "uses fewer maize cobs or firewood pieces than three-stone fires". The stoves were thus felt to be cost-saving. A field note made during a conversation with a resident, which – when raised – resonated with many others, read:

> (Female participant explained that) *it saves firewood, so saves money too. Sometimes she has to buy firewood, money goes further when using (a firewood cookstove).*

Variations on this, which were also commonly stated, were that the fire in the stoves was shielded from the wind and that the stove "keeps the heat", thus allowing for ongoing cooking or bathwater warming without the continuing use of fuel.

The second most commonly noted benefit of the stoves was faster cooking time *("imafulumira")*, with some also noting the stove heating up more quickly than the time taken by a fire.

> *Our relish is now cooked in 10 minutes – previously, with a three-stone fire, it would take until after 12.*
>
> (Female resident)

Fewer residents raised the issue of smoke in discussing benefits, indicating what this may not have been a priority. When asked specifically about smoke levels, opinions were split, with some feeling that the stoves produced more smoke but others feeling that fires were worse. When discussing smoke levels, many people talked about fuel:

> *With wood, the firewood stove is better, even if using maize cobs, although with these there's more smoke than with wood.*
>
> *Wet wood is smoky at first, then it dries and is better – there's no difference between the stove and three-stone fire. I would still use the firewood stove with wet wood.*
>
> (Female residents)

It was noted that the benefit of not having to tend to the fire in the stove as much as with a three-stone fire (as it was protected from the wind) and being able to move the stove inside or outside, allowed them a degree of control over their smoke exposures while cooking. This was supported by a quantitative finding of more cooking taking place outdoors in the post-intervention phase than pre-intervention (29).

Perceived disadvantages of cookstoves

The main issue raised with the cookstoves was that of breakage. We observed a number of stoves which had cracks in the sides already, although in most cases, these stoves continued to be used. The cracks rarely prohibited the use of stoves but did mean that these participants refrained from using very large pots on the stoves, out of caution, and from moving them to different places.

We came across a few stoves in which, over time, cracks had progressed to significant breakage (and a piece of the stove was completely displaced). In one of these cases, the resident had bound wire around the cookstove rim to hold it together, allowing her to continue to use the stove. In the other cases, the stoves could no longer be used and were discarded, with residents in these households having reverted to the use of three-stone fires. When asked about replacing the broken stoves, residents were positive, with most stating that they would pay between MWK1,000 and MWK2,000 (approximately US$1.20–US$2.50): approximately the market price of the stoves. The extract from a conversation below illustrates many residents' thoughts on replacing the stoves:

Interviewer: *Would you buy another? How much would you spend?*

Female resident: *Yes. 1,000, 1,500, 2,000 kwacha.* Anthu azolowera *(people have now become used to the stoves).*

The main concern for most was that the stoves were not available for sale in the area and that transport to the nearest market where they could be purchased would make their replacement unaffordable.

5.5 Discussion

Three to five months after the introduction of locally made clay stoves in the village, the new stoves were being used in most households and for most of the cooking and bathwater warming activity. In the sample of participants involved in personal exposure monitoring, there was no change in cooking-associated $PM_{2.5}$ exposures with the introduction of the new stoves, although 'baseline' exposures – in the absence of specific combustion activity – were lower post-intervention. Qualitative data revealed a widespread approval of the stoves amongst residents, with the main reason stated being their more efficient use of fuel. Cracking of the stoves with use was a key issue raised and is a relatively commonly reported issue with these basic stoves, often related to quality of clay or manufacturing processes (38, 39), although residents seemed keen to replace the stoves, should they be available for sale.

The widespread use of the new stoves was apparent in both the time-activity data collected alongside air quality monitoring and in participant observation data, with both sources clearly indicating a replacement of previous cooking methods with the new stoves. This is notable, given the prevalence of 'stacking' (combined use of multiple cooking modalities, old and new, rather than replacement) following the introduction of 'improved' cooking technologies (40-43). This relates to the reasons for continued use of traditional stoves, which vary but include limitations of newly introduced technologies, need for concurrent cooking on multiple stoves, and fuel access and cost, as well as (less commonly) different context-specific cooking needs (40, 41, 43, 44). Participants in this study raised some of these issues, namely that of using multiple devices concurrently, although when asked they stated that they would use two stoves if they were available. Issues with fuel access were also sometimes raised, in keeping with previous findings around resource limitations in this setting (4).

Despite the widespread cookstove use amongst the cohort, there was no difference in individuals' $PM_{2.5}$ exposures, either overall or during cooking periods, after introduction of the stoves. This is perhaps unsurprising given the lack of clear evidence of exposure reduction with these basic cookstove types, compared with traditional cooking fires (45). Participants' observations of faster cooking time and less need to tend the fire when cooking on the new stoves signpost the potential for reductions in personal emissions on a larger scale – although this was not seen in our small sample of participants. Our finding of reductions in 'background' exposure (during non-cooking time) could reflect a previously reported greater reduction in smouldering emissions (46) and, given the decrease further below WHO-recommended thresholds, may be an encouraging direction of change from traditional stoves.

These outcomes could be framed in terms of implementation science frameworks, such as the RE-AIM (Reach, Effectiveness, Adoption, Implementation, and Maintenance) framework (47, 48), with statements relating to the high levels of 'adoption' and 'reach' and poorer 'effectiveness' outcomes – judged in terms of researcher plans to reduce air pollution – and thoughts around ensuring 'maintenance' of the intervention in the longer term. This approach, with assessments made only with respect to researchers' predetermined aims and outcomes, was not the aim of the study, however. Our ethnographic work allowed insights into participants' lived experiences, enriching the evaluation and helping us understand its value from a range of perspectives.

In qualitative discussions, residents' main comments on the new stoves related not to 'smoke', but to perceived reductions in fuel use compared with the three-stone fires that they replaced, reflecting improvements in burning efficiency. This efficiency benefit is reported in the literature, although improvements with basic stoves tend to be modest compared with those achieved by more advanced cookstoves (45, 49, 50). The positive reception to the stoves seen in our study echoes community responses to the introduction of the Jambar (another simple biomass stove with efficiency benefits) in rural Senegal (51, 52). Jeuland et al. note that "reducing firewood and charcoal consumption are important objectives in themselves – both from environmental and poverty alleviation perspectives" (22). This is particularly relevant in a setting such as rural Malawi in which many residents' lives are shaped by severe economic scarcity and where access to food, as well as fuel on which to cook daily meals, are prime concerns (4).

The researchers who conducted the trial in Senegal and others have noted that participants are willing to pay for new stoves despite their initial free provision and that the widespread provision of stoves to all community members positively influences their sustained uptake (16, 52). The current study corroborated these findings: positive reports of the stoves were far more forthcoming from community members after village-wide adoption compared with before the intervention from the few households which owned the stoves (4). This village-level approach is also important in view of the shared nature of air pollution, with widespread uptake of cleaner technologies required to accrue air quality benefits (53, 54).

The strengths of our study lie in the combined use of qualitative observations and quantitative data collection to allow a realist evaluation of the intervention – delivered on a whole-village level – in its intended context, with activity-matched exposure data. We acknowledge that our study had limitations, namely the small sample of participants involved in the quantitative 'air quality monitoring' component and the slight difference in seasonal timing of the pre-intervention and post-intervention phases, resulting in only the post-intervention phase involving the widespread use of maize cobs as fuel. Outcomes of air quality monitoring were broadly in keeping with expectations; however, there was additional evidence around potential reductions in exposures during the 'smouldering' phase. These findings should be further explored with larger-scale monitoring studies, using techniques such as those we have employed to decouple cooking-related and non–cooking-related exposures.

5.6 Conclusions

Whilst there were no cooking-associated reductions in $PM_{2.5}$ exposure after introduction of the cookstoves, the stoves were welcomed and widely used by residents across the village. Residents valued the efficiency and fast cooking of these stoves – responding to key local priorities – and these factors, as well as less need to tend the fire and the possibility of moving the site of cooking also hold the potential for small reductions in population-level exposure.

Whilst significant improvements in air quality will require a more comprehensive approach (24, 55, 56), accessible cooking solutions, such as these stoves, with the potential to meet communities' immediate needs, represent a valued interim alternative to cooking on open fires. Scale-up of production and distribution to allow more households to replace their stoves once broken, or even schemes to support local production, are required to allow more communities access to these simple technologies.

5.7 Declarations

5.7.1 Ethical considerations

The study was approved and sponsored by the LSTM Research Ethics Committee (20-022). In-country ethical approval was granted by the College of Medicine Research and Ethics Committee (COMREC) in Blantyre (P.06/20/3069). Informed consent processes were completed for all participants involved in air quality monitoring. For other village residents, an extended process of community consent and introduction was undertaken, with engagement throughout the project ensuring continued consent for participation (57).

5.7.2 Consent for publication

Not applicable

5.7.3 Availability of data and materials

Underlying quantitative data and supplementary analyses

Harvard Dataverse: Comparative pre-post $PM_{2.5}$ data, https://doi.org/10.7910/DVN/PNYOTX

Data are available under the terms of the Creative Commons Zero "No rights reserved" data waiver (CC0 1.0 Public domain dedication).

Qualitative data from the ethnography are not publicly available due to confidentiality concerns, but limited data may be made available on individual request.

5.7.4 Competing interests

No competing interests were declared.

5.7.5 Funding

This work was supported by a Wellcome Trust Clinical PhD Fellowship awarded to SS (University of Liverpool, Liverpool, UK, block award 203919/Z/16/Z).

5.7.6 Authors' contributions

SS conceived and designed the work and was involved with data collection, analysis, and interpretation, as well as drafting of the final paper.

HS contributed to study design and was involved with data collection and management.

DM supported data collection and contributed perspectives to reflexive discussions.

MK, JR, KM, and MC contributed to manuscript editing.

All authors read and approved the final manuscript.

5.8 Reflexivity statement

The following reflexivity statement details key elements of the research partnership, conduct and reporting of the work presented above, in the hope that transparency with regard to transnational research practices will lay a foundation for more equitable ways of conducting collaborative research across the academic system.

Study conceptualization	**1.**	**How does this study address local research and policy priorities?** Air pollution is a global health priority. Malawi is a low-income country with high levels of air pollution and consequent morbidity. Cooking using solid fuels is thought to be a key contributor to airborne pollutant exposure in rural populations. Our interventional study – informed by an in-depth ethnographic account of air pollution (or 'smoke') in the setting – involved the introduction of a locally made cookstove in an effort to reduce individuals' exposures while also considering residents' other priorities relating to their health and well-being.
	2.	**How were local researchers involved in study design?** The research assistant (HS) for this study is a local social scientist based in Malawi with previous experience doing research in this area. He was involved with study design and data collection and ensured that approaches and methods were context-appropriate throughout. The fieldworker (DM) is a resident of the village in which the study is based and contributed perspectives to study design and implementation, as well as to optimising linkages with the community throughout the wider study.

Research management	**3. How has funding been used to support the local research team(s)?** Part of the research funding was used to provide salaries for local researchers – as above – and staff involved in the broader research grant, including research governance and grants management.
Data acquisition and analysis	**4. How are research staff who conducted data collection acknowledged?** The research assistant and fieldworker worked with the main researcher on data collection, and the research assistant also supported data management activities. Both are authors of this paper, with their specific contributions acknowledged appropriately.
	5. How have members of the research partnership been provided with access to study data? Study data are archived at Malawi-Liverpool-Wellcome Trust (MLW). Local researchers have direct access to the data.
	6. How were data used to develop analytical skills within the partnership? The PhD researcher (SS) supported the research assistant in quantitative data management, as well as analysis of quantitative and qualitative data, helping to develop these skills further.
Data interpretation	**7. How have research partners collaborated in interpreting study data?** Data interpretation involved discussions around analytical decisions and methods, which incorporated various members of the team (based in Malawi and the UK)

Drafting and revising for intellectual content	**8. How were research partners supported to develop writing skills?** The lead author of this paper is a doctoral candidate. She led in writing the paper, with reflective input and advice from all co-authors. **9. How will research products be shared to address local needs?** Preliminary findings have been shared within the village at dissemination events. Earlier quantitative data have been presented at local research dissemination conferences and within the research institution (MLW), and these forms of sharing will continue with the present data. This information will be made available to the wider global scientific community for discussion and development of the findings.
Authorship	**10. How is the leadership, contribution, and ownership of this work by LMIC researchers recognised within the authorship?** Please refer to the section on authors contributions in. Each author's role is described, including researchers from LMICs. **11. How have early-career researchers across the partnership been included within the authorship team?** Please refer to question 8 above regarding leadership of the project. The study also incorporated a junior researcher in the LMIC setting as research assistant and a local fieldworker who had not previously had any research involvement, both included as authors. **12. How has gender balance been addressed within the authorship?**

The research lead (whose doctoral work is represented here) is female, as are 3/7 of the authors, with representation from both local LMIC and HIC settings. Contributions to the study are acknowledged in the 'authors' contributions' section.

Training	**13.**	**How has the project contributed to training of LMIC researchers?** The research assistant (HS) was involved in the research process throughout, developing key skills, and he was supported in successfully applying for a Masters' scholarship in global health research. Involvement of the local fieldworker (DM) constituted her first experience of research participation. Both significantly contributed to the project and are recognised accordingly in the authorship. These experiences will lay the foundation for further academic career development.
Infrastructure	**14.**	**How has the project contributed to improvements in local infrastructure?** Whilst this is a small-scale study, the project team strived to support constructive engagement between the village community and the research institution throughout. Stoves were provided to all households as part of the study, and links have been made with the local provider to enable residents to purchase replacement stoves in the future. Work is also underway to create a nursery/health centre in the village to express thanks to residents for their involvement and to provide continuity of employment for the local fieldworker. With reference to question 3 above, research governance, ethics, and grant management

systems of the local implementing partner (MLW) were supported through this grant.

Governance **15. What safeguarding procedures were used to protect local study participants and researchers?**

The local ethics body and the LSTM Research Ethics Committee reviewed and approved the study protocol ensuring that both participants and researchers are protected throughout the study. Among other considerations, participants provided informed consent prior to their participation and, specifically, a named safeguarding lead (SS) was in place throughout, with various avenues of contact for participants to report any concerns, along with structures for appropriate referral of any such reports.

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Chapter 6: Approaches to ethical decision-making in the ethnographic field

Following presentation of my findings in chapters 2 to 5, I now introduce the first of two methodological chapters. The current chapter describes my approach to the research field and how we – as a research team – managed often-complex ethical dilemmas which emerged during the ethnographic period, in particular the issue of participant compensation for research involvement. These points are described with an awareness of the wider global and historical contexts underpinning this 'global health research' endeavour. Through this, we explore how ethical issues in global health research may be negotiated and what this means for researcher-participant engagement in such transnational projects.

Participant compensation in global health research: a case study

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6.1 Abstract

Background: Compensation for research participants can be provided for various reasons, including reimbursement of costs, compensation for time lost, discomfort, inconvenience, or expression of appreciation for participation. This compensation involves numerous ethical complexities, at times entailing competing risks. In the context of transnational research – often incorporating contexts of economic inequality, power differentials, and neocolonialism – these issues extend into wider questions of ethical research conduct.

Methods: We describe experiences of conducting a community-based study of air pollution in southern Malawi, incorporating ethnographic, participatory, and air quality monitoring elements. Decisions surrounding participant compensation evolved in response to changing circumstances in the field.

Results: Attention to careful researcher-participant relationships and responsiveness to community perspectives allowed dynamic, contextualised decision-making around participant compensation. Despite widely cited risks, including (but not restricted to) undue influence of monetary compensation on participation, we learned that failure to adequately recognise and compensate participants has its own risks, notably the possibility of 'ethics dumping'.

Conclusions: As with all elements of research conduct, regarding participant compensation, we recommend active engagement with research participants and communities, with

integration of contextual insights throughout. Equitable research relationships encompass four central values: fairness, care, honesty, and respect.

Keywords: ethics dumping; global health; participant compensation; research ethics

6.2 Introduction

Transnational health research has grown exponentially in the last 10 years (1). An accompanying increase in the scrutiny of researcher-participant relationships, on both macro and micro levels, in this time has led to questions around who benefits from research projects – questions now at the forefront of academic debates (2-5). The ethical question of 'value' in medical research, articulated in terms of "a negotiation between the interests of communities, the protocols of science, the priorities of global health" (6), is fundamental in considering what constitutes good research conduct.

Research carried out in low- or middle-income countries by researchers from high-income country institutions implicates a population who are often comparatively disempowered and economically vulnerable. This dynamic enables the practice of ethics dumping, described as "the export of unethical research practices from a high-income to a resource-poor setting" (7). Ethics dumping may take the form of export of research for the purposes of eluding strict ethical regulations or may be more subtle. Such cases include researchers applying lower standards of ethical scrutiny in the belief that their work is beneficial to vulnerable populations, particularly in low-income settings, or a lack of attention to sociocultural values in their research settings (8).

Individuals considering participating in research balance the risks of harm with the potential benefits. Such benefits may include direct benefits from study interventions, indirect/collateral benefits, e.g., healthcare or monetary payments, or aspirational benefits arising from the products of the study, e.g., new vaccines (9). Collateral benefits stand out particularly for people living with economic insecurity. We can distinguish between three types of payments:

- Reimbursement for expenses incurred or loss of wages

- Payments incentivising participation
- Payments to demonstrate appreciation for participants' involvement.

In settings of widespread economic vulnerability, decisions around provision of financial payments or goods and/or services can be complex. Ethics dumping here could represent researchers failing to fully value participants' research contributions and thus providing inadequate compensation, or researchers allowing monetary payments or other influences to increase participation amongst communities who would otherwise be opposed to involvement – so-called undue influence (10-12). Additional concerns around participant compensation, again rooted in wider contextual inequities, include risks of comparatively large payments disrupting household or local dynamics, or adversely affecting local researchers through systemic inflation (13, 14). These concerns reflect a contested field with a lack of clarity regarding what constitutes best practice.

A final point, relevant to the debate on participant and community compensation and wider aspects of research practice, is that poorly conducted transnational research fails to respect the sociocultural values of 'researched' communities, leaving people open to exploitation and mistreatment. Such ethics dumping practices risk furthering existing inequalities and reinforcing historically and politically shaped extractive relationships. The imperative in transnational research to consider the benefits for potential participants and their communities is, therefore, paramount.

This chapter presents the experiences of a research collaboration between the UK and Malawi conducting a mixed-methods study of air pollution in Malawi, with reference to participant compensation and related ethical issues. We draw on the existing literature to situate our experiences and thereby contribute to the wider ethical debates on transnational health research.

6.3 Methods

6.3.1 Study outline

Entitled '*Pamodzi*', meaning 'Together' in Chichewa (the main Malawian language), this ethnographic project applied participant observation, air quality monitoring, and participatory approaches to the issue of air pollution in one village on the outskirts of Blantyre.

The research team comprised a female British PhD candidate, a male Malawian research assistant, and a female Malawian fieldworker who was a resident of the study village. The study was based at an international research institution in Malawi, which hosts many researchers and projects originating outside of Africa.

Pamodzi aimed to understand the role of smoke within village life, how 'air pollution' was prioritised within daily concerns (if at all), and to describe differential smoke exposures across the community. Workshops then brought together residents to develop context-appropriate 'clean air' solutions. The resulting intervention – a locally produced clay cookstove for all households and recommendations for cooking to take place in well-ventilated spaces – was be piloted across the village in the next phase. The project was deeply rooted in the local village community, potentially involving all consenting residents.

6.3.2 Study setting

Malawi, in southern Africa, has a population of approximately 19 million (15). Most of the population are rural, with widespread poverty. In Malawi kwacha (MWK), the stated minimum wage is MWK1,346 per day (approximately US$1.30), although only around 1 in 10 Malawians are formally employed. Most Malawians are subsistence farmers with additional ad hoc piecework or self-employment providing extra income (16, 17). In recent years, poverty and consequent food insecurity have been exacerbated by floods and droughts, which threaten to worsen with the advancing climate crisis (18-20). Thus, economic limitation and precarity are important aspects of individuals' lives (with access to electricity very limited, for example) and in shaping researcher-participant power differentials, specifically in terms of participant compensation.

During the colonial period and beyond, biomedical research, lacking in the current ethical regulations and safeguards, employed various exploitative and dishonest practices. Accounts of information concealment and use of force, often through local chiefs, to compel individuals into participation are widespread (21, 22). In Malawi, beliefs about 'bloodsuckers' – rumours involving the stealing of blood through witchcraft, or its removal using modern technology, with subsequent witchcraft-related uses – are ever-present, accompanying many medical and research projects (although not, to our knowledge, *Pamodzi*) (23). While at times seemingly simple responses to uncertainty – around food insecurity, for example – the underlying belief systems are likely, at least in part, to stem from colonial power dynamics and transnational research practices (22-24). This is particularly relevant where bloodsucker rumours are aimed at overseas researchers and non-governmental organisation (NGO) staff. Analyses of this issue point to histories of extractive imperial practices, with blood often felt to represent the 'life force' and accumulation of unexplained wealth a reification of the inequality inherent in these relationships (24).

Malawi gained independence in 1964, but legacies of colonial practices – including the use of power to impose medical and research interventions on colonised populations without their fully informed consent (25, 26) – are ever-present and relevant when planning and practising transnational collaborative research.

6.3.3 Study procedures

The *Pamodzi* village-based study used local introductions, starting with the chief and group village head (overall chief of a wider area), then the community health volunteer, and other key village members, including religious leaders. Discussions with residents followed, over a 1-month period, prompting conversations around the project concept, acceptability, and implementation. Dialogue with the chief and community elders in this period led to a form of community approval which prefaced the ensuing consent processes (27). Recruitment discussions, involving iterative, personalised consultations also took place during and beyond this phase.

Individual and household consent used information leaflets and consent forms alongside verbal explanations. An extended process over at least two time points, arranged individually with participants, allowed for careful consideration by all parties and true freedom to withdraw. Walk-around consultations in the village at various points during the study ensured community engagement and ongoing consent throughout.

Study methods included participant observation, in and around individual households and extended throughout the village, and personalised air quality monitoring. Purposeful sampling was used for recruitment. Selected households varied by size, gender of household head, and other features, and individuals involved in air quality monitoring were recruited to reflect variations in lifestyles and exposures (28). The subsequent participatory methods lie outside the scope of this chapter. A summary of study components and participants is provided in Table 6.1.

Table 6.1. Components of the study and participants included in each

Study component	**Participants**
General village-based participant observation	Whole village potentially involved – >3,000 people
Focused household participant observation	Members of six households
Additional individual air quality monitoring	20 adults
Participatory workshops (six in total)	16 adults per workshop

Participant observation formed the study foundation, with the researcher – accompanied by the research assistant and/or fieldworker – spending time in households and participating in cooking, farming, and other daily activities. This household-based element allowed a graded introduction to the community. Each household observation lasted around 2–3 weeks, affording deep insights into the contexts in which smoke exists in the village. Mobile air quality monitors carried by researchers in small waist bags during this period (Figure 6.1) gave quantitative estimates of differential exposures to airborne particulate matter by time, place, person, and activity.

Figure 6.1. Largest monitor size and example of a waist bag with monitors inside (worn by research assistant)

To further develop these quantitative data, volunteers from a few participant observation households agreed to carry monitors overnight after researchers left the household. A short data review the following morning helped identify exposure peaks and collect information about smoke sources. After identifying issues, largely around insufficient data, we amended the study protocol to allow further sampling in a separate, extended group of individuals (not previously involved in participant observation), each carrying the monitors for standalone 24-hour periods. Inclusion of these additional study participants introduced further complexities around participant compensation.

6.3.4 Participant compensation aspects

Initial plans were for a proportion of the research funds to be set aside as a ‘community compensation’ fund, rather than individual monetary compensation, the nature of this fund being confirmed once more contextual information about the village emerged. We decided on this benefit-sharing approach in view of the inclusive nature of the project and recognising traditional African community-based value systems (29-31).

The decision to provide compensation per se was informed by the fact that 'aspirational benefits' from the research (cleaner air and improved health) were not felt priorities for participants, at least at the project's start. Monetary compensation thus allowed us to acknowledge and reciprocate burdens placed on community members in contributing to the project; it also allowed us to balance the benefits to the research team (31, 32).

On application for in-country ethical approval, we learned that Malawian ethics committee guidance required monetary participant compensation amounting to US$10, although the distribution of this was not specified (33). In view of the varying forms of research involvement in different components (Table 6.1), specific decisions regarding compensation were therefore required. Together, with senior Malawian researchers, we approached these decisions with the intention of maximising good (fair and appropriate compensation) and minimising harm. Plans around specific payments were then written into the protocol, with these being taken from a sum of money set aside for compensation in the project budget. The remaining sum (following individual and household compensation payments) was used as community compensation at the end of the project.

For initial household-based participant observations, MWK8,000, equating to just over US$10, was provided to each household in recognition of the potential disruptions caused by researchers' prolonged presence. Compensation was on a household basis rather than an individual basis as activities were based around the household unit and because included members of any household often varied from day to day. Although this meant the MWK8,000 sum being spread over a number of household members, this was deemed fair.

In addition, a set contribution was made to cover food required to extend daily meals to the researchers present in the household. This sum (equating to MWK2,000, approximately US$2.75, per day) was based on food prices and approximate portions per person, but with a margin to ensure (more than) adequate reimbursement at all times. These sums of money were presented with explanations of their differing reasons: the first as a way of acknowledging participants' involvement and thanking them for their time and inconvenience, and the second as direct reimbursement for money spent on researchers' food.

In the initial participant observation households, volunteers continuing to carry monitors did not receive extra monetary compensation. At this point, there were no plans for additional personal air quality monitoring, so the above constituted the entirety of the proposed individual and household payments. Developments in the protocol with repercussions for compensation are now described.

6.4 Results

6.4.1 Intermediate study outcomes

Household observations and concomitant air quality monitoring progressed smoothly with development of good research relationships and widespread positive responses. Compensation was gratefully received, and many people actively volunteered their households for involvement – more than we could possibly include in the time frame. The extent to which this enthusiasm to participate was motivated by compensation payments remains uncertain.

Although intended research beneficiaries were members of the village, aspirational research benefits (cleaner air) did not drive involvement. As the ethnography found, smoke was not generally seen as a problem for residents, who had more pressing daily concerns. The inclination to help a stranger, however, was undoubtedly a motivator to participation for many. Other factors may have included the novelty of having a foreign researcher in the household assisting with chores, or anticipation of unarticulated benefits stemming from association with a research team from a well-funded institution.

The research team's presence was, on a number of occasions, linked to "good things coming to the village" (as expressed by the chief during an early village meeting). Such thoughts may be shaped by experiences or accounts of research involvement in the region, with contributions from comparatively rich research institutions benefitting people living in extreme economic vulnerability (34). While there had been no recent research in this study area, there was widespread awareness of 'CAPS' (Cooking and Pneumonia Study), a large trial of relatively expensive solar-powered cookstoves in nearby Chikwawa District (35). These stoves were often cited as examples of 'clean cooking' during consultation discussions. Linked with our research institution, CAPS and its ancillary studies afforded compensation and benefits to participants, including cookstoves, pots, and monetary compensation for various forms of involvement (36).

On proposing the extended plan of including additional participants to carry air quality monitors, feedback from community members via the resident fieldworker indicated discomfort around the expectation that these individuals would participate without receiving any financial compensation. Specifically, some felt it would be unjust to expect this when other participants had received money for their contributions. As researchers, we acknowledged this concern, and the proposal was amended to incorporate compensation of MWK8,000 for each person involved in standalone air quality monitoring.

This was well received by the community, and a large number of individuals then volunteered to carry monitors, although a few still declined. Outright refusal to participate was rare throughout the study and in the few cases where reasons were given, these were around not having enough time. Our ethnographic observations in general revealed a widespread willingness to help and reluctance to appear obstructive, somewhat obscuring findings on motivators and deterrents to participation. Unease around the monitoring equipment was occasionally seen, however, e.g., when one couple refused to touch the monitors on their demonstration.

6.4.2 Participant compensation decision-making

In our decisions around individual compensation, we aimed to maximise benefit and minimise harm. This involved a number of considerations, outlined here as a basis for the wider ethical debate.

We compensated participants for disruption of their daily activities, engagement with outsiders, and discomfort or inconvenience of carrying a monitor, amongst other factors, as well as to demonstrate our appreciation for their involvement.

Our presence in households as participant-observers often slowed down chores, such as food preparation, and necessitated explanations to passers-by (at the local market, for instance). Furthermore, despite our appeals to be treated as ordinary household members, extra efforts were frequently made to welcome us, most visibly in terms of the frequency and substance of meals prepared when we were present. Whilst money spent on researchers' food was reimbursed, the extra compensation recognised these additional burdens which our presence entailed.

Monitors, although quite small, may have been troublesome to carry, particularly in the context of daily physical work, and carriers took care of these instruments entrusted to them. They may also have attracted unwanted attention, particularly for earlier volunteers at a time when residents were perhaps less familiar with the devices. To an extent, monitors also constituted a breach of confidentiality for the wearers (although, in practice, participants were very open about study involvement). A degree of compensation for such disruptions could again represent one way of recognising these burdens and showing respect to participants.

Community members themselves raised the issue of comparative justice, suggesting that economic compensation should be provided for carrying the monitors. This demonstrated how communities' judgements of inconvenience or disruption, and perspectives regarding fairness of compensation, can inform such decisions.

We also attempted in our decisions to consider 'fairness across research settings': how participants contributing in similar ways in similar studies in different geographical locations might be compensated differently. Complexities relating to our use of mixed research methods, including participant observation, made this comparison difficult, however. Ethnographic studies vary widely in their approaches, with 'appropriate' compensation representing a culturally-situated concept, with ongoing negotiated processes involving researchers and study populations (37).

Potential risks associated with monetary compensation also featured in our deliberations. Our ethnography revealed how lives in the village are shaped by a resilience to profound economic poverty, which influences daily priorities and perspectives. In this context, US$10 is a comparatively large amount of money, carrying the potential to cause disruption within and between households and, as some have proposed, ‘undue inducement’ to research participation (10, 11, 14). In our study, deep and honest engagement with residents and regular discussions with the resident fieldworker afforded an extra level of community feedback, and we saw no evidence of disruption or undue inducement in the study, although the possibility of undetected low-level disruption within the community remains.

Finally, we considered the risk of comparatively large amounts of monetary compensation altering local expectations of compensation, thus negatively impacting local researchers or studies with more limited funding. Our decision regarding the compensation amount (in terms of the core sum provided) was set by the institutional review board, allowing a degree of consistency across all health-related studies in the area. In making supplementary decisions around the distribution of this sum (for instance, in terms of the decision to allow MWK8,000 for each household in the first component but MWK8,000 per participant in the air quality monitoring component), we were guided by community views, allowing some flexibility and contextual responsiveness.

6.5 Discussion

We now analyse the key ethical issues surrounding participant compensation in the current study in the context of four values in transnational research proposed by Schroeder et al. (7): fairness, care, honesty and respect. These values and relevant aspects of the study to each value are outlined in Table 6.2, with more in-depth explorations below.

Table 6.2. Four values in transnational research and aspects of the current study relevant to each

Value	Relevant aspects
Fairness	Relative benefits to researchers and participants Amount of compensation in relation to participant burden Comparative justice between participants involved in different components of the study Comparative justice between participants in similar studies in different locations
Care	Prioritising participants' welfare – potential for 'undue influence on participation' or community/household disruption caused by monetary compensation Role of community perspectives in decisions around participant compensation Awareness of the potential effects of historical and political contexts and power differentials, with those in positions of power safeguarding the interests of relatively disempowered participants
Honesty	Clarity and honesty of consent processes Awareness of ongoing, renegotiated nature of consent Community engagement throughout project introduction and implementation
Respect	Respect for existing social structures in the setting Initial engagement of chiefs and key village stakeholders in allowing project to go ahead Awareness of how cultural norms and values may influence research participation

Fairness, or justice, is considered an important value, but its interpretation is deeply contextual, and implementation in transnational research practice can be complex and multidimensional (38-40). Wider discussions around risks of exploitation in transnational research address comparative considerations of the relative benefits for researchers and participants, and – for research involving economic compensation – contemplation on appropriate levels of participant benefits (9, 38).

The question of 'fair compensation' is particularly important in our study. Incurred costs can easily be reimbursed, as in the case of contributions to cover participants' money spent on researchers' food during household participant observations. More abstract burdens, such as researchers' presence for long periods or carrying of monitors, are more complex to value. Approaches to these decisions include market-driven perspectives, as well as more distributive perspectives, the latter of which aim to manage underlying structural inequities in transnational research (40-42).

In our research experience, implementing a community-wide project and questions of which participants to compensate (and how to compensate them) introduced additional levels of complexity. Our village-level compensation proposal acknowledged the typical community-centred value-systems existing in African settings, such as Malawi (29-31), and was in keeping with evidence suggesting its use for collateral non-monetary benefits, such as healthcare support (14, 43).

Through responsiveness to community voices, we learned that village-level compensation could not replace individual compensation for certain participation types – a finding that is echoed in the literature from similar settings (43). This brought in an additional aspect of fairness: justice across participants involved in different study components.

In attempting to compare research contributions and make these decisions, we found that our perceptions of fairness did not always match those of community members. Our assumption – that carrying personal air quality monitors would be relatively simple, not requiring monetary compensation – was not supported by local residents' views. This was perhaps understandable in view of the above-mentioned juxtaposition between how research benefits researchers and participants. In a project offering sufficient direct benefits to participants (from the research intervention) or not involving the same degrees of inequity – e.g., with participants more heavily invested in the research aim itself and/or with fewer competing priorities – this balance of interests might be different.

In the current situation, however, where power imbalances left decision-makers (usually senior researchers) able to make judgements, leaving a relatively disempowered population to respond by agreeing to participate (or not), ethics dumping was a real risk. Our study design allowed us to solicit community views and alter protocols accordingly, but other studies might require different approaches to ascertaining locally appropriate practices and integrating them into research plans (13, 27).

In setting compensation levels, we were bound by local institutional guidance. While accounting, to some extent, for differences in research procedure invasiveness, these guidelines remain relatively blunt tools, with no allowance for potential 'social invasiveness' of prolonged immersive participant observation, for instance (33). Mandated rates allow equal compensation across all similar research participants nationally but fail to fully account for certain, particularly qualitative, research methods and circumstances and can potentially disadvantage researchers with less funding (14, 33, 44).

An alternative approach for determining fair compensation is for investigators to seek case-by-case advice from local research ethics committees applying contextual knowledge (27). One of our advisors cites experiences of using locally based NGOs to support and inform compensation decisions, again in an independent capacity (D. Schroeder, written communication, April 2020). Lastly, community representatives and patient groups could contribute to decisions independently of ethics review boards or research institutions (13, 45, 46). In view of the great variation in research study types and approaches, these decisions must be made by individual research teams.

The provision of economic compensation, particularly in a context of poverty, has been associated with risks of unduly influencing potential participants and of conflict within households and communities (10, 11, 14). The concept of ethics dumping applies again here, where lower standards of ethical scrutiny in low-income settings could leave populations open to the adverse consequences of poor compensation practices. Such risks can be considered under the category of care, where, it is said, the responsibility of researchers is to "take care of the interests of those enrolled in research studies to the extent that one always prioritises their welfare over any other goals" (7).

The *Pamodzi* research assistant provided insights into aspects of Malawian culture potentially amplifying risk of participant coercion, such as the widespread norm against actively opposing an offer (e.g., refusing research participation). Existing power differentials and colonial histories further this risk. The first step in ensuring 'care' was to recognise these inequalities and put provisions in place to mitigate these possibilities.

Initial discussions with key community leaders provided an extra safeguard for potentially vulnerable residents (27, 47, 48). Whilst 'community approval' can itself be coercive in authoritarian settings and without adequate contextual understanding, we ensured that these initial approvals never replaced or compromised empowered individual consent processes and ongoing equitable engagement with communities – again, vital for protecting research participants' interests (49).

This relates to the third value: honesty. Where honesty and care combine, researchers recognise the true nature of consent as a continuous renegotiated process throughout the research period (50, 51). This open communication and community responsiveness – with a central role for the local fieldworker – is vital to ensuring continuing fair research practices in participation and compensation.

While our project entailed specific engagement mechanisms, larger research endeavours in similar settings have used community advisory groups to facilitate feedback (46, 52-54). Complexities in terms of roles and relationships must be navigated here to ensure effective representation for potentially vulnerable participants and empowerment of community representatives to be advocates, rather than enablers, of research implementation (45, 55).

The final value to consider – that of respect – must particularly underlie the entirety of a research process (from planning through implementation and beyond) and demands deep contextual engagement. Our project would not have been successful without Malawian team members at all levels, with the resident fieldworker – a lifelong member of the village with extended family also living in the village – particularly valuable for promoting participant perspectives. Respectful research conduct also meant acknowledging existing local social structures, including traditional leadership, religious leaders, and local health volunteers (56). Our project particularly recognised and respected the social position of the village chief, whilst not letting it override individual decision-making, in contrast to the exploitation of the chief's power in accounts from the colonial era (21, 22).

Lastly, our approaches to participation and consent recognised potential differences in ethical approaches between typically individualised perspectives of many in the Global North and classical African collective bioethics (57). This strengthened our commitment to facilitating collective discussion and decision-making. Avoidance of this aspect of ethics dumping (failure to consider sociocultural values of the research context) may again look different across research projects, only requiring a 'respect' for the research setting and participants' values throughout.

This chapter has used a case study to explore wider ethical issues, discussing ways to improve responsive and responsible research practice. While we aimed to identify alternative examples of ethical implementation of the values where our own were lacking or potentially challenging to reproduce, this was not always possible. Ultimately, researchers bear the burden of determining ethically appropriate practice in individual research settings and study types.

While the focus of discussion has been transnational research, with the attendant contexts of neocolonialism and inequity, some themes will also be applicable to research elsewhere. The biomedical establishment has traditionally assumed a sense of 'expert knowledge', from which lay participants are excluded. This then speaks to a power imbalance between researchers and participants, even in the UK, which makes relevant much of the earlier discussion around equitable research conduct. For participants in circumstances of relative economic deprivation, this inequality becomes more marked, increasing potential vulnerability to research exploitation.

Based on the values examined above, the TRUST project – a multinational collaborative initiative aimed at improving adherence to high ethical standards globally and countering ethics dumping – proposed the first comprehensive global code of conduct to guide researchers in transnational research settings. Accompanied by supporting tools and materials, the code makes individuals and communities in the Global South aware of what they should expect in terms of fairness, care, honesty, and respect and assists researchers in contemplating such ethical issues (58-60). We found the values set forth in this code very helpful, particularly in terms of organising our thoughts on ethical research approaches and considering how such approaches might be applied in future studies. We suggest that these values could assist others who aim for equitable research partnerships.

6.6 Conclusions

Issues of participant compensation in transnational health research are often negotiated within contexts of economic inequity and complex power dynamics. Colonial histories and their enduring influences also shape these research environments. Risks of participant exploitation in these contexts must be taken seriously, although perspectives differ on how best to manage these risks.

The case above illustrates how the values of fairness, care, honesty, and respect can be used to understand and respond to specific issues relating to participant compensation. Key recommendations concern the importance of meaningful engagement with study populations, with community insights contributing to study planning and implementation throughout the research process.

6.7 Declarations

6.7.1 Acknowledgements

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6.7.3 Competing interests

None declared

6.7.4 Ethical approval

This study was approved by the Liverpool School of Tropical Medicine Research Ethics Committee (approval number 19-007), who also provided study sponsorship. In-country ethical approval was granted by the College of Medicine Research and Ethics Committee (COMREC) in Blantyre, Malawi (approval number P.02/19/2600). All procedures were followed in accordance with the ethical standards of the Helsinki Declaration (1964, amended most recently in 2008) of the World Medical Association; written consent was obtained from participants where appropriate.

6.7.5 Authors' contributions

SS, MC, MK, and KM conceived the study.

SS, MC, MK, and HK designed the study protocol.

SS and HK carried out the fieldwork.

SS, HK, and MK carried out the data analysis and interpretation.

SS, HK, and DN drafted the manuscript.

HK, DN, and MC critically revised the manuscript for intellectual content.

All authors read and approved the final manuscript.

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Chapter 7: Researcher-participant intersubjectivities throughout the research period

In this chapter, I first describe elements of my positionality as a researcher starting the project then discuss the various shifts in researcher-participant intersubjectivity throughout the fieldwork period. This starts at the point of project introduction and moves through the use of various research methods during the ethnographic period to (and beyond) the arrival of the COVID-19 pandemic, which brought a pausing of research activities and a change in my role in the village. Learning points and recommendations from this relate to the value of extended in-person engagement in the field and the potential benefits of these strong relationships for wider community work.

Shifting positionalities in a time of COVID-19: the transnational public health doctor and ethnographer

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7.1 Abstract

Ethnographic research is characterised by in-person engagement with individuals and groups within a social setting, usually over an extended time frame. These elements provide valuable insights which cannot be gained through other forms of research. In addition, such levels of involvement in 'the field' create complex, shifting researcher-participant relationships which themselves shape the course of the project and its findings. The COVID-19 pandemic disrupted many research projects, but impacts on ethnographic research, with its emphasis on physical presence in the field and interpersonal relationships, reveals much about these key elements of our praxis.

I discuss how the pandemic influenced the progress of an ethnographic research project, based in Malawi, including consideration of how, as lead for the project, my clinical/public health positionalities interacted with relationships in the village and the arrival of COVID-19 in Malawi. This account reveals shifting intersubjectivities of researchers and participants as the pandemic brought changes in the nature of the engagement, from ethnographic explorations into the roles of smoke in everyday life, through fieldwork suspension and a contextualised COVID-19 response. These experiences demonstrate how a basis of reflexive ethnographic engagement with communities can underpin thoughtful responses to upcoming challenges, with implications for future 'global health' work, both within and beyond the pandemic context.

7.2 Background: the *Pamodzi* project

This chapter presents personal reflections on an ethnographic endeavour in rural Malawi and ramifications of the COVID-19 pandemic on work in the village. In particular, I – as the main researcher (a female doctoral candidate from the UK with a background in public health) – describe and explore my position in the field and related intersubjectivities, as they developed throughout the ethnographic fieldwork, and subsequently with the onset of the pandemic.

This local, standalone ethnographic project called *'Pamodzi'*, meaning 'Together' in Chichewa (the main language in Malawi), a title which reflects an aspiration for collaborative approaches between researchers and community members. The project considered smoke – seen from Western biomedical perspectives as air pollution – and aimed to create an ethnographic account of this smoke (*utsi* in Chichewa) as experienced by residents of a single village in rural Malawi. This included smoke from cooking fires, as well as from other fires and alternative sources of combustion in residents' lives. Extended periods of participant observation in households and public spaces in the village helped us gain insights into how smoke was placed within residents' wider concerns and priorities. In addition, bringing to the field what knowledge we had, in terms of the harmful longer-term effects of air pollution on health, the project aimed to bring together perspectives on the issue to deliver more contextualised insights into smoke in this setting. I also aimed then to work with participants in the village to co-develop potential 'cleaner air' solutions, but this was left open to reimagining after the initial phase. Further details of the project and our epistemological approaches are covered in previous chapters in this thesis, (1).

The project started with our meeting a number of village chiefs and briefly discussing our ideas. We chose a village which was rural in nature, in keeping with most of the country, relatively near to where we were staying and where the local chief and community health worker were supportive and interested in our project. The 8-month period of in-person participant observation, which comprised the main body of the ethnographic project, started with a period of walking around the village discussing initial research ideas and hearing individuals' thoughts on our plans.

The mainstay of the participant observation involved accompanying household members (predominantly women) in their typical daily activities, including food preparation, cooking, washing dishes, carrying water, and farming. I conducted most of the participant observation alongside a male Malawian research assistant, who was employed through the research institution before the start of any fieldwork and contributed much to the development of the research project. Our extended presence in the village allowed me to develop a broader understanding of daily life in this setting, joining in with children's (cooking-related) games, relaxing on straw mats with household members, and chatting after a morning at the farm, for instance, as well as participating in daily chores. A few months into the project, with the help of the assistant, I engaged a female member of the village community to work as a type of fieldworker, assisting in day-to-day arrangements and providing closer links with residents across the whole village.

Concurrent air quality monitoring, involving the use of individual air quality monitors worn in waist bags, allowed us to quantify levels of airborne particulate matter throughout these activities, adding another perspective – this time more biomedical – to the account. In addition, face-to-face interviews with household heads and a series of six participatory workshops, involving researchers and village residents, allowed the inclusion of additional thoughts around smoke and created opportunities for now-engaged participants from the village to share thoughts around achieving cleaner air.

The epistemological approach of this transnational research project emphasised the recognition and valuing of participants' knowledges alongside those of the researchers (2), with shared understandings developing through the research process.

7.3 Wider context: traditional 'global health' approaches

The field of 'global health' inherits a legacy of problematic ethical practice and researcher-participant relations nested in imperialist transnational relations (3). In research terms, this is also played out in the academic imperialism which had asserted control over the relative valuing of knowledges, the extractive nature of knowledge production, and the presentation and dissemination of the academic product in global health research to date (4-6). Whilst these matters may initially seem conceptually far from the 'field', in terms of the Malawian village where the ethnographic project was based, overarching colonial legacies and enduring economic relations continue to touch individuals' daily lives here in myriad ways (1). The influences of these complex historical and political factors were evident from the start of the research project, with further developments in response to the COVID-19 epidemic in Malawi.

7.4 Researcher positionality

I am a female British researcher in public health (and clinician by background), trained in the UK. I am an independent researcher (a Wellcome Trust Clinical Fellow), but the research project was conducted under the umbrella of the Malawi-Liverpool-Wellcome Trust in Blantyre, Malawi. I had no prior experience living in any African country and, whilst I am not typically 'White' (I am of Iranian descent), my appearance and the way I am seen, partly reflecting my childhood and early adulthood in the UK, have led to my experiences in the world being similar to those of a White person, with little exposure to explicit or implicit racism, for instance. Similarly, my perspectives – shaped by Western formal education and socialisation – reflect British approaches to such topics as identity, society, and health.

In the village, I was cognisant of how elements of my training lent me a 'public health perspective' in terms of my conceptualisation of issues relating to health and well-being of individuals and communities. This included my understanding of smoke, in terms of a barrier to 'clean air' (and, therefore, to bodily health), although I understood this as one element of a wider social and political environment. Western medical influences, although tempered by anthropology training and relativist elements of my research approach, also shaped my understandings around other issues arising in the field – for example, episodes of illness in participants.

A final element of pre-existing positionality relates to my motivations for undertaking the research. As a public health researcher, my interest in the subject of 'air pollution' had undeniably started from an awareness of its health effects, but – partly in response to seeing more typical clinical research approaches stemming from high-income institutions – I sought to understand this pollution (or 'smoke') as it was locally experienced in its wider social, cultural and historical context. The choice of research site thus also linked back to previous research projects in similar settings (7). The ethnographic approach, for me, was important in providing the desired insights, in contrast to the more common behavioural and technological intervention studies in the field of air pollution research, with an aim to make any recommendations as relevant as possible to individuals' lives in the village. Essentially, this related to a belief in justice in global health, rather than an attempt to help others as an act of charity (8). This remained an important motivator throughout the trajectory of the research period.

7.5 Researchers' arrival in the field and development of relationships during the *Pamodzi* project

My roles and relationships within the ethnographic 'field' developed throughout the research period and beyond and were subject to iterative reflection by myself and in discussion with the research assistant and local fieldworker, with episodic discussions also with qualitative senior researchers in the supervisory team helping expand these reflective considerations. Perhaps the most immediately apparent aspect of the researcher-participant relationship at the outset of the project was economic: as a relatively light-skinned British person in the village, I was immediately recognisable as an 'outsider' and thus was often asked, directly or indirectly, for money. This was perhaps inevitable in the context of extreme scarcity and transnational inequity between our contrasting backgrounds. Above and beyond purely economic factors, the colonial histories of the UK and Malawi, and subsequent neocolonial relations, also undoubtably overshadowed relationships in terms of power differentials.

The significance of these dynamics was striking when compared to the influence of gender in the village. During the time spent with women in households, while there was occasionally a sense of female kinship – in conversations about our children, for example – the differences in our lived experiences (together with my struggles with language) dominated. This meant that, in practice, despite the gender aspects, my (male) research assistant felt more of an overarching shared identity with these residents than I did. This was an interesting indication of the magnitude of experiential difference between myself and participants in the village and testament to my research assistant's skill in expertly bridging the gap.

A further element of residents' initial responses was a preformed expectation amongst residents of the form the project would take – stemming from experiences of similar transnational (health) research projects. This widespread narrative involved a description of an existing problem to be solved by visiting 'expert' research teams (usually by imported solutions, often involving some type of technology). On our arrival in the village, researchers and the project itself were seen in these terms – with village residents often asking questions around what we were bringing, introducing or teaching them – and it was not until a few weeks into our initial discussions and participant observations when residents' perspectives began to break away from this.

The balance of power in our ongoing relationships was nuanced and dynamic, however. Throughout much of the participant observation, residents in focused participant observation households were relatively at ease, assuming a role akin to teachers or guides, in relation to routine activities in the village. Throughout these activities, I was the only non-Malawian person present, equipped with limited Chichewa or cultural knowledge, but a perpetual eagerness to learn. The possibility of my prolonged physical presence in the field, often involving a vulnerability for me, in particular, as when I attended a coming-of-age ceremony (*chinamwali*) restricted to women, contributed to an enduring sense of trust within these relationships. This was apparent from the regular invitations into households to participate in daily activities, to special occasions, jokes, conversations, and even ad hoc dancing amongst women in excited conversations about upcoming ceremonies, for instance.

Researcher-participant dynamics were made more complex by the introduction of additional methods, for instance, wherein participants were asked to wear air quality monitors, and wherein recorded interviews took place, and the traces were then displayed on a screen and discussed with participants. This highlighted the shared learning emerging from the project, as we heard about local smoke-producing practices and participants' responses to smoke whilst bringing new ways of quantifying smoke levels. Local wisdom around fuel use and place of cooking did take into account avoidance of smoke to an extent, for instance, although much of our learning was also around the wider restrictions in lived experiences, which often made longer-term health concerns relating to smoke a secondary consideration (1).

Participatory workshops – held in Chichewa by an external facilitator – further challenged the assumptions around power within relationships, as researchers took part in games, exercises, and discussions alongside residents. A careful use of methods here aimed for a community of co-learning and questioning, creating new spaces for participation and discovery (9). This lent the entire ethnographic period a sense of constantly shifting intersubjectivities, which served to destabilise any unilateral power imbalance.

7.6 Initial responses to the threat of COVID-19: ending ethnographic fieldwork

COVID-19 emerged at a time when ethnographic activities were naturally receding, with only a few final air quality monitoring activities and some general village discussions ongoing. I was very aware of the likelihood of the SARS-CoV-2 virus (COVID-19) being introduced to Malawi through the geographical mobility of economically privileged groups (particularly to and from continents with already high numbers of cases, such as Europe). This awareness, together with our now-warm relationships with many extended families throughout the village, left me thinking hard about ways to protect village residents from the threat of COVID-19. In particular, partly influenced by my medical grounding, I thought of older members of the community who would likely be at increased risk from the disease, and of the challenges in accessing clinical care for people in the village setting.

My first action as project leader, therefore, was to start drawing study activities in the village to a close, explaining to participants what we knew of the nature of COVID-19 and about our plans to stop the fieldwork. We were clear that we, as researchers, did not want to be a source of possible disease and, thus, were obligated to move away physically at that time – whilst sad in many ways, this separation constituted an important protective action. This was the start of an emergence of different intersubjectivities in our research relationships, as my medical and 'public health'-related positionalities shaped responses to the unfolding pandemic.

Although we had, in any case, been approaching an end to the fieldwork, the decision to stop under these conditions brought unique challenges. The decision, having been made at short notice and in response to the pandemic, was relatively unplanned and thus felt imposed upon us rather than being co-developed in the field, as many other aspects of the work had been. Persisting unknown elements relating to COVID-19 added to this difficulty, accentuating the sense of general uncertainty which often accompanies the process of leaving the field (10). Lastly, village-wide activities – which we would have carried out to mark this point of (albeit temporary) closure, express our gratitude to village residents for welcoming us, and discuss some of our findings – were not possible due to COVID-19 precautions. Instead, these functions had to be fulfilled through ad hoc conversations with individuals and small groups, alongside explanations of why physical contact (such as shaking hands) was being restricted, and so on[1]. This divergence in concern around COVID-19, with the pause in activities being driven by us as researchers, again accentuated the differences in researcher-participant positionalities and concurrent issues of power in terms of decision-making around the project.

A key difference here between our 'leaving the field' and accounts of this in the literature – and, indeed, compared with what we had expected at this point – lay in the nature of our departure (10-12). In the present case, while our daily physical presence as ethnographers was coming to a close, our engagement in the field continued, albeit with a shift in terms of roles. This lack of finality made the process more complex but highlighted the processual (as opposed to one-off) nature of ethnographic exits. This process, as suggested by Michailova et al. (11), was invaluable in stimulating the current exploration of researcher identities and intersubjectivities in the field.

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[1] Residents had, in fact, heard about COVID-19 at this point from government messages on the radio, and through social media and word of mouth. They were, therefore, aware of preventative measures, which were also being introduced nationally. As a result, although we took care to explain our actions and the reasoning behind them, these did not come as a surprise to participants, in the context of wider events.

Further to this physical withdrawal, drawing on my background as a public health doctor, and building on what we knew about the village setting, we went beyond simple health education activities, taking steps to ensure that residents would be able to put into practice common COVID-19 prevention recommendations after we left. We provided soap and buckets to allow handwashing at key points in the village and, later, cloth facemasks for residents. These developments shifted our positioning in the village – with a role more weighted towards bringing external knowledge and resources to residents in the village – and positioned me, more explicitly, in alignment with my prior public health role.

In view of the nature of researcher-community dynamics fostered thus far, involving collaborative integration of local and external knowledge, the ethnographic project felt resilient to this challenge. Residents themselves did not feel COVID-19 to be a relevant issue in their lives. Thus, while residents were respectful and appreciative of the support, with handwashing stations displayed at prominent points in the village, for example, the trust built in many relationships permitted a degree of candidness not often seen in more formal relationships in Malawi. This was evident particularly in the gentle joking around the threat to us – "people coming from town" – posed by COVID-19.

The step away from in-person fieldwork (and review of the ethnographic field notes at this time) highlighted the privilege which had been afforded to us (my research assistant and me), as ethnographers, in previous months. Our physical presence within the village community during this time, laying the groundwork for trusting relationships, had allowed us to better understand how 'smoke' fit within the wider environment of individuals' daily lives in and around the village. In the months following the suspension of our ethnographic fieldwork, my research assistant and I were often asked – on sporadic visits to the village for other purposes – why we were no longer present. On hearing our response, the usual reply was "but there isn't any COVID-19 here". Whilst highlighting communities' perceptions of COVID-19, this also suggested that residents did not consider us, as researchers, to be bringing risk of disease, as may have been the case. Nevertheless, the pause in ethnographic fieldwork continued, and other more traditional public health activities temporarily took its place.

7.7 COVID-19 in Malawi: further 'public health' responses

In the ensuing weeks, daily numbers of COVID-19 cases in Malawi slowly climbed, and perceptions of village residents were substantiated as cases were mainly seen in the city. In more systematic considerations of how rural communities in Malawi (constituting a large majority of the country) may be protected, as much as possible, from the spread of the disease (13), my original 'public health' positionality again came to the fore. At this point, my research assistant and I became involved in a local COVID-19 response project: '*Kuteteza*' (meaning 'to protect' in the local language, Chichewa). *Kuteteza* involved supported 'shielding' of consenting residents >60 years of age: household-level arrangements were made to allow these older individuals to stay alone – minimising their external social contacts – and to be supported in chores, such as collection of water, food, or cooking fuel. The small amounts of funding available covered additional soap, handwashing buckets, and masks for involved households. The village in which our ethnographic project had been based was one of the first to be introduced to this project. We approached the local chief and other gatekeepers personally in the first instance to discuss the approaches, although the mainstay of the project employed local health surveillance assistants and local volunteers for implementation.

While maintaining engagement with communities and a voluntary approach to participation throughout, the project still represented a further departure from the aims and attitudes espoused by the ethnographic research project. The introductory discussions and provision of information reinforced a slight shift in our positions in the village, with the foregrounding of our imported knowledge and suggestions of relevant responses for residents to take. The handover of day-to-day operations in the project to local staff allowed us to step away from this role, however, and it subsequently appeared that the less-formal, somewhat closer relations forged throughout the ethnographic period had, to an extent, endured. Key contacts in the village sporadically contacted us informally through text and social media messages, in addition to the regular situational updates, asking when we might return. The continued uncertainty around the national epidemic made project planning – and, therefore, responses to these enquiries – difficult and, again, highlighted the source of decisions as external to the village, rather than participant-driven.

Once the first wave of COVID-19 had subsided, we were able to recommence the research project, with small, outdoor village meetings and the introduction of locally made cookstoves for cooking. Evaluation of these was largely ethnographic in nature, involving walks around the village and ad hoc conversations with residents, with whom we were now familiar. Whilst in-depth discussion of this third phase of activity (following initial ethnographic work, then COVID-related activities) lies outside the scope of this chapter, it is relevant to note how this did allow a return to our original project considerations. The sense of our contributing to village life with the stoves – which were very well received – was made clear by participants around the village. This felt significant to me after the generous welcome and patience we had experienced from so many participants throughout the project. Our presence also allowed a more formal conclusion to the project and, hence, a sense of closure for all involved.

7.8 COVID-19 in Malawi: perceptions and experiences in the village

In Malawi, the direct impact of the COVID-19 epidemic continued to be felt mostly in urban areas. Newspaper reports and local conversations highlighted deaths of statesmen, pastors, and other members of the urban elite (14-17). Further, for reasons that remain unclear (18), the frequency of new COVID-19 cases in Malawi, particularly in the first wave (around June to August 2020), was much lower than expected by many in the global community (19, 20).

In the village, we observed this first-hand through messages, phone calls, and on occasional careful visits over the following months: it became clear that local perceptions of COVID-19 remained largely unchanged. Accounts from residents, including the chief, painted a picture of few, if any, identified cases of COVID-19–related illness or death and no noticeable change in local morbidity or mortality rates. Village residents often described COVID-19 as "*matenda a ku tawuni"* (disease of the town), or even *"matenda a anthu okudya za mafuta*" (disease of people who eat relish containing oil, i.e., rich people). For members of the village community who encountered ample risks and hardships in the course of their daily lives , it seemed that the threat posed by this disease was more of a theoretical one than a fear rooted in lived experience (1). This echoed, in some ways, residents' initial responses to the idea of smoke as a potential source of harm, which was introduced in the original project.

COVID-19 did not, however, leave residents' lives untouched. Indirect impacts of the epidemic included increased transport costs due to social distancing on minibuses and increased fuel prices; and expenditure on masks, required for use in government facilities, for example. For many, healthcare access was also impacted, as widespread rumours, largely relating to the intentional spread of COVID-19 by healthcare professionals, created fear around government health facilities, and community members turned, instead, to private clinics or stopped attending formal healthcare settings altogether (E. Makepeace, researcher and consultant, written communication, March 2021). Nevertheless, a common perspective from those living in the village remained one of sympathy for us as town dwellers, whose lives seemed to have been more appreciably impacted by the epidemic.

In the light of this, it was striking to see international coverage, particularly from non-governmental organisations, which tended towards conventional narratives of Africa as a site of suffering and of African bodies as needing salvation by the West. These reports persisted even when the classic overwhelmed health systems and 'bodies on the streets' did not transpire. Again, we were witness to how legacies of transnational relationships persisted in the global imagination (21).

Through the window of the ethnographic project in Malawi and beyond, through its official suspension, I gained insights into the enduring legacies of colonial and post-colonial transnational relations for research relationships such as ours. In this case, the COVID-19 pandemic illuminated the ways in which these historically grounded global health relations persist in shaping perspectives on – and responses to – new global health challenges.

7.9 Discussion

In this chapter, I have attempted to provide an account of changing roles and relationships in the field, influenced by the emergence of COVID-19. This reveals how our presence in the village, as researchers (over the prior months of in-person participant observation), helped us develop robust relationships, allowing for meaningful, engaged 'public health' responses to COVID-19 when it arrived. Upon our arrival in the village, it was clear that national and institutional colonial histories played a part in shaping how we were perceived. Conversely, the COVID-19 pandemic soon revealed how colonial relations continue to frame popular perceptions of Malawi in the Western imagination as a site of suffering and dependency. Extended in-person ethnographic experience revealed alternative perspectives based on real experiences in 'the field'.

A key aspect of ethnographic fieldwork involved elements of embodiment running through my immersion in daily activities alongside female residents. Various elements of my position as an outsider in this context – as a researcher from a Western background, with entirely different life experiences to this point – clearly restricted my access to a complete understanding of participants' lived experiences.

Acknowledging this, the embodied experience of cooking *nsima* on a three-stone fire, as well as various other daily activities, permitted what has been described as a "a sensory engagement with others' lifeworlds and lived realities" (22, p.21). Husserl's concept of intersubjectivity is relevant here, relating to the *possibility* of being in another's place – of understanding another's perspective (23). This critical facet of ethnography could not have been achieved through other qualitative approaches, such as interviews or focus group discussions. As women schooled me in turning the thick *nsima* without pausing, despite the smoke making my eyes and nose run and splashes of the boiling mixture hitting my bare feet, shared understandings also forged a deep rapport transcending those typically seen when alternative modes of research are employed (24).

While it has been posited that these processes can lead to a dissolution of the power differentials between the ethnographers and their participants, bringing them to an equal footing (22), for me this represents a claim too far. The arrangement of historical and structural factors shaping my position in the field could never be dispersed so quickly or completely. However, what transpired was a sense of a changed relationship emerging from these accumulating encounters. With the emergence of the COVID-19 pandemic, the repercussions of these relationships, stretching beyond the period of my presence in the ethnographic role, became clear.

In subsequent months, in redirecting energies towards responding to the pandemic threat, I found that, alongside elements of my original 'public health' perspective, such as traditional scientific evidence on COVID-19 transmission, the deep understanding of residents' lived experiences helped inform suggestions brought to the village. These relationships with residents allowed us insights into their perceptions around COVID-19 and paved the way for them to provide us with honest feedback on our attempts to help. This dynamic echoed the initial project aspirations, as I aimed to bring my clinical and scientific knowledge into conversation with participants' situated knowledges.

Similar roles in medical anthropology have been identified and put into practice by social scientists involved in the Ebola response in West Africa (25). The Ebola Response Anthropology Platform (ERAP) and, subsequently, the Social Science in Humanitarian Action Platform (SSHAP) share examples of how local and international social scientists have contributed to context-sensitive, and thus more engaged and effective, crisis responses in various low-resource settings (26, 27). This includes attention to local practices, such as care of the sick and burial in epidemic settings.

In a recent publication, Melissa Leach, one of the anthropologists involved in creating ERAP, highlighted the need for ethnographers to reflect on their own positionalities and approaches to their field sites (28). In interrogating my history as a Western (British) researcher entering Malawi, I have been aware of colonial histories and of the role of anthropology – at times – in supporting the colonial project (29, 30). The parallel troubled histories of colonial tropical medicine in countries, such as Malawi (31, 32), give ample cause for reflection on the relationships with power that I carry with me on my approach to the ethnographic 'field'.

The complexity of these legacies and roles in anthropology are also important, however. From early in the history of anthropology, key figures have spoken against deployment of the discipline towards imperialist aims (33). In a subtler sense, we are witnessing current applications of anthropological insight in global health projects introducing shifts in perspective and moving beyond colonially inspired narratives – of 'donor–recipient'-type relationships, for example – and towards a more connected presence within communities. This can, in turn, create increasingly balanced and thoughtful contributions to global health endeavours.

A final point on this piece is to note that this reflective account is limited to my personal experiences. It does not speak to the experiences of other members of the research team and could be said to underrepresent study participants' own perspectives, thus echoing the ongoing imbalance in global health research. Proposed solutions to this include the use of participatory research approaches and changes to academic systems (including funding, publishing, and so on) to reduce barriers to academic involvement and representation for low- and middle- income country actors themselves (34-37).

7.10 Conclusions

Ethnography is unique and relatively uncommonly utilised in comparison with other qualitative research methods. The ethnographic researcher is afforded the privilege of broad and in-depth insights into communities' daily lives, values, and priorities. Participant observation methodologies involve intricate participant-researcher relationships, with the historical and geographical elements of many global health research projects introducing further complexity.

The experiences outlined in this chapter illustrate how the practice of ethnographic fieldwork created understandings and relationships which influenced the subsequently devised public health responses to the COVID-19 pandemic when it arose. Whilst navigating developing relationships in the field and my own positionalities was, at times, challenging, prior experiences conducting ethnography proved invaluable in planning and carrying out contextually relevant and appropriate pandemic responses.

7.11 Declarations

7.11.1 Acknowledgements

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7.11.2 Data availability statement

The raw data supporting this work, in the form of field notes and reflective notes, cannot be made available due to the personal and confidential nature of the content and risks of compromising participant confidentiality.

7.11.3 Author contributions

SS devised the research project discussed and is the doctoral candidate. The current chapter is a personal reflection by SS on her research and related experiences. Whilst others were involved in the project and related work, and were engaged in reflexive discussions, the current piece represents the thoughts and perspectives of SS alone.

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Chapter 8: Discussion

I begin this final chapter by summarising the main findings of the papers comprising the body of the PhD and the findings of the additional methodological papers. Drawing from this, I explore and theorise the conceptual and epistemological 'journey' taken as the project developed and as I learned more about air pollution, or 'smoke' and its relation to wider experiences of health, well-being, and daily life in rural Malawi. I also discuss learning points around global health praxis and, in particular, aspects of researcher/community engagement which became relevant during the research project. Finally, I outline strengths and limitations of the project and suggest directions for future research.

8.1 Summary of individual papers comprising the thesis body

8.1.1 Systematic review

The work started with a systematic review of randomised controlled trials (RCTs) to assess the evidence for clinical respiratory effectiveness of air pollution reduction interventions in low- and middle-income country (LMIC) settings (1). Most interventions in this review were improved cookstoves (12/14, of which 10/12 were biomass stoves). These individual household-level interventions did not consistently improve respiratory health outcomes, despite some studies achieving reductions in emissions and/or improvements in certain respiratory symptoms amongst participants.

8.1.2 Baseline air quality monitoring findings

Next, I presented quantitative and qualitative data from a period of initial ethnographic fieldwork in Malawi (2). This involved 7 months of ethnographic research in a single village, including in-person participant observation, individual interviews, participatory workshops, and concurrent personal air quality monitoring. Of the two papers presented here, the first reported results of baseline air quality monitoring on a sample of adult residents in the village. Our approaches and measurements were informed by participant observation around the village, which provided a large amount of fine-grain data on daily life in the setting and helped us understand how exposure data from the monitors matched with events in the setting (with a large majority of 'spikes' in exposure relating to cooking and related activities).

Through a process of activity-exposure matching, we found differences in cooking-related exposures by fuel, cooking device, and place. The use of firewood on a three-stone fire (the most commonly used combination in the village) was linked with highest fine particulate matter ($PM_{2.5}$) exposures. An analysis of personal cooking exposure by place of cooking found – counterintuitively – that whilst cooking in less-ventilated places, such as enclosed kitchens, women were exposed to lower $PM_{2.5}$ concentrations.

8.1.3 Broader ethnographic findings

The third paper (3) explored the social setting in which air pollution (or 'smoke') operates in the village, what wider determinants govern communities' exposures, and how these exposures are framed in terms of individuals' lived experiences. This continued the epistemological shift – from the initial exclusively positivist frame of enquiry – as we now looked to understand residents' priorities around health and well-being (in their widest sense). The paper describes the many ways in which scarcity in this setting (through precarity, limitation, and daily hardship) impacts individuals' daily air pollution exposures, including their capacity to evade these exposures.

8.1.4 Mixed-method evaluation of village-level clean air intervention

Finally, taking these insights forward, we introduced a contextually appropriate cookstove to village residents, providing a free stove to all households (4). Subsequent continued participant observation across the village and repeat air quality monitoring in the original sample of residents allowed a mixed-method realist evaluation of intervention impacts, both in terms of individual $PM_{2.5}$ exposures – again by activity and cooking features – and participants' own perspectives. We found no change in overall exposure concentrations, but there were small reductions in non-cooking exposures post-intervention. These were possibly related to reduced smouldering emissions with the stoves. Residents were very positive about the new stoves, almost universally using them to replace their three-stone fires. The main benefits of the stoves from participants' perspectives, however, related to fuel saving rather than smoke avoidance, which was not a primary concern for most.

8.1.5 Methodological papers concerning research conduct throughout the project

The two additional papers were more methodological in nature, incorporating my reflexive considerations and discussions throughout the PhD around fieldwork conduct and relationships (5, 6). First, I used the issue of participant compensation to open a wider discussion about ethical issues and conduct in global health research projects (6). Through my experiences in the field during a complex, community-based project, I learned the value of contextualised decision-making which is responsive to community perspectives. I found that this deep engagement with communities acted as a foundation for equitable, respectful researcher-participant relationships (6), strengthening the research project and increasing the trustworthiness of our findings.

The second methodological paper was built on observations and reflections throughout the first period of ethnographic fieldwork and through the time when fieldwork was suspended due to the onset of the COVID-19 pandemicin Malawi (5). This piece is more personal, reflecting first on my positionality, then on my shifting roles and intersubjectivities in the village setting throughout this unprecedented period. Again, the value of extended time spent, in-person, with residents became clear here. Whilst I was, at times, challenged by managing my different 'roles' (notably, when our ethnographic work was superseded by COVID-19 response work), the relationships which had developed in the village allowed for open communication and engagement to continue, even when we were discussing COVID-19 rather than cooking. I propose that this engaged approach, building on pre-existing trusting and equitable relationships, could be important in future emergency responses, bringing a sharing of knowledges which will improve the relevance of any subsequent actions.

In line with this theme of equitable relationships in global health research (6), during my PhD period, I was involved in a series of workshops on international health research partnerships and the concept of equitable academic authorship. Through these we then developed a consensus statement paper on measures to promote equitable authorship in research publications from international partnerships (7). A key recommendation was that authors should submit structured reflexivity statements with all papers and that these should be considered by journals as part of their decisions on whether to accept manuscripts and published alongside papers for transparency. Reflexivity statements submitted for my final two papers are incorporated in this thesis alongside the relevant chapters (2, 4).

8.2 Discussion of main findings in reference to wider literature and theory

8.2.1 Interventions to reduce the clinical respiratory impacts of household air pollution

I started the PhD with a systematic evaluation of existing RCT-level evidence of interventions aiming to reduce respiratory morbidity and mortality. This was largely because, in view of my clinical and public health backgrounds, I was acutely aware of the impacts of air pollution on the respiratory system. I took a positivist approach to this question, with a clearly described question and parameters from the outset, including intervention types, comparators, outcomes, and study designs. The finding of no overall improvement in the main clinical outcome (childhood pneumonia) – despite some symptomatic improvements – was discouraging (8-10). A possible reason for the inconsistency in these outcomes is that improved cookstoves, particularly those reliant on biomass, are unable to reduce exposures sufficiently to impact clinical outcomes (1, 11-14). Additional sources of (indoor and outdoor) air pollution, contributing to individuals' overall exposure landscapes, could also partly explain why single interventions may not achieve improvements in the clinical consequences of air pollution in some settings (15).

Beyond the strict limitations of RCTs, there is observational evidence of the association between clean fuels and better respiratory health outcomes (16). Evidence for the role of liquid petroleum gas (LPG), in particular, is building (17, 18), although outcomes are still mixed. A recent LPG stove trial did not improve severe pneumonia risk in infants whose mothers were provided with the stoves (19), and clinical outcomes of a further large LPG trial are awaited, although exposure outcomes have been encouraging (20). High rates of adoption and continued use in this trial could go some way to explaining these exposure outcomes (21).

In terms of effective long-term solutions to the issue of household air pollution, utility-scale provision of electricity – as a service rather than a marketed product – will most reliably deliver the required exposure reductions, and hence improve health outcomes (22, 23). However, this currently remains challenging for very low-resource settings, such as rural Malawi.

Looking upstream, we see that the wider structural factors which shape access to clean fuels also influence other determinants of exposure, as well as the exposure-response relationship itself. For example, socioeconomic status is linked to the ability to buy cleaner cooking technologies, continue to buy fuel, access education, make improvements to house quality (such as a separate kitchen, which can help shield children from cooking exposures) and avoid additional exposures, such as occupational ambient exposures related to road traffic (24-26). Food insecurity leading to poor nutrition in utero or during early infant development can add to the adverse impacts of air pollution on lung development (27, 28), and the incidence of causative organisms responsible for pneumonia, such as respiratory syncytial virus (RSV) – as well as related morbidity and mortality – are also patterned by socioeconomic factors (29, 30).

8.2.2 Activity-paired air quality monitoring in rural Malawi

Findings from personal monitoring paired with in-person observations in the village (during the preliminary period), then activity reviews with individual participants following each 24-hour period, revealed the centrality of cooking to daily life in this setting and the importance of cooking exposures in individuals' exposure landscapes, both in terms of frequency and magnitude of $PM_{2.5}$ and carbon monoxide (CO) exposures. This contrasts with more urban settings, where ambient air pollution – from transport and industrial sources, for instance – are greater contributors to individuals' overall exposures (31-33). Differences were seen in $PM_{2.5}$ and CO exposures according to cooking modality, but the impacts of fuel and cooking device on cooking exposures were limited, with no completely 'clean' cooking option available in this environment. This finding links back to the previous discussion around challenges for single interventions – particularly biomass stoves – in sufficiently reducing individuals' air pollution exposures. It also further indicates the importance of universal access to electricity, as a replacement for biomass, in bringing clinically meaningful reductions in air pollution exposures.

Our observations in the village, alongside the monitoring, allowed us valuable insights into aspects of exposure differentials, notably in terms of the impacts of place of cooking on cooking-related exposures, where cooking in ostensibly less-ventilated areas (kitchens) was associated with lower $PM_{2.5}$ and CO concentrations than cooking outside the household or on a walled veranda. We observed how women's movements while cooking in enclosed places involved constant movement in and out of the kitchen, allowing them to tend to the fire when necessary, whilst leaving the kitchen to evade the smoke when possible, also protecting family members, such as children playing out in the yard. We thus saw how women do take steps, where possible, to temper their own and their families' exposures to smoke, even where larger interventions are not possible under the circumstances. This is in keeping with studies in similar settings which attest to an awareness of negative effects of air pollution amongst cooks, often in terms of symptoms of irritation from smoke rather than longer-term health effects (34-37).

8.2.3 Widening perspectives on air pollution and health in the Malawian village

Beyond descriptive findings around cooking modalities in the village, qualitative findings from extended participant observation, interviews, and participatory activities allowed us to form deeper understandings of how air pollution, or 'smoke', exists in the context of individuals' daily lives in the village. Critically, we were able to explore the mechanisms through which scarcity shaped residents' daily smoke exposures.

I initially considered the varying influences on smoke exposure through the lens of a socioecological model (Figure 8.1), with enabling factors interacting with micro and macro systems within which individual cooking choices are negotiated (38). Interplay occurs between various levels of influence – for example, individual or household-level preferences, regional or national differences in availability of different fuels or devices, and culturally shaped food tastes. Socioecological models can explicitly incorporate overarching levels of influence on individual practices (38-40), hence their utility in understanding so-called 'health behaviours' in context (41, 42). In the context of cooking-related smoke in the Malawian village, environmental factors creating fuel shortages or broader issues of economic scarcity could be seen to be acting at this level.

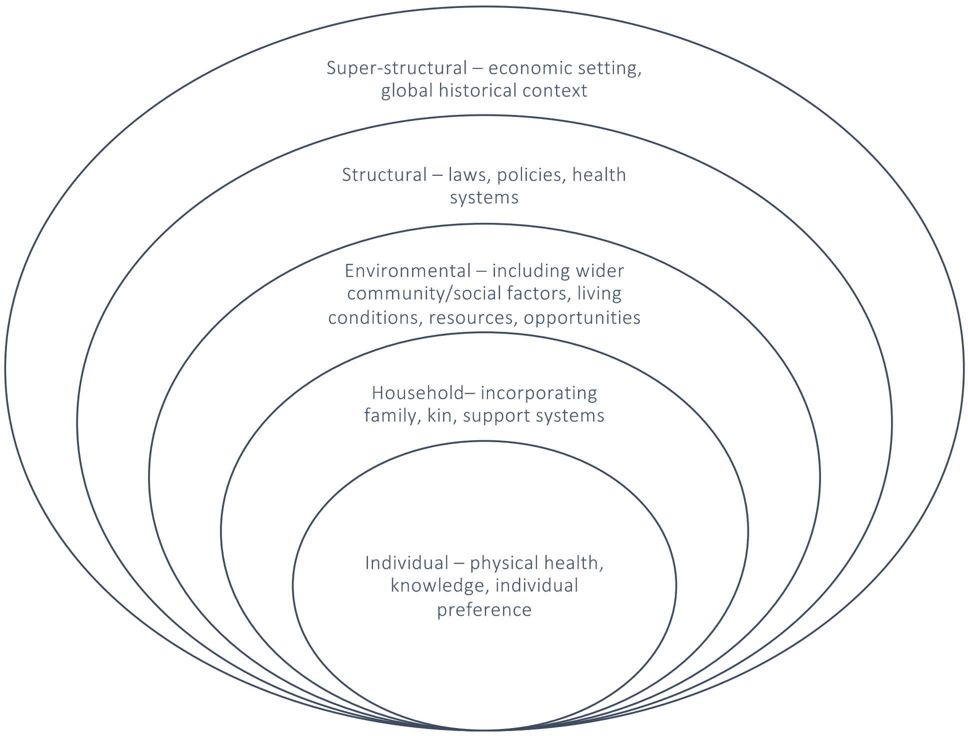

Figure 8.1. Adapted socioecological model depicting layers of influence on cooking practices in Malawi, based on versions by Sweat and Denison and Campbell (43, 44)

Sweat and Denison provide particular insights into individuals' lives in LMIC settings by integrating an additional 'super-structural' level in their socioecological model, subsequently developed by others in the field of HIV research (44). This describes high-level factors, such as poverty and imperialism, (43) which are recognised determinants of health (45-48).

Existing studies of air pollution and health, which employ socioecological models in their analysis, have tended to use the models as a cue to describing top-level relationships between environmental factors (including poverty and clean energy access) and child health outcomes (49, 50). In a paper by Lambe et al. (51), comprised of case studies on the introduction of technologies or services in Zambia and Kenya, the authors use a socioecological model to discuss of off-grid electricity uptake in rural Zambia, outlining the role of key contextual barriers, including season-related economic precarity. This highlights the importance of embedding interventions in wider local contexts, with an understanding of users' needs and priorities. Contextual insights, in the form of situational analysis, as well as more in-depth ethnographic and participatory approaches, have proved valuable in considering and informing clean cooking solutions (52-55).

Our ethnographic insights address a gap in the literature by applying anthropological insights to understand communities' perceptions on solid fuel use and 'smoke' more broadly, in the context of individuals' daily lives, rather than as an adjunct to a planned intervention (37). In the context of a socioecological model, we demonstrated how proximal factors (the inner layers, such as individual tastes, as well as local cultural and social aspects) were dominated by an overarching lack of resource/'opportunity' factors in a context which was essentially shaped by superstructural limitation, signposting the wider-reaching historical, geographical, and political factors described in the paper (3). For example, the severe economic constraints experienced by many in the village – which create situations of daily insecurity, hardship, and limitation – have their origins in global dynamics, including colonial and neocolonial processes, subsequent economic and trade systems, and ongoing climate inequities (3).

Applying a deeper understanding of what we learned from extended periods of in-person participant observation, my interpretations developed beyond the socioecological model. I came to understand the overarching conditions shaping so many aspects of life (including smoke exposures), not as another level in an existing model of 'health', but as a more central feature of individuals' daily lives. Emily Yates-Doerr (56) describes differences between so-called 'social determinants of health' approaches in public health, and medical anthropology approaches, which consider how environmental forces shape health, explaining that these broader factors – such as structural violence and inequity – are not bounded, but shape every element of individuals' experiences.

Yates-Doerr uses a 'material-semiotic' approach – applying critical inquiry to knowledge production itself (56, 57) – to move these considerations further beyond the socioecological model. For the conceptualisation of health, this means understanding health as relational:

continuously constructed through everyday actions, rather than as a pre-defined endpoint to be achieved or as sited in individuals' bodies (58). This is relevant to our findings in the village, where, through seeking understandings of participants' lives and well-being beyond pre-defined medical outcomes, we were able to reveal underlying structures shaping their self-defined health and well-being in multiple complex ways. We witnessed how reliable access to cooking fuel (be this firewood or charcoal) and household food security were key in terms of residents' daily priorities – a finding echoed by other qualitative explorations in the region (59). Further to this, we gained an understanding of how economic scarcity influenced these factors and how the primacy of these considerations influenced other dimensions of longer-term health (including, but not limited to, exposure to smoke from cooking).

Our analysis, centring initially around cooking fires and stoves, could be likened to elements of what Van der Geest and Whyte refer to as 'charms' (60). These physical objects provided a concrete focus for our thinking around wider elements of lived experience – structural historical, and geographical – embodied in the act of cooking.

8.2.4 Mixed-method evaluation of the *chitetezo mbaula* intervention

The sense of dissonance between various understandings of health – in particular, between the perspectives of health systems actors, clinicians, and researchers and the perspectives of the individuals at whom research/health enquiries and interventions are targeted (61-63) – ultimately emphasises the need for global health inquiry which is community-informed from the point of conceptualisation, through implementation and evaluation. This formed the perspective of the intervention element of the PhD. Having seen locally made clay cookstoves being used in a few households and hearing positive reports from residents of their ability to cook with little fuel and produce less smoke, we chose these stoves for the intervention, despite some reservations around their capacity to bring about sufficient reductions in emissions to improve individuals' clinical respiratory health.

The evaluation, purposely broad, included both quantitative assessment of individual exposures to $PM_{2.5}$ and qualitative explorations into how the stoves were used and perceived by household members (4). Results of this evaluation confirmed this sense of divergence between clinical efficacy, as judged by pre-defined quantitative biomedical criteria, as well as by subjective success from the perspective of stove users. Almost universal use of the stoves across the village were accompanied by widespread positive reports, most often relating to fuel conservation. Whilst quantitative exposure assessments found no significant reductions in (overall or cooking-related) $PM_{2.5}$ exposures following introduction of the stoves, this was not a primary concern for village residents, whose immediate needs were better met by the new intervention stoves.

In the longer term, however, the success of this intervention – even on these terms – is uncertain. Our experiences suggested that the costs of replacing broken stoves – incorporating transport to a market, modest purchase costs, and time taken – might exceed any longer-term benefits seen, particularly because reasonable alternatives (three-stone fires) are ubiquitous and available free of charge. As we discussed in the ethnographic paper, in a setting where severe scarcity and hardship were inherent to daily life, capacity for additional costs was very limited. Ultimately, the underlying structural violence creating and cementing these conditions must be addressed to secure real and lasting health improvements, both in terms of air pollution and respiratory health, as well as wider aspects of health for individuals living in these communities.

8.3 Strengths and limitations of the research

A key strength of this research lay in the bringing together of multiple qualitative and quantitative research methods to provide a multi-perspective account of the research topic. The central role of extended in-person participant observation in bringing together the various accounts allowed for a foregrounding of communities' lived experiences and a sense of contextual engagement throughout the project that enriched the resulting empirical findings, as well as the surrounding reflections on global health partnerships and practice.

In terms of quantitative assessment of air quality, the research benefitted from the use of recently available portable $PM_{2.5}$ monitors. These enabled monitoring of individuals' exposures throughout a 24-hour period which, when combined with details of individuals' activities over the period, provided faithful estimates of source apportionment and accounted for behavioural elements, such as individuals' movements inside and outside of the kitchen during a cooking episode. This more realistically reflected individuals' real-time exposures throughout the village environment compared with stationary monitoring.

Limitations of the project included the relatively small number of individuals (all adults) involved in the exposure monitoring components. Consequent sample size issues restricted any firm conclusions (for example, in terms of impacts of the cookstove intervention on individuals' exposures). In the future, similar studies would benefit from larger sample sizes and, possibly, the inclusion of children to form more concrete conclusions in these areas. The paired activity diaries, while contributing valuable data around exposure sources, relied on visual interpretation of exposure graphs, in combination with participants' accounts of their activity. This could introduce inaccuracies in categorisation of activity details, which could affect the fidelity of the quantitative exposure estimates.

Qualitative elements – in particular, the participant observation components – were limited by my low level of spoken Chichewa. This meant that, while I could often understand basic conversation, particularly when directed at me, I undoubtably missed situational nuances inherent in daily life, many of which could have enriched my understanding of the subtleties of the topic areas I have discussed. In managing these areas, my expert research assistant, Henry, worked hard on a daily basis, translating much of the conversation in real time and engaging my many questions and discussions both in and away from the village. Debora, our fieldworker based in the village, was also irreplaceable, providing further situated insights throughout the period (5). Whilst invaluable, these arrangements could not replace the immediate understandings which would have been gained had I been undertaking the research in my own first language, but the 'outsider' elements of my status that I experienced, as external to any Malawian society, did afford different perspectives on the research issues at hand (64). Issues of roles and positionality are explored and discussed in more detail in chapters 4 (supplementary materials), 6, and 7, and further repercussions of these issues of language are discussed in chapter 7.

8.4 Conclusions and recommendations for future work

I conclude that, even in a setting such as rural Malawi, where most individuals' exposures were almost exclusively related to household air pollution from cooking, sought-for improvements in clinical respiratory outcomes are unlikely to be achieved through improved cookstoves alone. Furthermore, findings in the village environment around scarcity-related limitations suggest that sufficient reductions in exposures might be hard to achieve even with the introduction of stoves using cleaner fuels, such as LPG, as long as market mechanisms are relied upon.

Ultimately, utility-level clean fuel provision to whole communities will significantly reduce individuals' exposures in these settings and, hence, impact clinical outcomes. A main policy recommendation, therefore, addresses the need for national investment in energy services, with an aim for universal access rather than provision as a product. There is a clear role here for national government to ensure that the quality of provision is high and that arrangements cater for potentially disenfranchised groups – including those living in hard-to-reach areas and in extreme poverty – ensuring that inequalities are not accentuated.

This provision is expensive and thus arguably inaccessible for a low-income country such as Malawi. In view of the origins of the global inequity, discussed earlier in the thesis, whose effects are being accentuated in recent years by the impacts of COVID-19 and the climate crisis (65-67), I argue that there should be focused attention on the longstanding debts of these countries to international institutions such as the World Bank. Debt cancellation could form a source of support for countries, such as Malawi, in strengthening much-needed infrastructure improvements, such as those required for wider access to clean energy and water.

In terms of future research recommendations, in agreement with Smith and Ray (23), I suggest the evaluation of potential models of large-scale LPG or electricity provision, including attention to potential delivery mechanisms, subsidies, and other determinants of equal access. Research exploring individuals' experiences of use will form an important part of such an evaluation, ensuring that daily scarcity, as seen in the Malawian village setting, does not present barriers to clean energy access and use. In settings of often-extreme scarcity, such as Malawi, trialling of smaller-scale provision, while still emphasising access, may be a necessary step on the path to universal clean energy. Examples of this may include exploration of LPG delivery mechanisms and organisation of reliable, regulated mini-grids for electricity.

In methodological terms, this research study demonstrated the benefits afforded by deep contextual insights into individuals' lived experiences in informing thinking about global health issues. I advocate the future application of these approaches, through interdisciplinary work, for developing sustainable, engaged responses to a range of global health challenges, ensuring that communities' felt needs, as well as externally assessed biomedical outcomes, are considered and addressed by these research agendas.

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