CHILD UNDERNUTRITION IN SUB-SAHARAN AFRICAN COUNTRIES: AN INVESTIGATION OF LIMITATIONS OF CURRENT APPROACHES AND RECOMMENDATIONS FOR CHANGE

BY

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ABSTRACT

Childhood undernutrition is of high public health significance, particularly within Sub-Saharan Africa. Undernutrition in childhood leads to impaired cognitive and physical development, poor academic performance, and decreased future economic productivity. Although significant efforts have been made to address child undernutrition in Sub-Saharan Africa, high levels of undernutrition persist. This thesis, a multi-methods study, goes beyond existing literature and policy to identify opportunities to accelerate the reduction of child undernutrition in Sub-Saharan African countries.

The first empirical chapter examines trends and inequalities in the prevalence of childhood undernutrition in African countries between 2000 and 2019. Notably, this study quantifies changes in the levels of childhood undernutrition in Africa and identifies subpopulations which could benefit from additional policy attention.

The second empirical chapter uses quantitative methods to investigate the association between exposure to household air pollution, from solid cooking fuels, and childhood undernutrition in LMICs. Notably, this robust study examines the association in numerous scenarios and within subpopulations.

The third empirical and fourth empirical chapters detail the findings of a qualitative study conducted in Lusaka district, Zambia. The third empirical chapter examines and compares the perceived causes of childhood undernutrition, according to primary caretakers of children under five years old and healthcare providers. The fourth empirical chapter explores primary caretakers' perceptions of and experiences with nutrition education, and perceived barriers and facilitators to clinically recommended behaviour changes.

Critically, the findings of this thesis underscore significant opportunities to accelerate the reduction of childhood undernutrition in Sub-Saharan African. This thesis has identified significant gaps and limitations within existing nutrition research and policies. First, this thesis has highlighted the value of incorporating wider determinants of undernutrition into existing research and policy. Second, this thesis has identified inadequacies in the implementation of nutrition policies and the provision of nutrition services in Lusaka district, Zambia. Presently, global nutrition policy focuses on improving WASH infrastructure and behaviour, treating severe acute malnutrition, and improving infant and young child feeding. While critical, the findings of this thesis suggest that, when implemented alongside current policies, addressing the gaps and inadequacies in existing research and policy could further accelerate the reduction of child undernutrition in Sub-Saharan Africa and place the continent on track to meet the 2025 Global Nutrition Targets for childhood wasting and stunting.

DEDICATION

This thesis is dedicated to my family, both given and chosen, for relentlessly supporting and protecting my aspirations.

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LIST OF ABBREVIATIONS

AARR	Average annual rate of reduction
ADB	Asian Development Bank
AfDB	African Development Bank
AUC	African Union Commission
CBV	Community Based Volunteer
CHA	Community Health Assistant
CMAM	Community-based Management of Acute Malnutrition
COHA	Cost of Hunger Analysis
DHS	Demographic and Health Survey
EBF	Exclusive breastfeeding
FAO	Food and Agriculture Organization
GDP	Gross domestic product
GMP	Growth monitoring and promotion
HAP	Household air pollution
HAZ	Height-for-age z-score
HCP	Healthcare provider
IFPRI	International Food Policy Research Institute
IUGR	Intrauterine growth restriction
IYCF	Infant and young child feeding
LMICs	Low and middle income countries
MGRS	Multicentre Growth Reference Study
NEPAD	New Partnership for Africa's Development
ORS	Oral rehydration salts
PC	Primary caretaker/caregiver
PEM	Protein energy malnutrition
RUSF	Ready to use supplementary food
RUTF	Ready to use therapeutic food
UN	United Nations
UNICEF	United Nations Children's Fund
USD	United States Dollar
WASH	Water, sanitation, and hygiene
WHO	World Health Organization
WHZ	Weight-for-height z-score

LIST OF PAPERS

The work included in this thesis is the product of original research conceptualised and conducted by Nakawala Lyapa Lufumpa. Doctoral supervisors advised in the study design, data analysis, and/or writing stage of each analytical chapter. All analytical chapters were written in paper format for submission to journals. Detailed below are the list of papers, either directly from this thesis or based on the work included in this thesis, that have been submitted for publication. Papers that were developed based on the work included in this thesis are included in the thesis Appendix.

Papers published directly from the thesis

Lufumpa, N., Lavis, A., Caleyachetty, R., Henry, M., Kabombwe, S., Manaseki-Holland, S. Exploring Attributions of Causality for Child Undernutrition Among Primary Caretakers and Healthcare Providers: Qualitative Analysis of Attributions of Causality. *Maternal and Child Nutrition.*

Papers under review directly from the thesis

Lufumpa, N., Lavis, A., Caleyachetty, R., Henry, M., Kabombwe, S., Manaseki-Holland, S. Primary Caregivers' Experiences of Nutrition Education for the Prevention of Child Undernutrition in Zambia: Barriers and Facilitators to Behaviour Change.

Papers under review based on the work included in this thesis

Caleyachetty, R.*, **Lufumpa, N.***, Kumar, N., Mohammed, NI., Bekele, H., Kurmi, O., Wells, J., Manaseki-Holland, S. Exposure to Household Air Pollution from Solid Cookfuels and Childhood Stunting.

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INTRODUCTION

CHILDHOOD UNDERNUTRITION IN SUB-SAHARAN AFRICA

Sub-Saharan Africa bears the highest burden of under-five deaths worldwide (1). In 2019, approximately 5.2 million children under the age of five died worldwide, the highest prevalence of which was in Sub-Saharan Africa where approximately 74 children under the age of five died per 1,000 live births (1). High under-five mortality rates, particularly in low and middle income countries (LMICs), are the direct result of poor child health outcomes. Malnutrition within children, undernutrition specifically, is responsible, both directly and indirectly, for nearly 45% of all under-five deaths in LMICs (2). In addition to its association with an increased risk of mortality, childhood undernutrition has been termed a life-sentence due to associated and long lasting health, social, and economic impacts (3).

Childhood undernutrition decreases the quality of life through numerous adverse effects. First, undernutrition weakens the immune system, increasing the risk infection (4). Second, childhood undernutrition is associated poor cognitive and physical development, both of which are largely irreversible (5). Other long-term secondary effects include a significant decrease in intellectual development, school performance and future earnings (4). Undernutrition has therefore resulted in large economic losses. Childhood undernutrition alone has resulted in an $899 million USD loss to the Ugandan economy, which amounts to approximately 5.6% of Uganda's GDP (6). In the case of another Sub-Saharan African country, Tanzania, the eradication of stunting - a result of undernutrition - could result in a $539 USD increase in annual lifetime earnings per individual (6).

Current approaches to address childhood undernutrition in Sub-Saharan Africa have focused on improving infant and young child feeding (IYCF), improving water, sanitation, and hygiene (WASH) infrastructure and behaviour, and increasing outpatient and community-based treatment and management of severe acute malnutrition (7-9).

Inadequate infant and young child feeding is an immediate cause of undernutrition, according to the UNICEF conceptual framework for undernutrition. Following the birth of a child, exclusive breastfeeding for the first six months of life is the most cost-effective way of ensuring that new-born babies meet their nutritional requirements (10). Within Sub-Saharan Africa, most new mothers are aware of the importance of breastfeeding and the percentage of children being breastfed has increased within the last decade (11). Knowledge of beneficial infant and young child feeding practices however, has not translated into feeding practices that adequately meet the nutritional needs of infants and young children in many LMICs. Most caretakers of infants and young children do not breastfeed exclusively for the recommended time period (12). Furthermore, once infants are weaned from exclusive breastfeeding, subsequent infant and young child feeding practices rarely meet the WHO recommended nutrition standards for growing children (13). Suboptimal feeding practices lead to an increased prevalence of malnutrition in the affected children and raise the risk of opportunistic infections and other health challenges (14).

Inadequate WASH infrastructure and behaviour is an underlying cause of undernutrition, per the UNICEF conceptual framework for undernutrition. In 2017, only 27% of the population in Sub-Saharan Africa used safely managed drinking water services and only 19% used safely managed sanitation services (15). These statistics were significantly worse in rural populations where only 12% of the population used safely managed drinking water services and just under 18% of the population used safely managed sanitation services. Inadequate WASH infrastructure and behaviour increases the risk of contracting infectious diseases, largely diarrhoeal diseases, which subsequently increases the risk of undernutrition (16). Diarrhoeal diseases are associated with a decreased intake of nutrients and decreased ability for the small intestine to absorb nutrients (17). Furthermore, decreased immune system function associated

with undernutrition increases both the likelihood of recurrent infections and the severity of infections (16).

Although all forms of undernutrition are associated with an increased risk of mortality, severe acute malnutrition is associated with a significantly higher risk of mortality. In comparison to children who are not undernourished, severe acute malnutrition increases the risk of mortality nearly 12 fold (18). Consequently, significant investments have been made into the early identification and treatment of wasting (low weight-for-height). Historically, severe acute malnutrition was treated in inpatient facilities. However, in an attempt to increase programme coverage and effectiveness, LMIC governments have introduced the use of outpatient treatment for severe acute malnutrition (19). Children without additional medical complications are provided ready to use therapeutic foods (RUTF). In addition to the use of outpatient treatment, community management of acute malnutrition (CMAM) was introduced to increase the coverage of nutrition services and further decrease associated mortality (20). CMAM encourages the early identification and treatment of acute malnutrition, alongside regular growth monitoring and the dissemination of nutrition education to encourage improved infant and young child feeding practices.

Despite noticeable improvements in economic performance and increased investments in child undernutrition programmes – particularly in the three areas detailed above, high rates of childhood undernutrition continue to persist in many Sub-Saharan African countries (1). As Sub-Saharan African countries continue to grow economically and invest in nutrition, it is imperative that we understand how to ensure that investments in childhood undernutrition result in sizeable improvements to child undernutrition outcomes and associated morbidity and/or mortality.

THESIS AIM

This research aims to influence the development of policies and programmes targeted towards the reduction of childhood undernutrition in Sub-Saharan African countries and other similar developing settings. This research identified limitations in current approaches to addressing childhood undernutrition in Sub-Saharan Africa and provided recommendations for change to accelerate the reduction of childhood undernutrition. The research aim was carried out through a multi-method study. Quantitative and qualitative research methods were employed to examine the research objectives detailed below. Each analytical chapter examined a separate research objective. Chapter two examined research objective one, chapter three examined research objective two, chapter four examined research objective three, and chapter five examined research objective four.

Research Objectives

1. Examine trends and inequalities in the prevalence of childhood undernutrition in 51 African countries.

2. Examine the association between exposure to household air pollution from solid cooking fuels and childhood undernutrition in 59 LMICs.

3. Explore attributions of causality for childhood undernutrition among primary caretakers and healthcare providers in Lusaka district, Zambia.

4. Explore primary caretakers' experiences with nutrition education in Lusaka district, Zambia.

THESIS OVERVIEW

This thesis is organised as follows, there are six chapters – background; four analytical chapters; and a discussion/conclusion chapter. Every analytical chapter of this thesis is presented in publication format. Each analytical chapter includes a chapter preface linking the paper's research objective to the overall thesis aim; the manuscript title page detailing author contributions for papers submitted (or to be submitted) to journals directly from this thesis; the manuscript; and a chapter summary summarising the key findings and linking each analytical chapter. A complete listing of the chapters/papers which are currently under review is included in the previous section.

Chapter One: Background

The background chapter explores existing knowledge about childhood malnutrition, with a focus on undernutrition. This chapter explores the different types of child undernutrition, the biological and economic impacts of childhood undernutrition, and determinants of childhood undernutrition. This chapter also includes an examination of current approaches to address child undernutrition in LMICs, highlighting opportunities to accelerate progress.

Chapter Two: Trends and Inequalities in Childhood Undernutrition in 51 African Countries

This chapter examines trends in the prevalence of childhood wasting and stunting in 51 African countries from 2000 to 2019. Inequalities in the prevalence and trends of childhood undernutrition were examined in the following subpopulations: UN subregions, rural/urban area of residence, household wealth quintiles, child age groups, levels of household air pollution and trends in household air pollution. The findings of this study underscore minimal progress in reducing childhood undernutrition in African countries. Should present trends

continue, African countries will be unable to reach the 2025 Global Nutrition Targets for childhood stunting and wasting. Furthermore, this study highlights significant inequalities in the reduction of childhood undernutrition within subpopulations.

Chapter Three: Exposure to Household Air Pollution from Solid Cookfuels and Childhood Undernutrition in 59 Low-Income and Middle-Income Countries: A Population-Based Cross-Sectional Study

Given the findings of the first analytical chapter, which point towards a need to strengthen approaches to address childhood undernutrition in Sub-Saharan African countries, this chapter explores the association between household air pollution (HAP), from solid cooking fuel use, and childhood stunting, wasting, and concurrent stunting and wasting in LMICs. Cross-sectional Demographic and Health Survey (DHS) data from 59 LMICs was analysed. The association between exposure to HAP and childhood undernutrition was further explored in the following subpopulations: area of residence, household wealth, exclusive breastfeeding, WHO region, maternal smoking, and child age. The findings of this study suggest a statistically significant association between exposure to HAP from solid cooking fuels and childhood undernutrition. Children living in households cooking with solid fuels were more likely to be stunted, wasted, or concurrently stunted and wasted. Furthermore, this study identified heterogeneity in the association between exposure to HAP and childhood undernutrition according to the following subgroups: area of residence, household wealth, WHO region, maternal smoking, and child age. Children living in households cooking with solid fuels were more likely to be stunted if they lived in rural regions, the poorest households, the Americas, had a mother who smoked, or were older in age. This study underscores the need for nutrition policy to further incorporate wider determinants of childhood undernutrition, such as HAP,

into nutrition action; and the need for nutrition research to evaluate the impact of interventions that address high levels of HAP, from solid fuel use, on child nutritional outcomes.

Chapter Four: Exploring Attributions of Causality for Child Undernutrition Among Primary Caretakers and Healthcare Providers: A Qualitative Analysis in Lusaka District, Zambia

This chapter examines and compares the attribution of causality for child undernutrition among primary caretakers of children under five years old and child health professionals in Zambia. A qualitative study was conducted in Lusaka district, Zambia using one-to-one and group semi-structured interviews with primary caretakers of children under five years old and healthcare providers. All interview data were transcribed and analysed using thematic analysis. The findings of this study revealed that primary caretakers and healthcare providers had diverging explanatory models of undernutrition, and consequently attributed causality different. Additionally, healthcare providers' explanatory models of child undernutrition were not reflective of the local context in which primary caretakers operated. This study underscores a need to address divergent explanatory models of child undernutrition and the impact of wider socioeconomic constraints on both primary caretakers and healthcare providers.

Chapter Five: Primary Caregivers' Experiences of Nutrition Education for the Prevention of Child Undernutrition in Zambia: Barriers and Facilitators to Behaviour Change

This chapter explores the experiences of primary caregivers of children under five years old with nutrition education in Lusaka district Zambia. Specifically, it examines primary caregivers' perceptions and experiences of nutrition education, as well as perceived barriers and facilitators to clinically recommended behaviour change. One-to-one and group semi-

structured interviews were conducted with primary caregivers of children under five years old and healthcare providers in Lusaka district, Zambia. All interviews were transcribed and analysed using thematic analysis. The findings revealed that although primary caregivers valued and actively sought out nutrition education, they highlighted barriers to accessing personalised education and barriers to implementing practices recommended through group education. Primary caregivers also identified social structures through which they accessed nutrition information and how they determined which behaviour changes to adopt in their households. The findings of this study underscore the need to address discrepancies between nutrition education policy and practice, and wider social and cultural constraints on primary caregivers in order to increase access to nutrition education and household implementation of clinically recommended behaviour changes.

Chapter Six: Discussion and Conclusion

The discussion and conclusion chapter summarises the complete body of work of this thesis. This chapter begins by reintroducing the overall aim of the thesis, restates the research objectives and key findings of each analytical chapter, details the policy implications of the thesis as a whole, summarises the strengths and limitations of the wider thesis, and identifies opportunities for additional research. This chapter ends with a brief concluding statement about the value of this body of work.

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CHAPTER ONE: BACKGROUND

1.1. CHAPTER PREFACE

This chapter begins by providing an overview of malnutrition in low and middle income countries (LMICs) – with a focus on macronutrient undernutrition, given its severity in Sub-Saharan Africa. This is followed by an examination of existing literature about determinants of childhood undernutrition, highlighting research gaps; and a description of current policy and programmatic approaches to address childhood undernutrition in LMICs. The chapter thereby provides context for the analytical chapters that will follow in this thesis, and underscores the value of this body of work and the use of multiple methods to create a comprehensive, multidimensional analysis.

1.2. MALNUTRITION

Definitions

Malnutrition is broadly defined as the inappropriate use, absorption, or intake of nutrients (1). Malnutrition encompasses both the excessive intake of nutrients and the inadequate intake of nutrients - "substances needed for growth, energy provision and other body functions" (2). The intake of nutrients occurs through the consumption of food, drink, and/or supplements. Nutrient absorption and utilisation, however, refer to the body's ability to absorb and utilise nutrients once they are consumed.

There are two categories of nutrients - macronutrients and micronutrients. Macronutrients are largely necessary for powering the body through the provision of energy. Micronutrients however, are necessary for supporting chemical functioning of the body (3). Macronutrients are broadly subdivided into three types: fats, carbohydrates, and protein (3). Micronutrients are subdivided into two types: minerals and vitamins (3). Due to the nature of the body's utilisation

of macronutrients and micronutrients, to be in adequate nutritional standing, individuals usually require a greater volume of macronutrients than they do micronutrients.

Individuals can either suffer from overnutrition or undernutrition - of either macronutrients or micronutrients. Within higher income countries, the most prevalent form of childhood malnutrition is macronutrient overnutrition. The percentage of overweight adults has consistently been highest in Europe and the Americas - as classified by WHO regions (4). Within LMICs, undernutrition of both macronutrients and micronutrients continues to be a pressing health concern. However, as LMICs experience economic growth, they are beginning to experience the double burden of malnutrition – overnutrition and undernutrition (4).

Despite the growing prevalence of childhood overnutrition in LMICs, the most prevalent form of childhood malnutrition in LMICs, and Sub-Saharan Africa in particular, remains childhood undernutrition (5). Close to 40% of all children under five years old in Sub-Saharan Africa suffer from one or more forms of malnutrition - ranging from 60% in Eritrea to 20% in Gambia (5). The following two sections detail the current state of micronutrient and macronutrient undernutrition in LMICs and the associated health impacts.

Micronutrient Undernutrition in Low and Middle Income Countries

Micronutrient undernutrition can occur for any of the many minerals and vitamins that our bodies need to function efficiently. Within the context of global health, the most common micronutrient deficiencies are: iodine deficiency, iron deficiency, and vitamin A deficiency (6). Iodine and iron deficiencies are mineral deficiencies and vitamin A is a vitamin deficiency. Recent estimates suggest that 59% of children under five year old in Sub-Saharan Africa are anaemic and 42% are vitamin A deficient (7). Micronutrient undernutrition is most common in

pregnant women and children, who both require an increased amount of minerals and vitamins due to higher physiological demands (7).

When ingested, iodine travels to the thyroid where it is converted into hormones that are used throughout the body to control three body functions – heart rate, temperature, and metabolism (8, 9). Iodine deficiency is most commonly associated with goitres – swelling of the thyroid gland (10). Iodine deficiency can also result in poor cognitive development in children as well as disrupted mental function in both adults and children (11). Additionally, pregnant women with an iodine deficiency have an increased risk of losing the child or giving birth to a child with congenital defects (11). Furthermore, the risk of premature death significantly increases when a young child suffers from an iodine deficiency (11).

Iron deficiency commonly results in iron deficiency anaemia (12). Iron is used in the body to produce haemoglobin and myoglobin. Haemoglobin carries oxygen in red blood cells while myoglobin does the same in muscles. There are hundreds of types of anaemia that exist, each caused by a wide array of factors (13). However, the most common cause of anaemia worldwide is iron deficiency (12). Anaemia is most dangerous in pregnant women, infants, and young children. Pregnant women suffering from iron deficiency anaemia are more likely to experience poor health outcomes, and the same is true of the foetus they are growing. Both mother and child have an increased risk of morbidity or mortality. Poor maternal outcomes as a result of iron deficiency anaemia include pre-eclampsia, bleeding and infections (14). Poor foetal outcomes include low birth weight, intrauterine growth retardations and preterm birth (14).

Vitamin A deficiency can result in a wide array of health disabilities and poor outcomes – the most common of which relate to vision and the immune system. Vitamin A is essential in the development and regulation of healthy skin, mucus membranes, bones, and teeth (15). Similar

to iron deficiency, vitamin A deficiency has especially detrimental effects on the health of pregnant women and young children. Within pregnant women, vitamin A deficiency can lead to night blindness and increases the risk of mortality. Within young children, vitamin A deficiency can result in vision impairment and/or a compromised immune system, which significantly increases the risk of death. Approximately 50% of vitamin A deficient children who suffer from vision impairment die within a year of becoming blind – that is between 125,000 to 250,000 preventable deaths a year (16).

Macronutrient Undernutrition in Low and Middle Income Countries

Another common form of undernutrition in LMICs is macronutrient undernutrition. Macronutrient undernutrition is commonly referred to as protein energy malnutrition (PEM). PEM is the result of an inadequate use, absorption, or intake of macronutrients – fats, carbohydrates, and/or protein (1, 3). PEM is broadly separated into three categories: stunting, wasting, and underweight. Stunting is largely the result of chronic PEM; wasting is largely the result of acute PEM; and underweight is largely the result of concurrent stunting and wasting.

All three forms of PEM are measured using anthropometric data – measurements of the body (i.e. height or weight) (1). Stunting is measured using a child's height-for-age. Wasting is measured using a child's weight-for-height. Underweight is measured using a child's weight-for-age. Severe acute malnutrition, wasting, can be further separated into two categories: kwashiorkor or marasmus. The principal cause of kwashiorkor is an inadequate intake of protein while that of marasmus is a deficiency in both protein and energy (1).

WHO reference anthropometric measurements are used to classify individuals as stunted, wasted, or underweight. From 1993 to 2003, the WHO carried out the Multicentre Growth Reference Study (MGRS) in five different countries (17). The purpose of this study was to

develop new reference values to track the growth of children worldwide. For this study, the WHO collected anthropometric data of children in six countries - USA, Norway, Oman, India, Ghana, and Brazil (17). Through the MGRS, the WHO identified median reference values that indicate optimal growth in children. Children are classified as moderately undernourished if their anthropometric measures are more than two standard deviations below the median reference values, and severely undernourished if their anthropometric measures are more than three standard deviations below the median reference values.

Although anthropometric measurements are considered standard measures of undernutrition, it is important to note two potential limitations of these measurements (18, 19). First, the use of anthropometric measurements assumes that undernutrition exists in a dichotomy that can be accurately captured with measures such as stunting or wasting. In many instances, children may suffer from undernutrition prior to becoming stunted or wasted (20). Second, while anthropometric measures are well suited to capture population level estimates of undernutrition (21), other indicators may be better suited to assess nutritional status at an individual level and identify undernutrition with higher sensitivity (22). Beyond anthropometry, additional nutrition assessments include biochemical and clinical assessments (23). Biochemical assessments include an assessment of micronutrient status through, for example, blood tests. Clinical assessments include an assessment, by a healthcare professional, of body composition, specifically fat-free mass or fat mass (23). The pathophysiology of undernutrition includes changes in body composition (24).

This thesis will focus on childhood macronutrient undernutrition in Sub-Saharan Africa. The term childhood undernutrition will be used to reference macronutrient undernutrition, unless stated otherwise. Addressing high levels of childhood stunting and wasting in LMICs was highlighted as a key priority area for the WHO's nutrition action and is included as two out of

the six 2025 Global Nutrition Targets to address child and maternal malnutrition worldwide (25). The following section explores in more detail the significant biological and economic impacts of childhood macronutrient undernutrition, and underscores the need to urgently address high levels of childhood wasting and stunting in Sub-Saharan Africa.

1.3. IMPACTS OF CHILDHOOD UNDERNUTRITION

Direct Impacts of Childhood Undernutrition: Biological Impacts

Undernutrition is associated with an increased risk of mortality and morbidity in childhood, adolescence, and adulthood. The consequences of undernutrition are especially grave when an individual suffers from undernutrition within the first few years of life. When a child suffers from undernutrition in the first few year of life, the impacts – as discussed in detail below – are long lasting and sometimes irreversible. This section will focus exclusively on the short- and long-term impacts of undernutrition experienced in the first five years of life, a critical period for child growth and development.

Childhood undernutrition primarily impacts a child's immune system and development (26, 27). Undernutrition compromises the immune system, increasing the risk of contracting infectious diseases and making the immune system less efficient at fighting off acquired diseases (28, 29). Infectious diseases further decrease nutrient intake, increase nutrient malabsorption, and increase nutrient requirements for biological functions (29). Undernutrition also increases the severity of diseases such as diarrhoea and acute lower respiratory infections, and the subsequent risk of mortality (30). Studies suggest that the risk of death, as a result of diarrhoea and acute lower respiratory infections, further increases depending on the severity of undernutrition (31, 32).

Childhood undernutrition also impacts cognitive and physical development. Childhood is a critical period for brain development (33). Undernutrition during this period can have severe implications on brain development and associated cognitive and behavioural development (34). A 2008 study of children in India between the ages of five and 10 determined that in relation to adequately nourished children, malnourished children - specifically stunted children - perform worse on neurological tests that evaluate the relationship between behaviour and brain function (35). Furthermore, the study determined that with age, the rate of development of cognitive functions and processes is slower in malnourished children (35). Cognitive functions refer to functions of intellect such as memory, comprehension, and learning (35). Cognitive processes refers to the processes of these cognitive functions (35).

In addition to the impact of childhood undernutrition on cognitive development, child undernutrition impacts physical development – most notably the height of a child (36). A large proportion of cases of stunting are irreversible. This, along with the sometimes irreversible impairments to cognitive development have led to a program and policy focus within the fields of public health and development economics on preventing and treating undernutrition in the first 1,000 days of life (37). The first 1,000 days of life begin once a foetus is created up until the child is 2 years old.

Although growth retardation as a result of child undernutrition is largely irreversible, the idea of catch-up growth is still being explored. The International Food Policy Research Institute (IFPRI) defines catch-up growth as "a reduction in a child's height deficit (compared to the international height standard) as the child ages" (38). The concept of catch-up growth is based on the idea that improved nutritional and health standing of a child within a certain age group can result in improved physical growth outcomes. Evidence from Philippines, Ethiopia, Peru, Vietnam, India, Brazil, Guatemala, South Africa, and Gambia suggests that children can

experience improvements in physical growth beyond the age of two (39-43). Notably, improvements in child height have been observed in children above two years old and in adolescence. Consequently, some studies have also identified improvements in cognitive scores (39, 43).

Growing evidence about the potential for catch-up growth calls for increased program and policy attention on addressing undernutrition outside of the 1,000 day period. This primarily includes addressing undernutrition in children above two years old and adolescent women (42, 44). Although there is a growing body of literature suggesting that the impacts of childhood undernutrition on cognitive and physical development may be reversible, research exploring factors which may promote or discourage catch-up growth is limited (43, 45). Furthermore, it is important to note that within the developing context, the circumstances that encourage and produce childhood undernutrition are usually long lasting, limiting the opportunity for catch-up growth.

In addition to the direct impacts of childhood undernutrition detailed above, undernourished children are at an increased risk of all-cause mortality. Analysis of prospective cohort and randomised control trial data from 11 LMICs estimated that severely stunted children under five years old are 5 times more likely to die than children with height/length-for-age z-scores above or equal to -1; and severely wasted children are 11 times more likely to die than children with a weight-for-height/length z-score above or equal to -1 (32). The risk of mortality further increases as z-scores decrease, suggesting a dose-response relationship. Studies further identified that the risk of all-cause mortality is highest for children who are concurrently stunted and wasted (46, 47). The hazard ratio for children who are concurrently stunted and wasted is nearly five times the hazard ratio of children who are only wasted and eight times the hazard ratio of children who are only stunted (46).

Indirect Impacts of Childhood Undernutrition: Economic Costs

In addition to the devastating health and growth impacts of childhood undernutrition, there are large economic costs to both individuals and nations. Poor cognitive development impacts a child's educational ability and attainment (48). Poor educational outcomes decrease the economic potential of an individual (49). Poor individual economic potential is further intensified by poor health - the direct result of a poorly functioning immune system. The Global Panel's conceptual framework of the impacts of malnutrition categorises the economic costs of malnutrition, highlighting the impact of malnutrition at different levels – individual, societal, and national (Figure 1) (50).

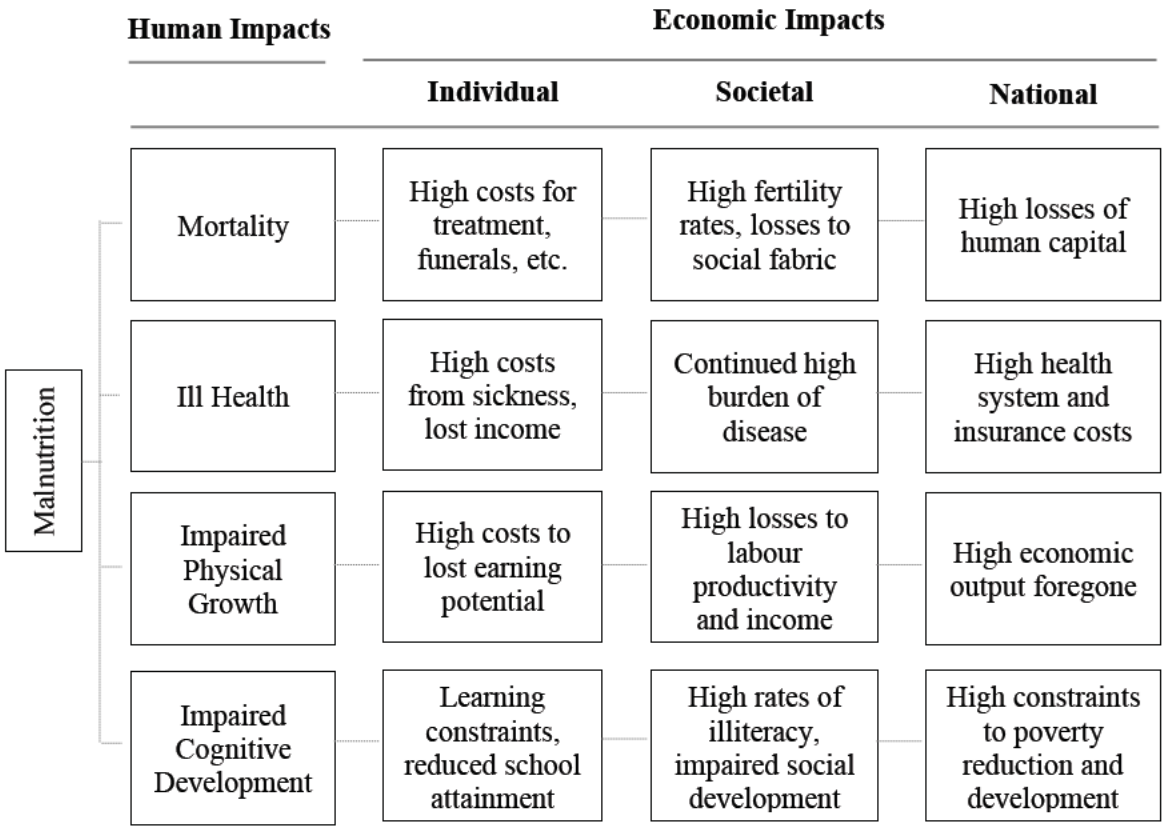

Figure 1: Global Panel Conceptual Framework of the Economic Impacts of Malnutrition (Source: Global Panel, 2016)

This section will focus exclusively on the costs of malnutrition specific to Sub-Saharan Africa, the primary region of interest. In the last decade, a decrease in poor child nutritional outcomes (such as stunting) has been observed worldwide. However, the rate at which child undernutrition is decreasing in Sub-Saharan Africa is slower than has been observed in other regions (51). Both South Asia and Sub-Saharan Africa have the highest rates of child undernutrition. However, from 2010 to 2020, the prevalence of stunting decreased in South Asia from 43.8% to 31.8% whereas Sub-Saharan Africa only observed a less than 6 percentage point decrease from 37.9% to 32.4% (52).

The African Union Commission (AUC) and the New Partnership of Africa's Development (NEPAD) launched the Cost of Hunger in Africa (COHA) study. The COHA study estimates the social and economic costs of child macronutrient undernutrition, to individuals and countries. As of 2020, the study has been conducted in 21 African countries. The first phase of the study was carried out in four countries: Uganda, Swaziland, Ethiopia, and Egypt. The COHA study specifically estimates the costs of child undernutrition on productivity, education, and health (49). To calculate the costs of child undernutrition, the authors of COHA devised a framework which depicts the costs associated with the impacts of child undernutrition (Figure 2).

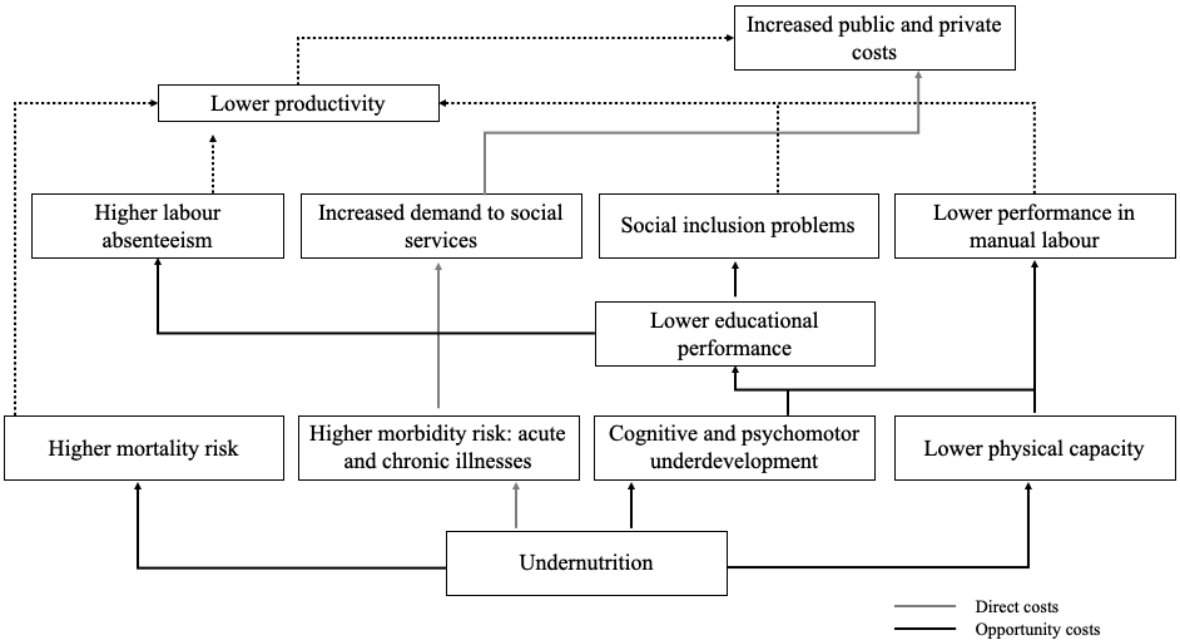

Figure 2: COHA Framework of Consequences of Undernutrition (Source: AUC et al, 2014)

Amongst the four first phase countries, it was estimated that child undernutrition costs individual countries between $899 million and $4.7 billion USD annually. In Ethiopia, losses totalled up to the equivalent of 16.5% of the country's GDP (49). In all four countries, costs are primarily from the impact of child undernutrition on productivity, followed by health costs.

1.4. DETERMINANTS OF CHILD UNDERNUTRITION

This section builds on previous sections of the background chapter, summarising existing literature about risk factors associated with childhood undernutrition in LMICs and highlighting gaps in existing research. In the early 1990s UNICEF developed a conceptual framework to organise the risk factors associated with malnutrition (53). This framework goes beyond earlier biomedical models of health, employing a biosocial approach (Figure 3).

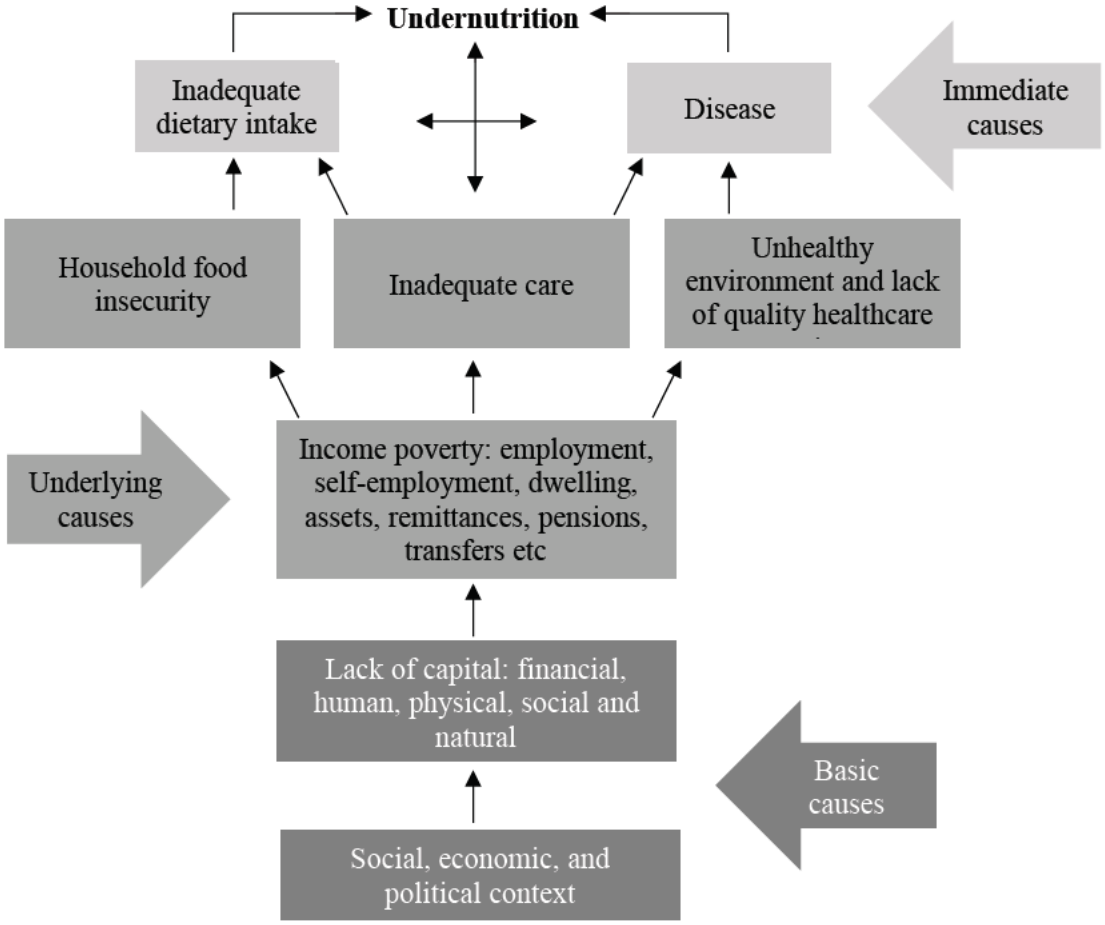

Figure 3: UNICEF Conceptual Framework for Malnutrition

The UNICEF conceptual framework of malnutrition broadly separates factors into three categories: (1) immediate causes; (2) underlying causes; and (3) basic causes. UNICEF defines immediate causes as "operating at the individual level"; underlying causes as "influencing household and communities"; and basic causes as influences "around the structure and processes of societies" (54). Per the UNICEF conceptual framework, basic causes directly impact the underlying causes, the underlying causes directly impact the immediate causes, and the immediate causes directly impact whether a child suffers from undernutrition or not.

There are two categories of immediate causes - inadequate dietary intake and disease (54). Inadequate dietary intake could be the result of a wide variety of factors such as inadequate

access to food – due to availability or affordability. Additionally, dietary intake may be inadequate due to improper child feeding practices. As it pertains to diseases as an immediate cause of childhood undernutrition, certain illnesses result in patients losing their appetite and/or having difficulty absorbing nutrients (55).

There are two levels of underlying causes of undernutrition. The primary level is income poverty. Income poverty, in this framework, refers to the financial resources available to a household. This primary level directly impacts the secondary level, composed of three categories of underlying causes: (1) household food insecurity; (2) inadequate care; and (3) unhealthy household environment and lack of health services (54). Food insecurity relates to the accessibility and affordability of nutritionally rich foods. Household food insecurity directly impacts the dietary intake of a child. Inadequate care, can be broadly identified as the inability of a caretaker to provide a child with the services necessary for optimal growth and development. Inadequate care directly impacts both immediate causes. Unhealthy household environment and lack of health services directly impacts one immediate cause – disease.

Per the UNICEF conceptual framework, there are two levels of basic causes of undernutrition. The primary level is the social, economic, and political context, followed by the secondary level - lack of capital. Capital, in this framework, refers to financial, human, physical, social, and natural capital. In this conceptual framework, the primary level directly impacts the secondary level which in turn impacts the underlying causes.

Although the UNICEF conceptual framework broadly organises the determinants of malnutrition, each category and level of determinants includes a multitude of potential factors. Furthermore, the impact of individual determinants and factors vary across and within populations. Research has identified numerous risk factors of childhood undernutrition in

LMICs and how the impact of these risk factors differ across and within LMICs. This is explored in additional detail in the following section.

Risk Factors for Childhood Undernutrition

This section begins by summarising the findings of two larger studies and providing a broad description of existing literature. The first large study is a systematic review examining risk factors associated with stunting and wasting in children under five years old in Sub-Saharan African countries (56). This systematic review identified 49 relevant publications. Among the included studies, factors associated with all forms of undernutrition included parental educational attainment, maternal body mass index (BMI), birthweight, birth size, child age, water, sanitation, and hygiene (WASH), sex, and area of residence. In most studies, the risk of stunting, wasting, and underweight was higher in children with a low birthweight or size, increasing child age, low parental educational attainment, low maternal BMI, poor WASH, male children, and children living in rural areas. Although childhood stunting and wasting largely shared the same risk factors, this systematic review identified a few factors which increased the risk of only one form of undernutrition. Existing literature suggests that childhood wasting is associated with fever, while prolonged breastfeeding for more than twelve months (and likely concurrent inadequate complementary feeding) is associated with childhood stunting.

The second large study is an analysis of Demographic and Health Survey (DHS) data from 35 LMICs. This study identified and compared the significance of risk factors of stunting, wasting, and underweight in and across LMICs (57). The study sample was restricted to children between one to five years old. This study specifically examined the association between childhood undernutrition and 9 direct and 17 indirect factors. Direct and indirect factors were defined according to the UNICEF conceptual framework. Direct factors were associated with

the immediate causes of undernutrition and indirect factors were associated with the underlying causes of undernutrition. Within the full sample of children from 35 LMICs, the factors with the strongest association with child undernutrition were indicators of poor maternal nutrition and low socioeconomic status. Among all included factors, short maternal stature had the strongest association with childhood stunting and underweight, and low maternal BMI had the strongest association with childhood wasting. Although this was the case within the complete sample of children from 35 LMICs, the magnitude of association differed across countries. Although short maternal stature was the factor with the strongest association to childhood stunting in multiple countries, the odds ratios ranged from 0.8 in Guinea to 15.5 in Togo. Additionally, within some countries, other factors had a stronger association with childhood stunting than maternal stature. In Côte d'Ivoire, the factor with the strongest association to childhood stunting was lack of maternal education.

The above larger studies underscore two points about existing literature which will be explored in detail below. First, childhood wasting and stunting share many of the same risk factors. Second, the magnitude and significance of risk factors varies across populations and within subpopulations.

Most of the existing literature examining risk factors of childhood undernutrition were either entirely specific to Sub-Saharan Africa or included a detailed analysis of child undernutrition in Sub-Saharan Africa alongside other regions. This was closely followed by analyses in South Asia and lastly Latin America.

Risk factors examined within existing literature can be broadly placed into one of the following ten categories - child and maternal micronutrient deficiencies; household/parent characteristics; WASH; child health; health of household members; cultural factors; infant and

young child feeding practices; community level factors; government factors; and shocks. The next section will briefly discuss three of the above categories with the largest bodies of work.

Among the ten categories listed above, the most expansively researched category was the role of household or parental characteristics in childhood undernutrition in LMICs. This is similar to the findings reported in the two larger studies discussed above (56, 57). Most of the publications pertaining to this category identified the importance of socioeconomic factors, maternal health, and household characteristics on the prevalence or likelihood of one or more forms of child undernutrition. Household or parental characteristics associated with the risk of childhood undernutrition include the following: mother's education level, the socioeconomic status of the household, the age of the mother, rural vs urban area of residence, and family size (58-60). A summary of some of the estimated associations between household and parental characteristics and child undernutrition are detailed below (Table 1).

Table 1: Literature Summary – Household and Parent Characteristic Risk Factors

	Publication	Study	Sample	Age	Relevant findings
Maternal Education	Wamani et al., 2006 (61)	Cross sectional	720 children	0-23 months	In comparison to children whose mothers completed primary school or higher, children in rural Uganda had an increased likelihood of stunting if their mother did not complete primary school (OR: 2.1, 95% CI: 1.2 - 3.8) In comparison to children whose mothers completed primary school or higher, children in rural Uganda had an increased likelihood of stunting if their mother had no schooling (OR: 2.1, 95% CI: 1.1 - 4.0)
	Harding et al., 2018 (62)	Cross sectional	252,797 children	0-59 months	In Nepal, children with illiterate mothers were more likely to be wasted (AOR: 1.7, p-value:<0.01)
	Publication	**Study**	**Sample**	**Age**	**Relevant findings**
Socioeconomic Status	Kikafunda et al., 1998 (59)	Cross sectional	261 children	0-30 months	In Uganda, the prevalence of childhood stunting in lower income households was higher than that in higher income households (p<0.05). 8% of children in mid-upper income households were stunted, 25% in lower income households, and 31% in very low income households.
	Harding et al., 2018 (62)	Cross sectional	252,797 children	0-59 months	In India, children in the poorest households were more likely to be wasted (AOR: 1.6, p-value:<0.05)
	Publication	**Study**	**Sample**	**Age**	**Relevant findings**
Maternal Age	Boah et al., 2019 (63)	Cross sectional	2,720 children	0-59 months	In comparison to children with mothers between 15-19 years old, children in Ghana with mothers between 20-29 years old were less likely to be stunted (AOR: 0.5, 95% CI: 0.3-1.1)

Table 2: Literature Summary – Household and Parent Characteristic Risk Factors (Continued)

	Publication	Study	Sample	Age	Relevant findings
Area of Residence	Yisak et al., 2015 (64)	Cross sectional	791 children	0-59 months	In comparison to children living in urban areas, children in Ethiopia were more likely to be stunted if they lived in rural areas (AOR: 2.9, 95% CI: 1.3 - 6.6)
	Harding et al., 2018 (62)	Cross sectional	252,797 children	0-59 months	In Bangladesh, children living in rural areas were more likely to be wasted (AOR: 1.2, p-value: <0.05)
	Publication	**Study**	**Sample**	**Age**	**Relevant findings**
Maternal Height	Gewa et al., 2012 (65)	Cross sectional	3,793 children	0-59 months	In Kenya, mothers with shorter height were more likely to have children who were stunted (AOR: 2.6, 95% CI: 1.6 - 4.3)
	Danaei et al., 2016 (66)	Multiple data sources	N/A*	24-35 months	Maternal nutrition and infection were responsible for 14% of cases of childhood stunting in 137 developing countries. Most of these cases were largely due to a maternal height of less than 160 cm. Decreased maternal height is associated with an increased likelihood of childhood stunting.
	Publication	**Study**	**Sample**	**Age**	**Relevant findings**
Family Size	Odunayo et al., 2006 (67)	Cross sectional	420 children	0-59 months	In Nigeria, the prevalence of wasting was higher in households with higher occupancy rates (p-value: 0.03).

*Data obtained from multiple sources to estimate population attributable fraction

The second most frequently examined risk factors within the literature pertained to child health. These papers included an analysis of child health and child undernutrition in Sub-Saharan Africa, South Asia, and Latin America. Most of these papers evaluated one or more of the following aspects of child health: (1) child health in utero; (2) child health immediately following the birth; (3) child health of children under the age of five; and (4) preventative health measures. A summary of the estimated associations are detailed below (Table 3).

Table 3: Literature Summary Statistics - Child Health Risk Factors

	Publication	Study	Sample	Age	Relevant findings
In Utero	Danaei et al., 2016 (66)	Multiple data sources	N/A*	24-35 months	IUGR and premature births are responsible for about 33% of cases of childhood stunting in 137 developing countries. IUGR alone is responsible for about 24% of cases of childhood stunting in 137 developing countries.
	Publication	**Study**	**Sample**	**Age**	**Relevant findings**
Neonatal	Tharakan et al., 1999 (68)	Cross sectional	734 children	0-6 years	In Botswana, a higher birth weight decreased the chances of childhood stunting (Regression Coefficient: -0.7, p-value:<0.05)
	Publication	**Study**	**Sample**	**Age**	**Relevant findings**
Under-Five	Das et al., 2011 (69)	Cross sectional	6,005 children	0-59 months	In Bangladesh, the "incidence of [acute respiratory infection] in the last two weeks" was associated with an increased likelihood of childhood underweight (OR: 1.2, p-value:<0.05) In Bangladesh, the "incidence of fever in the last two weeks" was associated with an increased likelihood of childhood underweight (OR: 1.3, p-value:<0.05)
	Publication	**Study**	**Sample**	**Age**	**Relevant findings**
Preventative	Bloss et al., 2014 (70)	Cross sectional	175 children	0-59 months	Children in Kenya with age appropriate immunizations were less likely to be stunted or underweight (OR: 0.45, p-value:<0.05)

*Data obtained from multiple sources to estimate population attributable fraction

Regarding the health of children in utero, papers provided evidence about the association between intrauterine growth restriction (IUGR), premature birth, and child undernutrition (66). Regarding children's health following birth, papers discussed the relationship between low

birth weight and child undernutrition (68, 71). Regarding the general health of children under the age of five, papers discussed risk factors such as the incidence of diseases/illnesses such as diarrhoea, coughs, fever and respiratory infections (68, 69). Additionally, a few papers underscored the role of hospitalisation in determining the likelihood of a child suffering from undernutrition (71). Regarding preventative care, a few papers identified an association between child medical consultation, immunisation and child undernutrition (70, 71).

The third most frequently discussed category of risk factors was WASH infrastructure and behaviour. WASH has been thoroughly researched as it relates to child undernutrition. There are a number of studies that detail the impact of water sources and child undernutrition. The relationship between WASH and child undernutrition can be broadly evaluated according to child health – one of the immediate causes of child undernutrition identified by the UNICEF conceptual framework. Poor WASH increases the risk of children contracting water borne diseases such as cholera and malaria. These water borne diseases may lead children to suffer from diarrhoea and ultimately enteric dysfunction. This culmination of factors increases the risk of undernutrition through decreased appetite and increased nutrient malabsorption (72).

The risk of children contracting water borne diseases increases significantly once a child is no longer exclusively breastfeeding. Once a child is no longer being exclusively breastfed and food is being prepared for them, there are two main dangers. First, food might be prepared with unclean water. Second, it is possible that the caretaker preparing the meal may not employ adequate sanitary habits - for example, not washing hands following the use of the toilet. In addition to these two factors, depending on the type of toilet facility present in a household or community, water borne diseases may be contracted more easily. A 2011 study carried out in Zambia found that rainy season usually leads to the contamination of groundwater sources by shallow pit latrines (73).

A 2013 systematic review pooled the most current literature about the relationship between child undernutrition and different forms of WASH interventions (74). According to this systematic review, WASH interventions have a small positive impact on childhood stunting, wasting, and underweight. However, most of the studies included in this systematic review had a high risk of bias, suggesting that the true effects may differ significantly from what was estimated. More recently, three randomised control trials conducted in Zimbabwe, Kenya, and Bangladesh found that WASH interventions did not positively impact linear growth or the incidence of childhood stunting (75). Furthermore, the WASH intervention only improved the incidence of diarrhoea in Bangladesh.

The risk factors detailed above, and widely researched, are largely proximal in relation to childhood undernutrition as outlined by the UNICEF conceptual framework for undernutrition. To date, most research has focused on the immediate and underlying causes of undernutrition. Although this is important, it is also vital to note the impact of more distal risk factors on both the immediate and underlying determinants of undernutrition. The following section briefly summarises relevant social science literature examining the role of social risk factors on childhood undernutrition.

Social Risk Factors for Childhood Undernutrition

Existing social science literature centres around the impact of social factors on breastfeeding, complementary feeding, and child care (76). This is reflective of the social ecological model of health which highlights the impact of social factors on individual behaviour (77, 78). Within this section, the social risk factors of childhood undernutrition will be separated into the following categories – relationships, cultural beliefs, and gender norms. Although the listed categories are interrelated, they are presented separately for clarity.

First, there is a wide body of work that underscores the influence of peers, family members, partners, healthcare providers, and children on child feeding and childcare practices. Within many studies, the relationship between primary caregivers and the above groups – excluding children, is referred to as the support system. Qualitative studies conducted in LMICs have consistently underscored the ability for the above social networks to serve as barriers or facilitators of household implementation of recommended infant and young child feeding practices (79-91). Firstly, primary caregivers rely on their social networks for nutrition information. In particular, studies have highlighted how community perceptions of certain infant and young child feeding practices have made them support systems which either encourage or hinder clinically recommended behaviour changes (81). Secondly, in instances where primary caregivers require temporary assistance looking after their children, they are likely to rely on these same social networks, who therefore influence feeding and childcare practices.

In addition to the above mentioned relationships, qualitative studies have underscored the value that primary caregivers place on their children's desires and preferences as they pertain to food (81, 82, 85, 87, 92, 93). First, studies have described primary caregivers who feed children according to their children's food preferences even if this is in conflict with clinically recommended feeding practices (81, 83). Second, studies have described primary caregivers who deviate infant and young child feeding practices from clinically recommended practices according to primary caregivers' perceptions about the value that children place on complementary foods or breastmilk (81, 85, 87, 92, 93).

In addition to relationships influencing feeding practices, cultural frameworks (94), which influence beliefs surrounding infant and young child feeding, have been highlighted as a potential hinderance to household implementation of clinically recommended practices (81).

A qualitative study conducted in South Africa highlighted cultural beliefs surrounding breastfeeding which impacted the duration of exclusive breastfeeding (84). Additionally, amongst communities, there are cultural beliefs about which foods are age appropriate, which foods are appropriate for children versus adults, and which foods are beneficial for child health (88, 95). These perceptions of and value judgements about foods are context specific and vary according to communities and countries. However, one common perception identified amongst Sub-Saharan African countries is that certain proteins are not acceptable for children to eat due to their texture (88, 95). This has implications on the nutritional adequacy of resulting child feeding practices.

Finally, it is important to recognise the gendered nature of child care and feeding. In most LMICs, women bear the largest responsibility for both childcare and feeding (96-98). However, although most women have autonomy in deciding what to cook and feed their children, they do not always have the financial ability to purchase desired food items or the autonomy to decide what food items will be purchased (90). As such, they have limited input into the food that their children eat. This is especially problematic in contexts where nutrition education targets mothers without regard for male household heads who commonly manage finances and purchase the necessary food items (99).

Key Findings from Literature Review

It is important to note three key findings pertaining to existing literature about risk factors of child undernutrition. First, most research has focused on the immediate and underlying determinants of childhood undernutrition, largely ignoring the potential impact of more distal and contextual determinants of childhood undernutrition (Figure 4). Second, the risk factors summarised above support the findings of the two larger studies. The magnitude of effect and

significance of risk factors varies across countries. Third, there is significant overlap in the risk factors associated with childhood stunting and wasting.

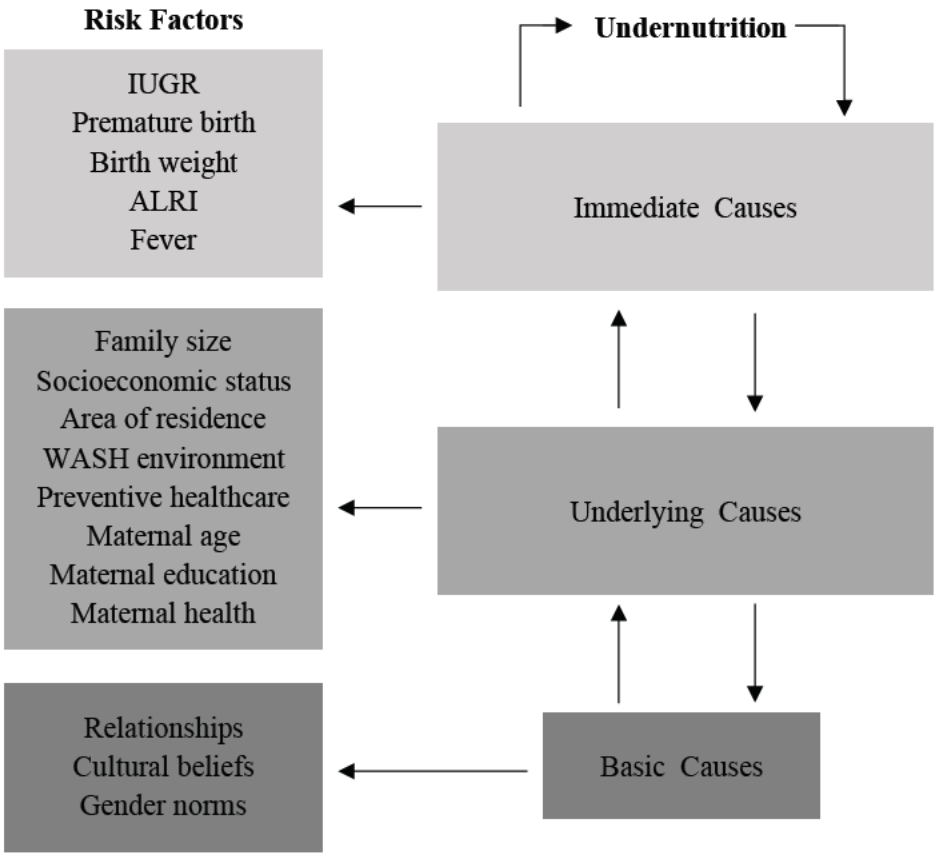

Figure 4: Risk Factors for Childhood Undernutrition Identified in the Literature, According to the UNICEF Conceptual Framework

1.5. CURRENT APPROACHES TO ADDRESS CHILD UNDERNUTRITION

In order to effectively address childhood undernutrition in LMICs, policy and programmatic approaches must be informed by existing literature – specifically literature identifying risk factors such as the ones detailed in the previous section. This section examines current approaches to address childhood undernutrition in LMICs and how existing literature has been translated into current nutrition action and policy.

Historically, nutrition programmes were placed into one of two categories: nutrition-sensitive or nutrition-specific programmes. While nutrition-specific programmes addressed the immediate causes of undernutrition, nutrition-sensitive programmes addressed the underlying causes of undernutrition. Due to the fact that the determinants of undernutrition are multisectoral, nutrition-sensitive programmes were developed in partnership with other sectors, largely the education and agriculture sectors. A revision of this framework has now identified four categories for nutrition action (100). Firstly, nutrition action is separated into direct and indirect interventions. Direct nutrition interventions primarily seek to improve nutrition outcomes. Indirect nutrition interventions primarily seek to improve non-nutrition outcomes and indirectly improve nutrition outcomes. Within each of the two categories, interventions are further categories according to whether they are interventions within the health sector or outside of the health sector.

Separate policies and programmes have been identified to address childhood stunting and wasting within LMICs. Programmes addressing childhood wasting largely focus on the treatment of wasting, also referred to within this section as acute malnutrition (101). Contrarily, programmes addressing childhood stunting largely target the prevention of stunting (101). The traditional, separate programmatic treatment of wasting and stunting is due to early research which quantified the risk of mortality from childhood wasting as significantly higher than other forms of undernutrition and research which states that the impacts of childhood stunting are both largely irreversible and long-lasting.

Broadly, WHO treatment guidelines for acute malnutrition include the provision of ready to use therapeutic food (RUTF), ready to use therapeutic milk, or ready to use supplementary food (RUSF) (102). Severe acute malnutrition is treated with RUTF and ready to use therapeutic milk. RUTF is provided through outpatient care to children who do not have

additional medical complications and have an appetite. Ready to use therapeutic milk is provided through inpatient care to children who have additional medical complications and/or do not have not appetite. Where feasible, RUSF is provided to children with moderate acute malnutrition.

In the past, severe acute malnutrition was treated solely within inpatient facilities. However, this resulted in low programme coverage and reduced efficiency. Within many LMICs, household access to healthcare facilities is limited. This is largely due to high relative costs of healthcare, large distances between households and healthcare facilities, and sometimes, limited dependency on the formal healthcare system. Outpatient treatment of severe acute malnutrition and community-based management of acute malnutrition (CMAM) were introduced to address these barriers and improve programmatic impact on associated mortality (103). CMAM includes the monitoring of growth to promote the early identification of wasting, where necessary the routine provision of outpatient therapeutic foods, and the dissemination of nutrition education to encourage improved infant and child feeding (104).

Programmes directed towards preventing childhood stunting in LMICs have largely focused on encouraging WHO recommended infant and young child feeding practices and improved water, sanitation, and hygiene (WASH) infrastructure and practices (101). Programmes targeting infant and young child feeding practices centre around improving health literacy about WHO recommended infant and young child feeding practices and where financially feasible, addressing household food insecurity (105).

The WHO recommends exclusive breastfeeding for the first six months, followed by complementary feeding which meets the minimum acceptable diet (106, 107). The minimum acceptable diet includes meeting both the minimum meal frequency and the minimum dietary diversity. The most widely implemented and WHO recommended programme to improve

health literacy is nutrition education. During nutrition education, healthcare providers or community health workers educate primary caretakers about WHO recommended feeding practices and encourage primary caretakers to implement recommended practices in their households. Programmes to address household food security largely include national social protection schemes, and school feeding programmes. Due to the fact that most social protection programmes in LMICs are unable to cover all households with financial difficulties, where feasible, nutrition education programmes include the distribution of supplementary food items.

Similarly, WASH programmes have focused on health literacy and introducing relevant infrastructure within communities. In order to improve health literacy pertaining to WASH, national governments and relevant agencies have educated individuals about recommended hygiene practices to reduce the risk of contracting diseases associated with poor WASH environments. Education occurs through both mass media campaigns and nutrition education. Relevant WASH infrastructure includes improved water sources and toilet facilities with access to clean water, no contamination of water sources by sanitation facilities, and no indirect human ingesting of human excrements (108).

In addition to the above, the World Bank recommended priority package to address childhood stunting and the 2013 Lancet Maternal and Child Nutrition series includes micronutrient supplementation in both pregnant women and children as an intervention with significant potential impacts on childhood undernutrition (109, 110). Many African governments have implemented robust micronutrient supplementation programmes, primarily targeting children.

1.6. THESIS AIM AND RATIONALE

In spite of significant financial investments towards addressing childhood undernutrition through the above policy and programmatic approaches, rates of childhood undernutrition in

Sub-Saharan African remain high. Nearly 57.5 million children in Africa are stunted – approximately one out of four children; and nearly 12.7 million children under five years old are wasted (51). Furthermore, the prevalence of childhood stunting in Middle and Eastern Africa is very high according to public health significance and the prevalence of childhood stunting in Southern and Western Africa is high according to public health significance (51). The aim of this thesis is therefore to inform the development and modification of programmes, policies, and research to further accelerate the reduction of childhood undernutrition in Sub-Saharan Africa and similar regions.

The Need for a Multi-Methods Approach

This thesis employs a multi-methods approach, as defined by Hunter and Brewer (111), a combination of two quantitative methods and one qualitative method is used to examine the thesis aim. Each study/analytical chapter employs a different method. Distinctions between multi-methods and mixed-methods approaches vary according to researchers and between different disciplines (112, 113). Some scholars differentiate between these approaches according to the combination of methods included in a body of work (111). In this framing, multi-methods research is defined as a body of work that includes more than one quantitative and/or qualitative method, whereas, mixed-methods research refers to a body of work which includes both quantitative and qualitative methods. Other scholars differentiate between multi- and mixed-methods approaches according to the stage at which data integration occurs (114). Traditionally, data integration for mixed-methods research largely occurs earlier in the research process such as during data collection or data analysis. In contrast, for multi-methods research, data integration occurs during the interpretation stage of research, once the findings of each study have been identified. Within this thesis, the multi-methods approach is differentiated from the mixed-methods approach by the point at which integration occurs. Each analytical

chapter examines a separate research objective, and, with the exception of the final two analytical chapters, each analytical chapter employs a different method. Although each chapter builds on the previous one, all findings are carefully integrated in the discussion/conclusion chapter.

Both quantitative and qualitative methods are necessary to identify opportunities to accelerate the reduction of childhood undernutrition in Sub-Saharan Africa. Studies have highlighted the value of multi-methods research, particularly within the field of public health (115, 116). Due to inherent differences in the epistemologies associated with quantitative and qualitative methodologies, the use of both methods within this thesis provides a comprehensive examination of the research aim and objectives. Quantitative methods are more suitable for quantifying and identifying associations and trends, and generalising these findings across a wider population (117). Qualitative methods are more suitable for exploring, in depth, individuals' understanding of public health issues and their experiences with associated healthcare services in a specific context (117). To effectively address childhood undernutrition in Sub-Saharan Africa, nutrition policies and programmes must address both quantifiable associations/trends and the local contexts which influence behaviour and use of healthcare services. In this thesis, quantitative methods are used to examine trends and inequalities in the prevalence of childhood undernutrition in African countries over the last twenty years and examine the association between childhood undernutrition and a potential risk factor which has been inadequately researched to date. Qualitative methods are then used to examine the social and cultural context which impacts conceptualisations of childhood undernutrition, clinically recommended behaviour changes, and key stakeholders' perceptions of and interactions with the healthcare system.

While highlighting the value of incorporating both quantitative and qualitative methods into this thesis, it is important to note the conflict between these approaches and how it was managed within this body of work. Qualitative and quantitative methods are grounded in different paradigms which encompass ontology – what reality is, and epistemology - how we come to know of this reality (118). Quantitative methods assume a positivist paradigm while qualitative methods, as incorporated in this thesis, assume an interpretivist paradigm (118). A positivist paradigm posits that reality and knowledge are objective and universal. Divergently, an interpretivist paradigm assumes that reality and knowledge are subjective and individually or socially constructed.

Positivist and interpretivist paradigms are in direct conflict, and inform separate methodologies. However, each paradigm, and its associated methodology and methods, is able to inform different aspects of complex development and public health issues (116, 119). Although each chapter assumes one specific paradigm, this thesis as a whole is not restricted to one paradigm, or one epistemological and ontological stand point. Instead, the thesis moves beyond these philosophical conflicts, intentionally including methods from both approaches to use the strengths of each approach to comprehensively examine the thesis aim. Each analytical chapter which uses a separate method and/or approach examines the thesis aim from a different level (i.e. individual/community, national, or regional), with each chapter also exploring how the findings from a wider level translate into experiences at a local level. The discussion/conclusion chapter then integrates all the findings and highlights how research from each level can be used to provide well-rounded policy and programmatic options to address childhood undernutrition in Sub-Saharan Africa.

The process of integrating the findings of both quantitative and qualitative components of a study has been referred to as triangulation. Triangulation, as defined by O'Cathain et al, refers

to one of two things – the confirmation of findings using different methods or the comprehensive exploration of a research aim/objective using different methods (120). Traditional uses of the multi-method approach have centred around the need to address the limitations of one approach with the other (121). As such, qualitative approaches have been used to *confirm* the findings of quantitative approaches or vice versa. Differently, this thesis does not use the two approaches to confirm each other's findings. Instead, it employs multi-methods to examine different aspects of childhood undernutrition in Sub-Saharan Africa, and identify a multitude of opportunities to accelerate the reduction of child undernutrition in Sub-Saharan Africa, employing the latter definition of triangulation detailed above. The qualitative and quantitative components of this thesis are used to complement each other in comprehensively exploring and addressing the overall thesis aim (122).

1.7. CHAPTER SUMMARY

This chapter has highlighted gaps in existing research about risk factors associated with childhood undernutrition and detailed current approaches to address childhood undernutrition in Sub-Saharan Africa and similar regions. The first analytical chapter begins by examining trends and inequalities in childhood undernutrition in 51 African countries. This study will explore Sub-Saharan African countries' progress in reducing rates of childhood undernutrition and progress in reaching the 2025 Global Nutrition Targets for childhood wasting and stunting. Furthermore, this study will identify inequalities in present trends within subpopulations, highlighting the most vulnerable populations which may require additional nutrition policy or programme attention in order to accelerate progress.

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CHAPTER TWO: TRENDS AND INEQUALITIES IN THE PREVALENCE OF CHILDHOOD UNDERNUTRITION IN 51 AFRICAN COUNTRIES

2.1. CHAPTER PREFACE

The aim of this thesis is to identify limitations in current nutrition policy and programmes, and highlight opportunities to accelerate the reduction of childhood undernutrition in Sub-Saharan Africa. In order to provide a comprehensive examination of the thesis aim, this first analytical chapter details the broad impact of current nutrition policy and programmes on the prevalence of childhood wasting and stunting in African countries. Furthermore, this chapter highlights the most vulnerable populations in African countries, as it pertains to childhood undernutrition. This chapter underscores the need to strengthen current approaches to address childhood undernutrition in African countries, particularly within subpopulations where the rate of reduction is slow.

2.2. ABSTRACT

In 2012, the World Health Assembly introduced the 2025 Global Nutrition Targets for child and maternal malnutrition. Consequently, significant financial investments have been made to address high levels of childhood stunting and wasting in African countries. This study examines trends and inequalities in the prevalence of childhood wasting and stunting in African countries over the last two decades.

This study uses nationally representative survey data collected between 2000 and 2019 in 51 African countries. Multilevel linear regression models controlling for UN subregions and random effects at the country level were used to estimate the average annual rate of reduction (AARR) and corresponding 95% confidence intervals (95% CI). Subgroup analysis was used to identify inequalities in the reduction of childhood undernutrition in subpopulations.

The prevalence of childhood undernutrition decreased in African countries between 2000 and 2019. Childhood stunting decreased an average of two percent annually (AARR: -0.02, 95% CI: -0.03,-0.01). Childhood wasting decreased an average of four percent annually (AARR: -0.04, 95% CI: -0.05,-0.02). Among subgroups, the reduction of child stunting was slower in rural regions, poorer households, females, children under two years old, and in Sub-Saharan African countries with a prevalence of household air pollution (HAP) below the mean. The reduction of child wasting was slower in rural regions, poorer households, females, children between 2-5 years old, and in Sub-Saharan African countries with a prevalence of HAP below the mean.

Should present trends continue, many African countries, and the African region as a whole, will not meet the 2025 Global Nutrition Targets for childhood wasting and stunting. There is a need to strengthen nutrition action in African countries in order to accelerate the reduction of childhood undernutrition. Additionally, significant inequalities exist in the reduction of

childhood undernutrition in subpopulations. Future nutrition action should also direct additional policy attention to the most vulnerable subpopulations.

2.3. INTRODUCTION

In 2019, 57.5 million children under five years old in Africa were stunted (low height-for-age) and 12.7 million were wasted (low weight-for-height) (1). Childhood stunting and wasting are the result of undernutrition – the inadequate intake, absorption, or utilisation of nutrients. Undernutrition in childhood is associated with an increased risk of mortality and morbidity (2, 3). Particularly, growth faltering in childhood is associated with impaired cognitive development, poor educational performance, and decreased future earnings (3, 4). Although 29% of the world's under five population resides in Africa, 40% of stunted children under five years old and 27% of wasted children under five years old live in Africa (1). The African continent bears a disproportionate burden of global cases of childhood undernutrition.

In 2012, the World Health Assembly introduced the Comprehensive Implementation Plan on Maternal, Infant, and Young Child Nutrition (5). Within this plan, the World Health Assembly identified six Global Nutrition Targets, to be achieved by 2025, to address six conditions of child or maternal malnutrition with the largest global burden on morbidity and mortality. Two of the Global Nutrition Targets pertained to two forms of childhood undernutrition – stunting and wasting. The stunting Global Nutrition Target is to achieve a 40% reduction in the number of stunted children, using 2012 values as the baseline (5). The wasting Global Nutrition Target is to decrease the prevalence of wasting and/or keep it below 5% (5). Presently, only 8 African countries are on track to meet the Global Nutrition Target for childhood stunting and only 12 African countries are on track to meet the Global Nutrition Target for childhood wasting (6).

Among all Global Nutrition Targets, childhood stunting and wasting receive the most donor funding (7). In 2017, $652 million USD of donor funding was allocated to childhood stunting and $347 million USD of donor funding was allocated to childhood wasting (7). Pertaining to childhood stunting, 39% of global nutrition financing is allocated to Sub-Saharan Africa (8).

As the African population continues to grow, financial investments in nutrition are expected to increase (8). In order to ensure that growing investments in nutrition, from both national governments and donors, are resulting in significant improvements to rates of childhood undernutrition in African countries, it is important to understand the associated trends in childhood undernutrition. Additionally, examining inequalities in child undernutrition trends could highlight subpopulations which could benefit from targeted interventions, and ultimately increase the number of African countries on track to meet the 2025 Global Nutrition Targets.

Although the UN and the Global Nutrition Report regularly examine trends in childhood undernutrition globally, to date, no study has explored the recent trends in childhood undernutrition in African countries (6, 9). This study examines trends and inequalities in childhood undernutrition in 51 African countries from 2000 to 2019. This study will provide further insight into Africa's progress towards achieving two of the 2025 Global Nutrition Targets specific to childhood stunting and wasting; and provide insight into the impact of growing nutrition financing and how nutrition financing can be maximised.

2.4. METHODS

Data Source

This study used data from three World Health Organization databases: (1) Nutrition Landscape Information System (NLiS), (2) Health Equity database, and (3) Household Air Pollution database (1).

The NLiS database includes standardised nationally representative estimates of the prevalence of childhood undernutrition. NLiS data are joint estimates sourced from repeated cross-sectional household survey data from LMICs. Surveys include the Demographic and Health

Survey (DHS), UNICEF Multiple Indicator Cluster Survey (MICS), and national surveys. NLiS data are available for varying time periods.

The Health Equity database includes standardised nationally representative estimates of the prevalence of child undernutrition within subpopulations. Data is disaggregated by sex, wealth quintiles, area of residence, and child age groups. The Household Air Pollution database includes nationally representative estimates of households with primary reliance on clean fuels for both cooking and lighting between 2000 and 2018. Household air pollution estimates are calculated annually for all countries.

Child Undernutrition

Two measures of childhood undernutrition were included in this analysis – the prevalence of stunting (low height-for-age) and the prevalence of wasting (low weight-for-height). Both variables are readily available in the NLiS and Health Equity databases. Stunting and wasting are calculated in accordance with the WHO reference anthropometric measurements (10). Z-scores are used to measure whether a child is moderately or severely undernourished. A height-for-age z-score less than negative two is categorised as childhood stunting. A weight-for-height z-score less than negative two is categorised as childhood wasting. Additional information about how z-scores are calculated is included in the appendix.

Subgroup Analysis

Heterogeneity in the trends of childhood undernutrition in Africa were measured in the following subgroups: UN subregions, area of residence – rural or urban, wealth quintiles, child age groups, child sex, levels of household air pollution, and trends in household air pollution.

The national prevalence of childhood undernutrition varies according to UN subregions, area of residence, wealth quintiles, child sex, and child age groups. The prevalence of child undernutrition is usually highest in rural areas, poorer wealth quintiles, children under two years old, and female children (11, 12). UN subregions in Africa include Northern Africa, Middle Africa, Western Africa, Eastern Africa, and Southern Africa. A full list of the countries included in each subregion is included in the appendix. Wealth quintiles were calculated separately for each country and survey year. Child age was separated into two categories - children under 2 years old and children 2 to 5 years old. Area of residence was recorded as urban or rural. Child sex was recorded as male or female.

Subgroup analysis pertaining to levels and trends of household air pollution were only carried out on Sub-Saharan African countries, where household air pollution is more prevalent. Recent studies suggest that exposure to household air pollution may be associated with childhood undernutrition (13). Studies posit that children exposed to household air pollution may have an increased likelihood of child undernutrition. Estimates of households relying primarily on clean fuels or technologies for cooking or lighting were used to estimate the prevalence of household air pollution. This analysis assumed that households relied on solid fuels for cooking or lighting if they did not rely primarily on clean fuels or technologies. A binary variable was created to estimate levels of household air pollution – (1) countries with a prevalence of household air pollution equal to or below the mean in 2018, or (2) countries with a prevalence of household air pollution above the mean in 2018. The mean prevalence of household air pollution in 2018 was used because the mean prevalence of household air pollution has remained largely consistent in Sub-Saharan Africa over the last two decades, ranging from 91% in 2000 and 86% in 2018 (14). Two categories were created to estimate trends in household air pollution – (1) countries whose prevalence of household air pollution decreased between 2000 and 2018,

and (2) countries whose prevalence of household air pollution was stagnant or increased between 2000 and 2018.

Statistical Analysis

A hierarchical pooled dataset was created by appending country-level data from 51 African countries. Countries formed level one and subregions formed level two. Subregions were identified according to UN classifications. All country-year data points were included if data was available for at least one survey period.

Multilevel linear regression models were used to estimate trends and inequalities in childhood undernutrition in Africa. A logistic transformation was applied to prevalence values to address skewed data. Models were run separately for each prevalence indicator. The average annual rate of reduction (AARR) and corresponding 95% confidence intervals (95% CI) are presented for each model. The AARR was estimated by subtracting the back-transformed coefficient from 1. The percent AARR was calculated by multiplying the AARR by 100 (15). A sample calculation is included in the appendix.

The models employed for this study are based on the models developed by de Onis to evaluate levels and trends in childhood undernutrition in LMICs (16). Each model controlled for UN subregions and random effects at the country level. Model specifications were determined through the comparison of the Akaike information criterion (AIC), Bayesian information criterion (BIC), and log likelihood values (16). For observations with survey data that was collected over a period of two or more years, the mean year was used within the model.

Subgroup analysis was conducted to examine whether trends in childhood undernutrition varied according to UN subregions, area of residence, wealth quintiles, child age groups, levels of household air pollution, and trends of household air pollution. P-values for interaction were

calculated to establish the statistical significance of differences within subgroups. P-values for interaction were derived by including an interaction term between survey year and the effect modifier in the original model (17).

Weighted analysis was conducted for all models. Weights were calculated separately for each country, according to the UN under-five population estimates for the included survey years (16, 18). Weights were calculated by dividing the mean under-five country population estimate over the included survey years by the mean under-five subregional population estimate over the included survey years. The mean survey year was used for countries with a survey conducted over two or more years.

Stata/SE version 16 was used for data cleaning and analysis.

2.5. RESULTS

Prevalence data included in this analysis were available from 248 surveys (Table 7), conducted between 2000 and 2019, in 51 African countries (Table 8). By UN subregions, the following number of African countries were included in this analysis: 6 out of 7 Northern African countries (86%), 9 Middle African countries (100%), 17 out of 18 Eastern African countries (94%), 5 Southern African countries (100%), and 15 out of 16 Western African countries (94%). Each country had an average of four surveys conducted between 2000 and 2019, ranging from 1 survey in Seychelles to 11 surveys in Burkina Faso (Table 7).

Descriptive Statistics

The mean prevalence of childhood stunting in African countries was 39% between 2000 and 2004, and 31% between 2015 and 2019. The mean prevalence of childhood stunting was consistently highest in Eastern African countries for all time periods between 2000 and 2019.

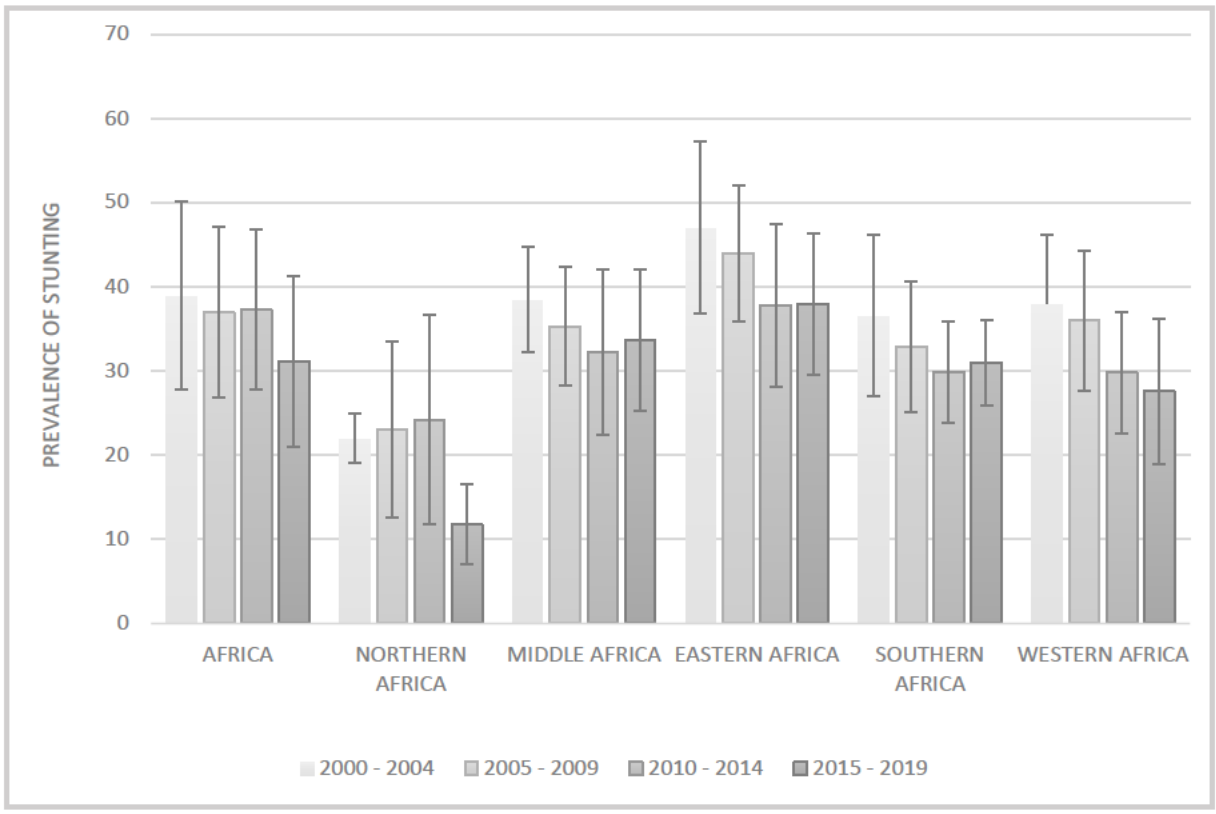

Figure 1: Prevalence of Stunting by Subregion, Unweighted

Over the last twenty years, the prevalence of childhood stunting in Africa was consistently highest in the poorest wealth quintiles and lowest in the richest wealth quintiles. The gap in stunting prevalence between the poorest and richest wealth quintiles appears to have increased slightly over time. Between 2000 and 2004, the prevalence of stunting was 48% in the poorest wealth quintile and 28% in the richest wealth quintile, a 20 percentage point difference. Between 2015 and 2019, the prevalence of stunting was 38% in the poorest wealth quintile and 17% in the richest wealth quintile, a 21 percentage point difference.

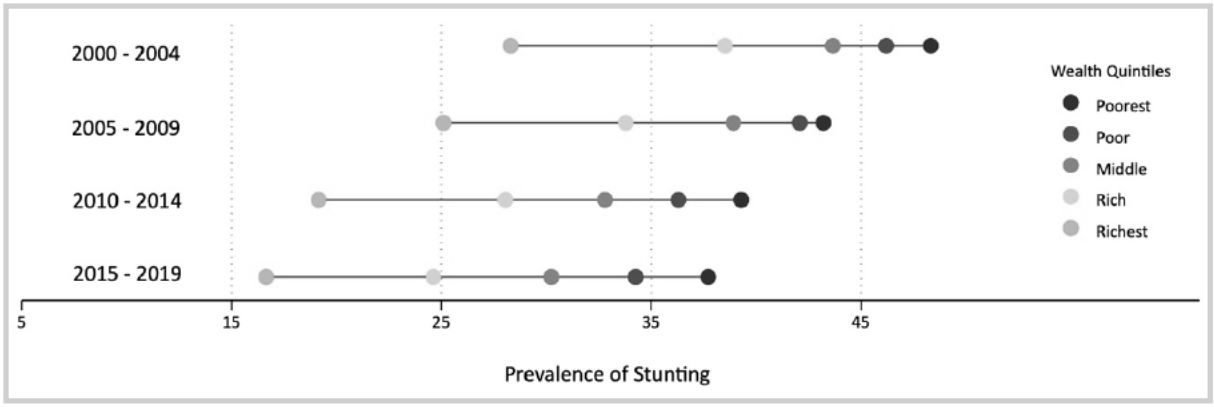

Figure 2: Prevalence of Stunting in Africa, by Wealth Quintile

Over the last two decades, the prevalence of stunting in Africa was consistently highest in males, children in rural regions, and children between 2 to 5 years old. Inequalities in the prevalence of stunting, according to area of residence and sex, decreased slightly between 2000 and 2019. Between 2000 and 2004, the prevalence of stunting was 44% in rural areas and 32% in urban areas, a 12 percentage point difference. Between 2015 and 2019, the prevalence of stunting was 33% in rural areas and 22% in urban areas, a 10 percentage point difference.

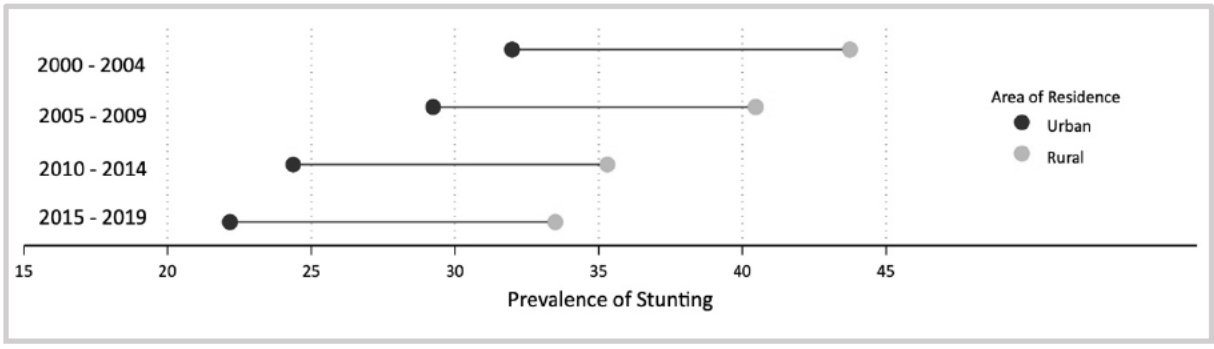

Figure 3: Prevalence of Stunting in Africa, by Area of Residence

Between 2000 and 2004, the prevalence of stunting was 38% in females and 43% in males, a five percentage point difference. The percentage point difference decreased slightly to four percentage points between 2015 and 2019.

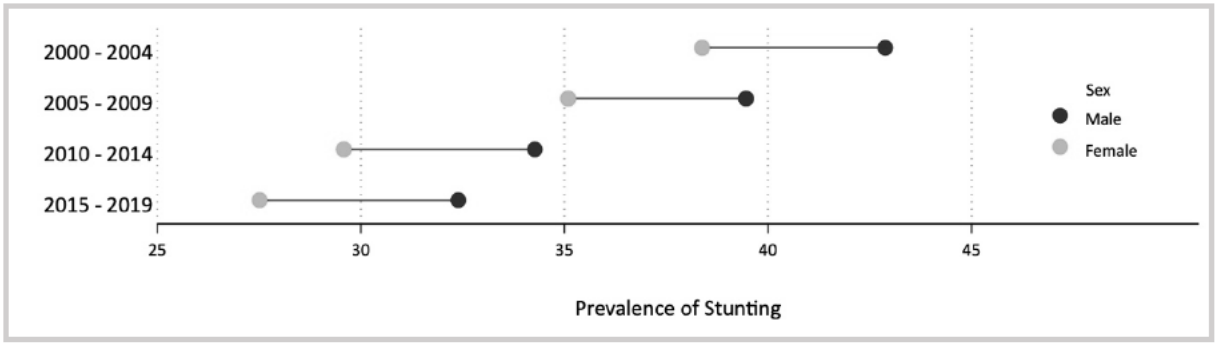

Figure 4: Prevalence of Stunting in Africa, by Sex

The difference in stunting prevalence values, by child age, decreased over the last twenty years. Between 2000 and 2004 there was a 12 percentage point difference in the prevalence of stunting in children under 2 years old and children 2-5 years old, with the prevalence of stunting being higher in children 2-5 years old. The percentage point difference in the prevalence of stunting according to child age decreased to seven between 2015 and 2019.

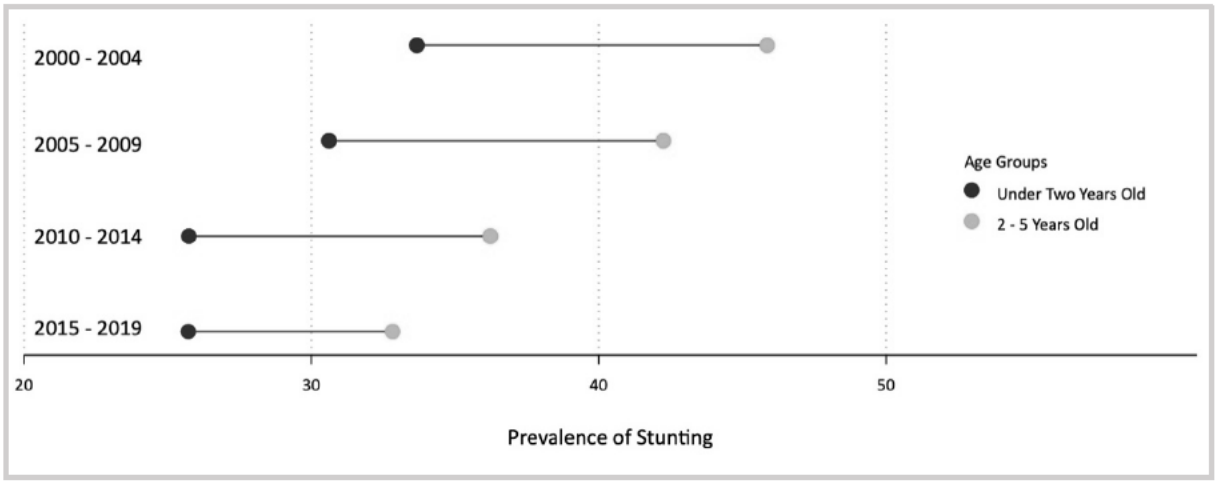

Figure 5: Prevalence of Stunting in Africa, by Age

The mean prevalence of wasting in African countries was 9% between 2000 and 2004, and 6% between 2015 and 2019. The mean prevalence of wasting was consistently highest in Western African countries for all time periods between 2000 and 2019.

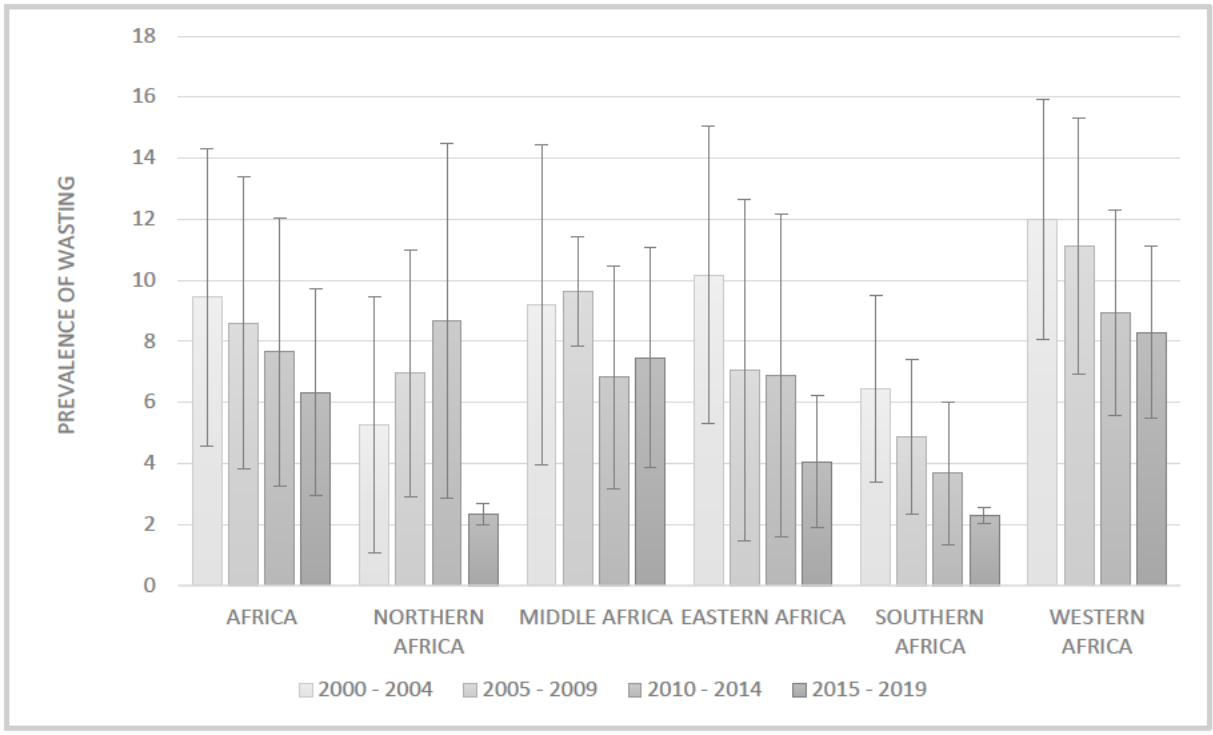

Figure 6: Prevalence of Wasting by Subregion, Unweighted

The prevalence of wasting in Africa was consistently highest in the poorest wealth quintiles and lowest in the richest wealth quintiles. The difference in wasting prevalence values, by wealth quintiles, decreased from 2000 to 2019. Between 2000 and 2004 there was a four percentage point difference in the prevalence of wasting, by wealth quintiles. The difference in prevalence of wasting, by wealth quintiles, decreased slightly to three percentage points between 2015 and 2019.

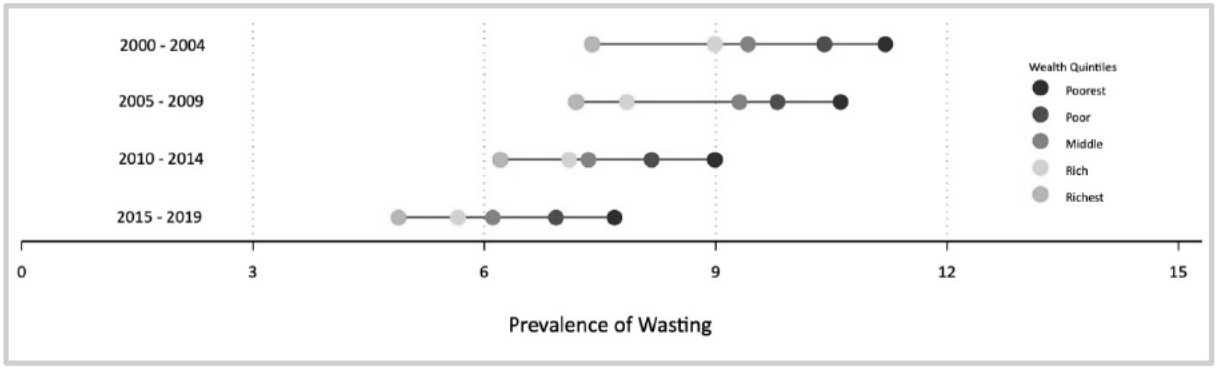

Figure 7: Prevalence of Wasting in Africa, by Wealth Quintile

The prevalence of wasting in Africa was highest in male children, children living in rural regions, and children under two years old. Inequalities in wasting prevalence, according to child age, area of residence, and sex, decreased between 2000 and 2019. There was a 1.5 percentage point difference in the prevalence of wasting in male and female children between 2000 and 2004. This decreased slightly to a 1.2 percentage point difference between 2015 and 2019.

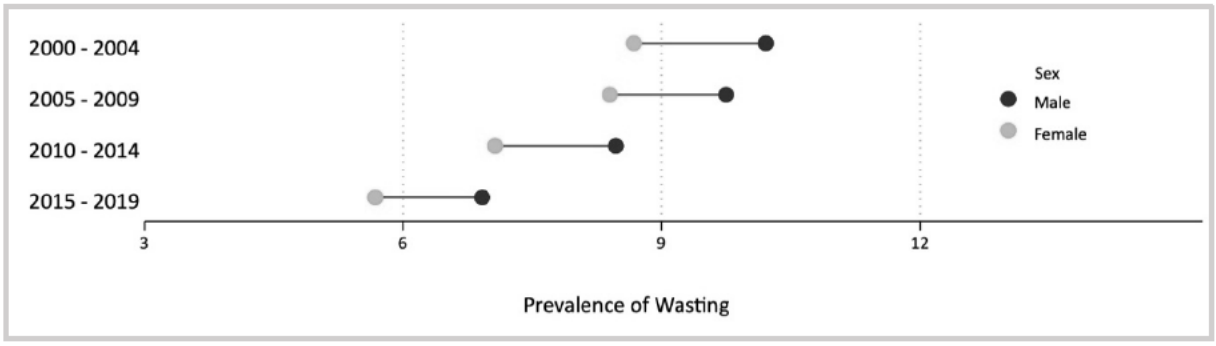

Figure 8: Prevalence of Wasting in Africa, by Sex

Between 2000 and 2004, the prevalence of wasting was 10% in rural areas and 8% in urban areas. There was a two percentage point difference in prevalence values, according to area of residence. The difference in prevalence values decreased to one percentage point between 2015 and 2019.

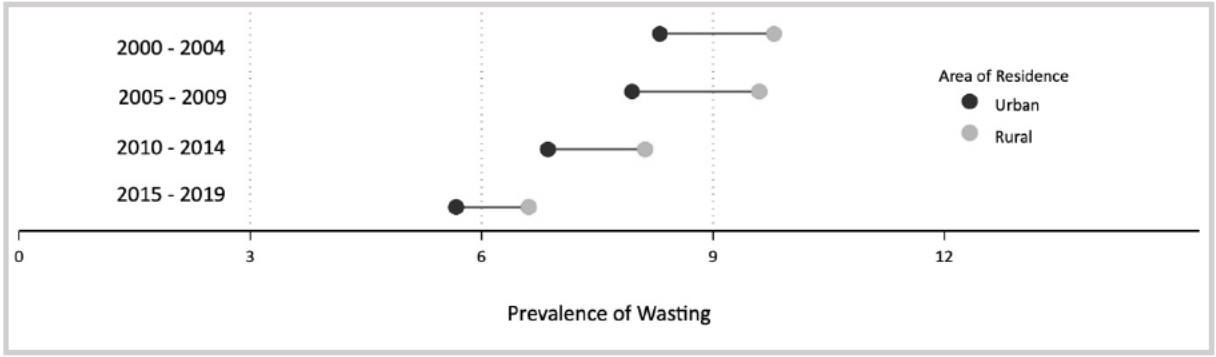

Figure 9: Prevalence of Wasting in Africa, by Area of Residence

According to child age groups, the difference in prevalence of wasting decreased from six percentage points between 2000 and 2004 to four percentage points between 2015 and 2019.

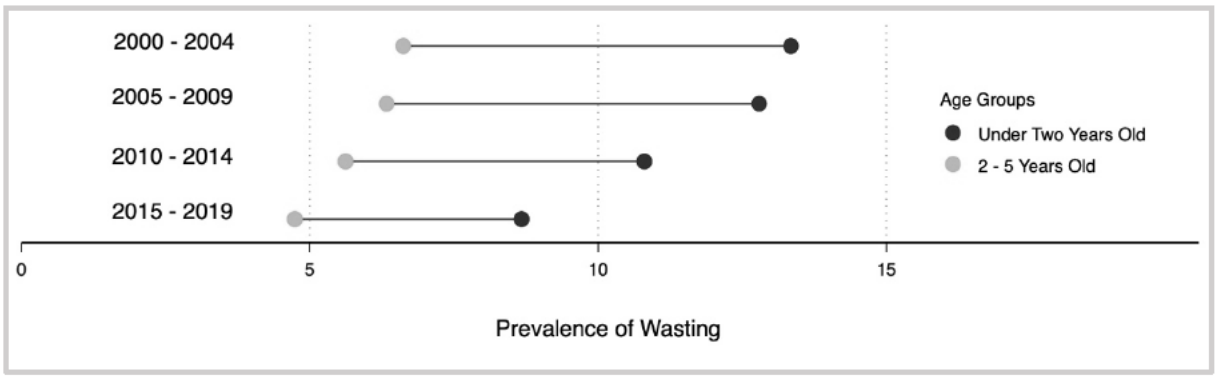

Figure 10: Prevalence of Wasting in Africa, by Age

According to levels of household air pollution (HAP) in Africa, the prevalence of childhood wasting and stunting were highest in African countries with a prevalence of HAP above the mean (Table 1). Inequalities in the prevalence of childhood stunting, according to the level of HAP, increased by 1.7 percentage point from 2000 to 2019. Inequalities in the prevalence of childhood wasting, according on the level of HAP, decreased by 2.1 percentage points between 2000 to 2019.

Table 1: Prevalence of Childhood Undernutrition in Africa, by Levels of HAP

	Prevalence of Stunting		Prevalence of Wasting	
	Levels of HAP: Below Mean	Levels of HAP: Above Mean	Levels of HAP: Below Mean	Levels of HAP: Above Mean
2000 – 2004	34.9	42.7	7.5	10.4
2005 – 2009	31.1	38.9	6.5	10.3
2010 – 2014	25.1	35.2	6.5	8.6
2015 – 2019	23.1	32.6	5.8	6.6

The prevalence of childhood stunting was consistently higher in countries where the prevalence of HAP increased between 2000 and 2019 . Inequalities in the prevalence of childhood stunting, according to trends in HAP, decreased by 4.4 percentage points from 2000 to 2019.

Between 2000 and 2004, the prevalence of wasting was higher in countries where the prevalence of HAP increased over the last twenty years. From 2005 to 2019, the prevalence of wasting was highest in countries where the prevalence of HAP decreased over the last twenty years. From 2010 to 2019, the prevalence of wasting was higher in countries where the prevalence of HAP increased between 2000 and 2019. Inequalities in the prevalence of childhood wasting, according to trends in HAP, decreased to nearly zero percentage points from 2000 to 2019.

Table 2: Prevalence of Childhood Undernutrition in Africa, by Trends of HAP

	Prevalence of Stunting		Prevalence of Wasting	
	Prevalence of HAP: Increased or Stagnant	Prevalence of HAP: Decreased	Prevalence of HAP: Increased or Stagnant	Prevalence of HAP: Decreased
2000 – 2004	43.2	38.2	9.8	9.2
2005 – 2009	39.9	33.5	8.9	10.0
2010 – 2014	34.6	27.2	7.8	7.1
2015 – 2019	29.8	29.2	6.5	6.5

Inferential Statistics

The prevalence of childhood stunting and wasting in African countries decreased between 2000 and 2019, after adjusting for subregions and random effects at the country level (Table 3). Childhood stunting decreased an average of two percent every year (95% CI: 3.16, 1.40). Childhood wasting decreased an average of four percent every year (95% CI: 5.27, 2.01).

Table 3: Trends in Childhood Undernutrition

	Stunting*		Wasting*	
	AARR Coefficient (95% CI)	**P-Value**	**AARR Coefficient (95% CI)**	**P-Value**
Year	0.023 (0.032, 0.014)	<0.001	0.037 (0.053, 0.020)	<0.001

* Controls for subregions, country level random effects, and population weights

The average annual rate of reduction (AARR) of childhood stunting differed according to area of residence, wealth quintiles, child sex, child age, and levels of HAP (Table 4). The AARR of childhood stunting was slightly lower in rural regions than in urban regions (p-value for interaction: <0.001). The decrease in childhood stunting was lower in poorer wealth quintiles than it was in richer wealth quintiles (p-value for interaction: <0.001). The AARR of stunting in the richest wealth quintile was more than double the AARR of stunting in the poorest wealth quintile. In comparison to boys, the AARR of childhood stunting in girls was slightly lower (p-value for interaction: <0.001). The decrease in childhood stunting was slower in children under 2 year olds than it was in children between 2-5 years old (p-value for interaction: <0.001). The AARR of childhood stunting in children between 2-5 years old was nearly one and half times the AARR of childhood stunting in children under 2 years old.

Amongst Sub-Saharan African countries, the AARR of childhood stunting varied according to levels of HAP. The reduction of childhood stunting was slower in countries with a HAP prevalence below the mean prevalence of HAP in Sub-Saharan Africa (p-value: <0.001). Trends in childhood stunting did not vary according to UN subregions (p-value: 0.43) or HAP trends from 2000 to 2018 (p-value: 0.39).

Table 4: Trends in Childhood Stunting, by Subgroup

	Stunting*	
Area of Residence	**AARR Coefficient (95% CI)**	**P-Value**
Rural	0.022 (0.034, 0.010)	<0.001
Urban	0.023 (0.033, 0.012)	<0.001
p-value for interaction	<0.001	
Wealth Quintiles	**AARR Coefficient (95% CI)**	**P-Value**
Poorest	0.016 (0.034, 0.003)	0.10
Poorer	0.021 (0.034, 0.007)	0.00
Middle	0.033 (0.044, 0.022)	<0.001
Richer	0.035 (0.046, 0.025)	<0.001
Richest	0.038 (0.049, 0.027)	<0.001
p-value for interaction	<0.001	
Sex	**AARR Coefficient (95% CI)**	**P-Value**
Female	0.023 (0.034, 0.012)	<0.001
Male	0.024 (0.035, 0.013)	<0.001
p-value for interaction	<0.001	
Age groups	**AARR Coefficient (95% CI)**	**P-Value**
Under 2 years old	0.018 (0.026, 0.010)	<0.001
2 – 5 years old	0.028 (0.042, 0.014)	<0.001
p-value for interaction	<0.001	
HAP**	**AARR Coefficient (95% CI)**	**P-Value**
≤ 86%	0.020 (0.037, 0.002)	0.03
> 86%	0.023 (0.033, 0.012)	<0.001
p-value for interaction	<0.001	

* Controls for subregions, country level random effects, and population weights.

** Only Sub-Saharan African countries included.

Trends in childhood wasting varied according to area of residence, wealth quintiles, child sex, age groups and levels of HAP (Table 5). In comparison to urban areas, the AARR of childhood wasting was slower in rural areas (p-value: 0.00). Childhood wasting decreased slower in poorer wealth quintiles than in richer quintiles (p-value: <0.001). The AARR of childhood wasting in the richest quintiles were nearly double the AARR of childhood wasting in the poorest quintiles. The decrease of childhood wasting was slower in girls than in boys (p-value: <0.001). Childhood wasting in children 2-5 years old decreased slower than childhood wasting in children under two years old (p-value: <0.001). The AARR of childhood wasting was nearly double in children under two years old than the AARR of childhood wasting in children between 2-5 years old. Similar subgroup trends in AARR were observed with severe childhood wasting in Africa.

Amongst Sub-Saharan African countries, trends in childhood wasting varied according to levels of HAP (p-value: <0.001). Childhood wasting decreased slightly slower in countries with a prevalence of HAP below the mean prevalence of HAP in Sub-Saharan Africa (p-value: <0.001). Trends in the prevalence of childhood wasting did not vary according to UN subregions (p-value: 0.36) or HAP trends from 2000 to 2018 (p-value: 0.18).

Table 5: Trends in Childhood Wasting, by Subgroup

	Wasting*	
Area of Residence	**AARR Coefficient (95% CI)**	**P-Value**
Rural	0.033 (0.050, 0.015)	<0.001
Urban	0.037 (0.061, 0.013)	0.00
p-value for interaction	0.00	
Wealth Quintiles	**AARR Coefficient (95% CI)**	**P-Value**
Poorest	0.027 (0.043, 0.012)	0.00
Poorer	0.031 (0.047, 0.015)	<0.001
Middle	0.035 (0.051, 0.018)	<0.001
Richer	0.036 (0.054, 0.018)	<0.001
Richest	0.054 (0.075, 0.032)	<0.001
p-value for interaction	<0.001	
Sex	**AARR Coefficient (95% CI)**	**P-Value**
Female	0.035 (0.052, 0.018)	<0.001
Male	0.039 (0.065, 0.013)	0.00
p-value for interaction	<0.001	
Age groups	**AARR Coefficient (95% CI)**	**P-Value**
Under 2 years old	0.044 (0.074, 0.013)	0.01
2 – 5 years old	0.028 (0.044, 0.013)	<0.001
p-value for interaction	<0.001	
HAP**	**AARR Coefficient (95% CI)**	**P-Value**
≤ 86%	0.032 (0.076, 0.014)	0.17
> 86%	0.036 (0.046, 0.026)	<0.001
p-value for interaction	<0.001	

* Controls for subregions, country level random effects, and population weights.

** Only Sub-Saharan African countries included.

2.6. DISCUSSION

This study explored trends and inequalities in childhood undernutrition in 51 African countries between 2000 and 2019. This analysis revealed that although childhood stunting and wasting decreased in African countries in the last two decades, the AARR was unequally distributed within subpopulations and amongst both forms of childhood undernutrition. This study goes beyond previous examinations of trends in childhood undernutrition to identify inequalities in the AARR of childhood stunting and wasting in the African continent over the last two decades. The African continent is the only region that observed an increase in the number of stunted children between 2000 and 2019 (9). This increase was also observed in every African subregion (9). In order to accelerate the reduction of childhood undernutrition and ensure that African countries are on track to meet the 2025 Global Nutrition Targets, it is important to identify trends and inequalities in childhood undernutrition.

The preliminary, descriptive analysis revealed significant inequalities in the prevalence of childhood undernutrition within subpopulations and limited improvement between 2000 and 2019. Importantly, this study revealed a higher prevalence of childhood stunting and wasting in males, in comparison to females, between 2000 and 2019. This finding is contrary to nutrition action which directs additional policy attention to female children under the assumption that they are at a higher risk of being stunted or wasted. Similar to the findings of this study, a recent systematic review and meta-analysis highlighted an increased likelihood of childhood stunting and wasting in males, in comparison to females (19). Thurstans et al. suggest that this sex difference may be due to biological or social differences between males and females which require additional research (19).

Additionally, this study revealed differences in the prevalence of childhood stunting within different age groups. Between 2000 and 2019, the prevalence of childhood stunting was

consistently higher in children between 2-5 years old, as opposed to children under two years old. This is in line with nutrition research which largely categorises stunting as the impact of repeated or prolonged episodes of undernutrition (20). Older children have had a larger period of time to experience episodes of undernutrition and its associated impact on linear growth.

The findings from the inferential analysis of this study were consistent across all models – in Africa, both forms of childhood undernutrition decreased in the last two decades. Although both forms of childhood undernutrition have decreased, the African continent is not on track to meet the stunting and wasting 2025 Global Nutrition Targets. First, in order to achieve a 40% reduction in the number of stunted children by 2025, the WHO and UNICEF recommend an AARR of childhood stunting of 3.9% (21). The findings of this study suggest that the AAAR of childhood stunting in Africa is only 2%. Second, although the AARR of childhood wasting is above the recommended 2% value, the regional prevalence of childhood wasting is still above the recommended 5% (21). According to the WHO and UNICEF grading for progress towards achieving the Global Nutrition Targets, although Africa has made some progress, the continent is still off track to meet the stunting and wasting targets by 2025 (21).

When stratified by socioeconomic factors, the AARR of both forms of childhood undernutrition were slower in rural areas and the poorest households. This is in line with studies that have identified socioeconomic factors as drivers of childhood undernutrition (11, 22). The AARR of both forms of childhood undernutrition was nearly double in the richest households, in comparison to the poorest households. Poverty, which is also significantly higher in rural regions, is associated with lower nutrient intake and poor child health outcomes (23). In 2016, 22% of children under five years old in the richest African households met the minimum acceptable diet (minimum meal frequency and minimum dietary diversity), compared to 11% of children under five years old in the poorest African households (6). Equally, exclusive

breastfeeding and the timely introduction of solid, semi-solid, and soft foods was lower in the poorest households (6). Similar inequalities in infant and young child feeding practices were observed between urban and rural regions in Africa (6). Although many African countries have experienced economic growth within the last two decades, the large disparity in AARR between the richest and poorest households highlights growing levels of income inequality (24). Consequently, the impact of economic growth on childhood undernutrition has been minimal in the poorest households. This is reflective of Vollmer et al's study which suggests a minimal association between economic growth and child undernutrition (25).

When stratified by child age, the AARR of childhood stunting in children 2-5 years old was nearly double the AARR of childhood stunting in children under two years old. This suggests the need to direct additional policy attention to childhood stunting in children under two years old. This is in line with earlier epidemiological research which emphasises the importance of addressing undernutrition in the first 1,000 days of life – from conception up until a child is two years old (26). The 1,000 day period was identified for two key reasons. First, linear growth faltering largely stabilises once a child reaches 2 years old (27, 28). Children under two years old have more biological demands for nutrients to ensure optimal growth and development; and the risk of contracting infectious diseases, which decrease nutrient absorption and intake, is highest within this age group (29). Second, the physical and cognitive impacts of stunting are largely irreversible after a child reaches 36 months (26). A new body of research suggests that children who experience childhood stunting may catch up in physical growth during adolescence, however, evidence about improvements on cognitive outcomes are limited (30).

A slower decrease of childhood stunting among children under two years old also suggests the need to place additional policy attention on addressing maternal nutrition and complementary feeding practices. Maternal nutrition is a significant driver of intrauterine growth restriction

and early childhood stunting (11). Additionally, this aligns with the earlier finding highlighting the significance of inadequate infant and young child practices in African countries.

Contrary to the inequality in trends of childhood stunting according to child age, the AARR of childhood wasting in children under two years old was nearly double the AARR of childhood wasting between 2-5 years old. This finding is likely reflective of the relationship between stunting and wasting. Present stunting is a risk factor for future wasting (31). It is possible that the slower AARR of childhood stunting in children under two years old (and corresponding higher prevalence of stunting) is associated with an increased likelihood of future wasting in children 2-5 years old (and corresponding lower AARR of childhood wasting in this age group). This finding suggests a need to address childhood wasting and stunting jointly (32). Although wasting and stunting are two different manifestations of undernutrition, they are strong predictors of each other, have similar risk factors, similar physiological impacts, and usually occur concurrently (20).

Lastly, a study conducted by Alderman and Headey suggests that the association between childhood undernutrition and basic determinants, namely household wealth and parental education, may differ according to child age (28). The association between stunting and basic determinants was strongest in children 2-5 years old and the association between wasting and basic determinants was strongest in children under two years old (28). The AARR of both forms of child undernutrition was higher in the age groups where the association between child undernutrition and basic determinants were highest. This finding further suggests increased policy attention must be directed to address socioeconomic factors associated with childhood undernutrition.

When Sub-Saharan African countries were stratified by level of HAP, the AARR of childhood undernutrition was slightly higher in countries with a prevalence of HAP above the mean.

Additionally, stratification by trends in HAP did not result in statistically significant differences in the AARR of childhood stunting or wasting. These findings are contrary to evidence from a small body of work which suggests that an association may exist between exposure to HAP and childhood undernutrition (13). It is likely that other variables which were not controlled for in this analysis are confounding the estimated AARR of childhood undernutrition within these subpopulations. Future research should explore in further detail the association between childhood undernutrition and HAP, controlling appropriately for potential confounders such as household demographics, and maternal and child factors.

Strengths and Limitations

The findings of this study are limited by the measures of childhood undernutrition and HAP employed. Although stunting and wasting are appropriate for measuring the onset of childhood undernutrition, our findings were unable to estimate trends in linear or ponderal growth. It is possible that trends in growth differ from the trends in the onset of childhood undernutrition. Measures such as the mean height-for-age z-score (HAZ) and the mean weight-for-height z-score (WHZ), which are more suitable indicators of child growth, were only available for a subset of countries and survey years. Instead of limiting the sample to surveys from which HAZ and WHZ could be calculated, we explored trends in the onset of childhood undernutrition on a larger sample size, increasing the statistical power of this analysis.

Additionally, although the binary measures of HAP included in this analysis were the most appropriate way of assessing variations in childhood undernutrition trends according to HAP, it is important to note potential limitations associated with dichotomising a continuous variable. Dichotomising the measure of HAP may have decreased the statistical power of this subgroup analysis (33). Dichotomising is associated with an increased risk of residual confounding, and, in some instances, the binary variable may be unable to account for variation within categories.

Furthermore, non-standardised cut-off points, such as the use of the sample mean to identify 'high' and 'low' categories may results in sample specific findings, decreasing the generalisability of the study findings.

2.7. CONCLUSION

This study has highlighted inequalities in the trends of childhood undernutrition in the African continent over the last two decades. Although the prevalence of childhood undernutrition has decreased over the last 19 years, progress is limited. Furthermore, progress towards reducing childhood stunting has been slower in rural regions, poorer households, female children, children under two, and children in Sub-Saharan African countries with a prevalence of HAP below the mean. Progress towards reducing childhood wasting has also been slower in rural regions, poorer households, female children, children between 2-5 years old, and children in Sub-Saharan African countries with a prevalence of HAP below the mean. Future interventions addressing childhood undernutrition in African countries need to be strengthened and should target populations with slower AARR.

2.8. CHAPTER SUMMARY

This chapter examined trends and inequalities in the prevalence of childhood wasting and stunting in 51 African countries between 2000 and 2019. The findings of this study reveal that although the prevalence of childhood stunting and wasting in Africa have decreased over the last twenty years, the continent is not on track to meet the 2025 Global Nutrition Targets for childhood stunting and wasting. Furthermore, there are significant inequalities in the rate of reduction within subpopulations. The following chapter examines the role of distal risk factors in the reduction of childhood undernutrition in LMICs. Specifically, the following study explores the association between exposure to household air pollution from solid cooking fuels and childhood undernutrition in LMICs.

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2.10. APPENDIX

Table 6: African Countries, by UN Subregion

Eastern Africa
Burundi
Comoros
Djibouti
Eritrea
Ethiopia
Kenya
Madagascar
Malawi
Mauritius
Mayotte
Mozambique
Réunion
Rwanda
Seychelles
Somalia
South Sudan
Uganda
United Republic of Tanzania
Zambia
Zimbabwe
Middle Africa
Angola
Cameroon
Central African Republic
Chad
Congo
Democratic Republic of the Congo
Equatorial Guinea
Gabon
Sao Tome and Principe
Southern Africa

Botswana
Eswatini
Lesotho
Namibia
South Africa
Western Africa
Benin
Burkina Faso
Cabo Verde
Côte d'Ivoire
Gambia
Ghana
Guinea
Guinea-Bissau
Liberia
Mali
Mauritania
Niger
Nigeria
Saint Helena
Senegal
Sierra Leone
Togo
Northern Africa
Algeria
Egypt
Libya
Morocco
Sudan
Tunisia
Western Sahara

Table 7: Childhood Undernutrition Surveys Included in the Full Analysis

	Stunting		Wasting	
Country	**Number**	**Percent**	**Number**	**Percent**
Algeria	4	1.62	4	1.61
Angola	2	0.81	2	0.81
Benin	3	1.21	3	1.21
Botswana	2	0.81	2	0.81
Burkina Faso	11	4.45	11	4.44
Burundi	5	2.02	5	2.02
Cameroon	5	2.02	5	2.02
Central African Republic	5	2.02	5	2.02
Chad	4	1.62	4	1.61
Comoros	2	0.81	2	0.81
Congo	3	1.21	3	1.21
Côte d'Ivoire	4	1.62	4	1.61
Democratic Republic of the Congo	4	1.62	4	1.61
Djibouti	2	0.81	2	0.81
Egypt	5	2.02	5	2.02
Equatorial Guinea	3	1.21	3	1.21
Eritrea	2	0.81	2	0.81
Eswatini	5	2.02	5	2.02
Ethiopia	6	2.43	6	2.42
Gabon	2	0.81	2	0.81
Gambia	6	2.43	6	2.42
Ghana	6	2.43	6	2.42
Guinea	6	2.43	6	2.42
Guinea-Bissau	4	1.62	4	1.61
Kenya	5	2.02	5	2.02
Lesotho	5	2.02	5	2.02
Liberia	5	2.02	5	2.02
Libya	2	0.81	2	0.81
Madagascar	4	1.62	4	1.61
Malawi	10	4.05	11	4.44
Mali	5	2.02	5	2.02
Mauritania	7	2.83	7	2.82
Morocco	3	1.21	3	1.21

Mozambique	5	2.02	5	2.02
Namibia	3	1.21	3	1.21
Niger	7	2.83	7	2.82
Nigeria	9	3.64	9	3.63
Rwanda	7	2.83	7	2.82
Sao Tome and Principe	4	1.62	4	1.61
Senegal	10	4.05	10	4.03
Seychelles	1	0.4	1	0.4
Sierra Leone	7	2.83	7	2.82
Somalia	3	1.21	3	1.21
South Africa	4	1.62	4	1.61
South Sudan	2	0.81	2	0.81
Sudan	3	1.21	3	1.21
Togo	6	2.43	6	2.42
Tunisia	4	1.62	4	1.61
Uganda	7	2.83	7	2.82
United Republic of Tanzania	8	3.24	8	3.23
Zambia	4	1.62	4	1.61
Zimbabwe	6	2.43	6	2.42

Table 8: Child Undernutrition Estimates from Surveys Included in the Full Analysis

Country	Survey Year	Stunting Prevalence	Wasting Prevalence
Algeria	2000	23.6	3.1
Algeria	2002	24.0	9.6
Algeria	2006	15.4	4.1
Algeria	2012-2013	11.7	4.1
Angola	2007	29.2	8.2
Angola	2015-2016	37.6	4.9
Benin	2001	36.2	9
Benin	2014	34.0	4.5
Benin	2017-2018	32.2	5
Botswana	2000	29.1	5.9
Botswana	2007-2008	28.9	7.3
Burkina Faso	2003	43.1	21.2
Burkina Faso	2006	40.0	24.4
Burkina Faso	2009	35.1	11.3
Burkina Faso	2010	34.7	15.5
Burkina Faso	2011	34.6	10.4
Burkina Faso	2012	32.8	10.7
Burkina Faso	2013	31.3	8.1
Burkina Faso	2014	29.0	8.5
Burkina Faso	2016	26.8	7.5
Burkina Faso	2017	21.1	8.6
Burkina Faso	2018	24.9	8.4
Burundi	2000	64.0	8.1
Burundi	2005	57.7	9
Burundi	2010-2011	57.6	6
Burundi	2016-2017	55.9	5.1
Burundi	2018-2019	54.2	5.1
Cameroon	2004	35.6	6.2
Cameroon	2006	37.6	7.6
Cameroon	2011	32.6	5.7
Cameroon	2014	31.7	5.2
Cameroon	2018	28.9	4.3
Central African Republic	2000	44.4	10.4
Central African Republic	2006	43.6	12.1

Central African Republic	2010-2011	40.7	7.4
Central African Republic	2012	39.7	7.4
Central African Republic	2018	40.8	6.6
Chad	2000	38.9	13.9
Chad	2004	44.4	16.2
Chad	2010	38.7	16.3
Chad	2014-2015	39.8	13.3
Comoros	2000	46.9	13.3
Comoros	2012	31.1	11.2
Congo	2005	31.2	8
Congo	2011-2012	24.4	6
Congo	2014-2015	21.2	8.2
Côte d'Ivoire	2006	41.3	8.4
Côte d'Ivoire	2007	39.0	14
Côte d'Ivoire	2011-2012	29.9	7.6
Côte d'Ivoire	2016	21.6	6.1
Democratic Republic of the Congo	2001	44.4	15.9
Democratic Republic of the Congo	2007	45.8	10.4
Democratic Republic of the Congo	2010	43.4	8.5
Democratic Republic of the Congo	2013-2014	42.7	8.1
Djibouti	2002	27.1	19.4
Djibouti	2012	33.5	21.5
Egypt	2000	24.4	0
Egypt	2003	20.2	5.2
Egypt	2005	23.9	5.3
Egypt	2008	30.7	7.9
Egypt	2014	22.3	9.5
Equatorial Guinea	2000	42.7	9.2
Equatorial Guinea	2004	35.0	2.8
Equatorial Guinea	2011	26.2	3.1
Eritrea	2002	43.0	15
Eritrea	2010	52.5	14.6
Eswatini	2000	36.5	1.7
Eswatini	2006-2007	29.2	2.9
Eswatini	2008	40.4	1.1
Eswatini	2010	30.9	0.8

Eswatini	2014	25.5	2
Ethiopia	2000	57.6	12.4
Ethiopia	2005	50.4	12.4
Ethiopia	2010-2011	44.4	9.8
Ethiopia	2014	40.4	8.7
Ethiopia	2016	38.4	10
Ethiopia	2019	36.8	7.2
Gabon	2000-2001	25.9	4.2
Gabon	2012	17.0	3.4
Gambia	2000	24.1	9.1
Gambia	2005-2006	27.7	7.4
Gambia	2010	23.4	9.5
Gambia	2012	21.1	9.5
Gambia	2013	24.6	11
Gambia	2018	13.6	6
Ghana	2003	35.5	8.4
Ghana	2006	27.9	6
Ghana	2008	28.4	8.7
Ghana	2011	22.8	6.2
Ghana	2014	18.8	4.7
Ghana	2017-2018	17.5	6.8
Guinea	2005	39.3	11
Guinea	2007-2008	40.0	8.3
Guinea	2011-2012	34.4	5.1
Guinea	2012	31.1	10
Guinea	2016	32.4	8.1
Guinea	2018	30.3	9.2
Guinea-Bissau	2000	33.8	11.8
Guinea-Bissau	2006	47.7	8.8
Guinea-Bissau	2010	32.0	5.9
Guinea-Bissau	2014	27.6	6
Kenya	2000	40.8	7.4
Kenya	2003	35.8	6.2
Kenya	2005-2006	40.3	6.9
Kenya	2008-2009	35.5	6.9
Kenya	2014	26.2	4.2

Lesotho	2000	52.7	6.8
Lesotho	2004-2005	44.7	5.6
Lesotho	2009-2010	39.3	3.8
Lesotho	2014	33.4	2.8
Lesotho	2018	34.6	2.1
Liberia	1999-2000	45.3	7.4
Liberia	2006-2007	39.6	7.9
Liberia	2010	39.0	4
Liberia	2013	32.1	5.6
Liberia	2016	30.1	4.3
Libya	2007	21.0	6.5
Libya	2014	38.1	10.2
Madagascar	2003-2004	52.7	15.1
Madagascar	2008-2009	49.4	0
Madagascar	2012-2013	48.9	7.5
Madagascar	2018	41.6	6.4
Malawi	2000	54.7	6.8
Malawi	2002	58.3	6.3
Malawi	2004-2005	52.5	6.3
Malawi	2006	53.1	4.2
Malawi	2009	48.8	1.8
Malawi	2010	47.3	4
Malawi	2013-2014	42.4	3.8
Malawi	2015-2016	37.4	2.8
Malawi	2016	44.2	2.4
Malawi	2017	NA	2.2
Malawi	2018	39.0	1.3
Mali	2001	42.5	12.6
Mali	2006	37.6	15.4
Mali	2009-2010	27.8	8.9
Mali	2015	30.4	13.5
Mali	2018	26.9	9
Mauritania	2000-2001	38.6	15.3
Mauritania	2007	31.5	13.6
Mauritania	2008	23.6	8.1
Mauritania	2011	29.7	13.9

Mauritania	2012	23.0	11.7
Mauritania	2015	27.9	14.8
Mauritania	2018	22.8	11.5
Morocco	2003-2004	23.1	10.8
Morocco	2010-2011	14.9	2.3
Morocco	2017-2018	15.1	2.6
Mozambique	2000-2001	50.7	8.1
Mozambique	2003	46.9	5.4
Mozambique	2008	43.5	4.2
Mozambique	2011	42.9	6.1
Mozambique	2014-2015	42.3	4.4
Namibia	2000	29.3	10
Namibia	2006-2007	29.2	7.6
Namibia	2013	22.7	7.1
Niger	2000	53.5	16.2
Niger	2006	54.8	12.5
Niger	2012	39.9	13.4
Niger	2013	42.5	12.4
Niger	2014	42.2	14.2
Niger	2016	41.3	10.4
Niger	2018	48.5	14.1
Nigeria	2003	42.5	11.2
Nigeria	2007	39.2	13.4
Nigeria	2008	40.6	14.5
Nigeria	2011	35.8	10.2
Nigeria	2013	36.5	18.1
Nigeria	2014	33.6	7.9
Nigeria	2015	33.0	7.3
Nigeria	2016-2017	43.6	10.8
Nigeria	2018	36.8	6.8
Rwanda	2000	47.9	8.7
Rwanda	2005	51.4	4.9
Rwanda	2009	52.0	4.6
Rwanda	2010-2011	44.3	2.9
Rwanda	2012	43.8	2.4
Rwanda	2014-2015	38.3	2.3

Rwanda	2015	36.9	2
Sao Tome and Principe	2000	35.5	3.9
Sao Tome and Principe	2006	28.9	9.6
Sao Tome and Principe	2008-2009	30.8	11.6
Sao Tome and Principe	2014	17.2	4
Senegal	2000	26.0	10
Senegal	2005	19.9	8.7
Senegal	2010-2011	26.7	9.8
Senegal	2012	15.5	8.7
Senegal	2012-2013	18.8	9
Senegal	2014	18.8	5.9
Senegal	2015	20.7	7.8
Senegal	2016	17.1	7.1
Senegal	2017	16.5	9
Senegal	2019	18.8	8.1
Seychelles	2012	7.9	4.3
Sierra Leone	2000	35.5	11.6
Sierra Leone	2005	45.0	10.2
Sierra Leone	2008	37.2	10.5
Sierra Leone	2010	44.4	8.5
Sierra Leone	2013	37.8	9.4
Sierra Leone	2017	29.3	5.1
Sierra Leone	2019	29.5	5.4
Somalia	2000	29.2	19.3
Somalia	2006	42.0	13.3
Somalia	2009	25.3	14.3
South Africa	2003-2004	35.5	7.8
South Africa	2008	24.9	4.8
South Africa	2012	27.2	5.6
South Africa	2016	27.4	2.5
South Sudan	2006	36.2	24.6
South Sudan	2010	31.3	22.7
Sudan	2006	38.3	14.5
Sudan	2010	34.1	15.4
Sudan	2014	38.2	16.3
Togo	2006	29.9	15.5

Togo	2008	26.9	6
Togo	2010	29.8	4.8
Togo	2012	26.2	5.5
Togo	2013-2014	27.6	6.6
Togo	2017	23.8	5
Tunisia	2000	16.8	2.9
Tunisia	2006	9.0	3.4
Tunisia	2011-2012	10.1	2.8
Tunisia	2018	8.4	2.1
Uganda	2000-2001	44.9	5
Uganda	2006	38.4	6.2
Uganda	2009-2010	38.2	4.4
Uganda	2011	33.5	4.6
Uganda	2011-2012	33.7	4.2
Uganda	2013-2014	34.0	3.8
Uganda	2016	28.9	3.5
United Republic of Tanzania	2004-2005	44.4	3.5
United Republic of Tanzania	2008-2009	43.2	2.9
United Republic of Tanzania	2009-2010	42.1	4.9
United Republic of Tanzania	2010-2011	35.0	6.2
United Republic of Tanzania	2012-2013	37.4	4.4
United Republic of Tanzania	2014	34.7	3.8
United Republic of Tanzania	2015-2016	34.5	4.5
United Republic of Tanzania	2018	31.8	3.5
Zambia	2001-2002	52.5	6.2
Zambia	2007	45.8	5.6
Zambia	2013-2014	40.0	6.2
Zambia	2018-2019	34.6	4.2
Zimbabwe	2005-2006	35.3	7.2
Zimbabwe	2009	35.1	2.4
Zimbabwe	2010-2011	32.2	3.2
Zimbabwe	2014	27.6	3.2
Zimbabwe	2015	27.1	3.3
Zimbabwe	2019	23.5	2.9

Z-Score Calculations: According to WHO Guidelines

$$Z - Score = \frac{Observed\ Value - Median\ Value\ of\ the\ Reference\ Population}{Standard\ Deviation\ of\ the\ Reference\ Population}$$

The reference values are calculated from a growth study that the WHO carried out from 1993 – 2003 in five different countries. The growth study measured the optimal rate of growth within children. Reference values are specific to the different sexes and a particular anthropometric measure or age. The references values are determined according to the form of undernutrition being measured. Examples for the three different forms of child undernutrition are detailed below.

Stunting refers to low height-for-age and wasting refers to low weight-for-height. To determine the z-scores for height-for-age, the reference value is specific to particular age (in months) and sex. To determine the z-score for weight-for-height, the reference value is specific to a particular height and sex.

$$Z - Score\ (Stunting) = \frac{Observed\ Height_{as} - Median\ Height\ (Ref.Population)_{as}}{Standard\ Deviation\ (Ref.Population)_{as}}$$

$$Z - Score\ (Wasting) = \frac{Observed\ Weight_{hs} - Median\ Weight\ (Ref.Population)_{hs}}{Standard\ Deviation\ (Ref.Population)_{hs}}$$

Average Annual Rate of Reduction Calculations: According to UNICEF Guidelines

$$AARR = (1 - e^{\beta}), \text{ where } \beta \text{ is the untransformed coefficient}$$

$$Percent\ AARR = (1 - e^{\beta}) * 100, \text{ where } \beta \text{ is the untransformed coefficient}$$

Sample Calculation

β = -0.02308

Step 1: $e^{-0.02308} = 0.9772$
Step 2: 1 – 0.9772 = 0.02282
Step 3: 0.02282*100 = 2.28

AARR: 0.0228
Percent AARR: 2.28%

The above method is also used to calculate the corresponding 95% confidence interval.

CHAPTER THREE: EXPOSURE TO HOUSEHOLD AIR POLLUTION FROM SOLID COOKFUELS AND CHILDHOOD UNDERNUTRITION IN 59 LOW AND MIDDLE INCOME COUNTRIES: A POPULATION-BASED CROSS-SECTIONAL STUDY

3.1. CHAPTER PREFACE

Expanding on the thesis aim, this chapter moves beyond current nutrition action to evaluate the association between exposure to household air pollution from solid cooking fuels and childhood undernutrition in LMICs. The previous analytical chapter highlighted a need to move beyond current approaches to accelerate the reduction of childhood undernutrition in Sub-Saharan Africa.

To date, energy infrastructure – cooking energy infrastructure in particular, has largely been excluded from nutrition policy and research. Nutrition action has focused on improving infant and young child feeding, WASH, and community level treatment and management of acute malnutrition. Although this nutrition action is important, this chapter suggests additional opportunities to build on existing nutrition action and accelerate the reduction childhood undernutrition in LMICs, and Sub-Saharan Africa in particular.

3.2. ABSTRACT

Undernutrition in the first few years of life increases the risk of poor health and decreases human capital. The current global nutrition strategy, which focuses on improved child feeding and WASH, has resulted in a slow decline of child undernutrition. In order to accelerate progress, wider risk factors of child undernutrition must be identified and incorporated into the global nutrition strategy. This study examines the association between exposure to household air pollution (HAP) and child undernutrition in 59 LMICs.

Cross-sectional Demographic and Health Survey data from 59 LMICs, conducted between January 2000 and June 2019, were analysed. The full analytical sample included over half a million children under five years old. Multilevel logistic regression models were used to examine the association of interest, accounting for child sex, child age, maternal education and number of children living in the household.

Children living in households using solid fuels, compared to children living in households using cleaner fuels, were more likely to be stunted (AOR: 1.58, 95% CI: 1.55 - 1.61), wasted (AOR: 1.14, 95% CI: 1.11 – 1.16), or concurrently stunted and wasted (AOR: 1.51, 95% CI: 1.44 – 1.59). Increasing the level of exposure to less clean fuels was associated with increasing odds of stunting and wasting. Amongst subgroups, children living in households using solid fuels were more likely to be stunted if they lived in rural regions, the poorest households, the Americas, had a mother who smoked, or were older. Low birthweight did not mediate the association between exposure to HAP and child undernutrition.

The successful clinical management of child undernutrition requires a combination of interventions that address all risk factors – exposure to HAP included.

3.3. INTRODUCTION

In 2019, 144 million children under five years old were stunted and 47 million children under five years old were wasted (1). Nearly all cases of child stunting (99.9%) and child wasting (96%) are concentrated in low-income and middle-income countries (LMICs) (2). Undernutrition in childhood impairs physical and cognitive development, and results in health, social, and economic costs over the life course (3, 4). Although the global prevalence of childhood stunting and wasting have decreased in the last two decades, the rate of decline has been slow, there has been an increase in the number of stunted children in Sub-Saharan Africa, and one in fourteen children under five years old are presently wasted (1). Should present trends in addressing child undernutrition in LMICs continue, the rate of decrease of stunting, wasting and other forms of child undernutrition would prevent many countries from reaching the 2025 WHO Global Nutrition Targets.

Current interventions addressing child undernutrition in LMICs focus on maternal nutrition during pregnancy; encouraging breastfeeding; improving complementary feeding practices; and improving water, sanitation, and hygiene (WASH) infrastructure and behaviour (5, 6). While effective, an accelerated reduction in child undernutrition also requires interventions that address wider risk factors. This paper examines the association between exposure to household air pollution (HAP) from solid cookfuels and child growth in LMICs.

Approximately 3 billion people, primarily in low-income countries, use solid fuels (wood, agricultural residue, dung, charcoal and coal) for cooking (7). Cooking with solid fuels over open fires or in simple stoves exposes household members to health-damaging pollutants, namely fine particulate matter (PM2.5), carbon monoxide (CO),

and polycyclic aromatic hydrocarbons (PAHs) (8, 9). As children typically spend a large amount of time with mothers and caregivers who also have cooking responsibilities, children under five years old experience high levels of exposure to solid fuel pollutants (10).

Exposure to pollutants during this critical period may interfere with growth through three processes. First, exposure to solid fuel pollutants is associated with respiratory infections (11), which decrease appetite and the small intestine's ability to absorb nutrients (12, 13), ultimately increasing the risk of both wasting and stunting. Second, inhalation of solid fuel pollutants also causes oxidative stress within the body (14), which can damage cells in the endocrine system and impact linear growth (15, 16). Third, oxidative stress could also lead to chronic inflammation which disrupts bone growth (17, 18), and ultimately impairs linear growth.

Amongst studies identified examining the association between exposure to HAP and child growth in LMICs (19-36), only fourteen of these studies, from twelve countries, isolated the association between exposure to HAP and child growth. Eight studies identified an association between an increased likelihood of childhood stunting and exposure to HAP (20, 21, 27-30, 32, 33), three studies did not find an association (22, 24, 31), and three studies produced mixed results (23, 25, 26). Three systematic reviews and one literature review confirmed these findings (37-40). Only one of the systematic reviews with a published manuscript assessed the quality of the evidence and graded it low. The fourteen studies identified were conducted on small samples of children, did not appropriately control for the role of socioeconomic factors or consider how the association between exposure to HAP and child growth differs in key subpopulations,

and varied according to the child age groups included and measurement of exposure to HAP.

Childhood undernutrition is a leading cause of human and economic costs at the individual, community, and national level (41). Current approaches to address childhood undernutrition discount the role of environmental factors, such as HAP. Examining the association between exposure to HAP and childhood undernutrition, and heterogeneity in the association within subpopulations is essential for the optimal reduction of childhood stunting in LMICs, which requires interventions that address its multitude of determinants. This study examines the association between exposure to HAP and child undernutrition in children aged 0-5 years in 59 LMICs, controlling for a priori confounders and accounting for potential subgroup variations in association. The large sample of standardised data from 59 LMICs strengthens the accuracy and generalisability of the results.

3.4. METHODS

Data Source

This study analysed data from the Demographic and Health Surveys (DHS), repeated cross-sectional surveys conducted in LMICs. Within each country, DHS data are collected from a nationally representative sample population of households. DHS data are collected in approximately five year intervals. This study assessed the most recent DHS data for 59 LMICs with available data for HAP and anthropometric measures (Table 2). Permission to use and download the DHS datasets was received through the DHS programme website (https://www.dhsprogram.com/). Standardised methodology and measurement tools have been developed for the collection of DHS data in each country. Additional information about DHS data collection methods and tools are

detailed on the DHS programme website (https://dhsprogram.com/What-We-Do/Methodology.cfm).

DHS use a stratified two-stage random sampling approach. Census enumeration areas (DHS clusters) are identified based on a probability proportional to sampling area. Within each of the selected enumeration areas, a random selection of households are identified from a complete listing of households. In each sampled household, all consenting women aged 15–49 years are interviewed, and their children aged 0-60 months are assessed for stunting and wasting. The analytical sample for this study was limited to living children under five years old with valid height and weight measurements.

All the women included in the DHS provided written consent for themselves and their children. The DHS received ethical approval from the ICF International (Calverton, MD, USA) institutional review board and locally from country-specific institutional review boards.

Child Undernutrition

Child undernutrition was measured with two standard WHO indicators – stunting and wasting. Due to the proposed pathways of impact, stunting was the primary outcome of interest, and wasting and concurrent stunting and wasting were included as a secondary outcomes. Studies suggest that children frequently suffer from stunting and wasting concurrently (42-45). Furthermore, present childhood stunting is a risk factor of future childhood wasting, and present childhood wasting is a risk factor for future childhood stunting (46).

Stunting and wasting were both measured according to the WHO reference anthropometric measurements for children (47). Height-for-age z-scores were used to measure whether a child was stunted or not. Weight-for-height z-scores were used to measure whether a child was wasted or not. Z-scores indicate the number of standard deviations a child's height or weight is from the median value in the reference population. A child with a z-score less than negative two was categorised as undernourished - stunted or wasted (47). Children with biologically implausible z-scores were excluded from the study. In accordance with the 2006 WHO guidelines, height-for-age z-scores less than negative six and weight-for-height z-scores less than negative five were considered biologically implausible (48). DHS include data about each child's age (in months and years), and measured height/length and weight.

This study included three binary measures of childhood undernutrition – a binary variable indicating whether a child was stunted or not; a binary variable indicating whether a child was wasted or not; and a binary variable indicating whether a child was stunted and wasted concurrently or not. Two continuous measures of child growth were also used to measure childhood undernutrition – height-for-age z-scores and weight-for-height z-scores.

Exposure to HAP

Exposure to HAP was ascertained by the type of fuel used for cooking. Each respondent was asked "What type of fuel does your household mainly use for cooking?". Responses were categorised as follows: (1) wood, (2) crop residues, (3) dung cakes, (4) coal/coke/lignite, (5) charcoal, (6) kerosene, (7) electricity, (8) liquid petroleum gas, (9) biogas, and (10) a residual category of other fuels. A binary exposure variable was constructed measuring the extent of exposure to HAP - high exposure (wood, crop

residues, dung cakes, coal/coke/lignite, charcoal, sawdust/wood chips, cardboard paper) or low exposure (electricity, electricity from other sources, liquid petroleum gas, biogas, kerosene, solar energy, or bottled glass) (49). Respondents who noted that food was not cooked indoors were also categorised as low exposure. Studies indicate that exposure to air pollution is lower when cooking outdoors, as opposed to indoors, due to improved ventilation (50-52).

For dose-response analysis, a three-level HAP exposure variable was created – low exposure (solar energy, electricity, electricity from other sources, liquid petroleum gas, biogas, no food cooked in the house), medium exposure (kerosene, charcoal, coal, paraffin, bottled gas), and high exposure (wood, crop residues, dung cakes, sawdust/wood chips, cardboard paper). This variable was created in accordance with the energy ladder, which states that the primary household fuel type changes according to socioeconomic status. The energy ladder separates fuel types into three categories - primitive fuels (firewood, agricultural waste, and animal waste), transition fuels (charcoal, kerosene, coal), and advanced fuels (liquid petroleum gas, electricity, and biofuels) (53).

A Priori Confounders

The models were adjusted for the following a priori confounders: child sex, child age in months, maternal education, and number of children under five years old in the household (54, 55). Child sex was recorded as either male or female. Child age in months was calculated from date of birth. Maternal education was assessed by self-report of the completed educational level (no education, primary, secondary, or higher).

A Priori Effect Modifiers

The following variables were considered a priori effect modifiers: area of residence – urban or rural, household wealth, exclusive breastfeeding (EBF), WHO region, maternal smoking, and child age (53-55). The risk of child undernutrition and exposure to HAP differ according to urban/rural area of residence and household wealth – children are more likely to be undernourished and/or live in households cooking with solid fuels in rural areas and poorer households (53). The risk of undernutrition differs between children, under six-months, who are EBF and those who are not. The WHO recommends that children under six-months are exclusively breastfed to adequately meet their nutritional needs, and ensure good health, growth, and development (56). Children under six-months who are not exclusively breastfed have an increased risk of undernutrition, especially in LMICs. The risk of childhood undernutrition also differs by child age group. The risk of linear growth faltering largely stabilises after 24 months (57). The risk of exposure to HAP differs between WHO regions and according to maternal smoking – the prevalence of solid fuel use for cooking differs according to WHO regions, and maternal smoking increases a child's exposure to HAP (53). The mechanism of exposure to HAP also varies according to child age. Children under one month of age are mainly exposed to HAP through their mothers – the impact of maternal exposure to HAP are largely evident in neonates, while the impact of child exposure to HAP is largely evident in children one month old and older.

Household wealth was measured through a DHS constructed wealth index. Principal component analysis is used to develop each wealth index, which accounts for household ownership of durable goods (i.e. cars, or radios) and housing quality (i.e. WASH facilities, or roofing material). The wealth index is further categorised into quintiles - poorest, poorer, middle, richer, or richest. The household wealth index is calculated

separately for each country and survey. Exclusive breastfeeding was defined for children under six months, and was assessed from the question – "Are you currently breastfeeding (name of the child)?". A "yes" response led to further questions on additional food and liquid given to the child in the past 24 hours. Children were categorised as exclusively breastfed if they had been breastfed in the 24 hours preceding the survey and had not been fed any other type of food. Regions, according to WHO categorisations, are the following: the Americas, African, European, Eastern Mediterranean, South-East Asian and Western Pacific. Maternal smoking in the DHS is assessed via questionnaire. Participants were asked four questions which are answered either "yes" or "no" regarding current cigarette, pipe or other country specific tobacco usage. Any "yes" response to the use of smoking products was classified as maternal smoking, creating a binary variable. Two child age group variables were created. For the first child age group variable, children were separated into three groups – under six months, six to under 24 months, and 24 months and older. For the second age variable, children were separated into two groups – under one month, and one month and older.

A Priori Mediator

Low birthweight was included as a mediator in this analysis. Maternal exposure to household air pollution is a risk factor for low birthweight, a risk factor for childhood undernutrition (58). Two measures of low birthweight are included in the DHS dataset, one being a self-reported estimate of a child's birthweight (very large, larger than average, average, smaller than average and very small) and the other being the child's birthweight in kilograms. A binary variable was constructed, indicating whether a child had a low birthweight or not. Child's birthweight in kilograms was used as the primary

construction variable. In accordance with WHO guidelines, children with a birthweight less than 2.5 kilograms were recoded as having a low birthweight (59). For children with missing birthweights in kilograms, the self-reported measure was recoded to identify a child as low birthweight if the self-reported estimate was 'very small' or 'smaller than average' (60). Children born from a multiple pregnancy (i.e. twins) were excluded from this mediation analysis (61, 62). Multiple pregnancies are associated with an increased risk of low birthweight and have been excluded in similar analysis of low birthweight (61).

Statistical Analysis

A three-level hierarchical pooled sample was created by appending individual-level DHS data from 59 LMICs. Children formed level 1, clusters formed level 2 and countries formed level 3. Children were excluded from the study sample if one or more of the following were true: children did not live with their mother, children were not alive, mother was not a de jure resident of the household, children were over five years old, children with an implausible date of birth, children with missing HAP and/or anthropometric data, or children with implausible height/weight z-scores.

Descriptive statistics were calculated for all variables included in this analysis. Means, standard error, and range values are presented for continuous variables; and percentages are presented for categorical variables. Where p-values are presented for descriptive statistics, the Pearson chi-squared test was used to evaluate the statistical significance of differences in percentages.

Multilevel logistic regression models were used to estimate the association between exposure to HAP and childhood undernutrition, in order to account for the hierarchical

data structure and appropriately control for variance at each level. The assumptions of multilevel logistic regression models - linearity, homogeneity of variance, and normal distribution of residuals were tested by plotting residuals. Multicollinearity was assessed by calculating the variance inflation factor.

Adjusted odds ratios (AOR) and 95% confidence intervals (95% CI) for the associations of interest are presented. All models accounted for a priori confounders: child age, child sex, maternal education and number of children living within the household; and controlled for random effects at level 2 and level 3.

Subgroup analyses were conducted for the primary outcome variable, examining the association for: urban/rural area of residence, household wealth, EBF, WHO regions, maternal smoking, and child age groups. Subgroup specific AOR and 95% CI are presented, and p-values for interaction to test for within-subgroup differences in the association are provided. P-values for interaction were calculated by including an interaction term, between exposure to HAP and the respective effect modifier, in the model (63).

In addition to the above primary analysis, additional models were run for secondary analysis. First, mediation analysis was conducted for the primary outcome variable, to examine whether low birthweight mediates the association between exposure to HAP and childhood undernutrition. Second, multilevel linear regression models were used to estimate the association between exposure to HAP and linear and ponderal child growth. Third, a model was run examining the dose-response relationship between exposure to HAP and the primary outcome variable.

This analysis did not include data weights, since DHS sample weights are calculated separately for each country and not recommended for multilevel analysis (64). A meta-analysis, using country-specific weights, was also conducted for comparison.

Stata/SE version 16.0 (StataCorp, College Station, TX) was used for data cleaning and preparation. Multilevel models were run in MLwiN 3.04 using the runmlwin programme in Stata 16 (65). Multilevel model parameters were estimated using iterative generalised least squares and second order penalised quasi-likelihood algorithms.

3.5. RESULTS

DHS datasets from 2000 to 2019 were available for 69 LMICs. 59 (86%) of these country datasets included data about HAP and child anthropometry and were included in this study (Table 2). By WHO region, the following number of LMICs were included in this study, 41 out of 45 in Africa; 3 out of 16 in Eastern Mediterranean; 3 out of 20 in Europe; 7 out of 25 in the Americas; 4 out of 11 in South-East Asia; and 1 out of 18 in Western Pacific.

586,365 children were eligible for inclusion in this study (Figure 1). Of these children, 60 (<1%) were excluded due to a measurement error with the child's date of birth. An additional 343 children (<1%) were excluded due to missing HAP values or a mother who does not cook. A further 471 children (<1%) were excluded from this analysis due to missing values for maternal education and 17,584 children (3%) were excluded due to missing or implausible height/length measurements. 567,907 children five years old and younger (97%) were included in the final primary analytical sample.

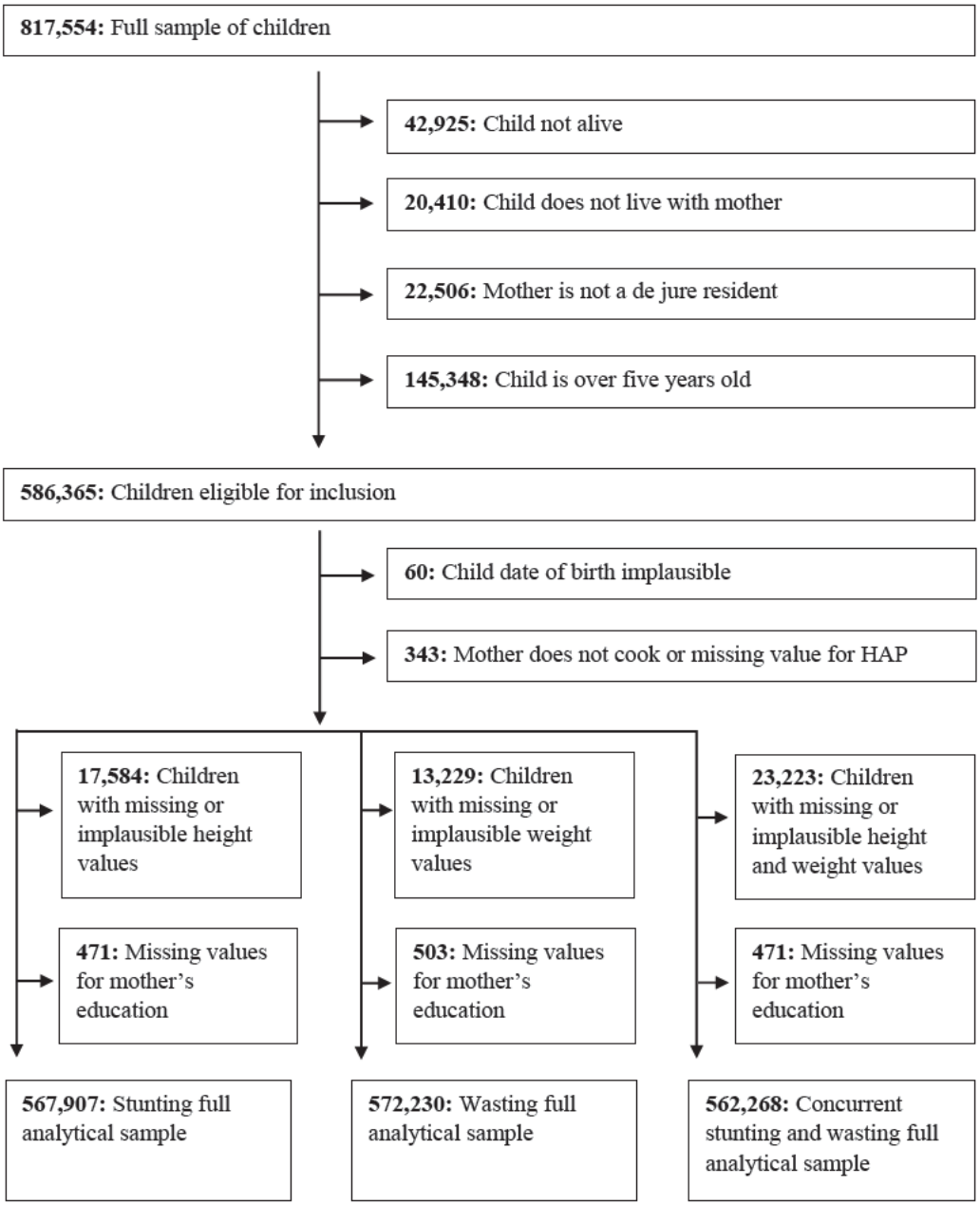

Figure 1: Analytical Sample Selection

Descriptive Statistics

The mean child age was 29 months and an average of two children (five years old and younger) lived in each household. 49% of the sample population was female and 70% lived in rural regions. 31% of all mothers had no education, 3% smoked, and 46% of mothers with children under six months were exclusively breastfeeding.

Table 1: Descriptive Statistics of the Full Analytical Sample

	N	Mean	Standard Error	Min.	Max.
Child age, months	585,962	29.29	0.02	0.00	59.99
Number of children	585,962	1.96	0.00	0.00	18.00

Wealth Quintiles	**N**	**Percentage**
Poorest	152,863	26.38
Poorer	131,428	22.68
Middle	114,239	19.71
Richer	98,985	17.08
Richest	81,983	14.15
Mother's Education	**N**	**Percentage**
None	183,258	31.28
Primary	153,117	26.13
Secondary	204,438	34.89
Higher	45,130	7.70
Child Sex	**N**	**Percentage**
Female	285,593	48.74
Male	300,369	51.26
Maternal Smoking	**N**	**Percentage**
Smoker	15,231	2.91
Area of Residence	**N**	**Percentage**
Urban	178,633	30.49
Rural	407,329	69.51
EBF	**N**	**Percentage**
Yes	28,029	45.68
WHO Regions	**N**	**Percentage**
Africa	262,452	44.79
Eastern Mediterranean	25,120	4.29
Europe	6,470	1.10
Americas	44,333	7.57
South-East Asia	243,109	41.49
Western Pacific	4,478	0.76

Among the children in the sample population, 34% were stunted – ranging from 7.9% in the Dominican Republic to 54.7% in Burundi (Figure 2). The mean height-for-age z-score was -1.35 (Standard Deviation: 1.68). A larger percentage of stunted children lived in rural regions (38.2% versus 25.5% in urban regions, p<0.001); and in the poorest households (43.8% versus 20.7% in the richest households, p<0.001). By WHO region, stunting was highest in Eastern Mediterranean (40.4%), followed by South East Asia (38.2%), Western Pacific (33.0%), Africa (32.5%), Americas (23.3%), and Europe (17.9%) (p<0.001). By age group, stunting was highest in older children and lowest in younger children (38.1% in children 24 months and older, 32.3% in children between 6 months and 24 months, and 19.4% in children under 6 months (p<0.001).

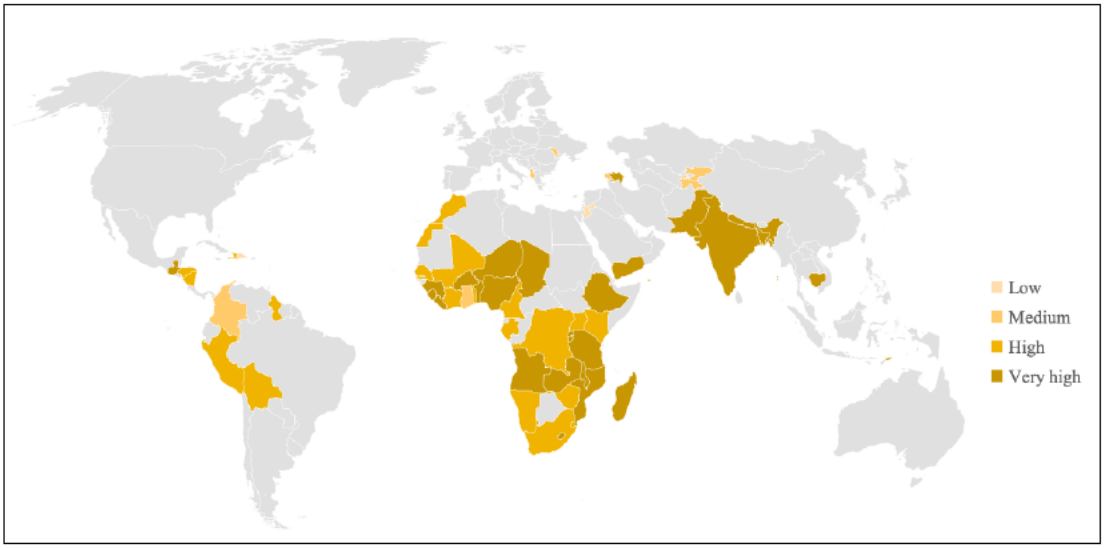

Figure 2: Prevalence of Childhood Stunting in the Sample Population

Among the children in the sample population, 13% were wasted – ranging from 0.7% in Peru to 24.4% in Timor-Leste (Figure 3). The mean weight-for-height z-score was -0.43 (Standard Deviation: 1.44). A larger percentage of wasted children lived in rural regions (14.0% versus 10.1% in urban regions, p<0.001); and in the poorest households (15.2% versus 10.9% in the richest households, p<0.001). Wasting was highest in South-East Asia (20.9%) and lowest in Americas (2.1%) (p<0.001). By age group,

wasting was highest in younger children and lowest in older children – 17.9% in children under 6 months, 14.9% in children between 6 and 24 months, and 10.1% in children 24 months and older (p<0.001).

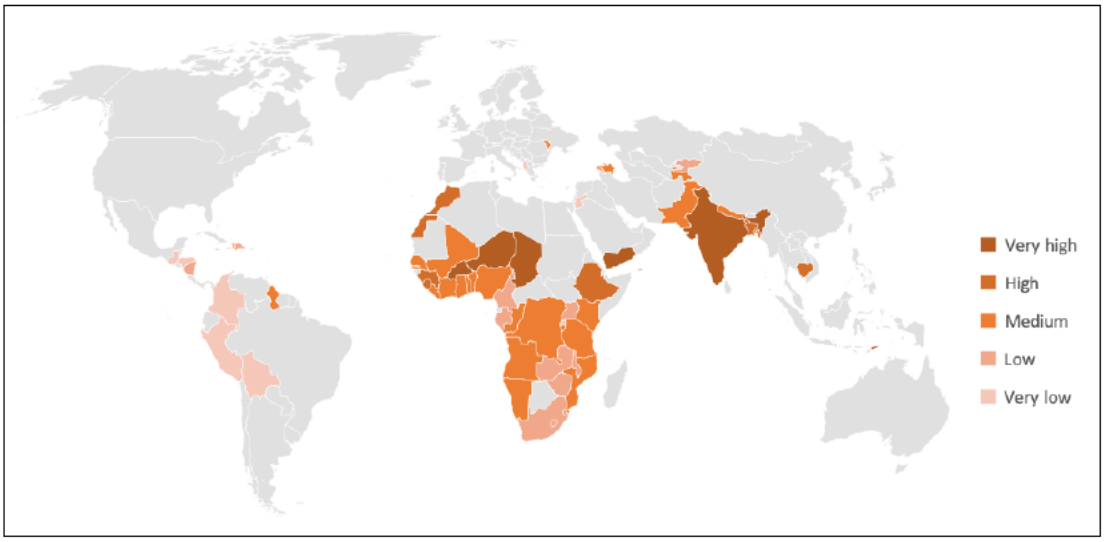

Figure 3: Prevalence of Childhood Wasting in the Sample Population

3.8% of the children in the sample population were concurrently stunted and wasted – ranging from 0.2% in Armenia to 7.7% in Niger. A larger percentage of children suffering from concurrent wasting and stunting lived in rural regions (4.4% versus 2.4% in urban regions, p<0.001); and in the poorest households (5.7% versus 2.0% in the richest households, p<0.001). Concurrent stunting and wasting was highest in South-East Asia (6.1%) and lowest in Europe (0.5%) (p<0.001). By age, concurrent stunting and wasting was highest in children between 6 and 24 months (4.6%), followed by children 24 months and older (3.8%), and children under 6 months (1.5%) (p<0.001).

Most children (72%) lived in households using solid fuels for cooking - ranging from 0% in Jordan to 99.9% in Sierra Leone. The percentage of children living in households using solid fuels for cooking was highest in the poorest households (91.0% in the poorest quintile and 36.2% in the richest quintile, p<0.001); and rural regions (84.1%

versus 43.2% in urban regions, p<0.001). By WHO region, the percentage of children living in households cooking with solid fuels was highest in Western Pacific (80.9%), followed by Africa (79.2%), South-East Asia (69.1%), Americas (57.9%), Eastern Mediterranean (52.2%), and Europe (20.9%) (p<0.001).

Inferential Statistics

Children living in households using solid fuels for cooking were more likely to be stunted (AOR: 1.58, 95% CI: 1.55 – 1.61) after adjusting for child sex, child age in months, maternal education, number of children living in the household, and random effects at level 2 and level 3 (Table 3). In comparison to households using clean cooking fuels, children living in solid fuel using households were also more likely to be wasted (AOR: 1.14, 95% CI: 1.11 – 1.16), or concurrently stunted and wasted (AOR: 1.51, 95% CI: 1.44 – 1.59) (Table 3).

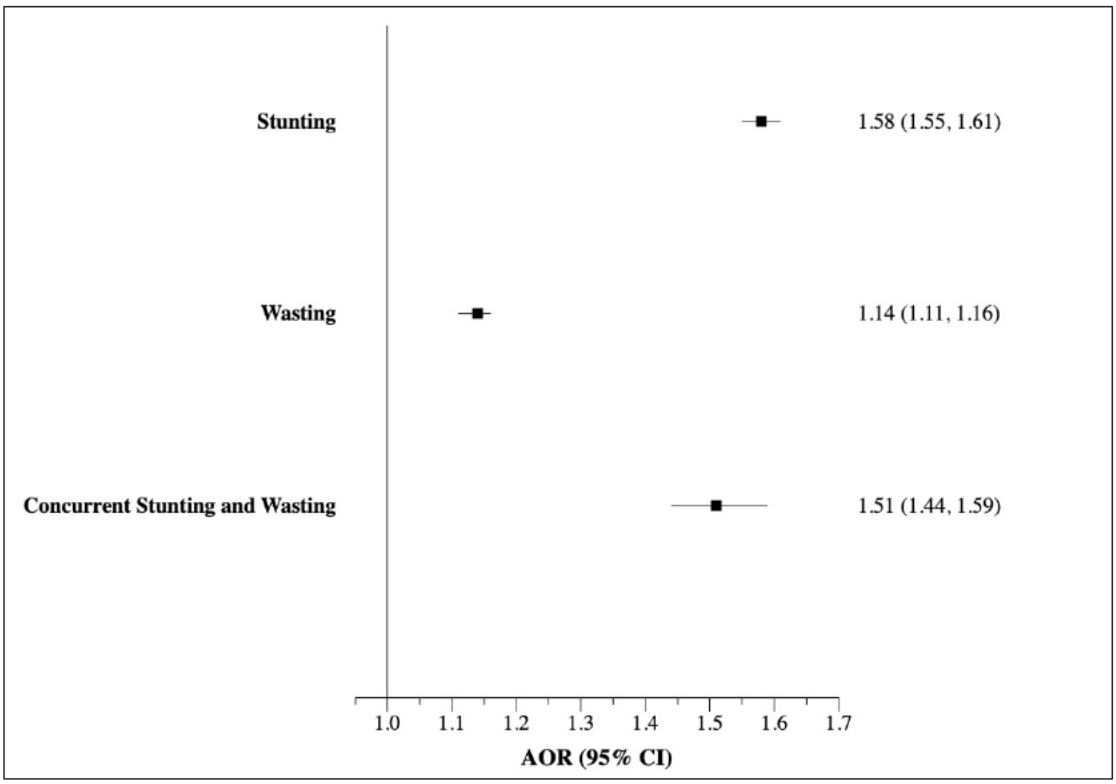

Figure 4: Association between Solid-Fuel Usage and Child Undernutrition

These findings were largely consistent with the results of the meta-analysis using country-specific weights. Children living in households using solid fuels for cooking were more likely to be stunted (Pooled AOR: 1.64, 95% CI: 1.47 – 1.84) and concurrently stunted and wasted (Pooled AOR: 1.21, 95% CI: 1.01 – 1.45). No statistically significant association existed household solid cooking fuel use and wasting (Pooled AOR: 1.06, 95% CI: 0.97 – 1.15).

Household use of solid cookfuels was also associated with decreased linear and ponderal growth (Table 4). Children living in households using solid cookfuels had lower height-for-age z-scores (Beta Coefficient: -0.37, 95% CI: -0.40, -0.34). Weight-for-height z-scores were also lower in children living in solid fuel using households (Beta Coefficient: -0.12, 95% CI: -0.14, -0.09).

The association between child stunting and exposure to HAP varied according to area of residence ($p<0.001$) (Table 6). In solid fuel using rural households, compared to solid fuel using urban households, children were more likely to be stunted (AOR: 1.52, 95% CI: 1.48 – 1.56).

Children in all household wealth quintiles were more likely to be stunted if they lived in a household cooking with solid fuel, however, the association differed across wealth quintiles ($p<0.001$) (Table 6). Children in solid fuel using households in the poorest wealth quintiles were most likely to be stunted (AOR: 1.23, 95% CI: 1.13 - 1.35).

In all WHO regions, children were more likely to be stunted if they lived in solid fuel using households. The association between HAP and the likelihood of stunting varied between WHO regions ($p<0.001$) (Table 6). Children in households cooking with solid fuels in the Americas were most likely to be stunted (AOR: 2.17, 95% CI: 2.02 – 2.34).

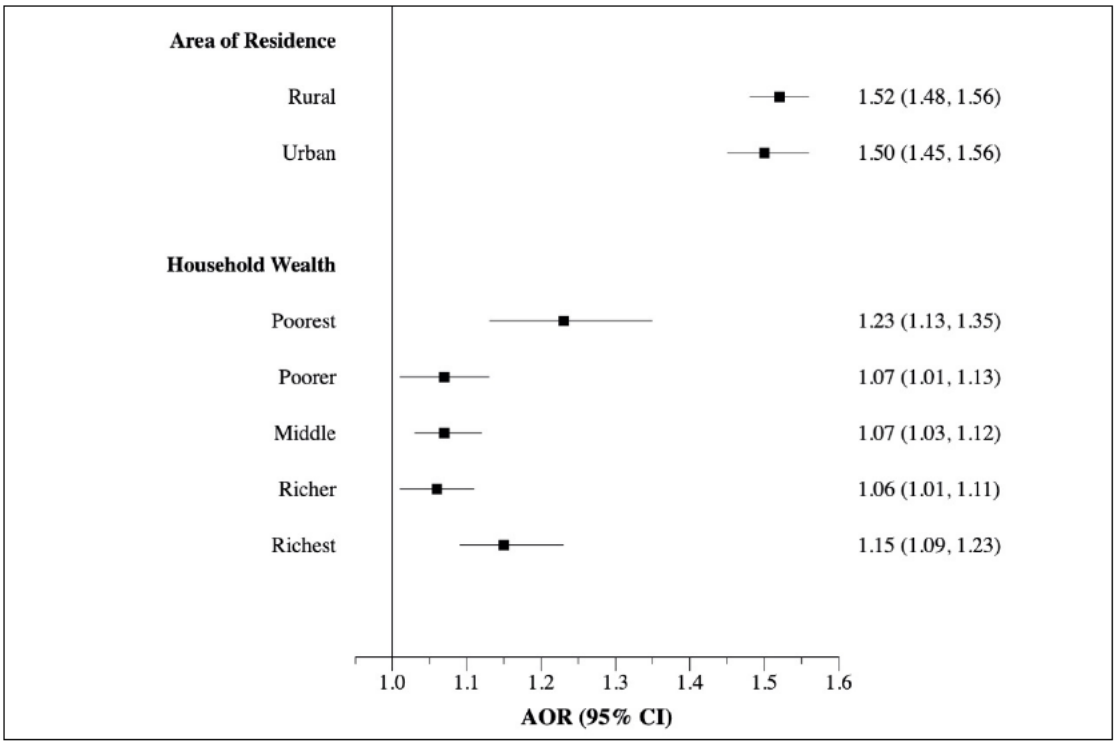

Figure 5: Association between Solid-Fuel Usage and Child Undernutrition

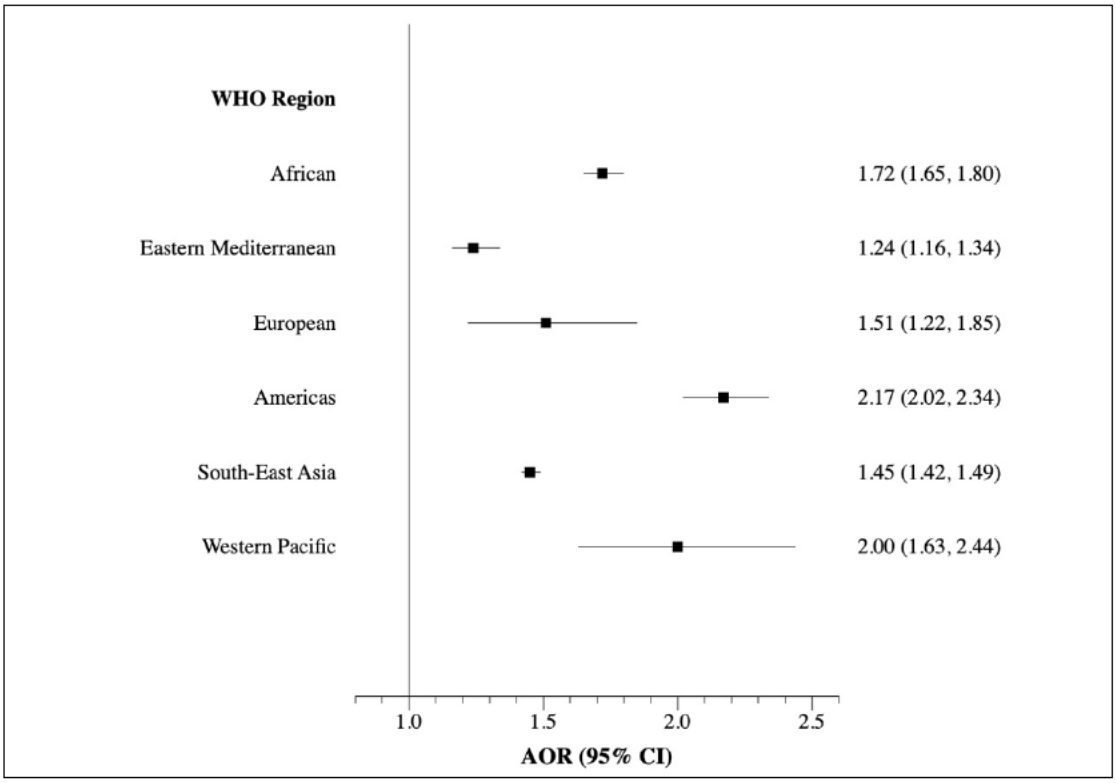

Figure 6: Association between Solid-Fuel Usage and Child Undernutrition

The likelihood of stunting among children living in households using solid fuels for cooking differed depending on whether their mother smoked or not ($p<0.001$) (Table 6). Children with mothers who smoked and lived in households using solid fuels for cooking, compared to children whose mothers did not smoke and lived in households using solid fuels for cooking, were more likely to be stunted (AOR: 1.80, 95% CI: 1.62 – 2.01).

Across all age groups, children living in households cooking with solid fuels were more likely to be stunted. The association between stunting and exposure to HAP varied according to child age ($p<0.001$) (Table 7). When age was separated into three categories, the likelihood of stunting among children living in households using solid fuels increased with age. Children 24 months or older living in solid fuel using households were most likely to be stunted (AOR: 1.67, 95% CI: 1.63 – 1.71).

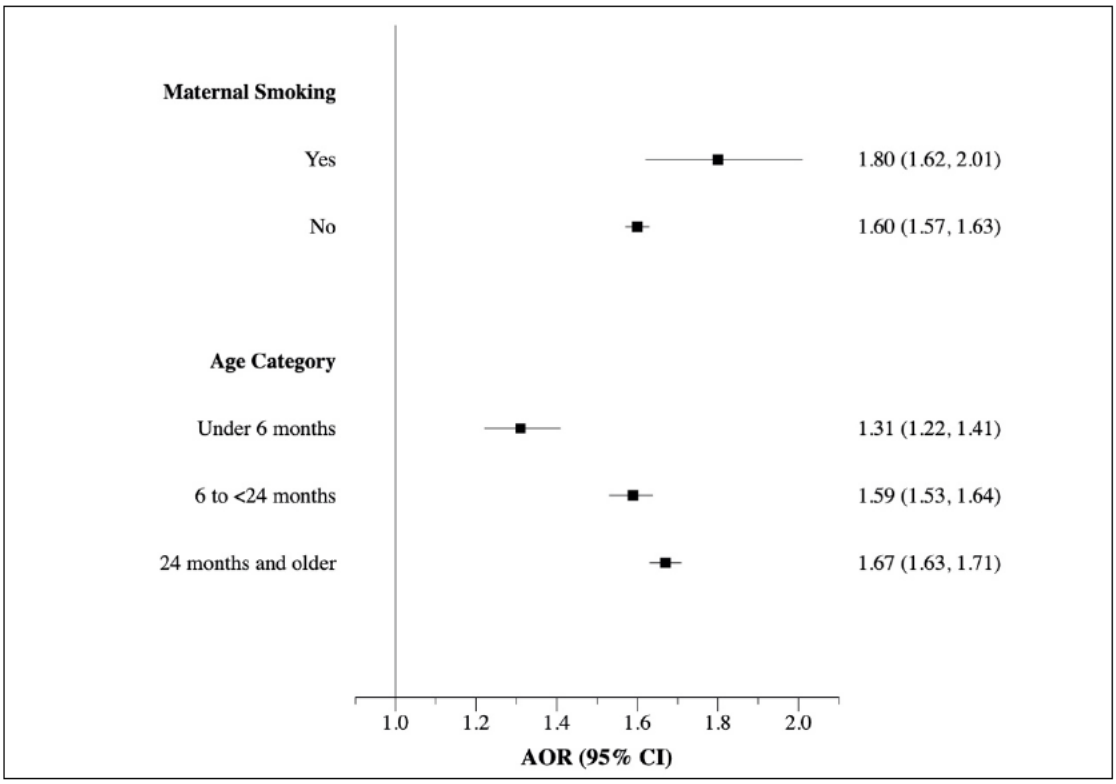

Figure 7: Association between Solid-Fuel Usage and Child Undernutrition

When exposure to HAP was separated into maternal versus child exposure, through two age categories, the association between stunting and HAP varied according to point of exposure ($p<0.001$) (Table 7). In comparison to children one month and older, children under one month (exposed to HAP through their mothers) and living in solid fuel using households were more likely to be stunted (AOR: 1.72, 95% CI: 1.04 – 2.87).

Among children under six months, the association between stunting and household solid fuel use did not vary according to whether a child was exclusively breastfeeding or not (p-value: 0.693) (Table 6).

When exposure to household air pollution was measured with a three-level categorical variable, increasing household exposure to less clean cooking fuels was associated with an increasing likelihood of stunting and wasting (Figure 8 and Table 5).

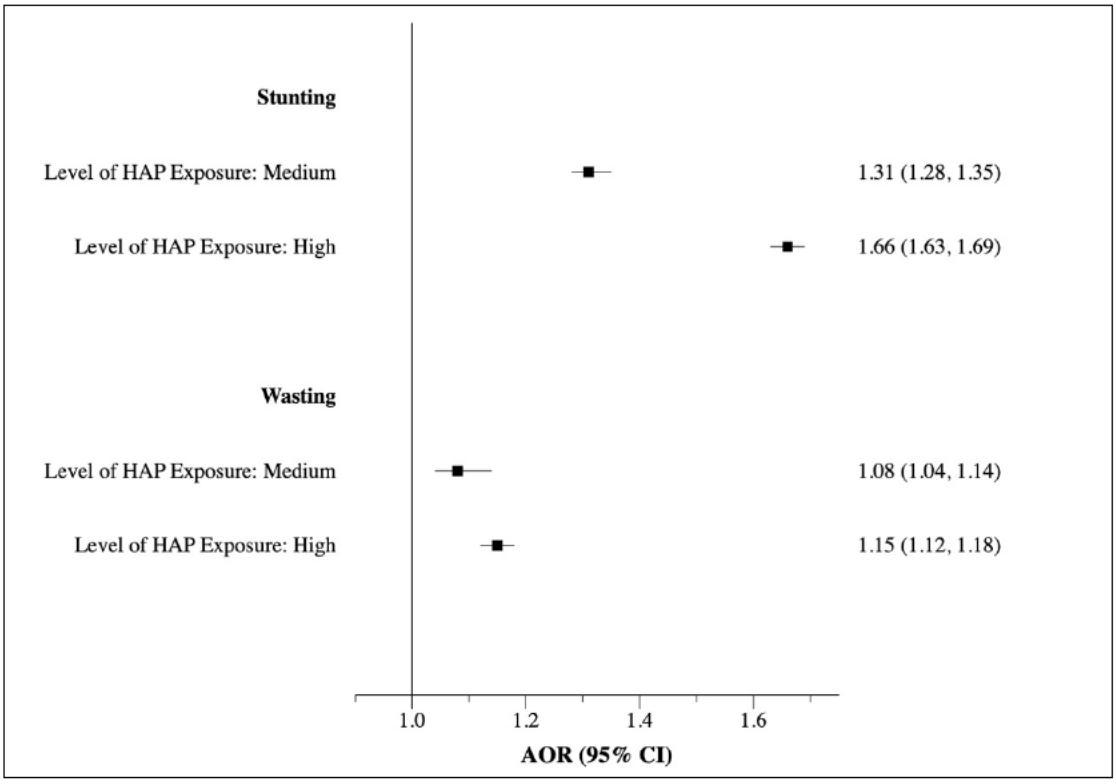

Figure 8: Association between Level of HAP Exposure and Child Undernutrition

Including a measure for low birthweight in the main model, for the purpose of mediation analysis, did not result in a significant difference in the association between exposure to HAP and childhood stunting (AOR: 1.58, 95% CI: 1.55 – 1.61) (Table 8).

3.6. DISCUSSION

This analysis of 567,907 children from the most recent DHS data from 59 LMICs, revealed that children who lived in households cooking with solid fuels were more likely to be stunted, wasted, or concurrently stunted and wasted. Additionally, exposure to HAP was associated with decreased linear and ponderal child growth. In the Americas, the risk of being stunted was more than doubled among children who lived in households cooking with solid fuels, in comparison to children who lived in households cooking with cleaner fuels. Children who lived in households cooking with solid fuels were also more likely to be stunted if they were in a rural region, the poorest households, the Americas, lived with a mother who smoked, older in age, and through maternal exposure.

A 2018 systematic review conducted by Vilcins et al (38) identified seven studies estimating the association between child undernutrition and household air pollution from solid cookfuels. The studies evaluated DHS data from seven countries (between 2005 and 2007) (32); 2005-2006 DHS data from India (36); 1998-1999 DHS data from India (25); 2006-2007 DHS data from Swaziland (24); 2010 primary case control data from Nepal (35); primary cohort data from South India (1998-2000) (27); and primary cross-sectional data from Uganda (prior to 1998) (34). Previous studies were limited by small sample sizes, varying measures of exposure to HAP, improper model adjustments for confounders, and limited subgroup analysis.

First, previous studies evaluating DHS data had small sample sizes ranging from 1,150 children between 6-36 months and 29,768 children under five years old. Previous studies evaluating primary data had samples of 261 children between 0-30 months and 11,728 children followed from birth until six months. This study estimates the association between child undernutrition and exposure to HAP, from solid cooking fuel, with the largest sample size evaluated to date. Employing data from 59 LMICs, resulted in a significantly larger sample of 567,907 children under five years old.

Second, this analysis used a standardised categorisation of the exposure variable, allowing for comparison of the association among subgroups. Only three of the studies included in Vilcin et al's systematic review categorised the exposure variable similarly, limiting comparability of results from all studies (38).

Third, although four of the studies included in Vilcin et al's systematic review calculated the AOR for childhood stunting and two studies calculated the adjusted relative risk ratio for stunting, the studies were highly susceptible to errors due to over adjustment bias. The models included in this study only controlled for confounders that were (1) associated with both the independent and dependent variable, and (2) not on the causal pathway.

Lastly, only four of the studies included in the systematic review conducted subgroup analysis to evaluate how the association of interest may be modified by region, second hand smoke, sex, and area of residence. This study examined heterogeneity in the association, through a more comprehensive subgroup analysis. The subgroup analysis was informed by existing literature regarding factors that increase the risk of childhood undernutrition and/or exposure to HAP – area of residence, household wealth, EBF, WHO regions, maternal smoking, and age groups (53, 66).

The findings of this study were consistent across all models - children living in households cooking with solid fuels were more likely to be undernourished or experience growth faltering. As households transition to cleaner household fuels, the likelihood of child undernutrition decreased. Subgroup analysis further revealed that the association between HAP and child undernutrition differs within subpopulations.

When stratified by wealth quintiles and area of residence, children living in households cooking with solid fuels in the poorest households and in rural regions were more likely to be stunted. Within these populations, the prevalence of household solid fuel use for both cooking and heating is significantly higher (67). This is due to the economic costs of cleaner fuels such as electricity, solar power, and kerosene. Solid fuels are more affordable and therefore financially accessible to households in rural regions and poorer households. Furthermore, studies suggest that the higher prevalence of solid fuel use in rural regions may also be due to reduced physical access to cleaner fuels (67).

Stratification by maternal smoking indicated that children in solid fuel using households were more likely to be stunted if their mother smoked. This suggests a compounded effect of exposure to multiple sources of air pollution and childhood stunting. Studies suggest that maternal smoking is associated with lower child height-for-age and an increased likelihood of severe stunting (32, 68).

Stratification by EBF was the only subgroup analysis that did not result in statistically significant differences in AORs within subgroups. This could be due to the confounding effect of duration of EBF, which is not measured in the DHS. EBF for the minimum six month period is particularly vital in decreasing the risk of child morbidity and mortality (56, 69). According to the most recent DHS data from LMICs, an average of 31% of children are exclusively breastfed for the recommended six month period (70).

On average, children within LMICs are only breastfed exclusively for three months (70).

Stratification by child age, suggested that the magnitude of association between exposure to HAP and childhood stunting increases with age. Studies suggest that linear growth faltering stabilises between 24-59 months of age. This has led to a large amount of global emphasis on undernutrition within the first 1,000 days of life. This finding suggests that as it relates to the association between exposure to HAP and childhood stunting, children are at an increased risk of stunting after the 1,000 day period. This may suggest a temporal association between exposure to HAP and child undernutrition. It is possible that long term exposure to HAP is associated with an increased likelihood of child undernutrition. Further studies are needed to evaluate the validity of this finding.

When stratified by child age group to separate the point of exposure between maternal and child exposure, children under one month living in households using solid fuels had an increased risk of stunting, in comparison to children one month and older living in households using solid fuels. First, it is possible that behavioural practices with children in this age group are associated with an increased level of exposure to HAP. Second, due to the fact that low birthweight was not found to be a mediator of the association between exposure to HAP and stunting, and the fact that there was no statistically significant difference in the association according EBF, it is possible that mothers are transferring pollutants to their children through breastmilk. Research has explored the presence of environmental pollutants in breastmilk and its associated impacts on child health (71-73). Children within this age group could be exposed to

pollutants through both child and maternal exposure, again indicating a compounded effect of multiple points of exposure to air pollution on child undernutrition.

When exposure to HAP was measured through a three-level variable, reflective of the energy ladder, the likelihood of child undernutrition decreased when households transitioned to cleaner fuels. This finding suggests that the magnitude of effect of HAP on child undernutrition is modified by the level of exposure. Although this finding is promising, research suggests that households in LMICs are more likely to stack fuels than they are to switch from one fuel type to another (74). Fuel stacking is defined as household use of fuels with varying levels of air pollution. Further research is needed to explore levels of exposure according to fuel stacking combinations.

Inclusion of low birthweight in the primary model, for the purposes of mediation analysis, did not affect the magnitude of the association between stunting and HAP. This suggests that the association between stunting and HAP is largely independent of the association between low birthweight and child undernutrition and low birthweight and exposure to HAP.

Biological Mechanisms

This study assumes three potential mechanisms for the association between HAP and child growth. First, exposure to HAP is associated with acute lower respiratory infections (53). Infectious diseases increase the risk of undernutrition through decreased appetite and decreased nutrient absorption by the small intestine (12, 13). Second, the inhalation of pollutants produces free radicals in the body. The immune systems of children, which are not fully developed, combined with increased inhalation of pollutants can lead to a surplus of free radicals in the body, known as oxidative stress

(14). There are two proposed mechanisms through which oxidative stress can affect child growth. First, free radicals can disrupts the endocrine systems through cell damage (14, 15). Disruption to the endocrine system affects the production and function of growth and thyroid hormones, which are critical for child growth (16). Second, oxidative stress leads to chronic inflammation, which can suppress bone growth processes and stimulate bone loss processes, resulting in disruptions to bone growth (17).

Strengths and Limitations

The findings of this study are limited by the DHS study design and data collection tools. This analysis was conducted using cross-sectional data. Firstly, this limited the ability to evaluate the temporal association between exposure to HAP and childhood undernutrition. Cross-sectional data does not include information about how long a household has been using the current cooking fuel type or a child's onset of stunting or wasting. However, DHS uses a standardised methodology to examine both exposure to HAP and childhood undernutrition across numerous LMICs, which strengthens the generalisability of the results. Future studies can address this concern with a longitudinal study design that examines the trajectory of exposure to HAP and child growth over time.

Analysis of data from an observational study, such as cross-sectional data, may also lead to residual confounding from unmeasured variables. This study adjusted for a priori confounders and stratified by a priori effect modifiers in the model specifications. However, cultural and/or behavioural factors surrounding child feeding practices and cooking practices, which are not measured in the DHS, may have biased the results. This may be the case in households where infant and young child feeding practices are

inadequate or cooking practices encourage the use solid fuels to achieve the desired meal taste.

The second limitation of the study is potential measurement error of exposure to HAP. DHS measures the primary type of cooking fuel used in a household, which was used as a proxy for exposure to HAP. The ideal measure of exposure to HAP would be an estimate of the concentration of pollutants, such as PM2.5 and CO, within households. This would require specialised measurement tools, and data collection over a sufficient period. Additionally, the DHS data included in this study do not measure variables that influence levels of exposure to HAP such as ventilation within homes and the location of children during cooking (75). Lastly, the proxy variable does not account for cross-contamination of air from nearby homes or ambient air pollution in cities. These limitations could result in a downward bias of association estimates. However, within large surveys such as the DHS, this is the most cost-effective approach for measuring HAP. More precise measurements of indoor air quality require expensive specialised tools and more time allocated for data collection and thus would not be possible within DHS in numerous countries. Furthermore, studies have shown that HAP is one of the largest sources of ambient air pollution in LMICs (7).

The third limitation of the study is potential measurement error of low birthweight. The measurement of birthweight included in the DHS is a combination of health card records and mother's recall. Due to an increased likelihood of non-facility births in LMICs, most birthweight data is from mother's recall. There is a risk of misreporting from mothers due to heaping, an inability to recall the exact birthweight, or relative estimates of what is considered a low birthweight. However, in the absence of more

complete and accurate data, the variable included in this analysis is the most appropriate measure of birthweight.

Despite these limitations, this study has several strengths. First, this study uses the most recent DHS data to study the association between exposure to HAP and child undernutrition across 59 LMICs. Additionally, the association of interest was examined with a standardised measure of HAP – household use of solid fuels for cooking. This ensures appropriate comparisons of the association across different populations. Furthermore, this study examined how the association between exposure to HAP and stunting differed according to seven a priori effect modifiers, thus identifying heterogeneity in the association within subpopulations.

Future Research

Future research should endeavour to address the above study limitations that resulted from the DHS study design. First, longitudinal studies should be used to explore the temporal association between child undernutrition and exposure to HAP. Second, future studies should examine the impact of different levels of exposure to HAP on child undernutrition. Child undernutrition outcomes should be integrated into studies examining the impact of interventions addressing high levels of HAP from solid cooking fuels and simple cookstoves.

Policy Implications

Addressing child undernutrition is a key policy agenda for many LMICs and two of the WHO's six Global Nutrition Targets for maternal and child malnutrition include reducing child undernutrition (5, 6). Stunting and wasting in childhood increase the risk of poor present and future health and economic outcomes (4). To date, WHO's

guidelines for addressing child undernutrition in LMICs primarily recommend encouraging appropriate feeding practices - exclusive breastfeeding for the first six months of life and appropriate meal diversity and frequency once complementary feeding begins (5, 6). While these interventions have resulted in a reduction in rates of childhood undernutrition, there has been an increase in the number of stunted children in Africa and the rate of decrease of both stunting and wasting is limited (76). Presently, only 31 countries are on track to meet the 2025 global stunting target and only 40 countries are on track to meet the 2025 global wasting target (76). Furthermore, while national rates of stunting are decreasing worldwide, within-country inequalities in the prevalence of stunting persist (76).

A comprehensive understanding of environmental factors associated with child undernutrition can encourage the introduction of more effective nutrition policies and programmes, and encourage an accelerated decrease of childhood undernutrition at both the national and subnational level. The prevalence of childhood undernutrition is unequally distributed between and within countries. This study indicates that children exposed to HAP are at a greater risk of being stunted, wasted, or concurrently stunted and wasted. Moreover, this association between exposure to HAP and childhood stunting is larger in rural households, poorer households, children with mothers who smoke, certain WHO regions – namely the Americas, and older children.

Although stunting was the primary outcome variable of this study, these findings should be interpreted within the context of the known association between stunting and wasting. First, wasting and stunting have common causes and risk factors (46). Second, previous episodes of wasting are a risk factor for future stunting (42). Third, wasting and stunting frequently occur concurrently. Concurrence of wasting and stunting is

associated with a significant increase in the risk of mortality (45). The prevalence of concurrence is highest in male children, and younger children – below 30 months of age (44). Given these associations, it is important to address stunting and wasting jointly.

Current policies and guidelines to reduce HAP recommend households use improved cook stoves, and transition from solid fuels to cleaner fuels for cooking, lighting, and heating (77). Inadequate national energy infrastructure, which drives suboptimal energy production and distribution, has limited household ability to implement the above recommendations. At the household level, implementation of these guidelines has been limited by factors such as socioeconomic status, cooking practices, and perceived benefits and/or harms of various fuel and stove types (78-81). Instead, sustained use of clean cooking technology has been limited and households are practicing stove/fuel stacking. As households transition to cleaner fuels and improved stoves, short-term recommendations to decrease child exposure to HAP may include improving ventilation systems within homes and altering cooking and/or child care practices to ensure that children are not in close proximity to pollutants (77).

3.7. CHAPTER SUMMARY

The findings of this chapter underscore the potential value of cooking energy infrastructure interventions in reducing childhood undernutrition in LMICs. Additional research examining the impact of cooking energy infrastructure interventions on child undernutrition is required to further strengthen the findings of this study. More broadly, the findings of this study suggest that incorporating wider risk factors into existing nutrition action could further accelerate the reduction of childhood undernutrition in Sub-Saharan Africa.

The next chapter builds on the previous findings of this thesis, and further explores opportunities to accelerate the reduction of childhood undernutrition in Zambia. In particular, the next chapter examines how primary caretakers of children under-five and healthcare providers in Lusaka district, Zambia attribute causality for childhood undernutrition, the implications of attributions for causality on practice, and recommendations to improve the effectiveness of existing nutrition policy and practice.

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3.9. APPENDIX

Table 2: Countries and Surveys Included in the Full Analytical Sample

Country	Survey year	N
Albania	2017-2018	2,478
Angola	2015-2016	6,438
Armenia	2015-2016	1,697
Azerbaijan	2006	2,028
Bangladesh	2014	6,509
Benin	2017-2018	11,525
Bolivia	2008	7,723
Burkina Faso	2010	6,600
Burundi	2016-2017	6,037
Cambodia	2014	4,404
Cameroon	2018	4,299
Chad	2014-2015	10,281
Colombia	2015	15,946
Comoros	2012	2,640
Congo	2011-2012	4,244
Congo Democratic Republic	2013-2014	8,297
Cote d'Ivoire	2011-2012	3,345
Dominican Republic	2013	3,258
Eswatini	2006-2007	2,041
Ethiopia	2016	9,502
Gabon	2012	3,250
Gambia	2013	3,191
Ghana	2014	2,680
Guatemala	2014-2015	11,640
Guinea	2018	3,466
Guyana	2009	1,598
Haiti	2016-2017	5,562
Honduras	2011-2012	9,665
India	2015-2016	224,987
Jordan	2017-18	6,123
Kenya	2014	18,623
Kyrgyz Republic	2012	3,944
Lesotho	2014	1,276
Liberia	2013	3,132
Madagascar	2008-2009	5,492
Malawi	2015-2016	5,200
Maldives	2016-2017	2,403
Mali	2018	8,348
Moldova	2005	1,310
Morocco	2003-2004	5,547
Mozambique	2011	9,547
Namibia	2013	1,858
Nepal	2016	2,215
Nicaragua	2001	6,043
Niger	2012	5,011

Nigeria	2018	11,271
Pakistan	2017-2018	4,080
Peru	2012	8,953
Rwanda	2014-2015	3,572
Sao Tome and Principe	2008-2009	1,690
Senegal	2018	5,898
Sierra Leone	2013	4,677
South Africa	2016	1,094
Tajikistan	2017	5,740
Tanzania	2015-2016	8,669
Timor-Leste	2016	6,144
Togo	2013-2014	3,171
Uganda	2016	4,337
Yemen	2013	14,030
Zambia	2018	8,633
Zimbabwe	2015	5,016

Table 3. Association between Solid Cooking Fuel Usage and Child Undernutrition

	Stunting	
	AOR (95% CI)	**p-value**
Full Analytical Sample	1.58 (1.55 – 1.61)	<0.001
	Wasting	
	AOR (95% CI)	**p-value**
Full Analytical Sample	1.14 (1.11 – 1.16)	<0.001
	Concurrent Stunting and Wasting	
	AOR (95% CI)	**p-value**
Full Analytical Sample	1.51 (1.44 – 1.59)	<0.001

* AOR: Adjusted Odds Ratio; 95% CI: 95% Confidence Interval

** All models control for child age, sex, mother's education, number of children, and random effects at the community and country level.

Table 4: Association between Solid Cooking Fuel Usage and Child Growth

	Height-for-Age Z-Score	
	Beta Coefficient (95% CI)	**p-value**
Full Analytical Sample	-0.37 (-0.40 – -0.34)	<0.001
	Weight-for-Height Z-Score	
	Beta Coefficient (95% CI)	**p-value**
Full Analytical Sample	-0.12 (-0.14 – -0.09)	<0.001

* 95% CI: 95% Confidence Interval

** All models control for child age, sex, mother's education, number of children, and random effects at the community and country level.

Table 5: Association between Level of Exposure to HAP and Child Undernutrition

	Stunting	
Household Air Pollution Exposure	**AOR (95% CI)**	**p-value**
Medium	1.31 (1.28 – 1.35)	<0.001
High	1.66 (1.63 – 1.69)	<0.001
	Wasting	
Household Air Pollution Exposure	**AOR (95% CI)**	**p-value**
Medium	1.08 (1.04 – 1.14)	0.001
High	1.15 (1.12 – 1.18)	<0.001

* AOR: Adjusted Odds Ratio; 95% CI: 95% Confidence Interval

** All models control for child age, sex, mother's education, number of children, and random effects at the community and country level.

Table 6: Association between Solid fuel Usage and Child Stunting, by Subgroup

	Stunting	
Area of Residence	**AOR (95% CI)**	**p-value**
Urban	1.50 (1.45 – 1.56)	<0.001
Rural	1.52 (1.48 – 1.56)	<0.001
p-value for interaction	<0.001	
Household Wealth Quintiles	**AOR (95% CI)**	**p-value**
Poorest	1.23 (1.13 – 1.35)	<0.001
Poorer	1.07 (1.01 – 1.13)	0.018
Middle	1.07 (1.03 – 1.12)	0.001
Richer	1.06 (1.01 – 1.11)	0.009
Richest	1.15 (1.09 – 1.23)	<0.001
p-value for interaction	<0.001	
WHO Regions	**AOR (95% CI)**	**p-value**
African	1.72 (1.65 – 1.80)	<0.001
Eastern Mediterranean	1.24 (1.16 – 1.34)	<0.001
European	1.51 (1.22 – 1.85)	<0.001
Americas	2.17 (2.02 - 2.34)	<0.001
South-East Asia	1.45 (1.42 – 1.49)	<0.001
Western Pacific	2.00 (1.63 - 2.44)	<0.001
p-value for interaction	<0.001	
Maternal Smoking	**AOR (95% CI)**	**p-value**
Yes	1.80 (1.62 – 2.01)	<0.001
No	1.60 (1.57 – 1.63)	<0.001
p-value for interaction	<0.001	
Exclusive Breastfeeding	**AOR (95% CI)**	**p-value**
Yes	1.36 (1.21 – 1.52)	<0.001
No	1.28 (1.15 – 1.41)	<0.001
p-value for interaction	0.693	

* AOR: Adjusted Odds Ratio; 95% CI: 95% Confidence Interval

** All models control for child age, sex, mother's education, number of children, and random effects at the community and country level.

Table 7: Association between Solid fuel Usage and Child Stunting, by Subgroup

	Stunting	
Age Category (1)	**AOR (95% CI)**	**p-value**
Under 6 months	1.31 (1.22 – 1.41)	<0.001
6 - <24 months	1.59 (1.53 – 1.64)	<0.001
24 months and older	1.67 (1.63 – 1.71)	<0.001
p-value for interaction	<0.001	
Age Category (2)	**AOR (95% CI)**	**p-value**
Under 1 month	1.72 (1.04 – 2.87)	0.036
1 months and older	1.58 (1.55 – 1.61)	<0.001
p-value for interaction	<0.001	

* AOR: Adjusted Odds Ratio; 95% CI: 95% Confidence Interval

** All models control for child age, sex, mother's education, number of children, and random effects at the community and country level.

Table 8: Association between Solid fuel Usage and Child Stunting, Mediation Analysis

	Stunting	
	AOR (95% CI)	**p-value**
Mediation Analysis: LBW	1.58 (1.55 - 1.61)	<0.001

* AOR: Adjusted Odds Ratio; 95% CI: 95% Confidence Interval; LBW: Low Birthweight

** All models control for child age, sex, mother's education, number of children, and random effects at the community and country level

CHAPTER FOUR: EXPLORING ATTRIBUTIONS OF CAUSALITY FOR CHILD UNDERNUTRITION AMONG PRIMARY CARETAKERS AND HEALTHCARE PROVIDERS: A QUALITATIVE ANALYSIS IN LUSAKA DISTRICT, ZAMBIA

4.1. CHAPTER PREFACE

This is the third analytical chapter and the first of two presenting the findings of a qualitative study conducted in Lusaka district, Zambia. This chapter examines conceptualisations of childhood undernutrition among primary caretakers of children under five years old and healthcare providers. Building on the preceding analytical chapters, this qualitative study also examined whether primary caretakers and healthcare providers attributed causality for childhood undernutrition to household air pollution from solid cooking fuels. Prior to presenting the third analytical chapter of this thesis, detailed below is some additional commentary about household air pollution within the context of the findings of the qualitative study.

Although the preceding analytical chapters suggest an association between household air pollution from solid cooking fuels and childhood undernutrition in LMICs, participants in the qualitative study did not conceptualise cooking energy infrastructure as a causal factor in childhood undernutrition.

Within the dataset, the primary cooking fuels used in households were charcoal, firewood, gas, and electricity. Most households with electric or gas stoves also owned stoves which used charcoal or firewood fuel, suggesting a high prevalence of fuel stacking. Primary caretakers in this dataset largely perceived charcoal and firewood stoves as harmful due to the potential of burns, and a few primary caretakers detailed the potential harm of smoke emitted while cooking. Due to these perceived dangers of solid cooking fuels, mothers described how they limited child exposure to cookstoves. Primary caretakers described carrying young babies on their backs, however, once the babies started walking and refused to be carried on their mother's back, they were left to play or watch TV while the mothers cooked. However, none

of the primary caretakers or healthcare providers perceived an association between cooking fuel type and childhood undernutrition.

Instead, their narratives clearly attributed causality for undernutrition in different ways that reflected the complexities of their day-to-day lives. Therefore, this chapter details how primary caretakers and healthcare providers attributed causality for child undernutrition. In so doing, it also further explores the aims of this thesis by examining the implications of conceptualisations of childhood undernutrition, proposing recommendations to address harmful implications, and underscores opportunities to accelerate the reduction of childhood undernutrition in Zambia and similar settings.

Title:

Exploring Attributions of Causality for Child Undernutrition Among Primary Caretakers and Healthcare Providers: A Qualitative Analysis in Lusaka District, Zambia

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Contributor Statement:

NL and AL designed the study. NL, with the assistance of SK, conducted the interviews. NL analysed the data and drafted the manuscript, with input from AL. All authors critically reviewed the manuscript.

4.2. ABSTRACT

Child undernutrition is responsible for 45% of all under-five deaths in LMICs, and numerous morbidities. While progress has been made, high levels of child undernutrition persist in Zambia. Existing studies have explored primary caretakers' (PCs) explanatory models of child undernutrition in LMICs, without comparison to those of healthcare providers (HCPs). This paper examines and compares the perceived causes of child undernutrition amongst PCs and HCPs in Zambia.

We conducted a qualitative study, using semi-structured one-to-one and group interviews, with 38 PCs and 10 HCPs to explore their perceptions of child undernutrition and its perceived causes in Lusaka district, Zambia. Interview data were analysed with thematic analysis.

Our findings indicate that PCs and HCPs in Lusaka district have divergent explanatory models of child undernutrition, and perceive parental agency differently. In divergently framing how they conceptualise undernutrition and who is able to prevent it, these models underpin different attributions of causality, and different opportunities for intervention. PCs highlighted factors such as child food preferences, child health, and household finances. Contrarily, HCPs stressed factors such as 'improper feeding', only highlighting factors such as wider economic conditions when these specifically impacted healthcare services. One factor, identified by both groups, was 'inadequate mothering'.

To accelerate the reduction of child undernutrition, interventions must address divergences between PCs' and HCPs' explanatory models. Additionally, attention needs to be paid to how wider socioeconomic and cultural contexts not only impact childhood undernutrition but shape attributions of causality.

4.3. INTRODUCTION

Childhood undernutrition is a complex problem that challenges low- and middle-income countries (LMICs). In Zambia, while the government has increased annual nutrition expenditure on children under five years old, the burden of childhood undernutrition persists (1). The current average annual rate of reduction of childhood stunting in Zambia is lower than World Health Assembly recommendation and rates of childhood wasting continue to fluctuate (2). Presently, one in three Zambian children under five years old is affected by one or more forms of undernutrition - stunting, wasting and micronutrient deficiencies (3).

Policy makers and professionals have promoted the UNICEF conceptual framework of malnutrition to advance nutrition policies and programmes for children globally (4). In contrast to earlier biomedical models of health, this framework valuably employs a biosocial approach which accounts for social, cultural, and environmental factors which impact the onset and course of disease (5-8). As it pertains to clinical practice, this framework, alongside existing literature, is intended to inform an improved understanding among healthcare providers (HCPs) of the wider structural and sociocultural determinants of childhood undernutrition, and a contextualised understanding of the varying impact of these determinants in their communities.

Previous studies have explored primary caretakers' (PCs') perceptions of the determinants of childhood undernutrition in varying contexts (9) and the wider 'explanatory models' in which these attributions of causality are embedded (10). However, existing literature has largely centred around PCs' perceived determinants of infant and young child feeding (IYCF), highlighting the impact of finances, cultural beliefs, social-cultural feeding norms, and gender on IYCF (11, 12). To date, no studies have compared how PCs and HCPs attribute causality for undernutrition differently, or the implications of these differences; this is the first study to do so.

An explanatory model (13) encompasses how a disease presents itself, what causes it, and how it can be treated; this is always shaped by wider cultural and social structures (14). Disconnects between PCs' and HCPs' explanatory models of disease have implications for prevention, treatment, and quality of care (15). In relation to childhood undernutrition, divergences in explanatory models, and specifically, attributions of causality that are a part of such a model, could affect health-seeking behaviours, the quality of nutrition services provided, and ultimately, childcare practices. Neglecting to discuss and compare the perspectives of HCPs and PCs may therefore undermine efforts to prevent and control childhood undernutrition.

This study explores and compares the perceived causes of child undernutrition among PCs of children under five years old and HCPs in Lusaka district, Zambia to inform the design of future nutrition interventions, the implementation of existing programmes, and broadly improve the impact of these interventions on child nutritional outcomes.

4.4. METHODS

We conducted a qualitative study of experiences of childhood undernutrition, grounded in the theoretical frameworks of medical anthropology (16), in Lusaka district, Zambia between May and August 2019. Ethical approval was obtained from the institution at which Author One was enrolled at the time of data collection and ERES Converge IRB (Zambia). Further approvals were obtained from the National Health and Research Authority, Lusaka Province Medical Office, and Lusaka District Health Office.

Setting

Lusaka district is an urban region with an estimated population of 2.6 million people (17). Study participants were identified from government healthcare facilities during under-five clinics. Within this region, healthcare facilities are largely accessible (3). Accordingly, growth

monitoring and promotion clinics, referred to within this paper as under-five clinics, are well attended. Under-five clinics are offered at all healthcare facilities and caretakers of children under five years old are encouraged to attend monthly.

Sampling Strategy

Three government healthcare facilities with higher rates of stunting, in the most recent quarter, were purposively selected. Facilities were identified according to rates of stunting, as opposed to other forms of undernutrition, since the prevalence of other forms of child undernutrition fluctuate easily as a result of short term events (18). One facility was identified from each of the three lowest levels of care to ensure larger catchment areas, capture a broad range of perspectives, and increase the representative nature of the data.

Within each healthcare facility, we identified HCPs involved in monitoring child growth at the under-five clinic. In turn, HCPs identified PCs with at least one child under five years old whose weight was decreasing or who was considered underweight, and who had engaged with the clinic for growth monitoring. Child weight was used to identify PC participants because it was measured monthly during growth monitoring, while height was measured less frequently. Furthermore, the under-five cards with records of child growth only detailed child weight. Within this sample, we excluded PCs whose child was under six months. The six month criterion is in accordance with WHO IYCF guidelines, adopted by the Zambian government in 1992, which recommend that complementary feeding begin at six months (19). At this point, children are at a higher risk of becoming undernourished. Before conducting any interviews, we obtained written consent from all participants.

Data Collection

Interviews with HCPs and PCs were conducted separately, at healthcare facilities. Where feasible, one-to-one interviews (n=31) were conducted. Group interviews (n=six) were only conducted due to time constraints such as participants' schedules. Group interviews with PCs included two to three participants, and the sole group interview with HCPs included five participants.

All interviews were guided by a semi-structured topic guide developed by Authors One and Two. This included questions and prompts about household food security, IYCF practices, childcare practices, cooking practices, and lived experiences related to child undernutrition. The topic guide was designed to be open and give participants room to discuss related topics that were of importance to them. The questions were also designed to elicit as much detail as the participant desired to give. Interviews were designed to last between 45 minutes and one hour. Participants were provided with refreshments during the duration of the interviews. Additionally, PC participants were provided with an additional food item and a packet of multi-purpose detergent as a token of appreciation. This was decided in collaboration with local stakeholders.

The first author, with the support of Author Four, conducted all interviews. Interviews were in English unless participants were more comfortable speaking in Nyanja or Bemba. Where this was the case, Author Four translated the questions and responses. With the consent of participants, we recorded all interviews with a voice recording device. These were transcribed verbatim in English and anonymised.

We determined data saturation was reached once we began identifying significant patterns in the responses of each group. However, we continued to conduct interviews past the point at

which we believed we had reached data saturation and confirmed data saturation during data analysis.

Analysis

Interview transcripts were analysed separately for each participant group using inductive thematic analysis (20, 21). Author One conducted initial coding on five interviews from each participant group and reviewed coded transcripts with Author Two. Once Authors One and Two were in agreement about the coded transcripts, Author One coded all transcripts line by line. Codes were grouped and themes developed. Themes were discussed, refined and agreed by Authors One and Two. Themes from PC and HCP data were then compared and contrasted. Interview data were managed using Version 12 of NVivo, QSR International's qualitative data analysis software. This paper was drafted by Author One with input from Author Two, and reviewed by all co-authors.

Reflexivity

Author One, a public health doctoral researcher, is a Zambian woman who spent her formative years in African countries, with periodic travel to Zambia. While Author One did not grow up in Zambia, she grew up in a Zambian household and is familiar with common Zambian cuisine, feeding practices, and childcare practices. Considering insider/outside literature, which defines the positioning of researchers as a continuum as opposed to a dichotomy; in some respects, Author One was viewed as an insider and in others, she was viewed as an outsider (22, 23). While Author One's background brought a deeper cultural understanding to the data collection process, she gave participants room to explore child undernutrition and limited the projection of her experiences and assumptions. Furthermore, interviews were conducted with Author

Four, who in many respects was considered more of an insider than Author One, to provide participants with a greater level of comfort.

No prior relationship existed between Author One, Author Four, and the study participants. Upon arrival at healthcare facilities, both were introduced to hospital staff by the medical superintendent. HCPs then explained to groups of PCs that Authors One and Four were researchers conducting research on child undernutrition.

4.5. FINDINGS

Forty-eight participants took part in this study – 38 PCs and ten HCPs. Participant characteristics are detailed below (Table 1 and Table 2).

Table 1: Healthcare Provider Participant Characteristics (N = 10)

	Healthcare Providers (N = 10)
Healthcare Facility	
Facility One	50%
Facility Two	N/A*
Facility Three	50%
Sex	
Female	100%
Job Title	
Nutritionist	20%
Nurse	20%
Psychosocial Counsellor	20%
Midwife	20%
Public Health Technologist	10%
Undisclosed	10%
Years of Experience	
1- 4	20%
5-9	20%
10+	30%
Undisclosed	30%

*Note: HCPs jointly served facilities two and three

Table 2: Primary Caretaker Participant Characteristics (N = 38)

	Primary Caretakers (N = 38)
Healthcare Facility	
Facility One	47%
Facility Two	16%
Facility Three	37%
Sex	
Female	95%
Male	5%
Relation to Child	
Mother	92%
Father	5%
Non-familial caretaker	3%
Age	
17-19	11%
20-24	26%
25-29	29%
30-34	18%
35+	13%
Undisclosed	3%
Number of Living Children	
1	42%
2	21%
3	13%
4	16%
5+	8%

Themes

Six perceived causes of childhood undernutrition emerged from participants' narratives. PCs highlighted children's food preferences, general child health, and household finances. Differently, HCPs emphasised 'improper feeding' and wider economic conditions. Both PCs and HCPs also stressed 'inadequate mothering' (Figure 1: Attributions of Causality for Child Undernutrition, by Participant Group

).

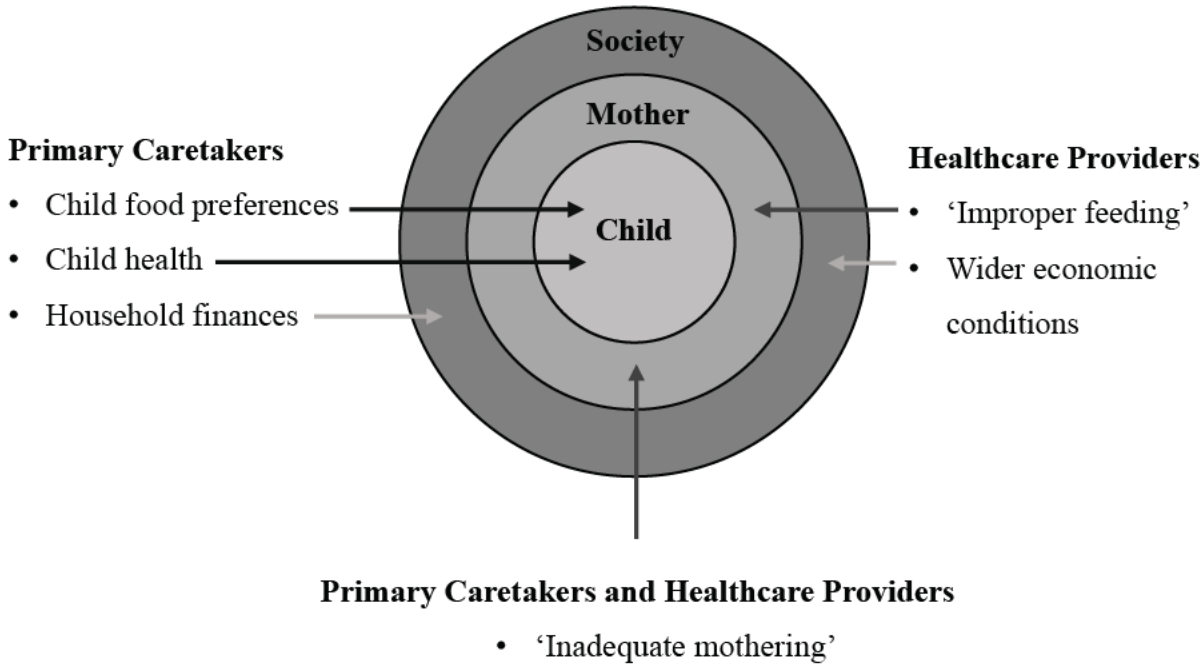

Figure 1: Attributions of Causality for Child Undernutrition, by Participant Group

Conceptualisations of Child Undernutrition

PCs' and HCPs' perceived causes of child undernutrition revealed different conceptualisations of what child undernutrition was between the two groups. When asked what they understood by the term undernutrition, PCs all focused on the *quantity* of food a child was eating, describing undernutrition as *"a disease whereby a child lacks food"* (Participant 42). PCs'

conceptualisations of undernutrition centred on severe acute malnutrition. In contrast, HCPs conceptualised what child undernutrition *is* differently, focusing on the *quality* of food instead of *quantity.* HCPs stressed the importance of a *"balanced diet"* and *"proper meals"* to prevent the development of undernutrition.

Food, Bodies, and Individual Agency

Children's Food Preferences

Primary Caretakers

Due to PCs' conceptualisation of child undernutrition as an illness that occurs when children are not fed an adequate amount of food, they emphasised causal factors as those which they perceived to impact food quantity. The first of these was highlighted by PCs' descriptions of children who: *"[refused] to eat"* (Participant 7). Parents' framing of children's food preferences as a perceived cause of undernutrition was confirmed by HCPs. One HCP described PCs who made statements such as *"this child likes maybe porridge [maize meal porridge]. If I give the child nshima [a staple food made of maize flour], she'll refuse"* (Participant 44).

PCs' perceptions of children's food preferences impacted both the amount and type of food they felt able to feed their children.

"*Sometimes, when his appetite comes, he will eat. When you try to feed in the afternoon, he refuses. You try to cook at another time, he may refuse."* (Participant 42)

"Because this one refuses porridge. Yes. . . So I only cook for him rice." (Participant 38)

To address these concerns, some PCs focused on encouraging children to eat the meals prepared for them regardless of whether they had a preference for the meal or not. Other PCs

resorted to only feeding children the food that they enjoyed. This sometimes meant that children were not eating meals of high nutritional value, but instead meals such as plain white rice or maize meal porridge.

Healthcare Providers

Because HCPs believed that child undernutrition occurred largely due to the inadequate *quality* of food, they did not conceptualise children's food preferences as a significant driver of child undernutrition, minimising the sense of 'struggle' that arose in PCs' interviews.

One HCP detailed that some PCs *"[have] just got this belief that. . . breakfast is just groundnuts – [maize meal] porridge with groundnuts"* (Participant 45). As such, *"if the child refuses to eat porridge with groundnuts, that child will be starving"* (Participant 45). Yet, this HCP stressed the wide array of *"different cereals"* which are available, such as *"soya [based breakfast cereal]"* (Participant 45). While HCPs were understanding of the fact that children can be fussy eaters, they stressed a wide variety of locally available and affordable food items which met the food preferences of children. Consequently, HCPs attributed causality differently, emphasising moral judgments which are discussed in later sections.

Child Health

Primary Caretakers

PCs also identified two embodied factors - body type and illness - which they perceived as influencing child feeding and, thus, causing undernutrition. A few PCs believed child undernutrition to be the result of a particular body type. This is a belief that HCPs described also having heard PCs express. One mother stated, *"Us parents, most of the time we say when the child is too thin, as tradition, we used to say it's how [the child] is"* (Participant 26). This belief was shared by mothers of children suffering from undernutrition who had tried many

sources of treatment, to no avail. One mother of a child suffering from chronic undernutrition mentioned that she had tried many remedies to treat and prevent this:

"He was – just had diarrhoea. That's how we went to the clinic. . . We would cook for him [maize meal] porridge with oranges. Just trying out, we would cook [maize meal] porridge with [dried fish] and at last, when things became difficult, we went to the village."

(Participant 5)

This mother had tried changing the child's diet, visiting healthcare facilities, and eventually consulted a traditional healer. She now believed that her child's poor growth was simply *"how the child is"* (Participant 5). Another mother mentioned that she believed that her undernourished child's body was akin to his father's thin body type: *"I think he took it from his father"* (Participant 9). In circumstances where PCs felt they had exhausted their options, they perceived themselves as no longer having agency.

Views of child undernutrition as a body type were embedded within the wider structural context of poor child health in Zambia and an associated sense of a lack of agency among PCs. One mother who regularly attended under-five clinics detailed the following: *"Sometimes, if [my child] is sick, he loses appetite. So if he is sick I will easily know that things will not be okay because he hasn't been eating"* (Participant 7). In addition to decreased appetite, PCs noticed that *"when the child is sick [the weight] goes down because the baby refuses to eat"* (Participant 22). Illnesses or conditions perceived as causing child undernutrition ranged from fevers, malaria, teething, diarrhoea, flu-like symptoms, and stomach pains.

However, despite the fact that most PCs took their children to healthcare facilities when they were ill, there was a widespread sense of hopelessness arising from the sense of a lack of agency over both the child's eating and health, across the data set.

Healthcare Providers

Although child health emerged as an important determinant of child undernutrition according to PCs, we noted a difference in HCPs' perceptions. They did not mention child health as a significant driver of child undernutrition. Instead, they described child health in their communities as *"fair"* (Participant 48) and *"not that bad"* (Participant 30). Furthermore, when asked about the state of child health in Zambia more widely, one HCP praised government initiatives.

"The ministry has really worked hard to draw up programmes which also include the outreach programme." (Participant 48)

As such, while PCs primarily identified drivers of child undernutrition in which they viewed themselves as having little or no agency, HCPs perceived PCs as having more agency, and thus responsibility, than they acknowledged. In so doing, HCPs negated the wider structural context in which PCs operate, which led to moral judgements.

Moral Discourses: Perceived Responsibilities

'Improper Feeding'

Healthcare Providers

While PCs detailed how child food preferences, and individual and structurally-framed embodied factors impacted feeding practices by exerting influence on what their child ate, HCPs strongly attributed causality for undernutrition to parents' actions. HCPs highlighted 'improper feeding practices', by parents, as an important driver of child undernutrition.

"Most of the mothers that we interview, we find that the children are not fed the right food." (Participant 29).

HCPs defined *"proper"* (Participant 44) feeding according to a meal's nutritional value, and stressed the importance of a *"balanced diet"* (Participant 48). These differences in perceived parental agency can be linked to fundamental divergences, noted above, between how each group conceptualised child undernutrition, as related to the *quality* or *quantity* of food.

In line with the fraught realities of caretaking more broadly, child feeding was viewed by HCPs as the responsibility of mothers. As such, when they deemed child feeding inadequate, blame was placed on mothers. 'Improper feeding' by mothers, was ascribed to low social status, generational and community-wide feeding practices, and a lack of knowledge about what HCPs deemed to be appropriate feeding practices.

Firstly, HCPs stated that lower income mothers wanted to feed their children what they believed children in higher income homes were eating – junk foods of low nutritional value. This paradigm of desired feeding practices and social status is explored in the *Household Finances* section below. Secondly, HCPs discussed what they framed as 'harmful' feeding practices which are *"[passed] on to the next generation"* (Participant 30).

For example, many mothers avoided feeding young children certain proteins such as poultry and red meat, in accordance with feeding practices encouraged by elders and community members. There was a shared belief that foods of such texture could not be prepared in an age-appropriate manner. Common and accepted methods of preparing poultry and red meat, ascribed to by mothers and challenged by HCPs, did not allow for a texture that was easy for young children to eat. While HCPs were understanding of mothers' reservations, they disagreed with this practice and encouraged mothers to embrace alternative methods of food preparation.

"[PCs] should just learn babies eat everything. It's just a matter of making it in a form that a child can eat." (Participant 45)

HCPs were aware of the wider cultural systems from which mothers' cooking and feeding practices emerged, however, they believed that mothers within these systems had more agency than they acknowledged.

Lastly, HCPs believed that among some mothers, there was a *"lack of knowledge"* (Participant 48) about how to best feed children. This was the case even though HCPs were committed to educating PCs during under-five clinics and outreach in communities. While many PCs agreed that they received health information from HCPs, they believed that the information was not personalised and could not easily be implemented in their households – *"some things, you can't manage"* (Participant 33).

'Inadequate Mothering'

Primary Caretakers and Healthcare Providers

As discussions about 'improper feeding' focused on women, they brought to light a wider conversation about parenting and what it means to mother a child within the Zambian context. Despite differences in the attribution of causality between both groups, PCs and HCPs both identified what they described as 'inadequate mothering' as a perceived cause of child undernutrition. When asked about drivers of child undernutrition within their communities, both PCs and HCPs made value judgements about mothers' child-rearing.

In a home, child wellbeing was viewed as a mother's duty by both groups. This gendered nature of child-rearing practices has been observed across various cultures. As it relates to child undernutrition, mothers in Zambia were in charge of cooking and feeding their children, and ensuring that they were in good health. One mother plainly stated, *"It's my responsibility to take care of my child"* (Participant 10). PCs and HCPs judged and blamed mothers who did not adequately carry out the above tasks. PCs and HCPs ultimately believed that 'inadequate

mothering' could cause child undernutrition as mothers would disregard their children's meal frequency and meal content.

"What I've seen in most mothers is that they don't really pay attention. . . You'll find a child, maybe a child hasn't eaten from morning. They're just giving her maybe lunch at 12:00. Or, they won't give her proper food." (Participant 23)

PCs and HCPs both attributed this trope of 'inadequate mothering' to laziness, preoccupation with professional work, and substance abuse. While some mothers were termed *"[lazy]"* (Participant 23), others were believed to have misdirected priorities. Both PCs and HCPs believed that working mothers did not feed their children or pay attention to what the children were being fed.

"Sometimes mothers are too busy. Like you're working. . . You just leave a child with a maid or the young sister. 'No, you give her whatever you give her'. Then the same child at home doesn't know what to give the baby. She'll just be giving her you know, [yoghurt drink], tea, biscuits the whole day until the mother comes back." (Participant 23)

Thus, PCs and HCPs judged working mothers' ability to ensure adequate child nutrition, believing that working mothers blindly trusted non-familial caretakers or older siblings to look after younger children. Siblings would end up giving babies food with low nutritional value. Non-familial caretakers were also frequently described as having no vested interest in the health of the children they care for: *"Some maids will say 'The baby is refusing to eat, so it's not my fault. After all, it's not my baby'"* (Participant 46).

While PCs and HCPs expressed the above judgements about working mothers, participants who were working mothers described how involved they were in child feeding. When asked how frequently in a day their children ate, and about the content of their meals, most working

mothers were able to provide detailed answers. One mother detailed a chart system she used to meal plan. As such, she stated that *"Even if I'm out, today they'll know that we're eating this"* (Participant 26). Similarly, other working mothers left their children's caretaker with detailed instructions about when and what to feed their child while they are at work. However, these same working mothers viewed themselves as exceptions.

HCPs occasionally attributed 'inadequate mothering' to substance abuse. This was largely the case for stay at home mothers. These mothers were described as women who felt *"they've got nothing to do"* (Participant 44). Mothers would resort to drinking alcohol and disregard childcare. While a few HCPs mentioned substance abuse among mothers, only one PC mentioned substance abuse among mothers as a perceived cause of 'inadequate mothering', and subsequently child undernutrition. This suggests that in this instance, HCPs may be further displacing responsibility for child undernutrition onto PCs while negating the role of structural factors.

Socioeconomic Factors: From the Household to the State

Household Finances

Primary Caretakers

In contrast to moral judgements which implied parental agency in 'improperly' feeding children, PCs identified household finances as a structural driver of child undernutrition. PCs recounted how household finances impacted food purchases, meal diversity and meal frequency. When PCs were asked how they decide what food to buy, PCs simply stated *"money"* (Participant 13).

"If there's enough money, we buy maybe chicken and then we add vegetables sometimes. If we don't have money for chicken, we buy [dried fish] and [veggies]. We cook and eat." (Participant 11)

With a higher budget, PCs bought more expensive protein such as meat. With a lower budget, PCs would purchase more affordable protein such as dried fish or soya pieces. While some mentioned how finances affected the food items they purchased, others expressed that finances decreased the amount of food they bought: *"If I have enough money, I still buy the [food] in bulk"* (Participant 26). When money was low, this same PC only *"selected those [foods] which [were] important"* (Participant 26).

The implications of finances on food purchases altered child feeding practices. Limited finances led to a decrease in both meal diversity and meal frequency among children.

"We feed the baby twice in a day. There is no money." (Participant 15)

"When they reach the age as this one, the baby needs to be fed three times a day. . . I give the baby the same [kind of] food throughout." (Participant 1)

In spite of financial difficulties, PCs continued to prioritise their children's nutrition. PCs frequently mentioned the importance of feeding their children first and making sure that their nutritional needs were met.

"When there is not enough money, I have little, I look at the family and then I say 'how do I use this money for the children to have enough'. . . Because I need to buy enough for the children to have enough to eat." (Participant 16)

Healthcare Providers

While HCPs sympathised with PCs, they did not consider household financial difficulties a significant driver of child undernutrition in their communities. HCPs placed judgment on stay at home mothers for limited household finances, stressed their efforts to minimise the impact of low finances on child nutrition, and sometimes blamed mothers for limited implementation of recommendations on how to mitigate the impact of low finances.

Within family structures where mothers were viewed as making a choice to not work, mothers were judged as *"being dependent on the men"* (Participant 45). Providing more context, one HCP explained that *"most mothers don't want to be independent and work"* but instead complain that *"the father is not bringing food"* (Participant 45). HCPs placed blame and judgment on stay at home mothers who they believed had the ability to *"sustain [themselves] and [their] family"* (Participant 48) but were choosing not to.

HCPs also emphasised that they educated mothers about how to feed their children with limited finances. HCPs highlighted interactive cooking demonstrations as an important way to educate PCs about how to best feed their children, especially when finances were low. HCPs stressed the importance of *"proper diets"* (Participant 48) and *"simple recipes"* (Participant 48) which are *"locally available"* (Participant 44) and *"cheap"* (Participant 27). Linking back to the paradigm of 'proper' and 'improper' feeding discussed above, one HCP detailed standard communications with PCs with low budgets saying, *"We always encourage [PCs] – give the child what you can afford. As long as you prepare it in a right way. It should be a proper meal"* (Participant 44).

HCPs were intentional about being inclusive in their distribution of knowledge about how to feed children with a low budget. As such, they believed that low budgets caused child undernutrition if one or more of the following occurred: (1) PCs did not apply the knowledge

that they received from HCPs or (2) when PCs wanted to feed their children foods of low nutritional value which are common in communities of higher socioeconomic status. In both scenarios, HCP perceived PCs as having more agency than they acknowledged and again placed moral judgements on PCs.

"We educate them. In fact, we encourage them to use local products. But because, you know, a community is a difficult place. Because you find different people with different status and different levels of education. So, for this reason, you find that mothers, they'll hear from the neighbour saying 'Ah, me, I want custard. Me, I want cerelac. Me, I can't manage. What should I do?'. So if they see that the other one is cooking something different, they start gossiping about it. So to avoid all those, they try to find [food] to suit the neighbours' status." (Participant 44)

Wider Economic Conditions

Healthcare Providers

Although HCPs and PCs disagreed about the significance of household finances in causing child undernutrition in their specific communities, HCPs did conceptualise economic precarity as a significant driver of child undernutrition, both locally and nationally. However, this was framed as impacting healthcare rather than at the family level on feeding practices. They stated that national poverty impacted HCPs' ability to access hard to reach populations and deliver health education services. Due to limited hospital funds, HCPs were unable to conduct regular growth monitoring and promotion in hard-to-reach communities.

"You want to go to some places, very far, like rural areas where you can go and do an outreach. But when you don't have transport, you normally have a challenge. So it's like those children are cut off." (Participant 47)

Furthermore, HCPs frequently mentioned that they *"have not done cookery demonstrations for a few months due to finances"* (Participant 48). HCPs believed that limited funding at the national level impacted their ability to educate PCs about how to improve the quality of the meals children were being fed. HCPs viewed themselves as agents of the state and emphasised economic conditions as a structural factor that impacted their own agency, but not that of PCs.

4.6. DISCUSSION

This paper has examined and compared primary caretakers' (PCs) and healthcare providers' (HCPs) perceptions of the causes of child undernutrition in Lusaka district, Zambia. Our findings reveal that PCs and HCPs have largely divergent 'explanatory models' (13) of child undernutrition and, crucially, that those of HCPs do not encompass the sociocultural factors that are both detailed in the UNICEF conceptual framework and highlighted by PCs in this study. PCs conceptualised child undernutrition as occurring primarily when children are not fed an adequate *quantity* of food. Whereas, HCPs stressed the significance of the *quality* of food over the quantity. Although each group perceived child undernutrition differently, PCs' emphasis on the quantity of food may be in reference to an adequate quantity of food of adequate *quality*, highlighting implicit similarities between both groups. Additionally, critically, HCPs and PCs had divergent perceptions of parental agency. In differently conceptualising undernutrition and PCs' ability to prevent it, these models underpin different attributions of causality, and thus opportunities for intervention, between the two groups.

To date, there has been limited comparison of explanatory models of child undernutrition among key populations with the largest direct impact on child wellbeing. Existing studies have only explored PCs' explanatory models of child undernutrition (24-27) largely excluding the perspectives of other key stakeholders such as HCPs.

Our study goes beyond previous research by exploring disconnects between HCPs' and PCs' explanatory models of child undernutrition, and the attributions of causality included in these models. In a different context, Kleinman et al (13) illustrated that divergent explanatory models among PCs and HCPs have implications for the quality of care received, health-seeking behaviours, and preventative measures implemented in households. This is reflected in the findings of our study; that PCs differently conceptualised child undernutrition led them to perceive certain health information as not reflective of the local context, to not always seek out healthcare services from HCPs, and to continue to practise cooking and feeding practices discouraged by HCPs. Understanding disconnects in explanatory models could therefore improve communication between HCPs and PCs, and could be used to improve the quality of services provided and modify interventions to address both known and perceived causes of childhood undernutrition (28, 29).

Importantly, while each group perceived child undernutrition differently there was overlap in their conceptualisations of undernutrition, which neither of them recognised or acknowledged. In some instances, PCs' emphasis on the *quantity* of food a child ate could be reflective of a perception among PCs that children were not eating an adequate quantity of food that PCs perceived to be of good *quality*, revealing an implicit similarity in both groups' conceptualisations of undernutrition. Notably, PCs' conceptualisations of child undernutrition were reflective of how HCPs explained undernutrition during nutrition education. However, HCPs conceptualised undernutrition differently than they explained it, indicating an important disconnect. In spite of this implicit similarity, many PCs did not explicitly highlight distinctions between food they perceived as good or bad when discussing the quantity of food. They focused largely on ensuring that the children ate an adequate quantity of food.

Each groups' conceptualisation of undernutrition consequently informed how they attributed causality. We identified six perceived causes of childhood undernutrition. PCs stressed structural factors which they perceived as limiting their agency and HCPs stressed individual factors in which they perceived PCs as having more agency than they acknowledged.

Structural factors are known to be determinants of childhood undernutrition (30). In our study, while HCPs perceived parental agency as independent of structural factors, PCs perceived parental agency as situated in and constrained by structural factors. This is reflective of Giddens' (31) conceptualisation of structural factors – factors which individuals perceive as modifying agency – either limiting or amplifying it. This notion of constraint ran through PCs' identification of factors which they perceived as modifying their parental agency - child food preferences, child health, and household finances.

In addition to financial and child dependent structural constraints highlighted by PCs, our data revealed social constraints that PCs perceived as limiting their agency. While individuals may have agency, there are socially bound practices which they may not act against due to existing power dynamics and perceived social repercussions (32). In our dataset, HCPs highlighted a perception among PCs that young children should not eat meat because it was not socially acceptable to cook meat into an age-appropriate texture, illustrating social restrictions on parental agency.

Galtung's (33) conceptualisation of structural violence is useful here in allowing us to further distinguish between structural factors which amplify agency and factors which limit agency. The limitation of parental agency, as opposed to the amplification of it, is reflective of the concept of structural violence and how this may weave through seemingly-individual, or even intimate, experiences and practices such as feeding and childcare (34). Within our dataset, the embodiment of structural violence was evidenced in how PCs' narratives elucidated them to

operate in the context of limited finances, children's food preferences, and chronic poor child health, or, what Berlant (35) has called in a different context, within 'compromised conditions of possibility'.

First, HCPs detailed that PCs with limited household finances expressed a desire to feed their children food that they associated with higher socioeconomic status. Abbots (36) has explored the association between food and social status; noting how the classification of food can be used to distinguish between socioeconomic groups and that individuals of lower socioeconomic status aspire to replicate feeding practices associated with higher socioeconomic status. Expanding on the earlier discussion of social constraints, it may be that such practices were rooted in PCs' desire for their households not to be viewed as 'other'. Given the existence of moral discussions surrounding food and feeding practices, and in an attempt to avoid judgment, PCs may be inclined to continue feeding practices which are not recommended by HCPs.

Second, PCs frequently described their parental agency as entangled with that of their children, with parental agency mapped through that of the child, which was seen in narratives of child food preferences. Yet, what also emerged within these accounts was a sense that PCs actively minimised their own agency and prioritised that of their children, as a form of care. Building on the concept of aspirational feeding in poverty, feeding children junk food can also be seen as part of a framework of caring for children and providing them comfort, especially in difficult economic contexts (37). Within a different context, families of lower socioeconomic status in high income countries have discussed food and feeding as positive experiences and memories in the midst of the difficulties of poverty (38). Additionally, junk food was referenced as a treat within this context (38). This is reflective of the idea that food and feeding are more than just nourishment for the body. Sociocultural analyses have widely described food's ability to

symbolise shared ideas and feelings, and feeding as a social activity through which individuals connect (39-42). This conceptualisation of food emerged from a study in Zambia which found that parents displayed affection for their children through feeding (43).

Third, in some instances where PCs had attempted to address undernutrition in their children but to no avail, PCs perceived a child's body as having agency of its own, either through seemingly embodied characteristics or through ill-health. This conceptualisation had the impact of leading PCs to no longer attempt to cure or prevent undernutrition. Flax et al (44) revealed a similar finding in Malawi, where child height was perceived by PCs as unmodifiable by parental action.

In order to address PCs' perceptions of limited or no parental agency, it could be helpful to strengthen the provision of tailored one-to-one nutrition education. This would assist PCs in addressing social, cultural, and economic constraints and could increase the likelihood of behaviour changes required to prevent child undernutrition. A pilot study conducted in Ndola, Zambia observed a statistically significant increase in dietary diversity, meal frequency, and the intake of animal protein following the provision of tailored one-to-one nutrition counselling (45, 46).

Additionally, it is important to address wider economic constraints on PCs. Specifically, there is a need for a systematic national distribution of supplementary foods to younger children. Where social protection schemes (47) are currently unable to access vulnerable populations (48), households experiencing household food insecurity may require access to supplementary food. A pilot study providing high energy protein supplements in Ndola, Zambia found significant improvements to child growth and health (45).

In contrast to PCs' conceptualisations, HCPs perceived PCs as having more agency than they themselves acknowledged. While HCPs were aware of the wider structural factors influencing

child feeding, they emphasised PCs' responsibility to ensure good child health. Within this framework, HCPs acted as agents of the state - responsible for distributing health knowledge. As such, HCPs minimised the impact of structural factors on PCs and emphasised moral judgements such as 'improper feeding' under the assumption that PCs had received the necessary information. This is reflective of older paradigms of public health, which have since been criticised, that assume rational behaviour once individuals receive full information (49). In practice, human behaviour is complex and dependent on an array of factors such as social networks, social status and norms, and mental models – how we perceive people, places, or things (50).

Crucially, HCPs only recognised structural factors, such as wider economic conditions, if they impacted HCPs' ability to carry out their job. This highlights that HCPs identify primarily as agents of the state rather than members of their respective communities. Although many HCPs live in the communities they cater to and may follow social norms, they identify themselves as outsiders – minimising the perceived plight of their community members and highlighting individual factors as drivers of child undernutrition. Studies have shown that HCPs' personal values and/or beliefs may impact their professional performance (51). This was demonstrated in our findings as HCPs emphasised moral judgments and perceived the appropriateness of health education differently than PCs.

Importantly, although local nutrition policies and IYCF training guidelines for HCPs incorporate a biosocial approach to child undernutrition, this is not reflected either in HCPs' conceptualisations of child undernutrition or the nutrition services provided. To ensure that HCPs are providing nutrition services which are contextually appropriate, it would be beneficial to provide HCPs with additional training that promotes the biosocial approach, as well as tailored training about the local context in which PCs operate. This could reduce moral

judgments of PCs, improve the quality of care provided, and further improve household implementation of recommended IYCF practices.

In addition to the moral judgments made by HCPs, and in spite of the wider contrasts between HCPs' and PCs' conceptualisations of causality, PCs also made moral judgements about mothers. HCPs and PCs both identified 'inadequate mothering' as a determinant of child undernutrition. This reveals the gendered nature of child undernutrition and the importance of feminist theory in understanding explanatory models of child undernutrition. Globally, within many households, child feeding and health are viewed as the responsibility of mothers (52, 53). As such, when inadequate feeding or health results in child undernutrition, mothers are usually blamed. HCPs and PCs both identified 'laziness' and misplaced priorities as perceived causes of 'inadequate mothering' - crucially in others and not themselves. 'Laziness' was used to describe mothers who were viewed as choosing not to practice socially acceptable forms of mothering, which involved embracing motherhood as one's primary identity and responsibility.

Moral judgements about mothers are reflective of a wider body of work examining the concept of mothering. Mothering is a construct which varies according to social, economic, and cultural contexts (54, 55). Multiple ideologies of mothering can exist in one setting, however, there is always a dominant ideology. Moral judgements are therefore the result of practices of mothering which deviate from the dominant ideology which, in most settings, is a variation of labour intensive caretaking (56). Previous research has identified two factors which could influence moral judgements about mothers (57). Firstly, moral judgements may be used to maintain a dominant ideology in a community, by shaming those who follow alternative ideologies. Secondly, moral judgements may reflect fundamental attribution error – a tendency to attribute causality for an outcome in others to individual level factors, such as the way a

woman mothers her child, while negating the potential impact of wider factors which individuals cannot control (58).

The aggregate of factors which were perceived as limiting mothers' ability to mother 'adequately' resonate with the structural contexts and violence that compromise agency, as noted above. The perception, among HCPs and PCs, of some forms of mothering as 'inadequate' does not account for the fact that socially acceptable forms of mothering, such as stay-at-home mothering with minimal assistance, are now less accessible due to the impact of wider structural factors such as poverty. This highlights a need to address the impact of economic constraints on both individual households and the functioning of healthcare facilities.

Strengths and Limitations

The findings of this study are limited by the sample population and sampling strategy. Although we sampled a small number of HCPs, their perceptions overlapped, suggesting that data saturation was achieved. However, it remains possible that our study has not captured the entirety of perceived causes of child undernutrition amongst PCs and HCPs. Specifically, our sampling strategy limited study participants to PCs who attended a healthcare facility, and thus did not access the voices of PCs who could or did not access this healthcare intervention. To mitigate this limitation, we identified study participants from the three lowest levels of healthcare facilities. Furthermore, we confirmed that under-five clinic attendance was relatively high. However, future research should purposively sample hard to reach populations.

Despite the above limitations, a strength of our study is its design. First, it enabled us to explore both PCs and HCPs' perceived causes of child undernutrition, thereby allowing for thorough comparisons. Second, our use of semi-structured interviews enabled focused questioning whilst also giving participants room to discuss topics that they themselves viewed as important.

Finally, conducting interviews in local languages improved participants' comfortability and ease of expression, further increasing the richness of the data.

Although the objective of this study was achieved, our findings highlight opportunities for additional research. First, although it was beyond the scope of this study, future studies should examine in additional detail PCs' perceptions about breastfeeding practices in children above six months of age and whether, in addition to the factors detailed in this paper, PCs perceive breastfeeding practices as impacting childhood undernutrition. Second, future research should go beyond the findings of this study to examine in more depth PCs' perceptions about their ability to parent and make decisions which ensure adequate nutrition in their children. Lastly, future studies should examine in additional depth how PCs assess child nutritional status.

4.7. CONCLUSION

Our study found that PCs and HCPs in Lusaka district, Zambia conceptualised child undernutrition and parental agency differently, and consequently, largely identified differing perceived causes for child undernutrition. This has implications for the effectiveness of policy and practice to address childhood undernutrition in Zambia and similar LMIC settings. In order to accelerate the reduction of childhood undernutrition in Zambia, our findings underscore the importance of tailored one-to-one nutrition education and addressing the wider economic constraints on both HCPs and PCs.

4.8. CHAPTER SUMMARY

This chapter identified divergences in how primary caretakers of children under five years old and healthcare providers attribute causality for childhood undernutrition, and the impact of these conceptualisations on clinical and household practices. Crucially, this study has highlighted the importance of understanding attributions of causality for childhood undernutrition and identifying potential divergences in conceptualisations among key stakeholders.

The next chapter goes beyond the previous analytical chapters of this thesis to explore primary caretakers' experiences with nutrition education in Lusaka district, Zambia. Nutrition education is widely implemented in LMICs, however, the degree of effectiveness of nutrition education is dependent on the implementation of nutrition education, primary caretakers' experiences with the programme, and the sociocultural environment which either allows or curtails clinically recommended behaviour change. The following chapter explores opportunities to improve the delivery of nutrition education and household implementation of clinically recommended behaviour changes in Lusaka district, Zambia.

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CHAPTER FIVE: PRIMARY CAREGIVERS' EXPERIENCES OF NUTRITION EDUCATION FOR THE PREVENTION OF CHILD UNDERNUTRITION IN ZAMBIA: BARRIERS AND FACILITATORS TO BEHAVIOUR CHANGE

5.1. CHAPTER PREFACE

The final analytical chapter of this thesis presents additional findings from the qualitative study conducted in Zambia. The preceding analytical chapter highlighted a need to improve the dissemination of nutrition education and associated behaviour changes among primary caretakers. This analytical chapter builds on this finding by examining primary caretakers' experiences with and perceptions of nutrition education, highlighting perceived barriers and facilitators to behaviour change.

As detailed in the background chapter, current approaches to address undernutrition in LMICs centre around improving health literacy of primary caretakers, to ultimately improve infant and young child feeding. One of the main programmes through which health literacy is improved is nutrition education. This chapter builds on the aim of this thesis by identifying opportunities to improve the effectiveness of a widely implemented nutrition programme – nutrition education.

Title:

Primary Caregivers' Experiences of Nutrition Education for the Prevention of Child Undernutrition in Zambia: Barriers and Facilitators to Behaviour Change

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Contributor Statement:

NL and AL designed the study. NL, with the assistance of SK, conducted the interviews. NL analysed the data and drafted the manuscript, with input from AL. All authors critically reviewed the manuscript.

5.2. ABSTRACT

Introduction: Nutrition education is widely practised in LMICs, however, its effectiveness within different settings has been shown to be variable. Within the Zambian context, high rates of childhood undernutrition persist in spite of the large-scale implementation of nutrition education. By examining primary caregivers' experiences with and perceptions of nutrition education for the prevention of childhood undernutrition in Lusaka district, Zambia, this paper aims to identify opportunities to improve the effectiveness of nutrition education in Zambia and similar settings.

Methods: A qualitative study in Lusaka district, Zambia. Data were collected through one-to-one and group semi-structured interviews with 38 primary caregivers of children under the age of five, and ten healthcare providers. Thematic analysis was used to analyse interview data.

Results: Primary caregivers actively sought out and valued nutrition education from healthcare providers. However, they identified three barriers to accessing personalised nutrition education, and two barriers to household implementation of cooking/feeding practices recommended during group nutrition education. In addition to accessing nutrition information from hospital-based healthcare providers, primary caregivers also detailed their reliance on social networks for additional nutrition information. Specifically, primary caregivers relied on family and community members, and detailed how they navigate behaviour changes within existing social structures.

Conclusion: Addressing primary caregivers' barriers to accessing and implementing nutrition education, and understanding the social networks that encourage or curtail behaviour changes in Lusaka district, Zambia are needed to improve the implementation and effectiveness of nutrition education.

5.3. INTRODUCTION

Globally, half of all under-five deaths are associated with one or more forms of childhood undernutrition: stunting, wasting, or micronutrient deficiencies (1). Childhood undernutrition impairs cognitive and physical development, and is associated with an increased risk of morbidity and mortality (2). In Zambia, 35% of children under five years old are stunted, 4.1% are wasted, and 1.4% are concurrently stunted and wasted (3, 4). Although the prevalence of childhood undernutrition in Zambia has decreased in the last decade, that of childhood stunting remains very high (4, 5).

Most Zambian children who suffer from undernutrition do not experience intrauterine growth restriction but become undernourished after birth as a result of infant and young child feeding (IYCF) practices. At six-months old, once complementary feeding begins, the risk of growth faltering increases significantly (6, 7). On average, it is reported that Zambian babies are exclusively breastfed for five months (8, 9). However, six months after birth, only 12.5% of Zambian children (aged 6-24 months) are being fed in accordance with WHO and UNICEF recommendations (9).

Nutrition education is recognised as a cost-effective intervention to improve IYCF and is included in the World Bank's recommended priority package to reach the 2025 Global Nutrition Targets for childhood stunting and wasting (10). The Zambian government promotes nutrition education as one of the main programmes to encourage healthy nutrition practices and sustained behaviour changes amongst primary caregivers (PCs) (11, 12). Despite this, the burden of childhood stunting is high and improvements to IYCF are limited (4).

Moreover, although nutrition education is widely implemented in Zambia and other LMICs, evidence of its effectiveness in terms of behaviour change and malnutrition outcomes is inconsistent (13). In theory, when implemented alongside interventions that address the

economic and environmental determinants of child undernutrition, nutrition education has the potential to decrease the incidence of child undernutrition (14) and is associated with improvements in anthropometric measures (15-21). However, the statistical significance and magnitude of effects vary across studies (15, 18, 19). The strength of available evidence is further weakened by a small number of studies and variations in how nutrition education is designed and implemented.

The effectiveness of nutrition education is contingent on appropriate design and implementation, and a social-ecological environment which allows or encourages positive behaviour changes. Previous studies have identified inadequacies and variability in the implementation of nutrition services in Zambian healthcare facilities (22-24). However, existing research has not examined PCs' experiences of nutrition education – their perceptions of barriers or facilitators, or how they navigate these. These are critical to informing the implementation of nutrition education. In this paper we examine the perspectives of PCs, specifically in Lusaka district, Zambia, on nutrition education, and evaluate the facilitators and barriers to behaviour change. In doing so, this paper contributes to the evidence base about how to improve the effectiveness of nutrition education and further prevent childhood undernutrition through sustained behaviour changes.

5.4. METHODS

Study Setting

We conducted a qualitative study, underpinned by the interpretive framework of medical anthropology (25), in Lusaka district, Zambia from May-August 2019. The study took place in three healthcare facilities, purposively selected from the three lowest levels of care, with high rates of childhood stunting. Healthcare facilities were purposively selected using quarterly data from the Lusaka District Health Office to identify facilities from the three lowest levels of care,

as these focus primarily on the provision of preventative healthcare services and health promotion.

Participants

PC participants were recruited from under-five clinics, which occur daily at all healthcare facilities. PCs are encouraged to bring their children under five years old to under-five clinics once a month for growth monitoring, nutrition education, and immunisation. PCs were approached for inclusion in this study if they had a child under five years who was no longer exclusively breastfeeding (six months or older), and the child was either underweight or their weight was decreasing.

HCPs introduced Authors One and Five to all PCs at the start of each under-five clinic. Subsequently, during individual growth monitoring, HCPs identified PCs with children who were underweight or whose weight was decreasing and referred them to Authors One and Five. Authors One and Five were introduced as students who were conducting research and wished to speak to PCs about their children's health.

HCPs were approached by both Author One and Five, for inclusion in this study, if they provided healthcare services at under-five clinics.

Prior to conducting interviews, written informed consent was obtained from all participants.

Data Collection

One-to-one and group semi-structured interviews were conducted, separately, with PCs and HCPs. One-to-one interviews were the primary form of data collection (31 interviews - 26 with PCs and five with HCPs). Group interviews were conducted to accommodate participants' time

constraints (six interviews - five interviews with two to three PCs and one interview with five HCPs).

Semi-structured interviews explored child undernutrition while allowing participants the space to discuss related topics that they felt it important to raise. Topic guides were developed by Author One with the input from Author Two. They included questions about lived experiences related to child undernutrition; experiences with healthcare services for child growth/undernutrition; childcare practices; infant and young child feeding practices; cooking practices; and household food security. Interviews were designed to last between 45 minutes and one hour, but exact duration was at the direction of the participant.

Author One conducted all interviews with the assistance of Author Five, who acted as an interpreter if participants were more comfortable speaking Bemba or Nyanja.

Interviews were audio recorded, transcribed verbatim in English, and anonymised. Interviews conducted in Bemba or Nyanja were translated by one of three university-trained research assistants. All translations were reviewed by a second research assistant.

Participants were recruited past the point at which we reached data saturation. Data saturation was confirmed during data analysis.

Analysis

Interview data were analysed using thematic analysis (26). They were inductively coded by Author One with input from Author Two. Author One coded five transcripts from each participant group, reviewed the codes with Author Two, and both authors agreed on the codes. Author One then coded all transcripts, grouped codes, and identified themes. Authors One and Two reviewed and agreed on all themes. All interview data were managed using NVivo 12.

Author One drafted the manuscript, with input from Author Two. All authors critically reviewed the manuscript.

Reflexivity

While conducting this study, Author One was a PhD candidate with training in Public Health and Public Policy. She received additional training in qualitative research methods prior to data collection. Author One is a Zambian woman raised in a Zambian household who grew up in African countries and visited Zambia periodically. She is familiar with child rearing practices that are common to Zambian households. Due to her background, Author One was largely perceived as an outsider by Zambians, however, she held some insider knowledge (27). In order to minimise the impact of insider knowledge on data collection, Author One made a conscious effort to refrain from projecting personal experiences and making assumptions about information shared by participants (28). Author Five, a graduate student born and raised in Zambia, who was perceived as more of an insider by participants, was included in the interview process to improve participant comfortability and, where necessary, for translation.

No authors were known to any of the participants prior to data collection.

5.5. FINDINGS

Our study population consisted of 38 primary caregivers (PCs) and ten healthcare providers (HCPs), with characteristics detailed in Table 1.

Table 1: Participant Characteristics (n = 48)

	Primary Caregivers (N = 38)	**Healthcare Providers (N = 10)**
Healthcare Facility		
Facility One	18 (47%)	5 (50%)
Facility Two	6 (16%)	N/A*
Facility Three	14 (37%)	5 (50%)
Sex		
Female	36 (95%)	10 (100%)
Male	2 (5%)	
Relation to Child		
Mother	35 (92%)	
Father	2 (5%)	
Non-familial caregiver	1 (3%)	
Age		
17-19	4 (11%)	
20-24	10 (26%)	
25-29	11 (29%)	
30-34	7 (18%)	
35+	5 (13%)	
Undisclosed	1 (3%)	
Number of Living Children		
1	16 (42%)	
2	8 (21%)	
3	5 (13%)	
4	6 (16%)	
5+	3 (8%)	
Job Title		
Nutritionist		2 (20%)
Nurse		2 (20%)
Psychosocial Counsellor		2 (20%)
Midwife		2 (20%)
Public Health Technologist		1 (10%)
Undisclosed		1 (10%)

*Note: HCPs jointly served facilities two and three

Themes about PCs' perceived barriers and facilitators of behaviour change, recommended through nutrition education to prevent childhood undernutrition, are examined below.

Acceptability of Nutrition Education among Primary Caregivers

When asked about nutrition education, PCs largely expressed its value to them and their trust in HCPs. They stressed the importance of *"healthy"* diets or *"balanced"* meals, echoing what they had been taught during nutrition education.

"We're supposed to have a balanced meal. . . Healthy food." (Participant 21, PC).

Healthy foods, as described by PCs, included *"fruits"*, *"vegetables"*, and *"proteins"*. In turn, PCs widely expressed their willingness to apply the nutrition education they had received from HCPs to promote optimal child growth.

In Zambia, nutrition education takes three forms: group education, personalised education, and nutrition counselling. At the beginning of under-five clinics, HCPs conduct group education, described as *"[giving] health education to everyone"* (Participant 48, HCP). In contrast, personalised education is only available to PCs with children whose weight is stagnant or decreasing but who are not yet underweight. Personalised education is designed to be delivered during individual growth monitoring. In theory, it is also the point at which PCs can ask HCPs specific questions about child nutrition.

"Once [we] just look at the baby's weight, usually [PCs] are taught there and then."

(Participant 27, HCP)

The third form of nutrition education, nutrition counselling, is available to PCs whose child is clinically underweight. Nutrition counselling is the most detailed form of nutrition education.

Each form of nutrition education is intended to have a different function: group education's purpose is to prevent growth faltering; personalised education is intended to be curative of suboptimal growth and preventative against undernutrition; and nutrition counselling is designed to cure undernutrition, particularly low weight-for-age.

Although PCs valued all forms of nutrition education, notably, many expressed a desire to access and use nutrition education to *prevent* childhood undernutrition or address growth faltering early. Accordingly, PC participants attended under-five clinics regularly for growth monitoring and to receive nutrition education in a timely manner. For example, one father stated that he frequently *"brought [his] child to the nearest health facility to check for advice"* to ensure that the *"baby grows into a very healthy baby"* (Participant 42, PC). However, despite proactive actions taken by PCs, those with children whose growth was already faltering, and who were therefore eligible for personalised education, highlighted barriers to accessing this form.

The following sections outline PCs' difficulties accessing personalised education to address suboptimal growth and prevent undernutrition; how they navigated the form of nutrition education that they were able to access – group education; and the social structures which influenced behaviour changes informed by nutrition education.

Perceived Barriers to Accessing Personalised Education

Delayed Delivery of Personalised Education

PCs in our dataset articulated a desire to engage with group and personalised education to prevent childhood undernutrition. However, despite the value that PCs placed on both forms of nutrition education, they expressed difficulty accessing personalised education as soon as growth faltering occurred. PCs attributed these difficulties to HCPs' delayed initiation of

personalised education and inadequate delivery of personalised nutrition education. These difficulties seemed to be underpinned by a lack of patient-centred care.

PCs detailed only receiving personalised education when their child's weight was already stagnant or had been decreasing for an extended period of time.

"[The baby] was just stuck on eleven point – eleven kgs. Like, for four months. That's when [the HCP] started explaining to say 'No, do you feed the child well? How many times does she eat?'" (Participant 23, PC)

The delayed delivery of personalised education is contrary to both what PCs desired and how HCPs described their provision of personalised education. PCs relied on HCPs to monitor child growth and instigate personalised education: *"You are the ones here who look at people's health. Because I can be cooking, giving him and seeing that he eats but you are the ones who see whether the child is ok in his body."* (Participant 14, PC). Accordingly, PCs perceived the delayed delivery of personalised education as delaying the point at which they could begin appropriately addressing suboptimal growth and actively preventing undernutrition.

Therefore, contrary to HCPs' training guidelines for delivering nutrition education, HCPs relied on PCs to take the initiative and ask pointed questions while PCs relied on HCPs to identify suboptimal growth and instigate personalised education. This is reflective of a wider phenomenon, identified by PCs, of HCPs disregarding their preferences and strained clinical communication.

Inadequate Delivery of Personalised Education: Poor Clinical Communication

When children had experienced growth faltering for an extended period of time and this diagnosis was finally shared with PCs, PCs described experiences of poor clinical communication. They recounted feeling that HCPs did not take the time to explain suboptimal

growth well to them. One PC detailed that she was informed of growth faltering at the end of the appointment, when there was no time to ask questions, *"as [the HCP was] writing on the [under-five card]"* (Participant 24, PC).

These clinical interactions between PCs and HCPs created an environment where PCs did not feel that they could ask for personalised education through formal avenues, instead, having to seek it informally, as described in later sections. One PC explained that interactions with HCPs during individual growth monitoring *"[weren't] really a conversation"* (Participant 23, PC). Only one PC in our dataset detailed feeling able to ask HCPs questions.

"In every session. . . there comes a time where they ask questions to say 'any questions?'. . . [then] you'd be advised." (Participant 42, PC)

PCs perceived these experiences of poor clinical communication as prohibiting them from both receiving and seeking personalised education. Consequently, in practice, PCs were receiving the generalised content of group education in place of the personalised education which they were eligible for and recognised they needed, and which functioned differently.

Disrespectful Delivery of Personalised Education

Among PCs who detailed receiving group education in place of personalised education, they described a lack of respectful care as a barrier to further seeking personalised education. In spite of the fact that HCPs described themselves in their interviews as welcoming and having a desire to ensure good child health, eleven PCs perceived HCPs as judgmental. One PC, for example, described a conversation she had with a HCP, during growth monitoring, as a result of growth faltering:

"He was just telling me like 'okay, why is the child not gaining?'. Like, 'why is [the weight] not changing? Why is the weight not changing?' So, I was like 'I don't know'." (Participant 23, PC)

This PC stated that the HCP went as far as to ask her *"do you feed [the baby]?"* (Participant 23, PC). PCs highlighted that they felt judged by HCPs if child growth was suboptimal, as though they were individually and solely at fault.

These experiences demonstrate a perception among PCs that HCPs did not always provide nutrition education in a way that was respectful or reflective of PCs' preference to treat growth faltering early. This ultimately disrupted PCs' access to and comfort in seeking personalised education to prevent undernutrition. The following section explores how PCs consequently navigated the group education that they described having access to, and the social-ecological context which impacted PCs' ability and willingness to foster behaviour changes recommended through nutrition education.

Perceived Barriers to Implementing Recommendations from Nutrition Education

Household Finances

Although PCs described difficulties accessing personalised education to prevent undernutrition, they detailed having adequate access to group education. However, they also expressed difficulties implementing behaviour changes recommended through group education. PCs largely attributed these difficulties to factors related to finances and social norms. Limited household finances were perceived by PCs as restricting their ability to purchase food that had been identified as *"necessary"* for child growth (Participant 32, PC). Financial barriers were reflective of widespread instances of economic precarity in Zambia.

To address the impacts of economic conditions on child feeding, during group education HCPs encouraged *"locally available foods"* (Participant 48, HCP) and described how to increase the nutritional value of staple foods by incorporating affordable proteins. Despite these teachings, some PCs highlighted their inability to purchase recommended affordable food items.

"The money that I earn is little. . . With the same [wages] we have to pay school fees. . . and food at home." (Participant 15, PC)

PCs' inability to implement affordable feeding and cooking practices recommended by HCPs could be reflective of PCs' desire to feed their children according to child food preferences as a form of care within the context of hardships associated with economic precarity. This is examined in detail in our previous work (29). Crucially, participants' narratives demonstrated how this difficulty is further compounded by the barriers to accessing personalised education. Due to those barriers, PCs were less likely to receive tailored nutrition information about affordable feeding practices that navigated both their children's food preferences and finances, further leaving them feeling unable to implement clinically recommended feeding practices.

Socio-Cultural Feeding Norms

Divergences between socially acceptable and clinically recommended feeding practices also emerged in our dataset, specifically in PCs' discussions about age-appropriate food. During group education, HCPs encouraged and taught PCs how to feed toddlers nshima (a staple dish) with a combination of vegetables and protein. HCPs recommended meat protein be cooked to a softer texture for young children.

In spite of HCPs' recommendations, most PCs still fed their children nshima with soup: *"Maybe you can prepare [dried fish], he can't eat. Pork, he can't eat pork. . . So, we just prepare soup for him, then give him with nshima"* (Participant 43, PC). HCPs described these

practices as passed from *"generation to generation"* and persistent *"even if [PCs] have the [recommended] food"* (Participant 45, HCP), highlighting the on-going influence of family members on child feeding and cooking practices. In this instance, socio-cultural norms and the influence of community/family members acted as a barrier to PCs' implementation of practices recommended through the group education that they were able to access. The wider social structures that either encourage or curtail recommended behaviour changes are explored further in the following section.

Social Structures Impacting Behavioural Changes

Sources of Nutrition Education

Beyond accessing nutrition information through formal avenues and within the context of PCs' inability to access the personalised education they needed and were eligible for, PCs highlighted social networks through which they sought alternative nutrition information.

"[I] am usually found with my elder sister . . . The time she had a child, I didn't have yet. So the first time I had a child she's the one who used to tell me." (Participant 11, PC)

"If it's in the family, I look at an elderly person. For example, we have an educated person in the village who has 14 children. These elderly people who managed to have children properly a long time, not us of today. All the 14 children grew up and got educated, so I know that that household is the one that is supposed to teach me about taking care of children." (Participant 14, PC)

This alternative nutrition education was sought from mothers, family members, and older community members, as well as people who were regarded by PCs as having raised healthy children, were educated, or who were trained HCPs.

Notably, in line with their frustrations with accessing and seeking personalised education, PCs specifically sought formal nutrition information from HCPs through informal avenues. This, again, highlights the value placed on formal nutrition education and PCs' trust in HCPs.

"We have a doctor friend of ours. So if we see any problem, we just call him and ask him then he will tell us. . . Either to take the child to the clinic or maybe do this or do that"

(Participant 23, PC)

PCs identified HCPs as a trusted source for nutrition education, particularly because of their educational background: *"[HCPs] are at this [educational level], they are the ones that can teach and encourage us"* (Participant 11, PC). This again indicates the willingness and desire, among PCs, to receive nutrition education from HCPs.

Navigating Conflicting Nutrition Education

Once PCs had gathered nutrition education from various sources, they detailed how they decided which knowledge to implement. First, most PCs compared the information they had received.

"What they tell us at the clinic and what my mother says at home are just the same so I just follow the same procedure." (Participant 35, PC)

PCs were more likely to implement information that had been confirmed by HCPs and/or their mothers. HCPs and PCs' mothers were highlighted as the most trusted sources for nutrition information.

In instances where PCs received conflicting information from their mothers and HCPs, they spoke hypothetically about seeking further additional sources to *"get confirmation"* (Participant 19, PC). PCs were more likely to implement information that was recommended

by more than one source, further illustrating the importance of community members in modifying or perpetuating cooking and feeding practices.

Within existing social structures through which PCs accessed alternative nutrition education, they suggested a hierarchy of perceived trustworthiness. When receiving alternative nutrition education from a source other than HCPs or their mothers, PCs expressed a degree of scepticism. In such instances, they only trusted information which they had seen others implement. One PC stated *"I can't implement the things that I know they [have not] done because they can destroy the child"* (Participant 14, PC). PCs also expressed a desire to see how recommended practices impacted the health of other children.

Once PCs had received nutrition information from one or more sources and assessed the information using the above methods, they described a willingness to try recommended practices and observe the impact on their children before fully incorporating the practices and adopting behaviour changes.

> *"I will decide to try it on my child to see how his health will be."* (Participant 7, PC)

5.6. DISCUSSION

This paper explored primary caregivers' (PCs) attitudes to and experiences of nutrition education in an urban district in Zambia, alternative sources for nutrition information, and the social structures which influence behaviour changes. Our findings revealed that PCs value nutrition education, even actively seeking it out to prevent child undernutrition. However, PCs identified three categories of factors which impacted the effectiveness of nutrition education: barriers to accessing personalised education once suboptimal growth had been detected; barriers to implementing recommended feeding/cooking practices; and social networks which influenced and constrained behaviour changes.

To date, a small body of work has examined the delivery of nutrition services in Zambian healthcare facilities and highlighted inadequacies in the availability of resources such as anthropometric measurement tools, inadequacies in HCPs' delivery of nutrition services, and PCs' dissatisfaction with existing services (22). However, existing studies have not examined PCs' experiences of nutrition education and how PCs navigate clinically recommended behaviour changes. This study has gone beyond existing literature by examining in depth PCs' experiences of accessing and receiving nutrition education, and offering insights into opportunities to improve the effectiveness of nutrition education in Zambia. Specifically, the study has highlighted opportunities to improve the delivery of personalised education and further encourage clinically recommended behaviour changes, thereby preventing childhood undernutrition.

Nutrition education is widely provided in Zambia and is a principal component of existing nutrition policy (11). The aim of nutrition education is to promote healthy nutrition practices and foster positive behaviour changes. However, within the Zambian context, nutrition education has not resulted in significant improvements to child feeding or growth (9, 23, 24, 30). The design and implementation of nutrition education, alongside the social-ecological systems affecting behaviour, have implications for nutrition education's impact on child growth and feeding (31, 32).

Within our dataset, first, PCs identified barriers to accessing personalised education when eligible for it. This revealed PCs' wider perceptions about the quality of care provided by HCPs and their experiences of strained communication with HCPs. The WHO defines care as high quality if it is safe, effective, accessible, efficient, equitable, and people-centred (33). PCs' experiences illustrated a lack of people-centred care, which was reflective of PCs' preferences to address growth faltering early; and an inadequacy of respectful care, which ensures that PCs

are treated with dignity and respect. Similar inadequacies exist in several Sub-Saharan African countries, in the context of maternity care (34, 35) and diseases such as HIV (36-38). Low-quality and disrespectful care is associated with increased reliance on social and non-medical sources for health information, poor health outcomes, and increased economic losses at the facility and population level (39).

Lack of access to high *quality* healthcare is also recognised within the UNICEF conceptual framework for malnutrition as an underlying determinant of undernutrition (40). In Zambia, a study conducted nearly two decades ago suggested that the provision of growth monitoring and promotion was suboptimal and the perception among PCs that the quality of care provided by HCPs during under-five clinics was unsatisfactory (23, 24). In 2008, the National Food and Nutrition Commission of Zambia disseminated course guidelines for IYCF counselling (41). This was followed by the Ministry of Health's dissemination of growth monitoring and promotion guidelines to both strengthen and standardise the provision of nutrition education (42). However, critically, and as is evidenced by our findings, to date, inadequacies in the provision of nutrition education persist. The provision of high quality, patient-centred and respectful care, which is reflective of PCs' circumstances and constraints, could further encourage healthy behaviour changes. Previous literature has highlighted personalised education as the most effective format to encourage behaviour change and improve complementary feeding practices (43).

Although PCs experienced difficulty accessing personalised education when eligible for it, they described being able to access group education. However, they highlighted two social and cultural barriers to implementing feeding and cooking practices recommended through group education – limited household finances and socio-cultural feeding norms. PCs perceived these factors as limiting their sense of agency. In particular, PCs expressed a lack of agency due to

their desire to feed children according to each child's food preferences, socioeconomic status, and socio-cultural norms around food and feeding. This is reflective of PCs' lived experiences and conceptualisation of child undernutrition detailed in our previous work (29). Similarly, PCs' experiences with barriers to accessing personalised education were associated with a wider sense of lack of agency in addressing suboptimal growth early and preventing undernutrition. Opportunities to ask focused questions to HCPs and receive tailored nutrition information could strengthen PCs' sense of agency and support household implementation of clinically recommended behaviour changes. These findings are reflective of the social-ecological model which highlights the importance of self-efficacy in encouraging clinically recommended behaviour changes (44).

Further to social and cultural factors acting as barriers to behaviour change is the recognition that social structures and networks can also act as facilitators of healthy behaviour change. Radcliffe-Brown defined social structures as the sum of social relations (45) and within our dataset, PCs' identified family members and community members as additional sources for nutrition information. The use of multiple sources for health information, known as knowledge pluralism, is well researched in LMICs and our study showed it in play, negatively influencing clinically recommended behaviour changes. Similarly, studies conducted in Zambia and other LMICs have detailed the influence of family and community members on individual feeding and cooking behaviours (46-48). In spite of the above, crucially, nutrition education programmes in Zambia continue to largely target mothers (42). There is a need to ensure that all community members who influence feeding and cooking behaviours are targeted for group education. This could also serve as a strategy to address socio-cultural feeding norms which contradict with clinically recommended practices.

In addition to the potential benefits of knowledge pluralism, it is important to note the potential dangers of non-medical sources for nutrition information. In circumstances where nutrition education differs according to the source, for example HCPs and female relatives, there is a risk of PCs implementing practices which are not clinically recommended. Within the context of other diseases, accessing health information from non-medical sources has been associated with altered treatment behaviour - particularly delayed accessing of healthcare facilities and primarily seeking non-biomedical sources of treatment (49).

Additionally, our findings highlight the value and trust that PCs place in HCPs, even seeking nutrition information from them through informal avenues, irrespective of their experiences of disrespectful or poor quality of care. This illustrates an openness, among PCs, to receiving nutrition education from community health workers (CHWs) and opportunities to strengthen the effectiveness of nutrition education. A report evaluating Zambian CHWs' involvement in the reduction of childhood undernutrition found that presently, CHWs only provide seven of the 17 recommended childhood nutrition services (50) – policy documents do not currently stipulate CHWs to provide counselling about complementary feeding practices, the introduction of complementary foods, and the feeding of children with diarrhoea (50). Widening and standardising the scope of nutrition education that CHWs provide could improve the delivery of personalised education within communities and address social constraints to behaviour change.

Finally, collectively, PCs' discussions centred around the impact of individual level factors, such as their clinical interactions with HCPs and household finances, on their sense of agency. However, it is important to recognise that wider structural factors are embodied in individual perceptions of agency. This concept has been referenced as structural violence by Galtung (51). As it pertains to global health, wider structural factors can include national economic precarity

and difficult political situations, which can affect an individual's financial and physical ability to purchase food items recommended through nutrition education and associated behaviour changes (52). In addition to addressing individual level factors impacting PCs' perceptions of agency, it is crucial that structural factors impacting individual perceptions of agency, such as a lack of adequate social security, are addressed simultaneously.

Strengths and Limitations

The findings of this study should be interpreted within the context of the limitations of our sampling strategy. Our sampling strategy restricted study participants to PCs attending under-five clinics and HCPs based at healthcare facilities. This may have limited the perspectives included in this dataset. In order to minimise the impact of this, we purposively selected lower level facilities which served wider catchment areas. Additionally, due to the fact that participants were identified at healthcare facilities, community members or CHWs who may influence child feeding practices were not included in this dataset and their social interactions/norms were not observed. In order to mitigate the impact of this on the data collected, HCPs based in healthcare facilities were asked about CHWs and community involvement in child rearing was explored through PCs. However, future research should examine this in additional depth.

5.7. CONCLUSION

This study has highlighted opportunities for the Zambian Ministry of Health to increase the effectiveness of nutrition education. Specifically, our findings point towards a need to address disrespectful and low-quality care surrounding the delivery of personalised education, the impact of social-cultural factors on PCs' perceived ability to implement clinically-recommended practices, and the impact of social structures on behaviour changes.

5.8. CHAPTER SUMMARY

The final analytical chapter of this thesis examined primary caretakers' experiences with nutrition education in Lusaka district, Zambia. The findings of this study highlight significant barriers to accessing nutrition information, barriers to implementing clinically recommended behaviour changes, and how social structures influence behaviour changes within the Zambian context. Notably, the findings of this study underscore opportunities for the Zambian government to further improve the effectiveness of nutrition education, its impact on child growth, and consequently accelerate the rate of reduction of childhood undernutrition nationally. The following chapter will summarise the findings and wider policy implications of the entire thesis, discuss the strengths and limitations of the thesis as a whole, and highlight opportunities for future research.

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CHAPTER SIX: DISCUSSION AND CONCLUSION

6.1. INTRODUCTION

African countries continue to experience a disproportionate burden of childhood undernutrition cases, and the associated morbidity and mortality. Approximately half of all cases of childhood stunting and nearly 1 out of 4 cases of childhood wasting occur in African countries (1). Given the magnitude and severity of this public health issue, significant financial investments have been made to mitigate it. In 2018, $973 million US Dollars in foreign aid were directed towards nutrition specific interventions in LMICs (2). Almost 60% of this foreign aid was distributed to African countries (3). Furthermore, although there was a global decrease in the amount of nutrition specific foreign aid distributed between 2017 and 2018 (2), within Africa there was a slight increase in both the amount of nutrition specific foreign aid received and the percent of foreign aid directed to nutrition specific interventions (3).

In order to ensure that growing investments in childhood undernutrition – through both direct and indirect nutrition interventions – have the necessary impact on childhood undernutrition in Sub-Saharan African countries, this thesis examined limitations of current approaches to address childhood undernutrition in Sub-Saharan Africa, and similar settings, and identified opportunities to accelerate the reduction of childhood undernutrition. This thesis includes three studies and four papers which were designed to explore separate research objectives pertaining to the overall thesis aim.

This chapter is organised as follows. First, a summary of the research objectives and key findings of each analytical chapter are presented within the context of existing research and nutrition action. Second, the policy implications of the key findings of this thesis are discussed. Third, the strengths and limitations of this body of work as a whole and opportunities for future research are detailed.

6.2. KEY FINDINGS

A brief summary of the key findings of this complete body of work are detailed in the table below (Table 1) and expanded on in the following section.

Table 1: Key Findings of Thesis, According to Research Objectives

Research Objectives	Key Findings
1. Examine trends and inequalities in the prevalence of childhood undernutrition in African countries over the last twenty years.	The prevalence of child undernutrition decreased across Africa between 2000 and 2019, however, the African continent is not on track to meet the 2025 Global Nutrition Targets for childhood undernutrition.
	Inequalities exist in the prevalence and reduction of child undernutrition in Africa and have not significantly improved in the last two decades.
2. Examine the association between household air pollution, from solid cookfuels, and childhood undernutrition in LMICs.	Children exposed to household air pollution from solid cooking fuels were more likely to suffer from one or more forms of undernutrition.
	Heterogeneity in the above association existed within subpopulations.
3. Explore attributions of causality for childhood undernutrition among primary caretakers of children and healthcare providers in Lusaka district, Zambia.	Primary caretakers and healthcare providers conceptualised child undernutrition differently and consequently attributed causality for child undernutrition differently.
	Primary caretakers highlighted structural factors which limited their parental agency. Differently, healthcare providers highlighted individual factors for which they perceived primary caretakers as having more agency than they acknowledged.
	Healthcare providers' explanatory models of child undernutrition were not reflective of the local context which primary caretakers described and operated in.
4. Explore primary caretakers' experiences with nutrition education in Lusaka district, Zambia.	Primary caretakers valued nutrition education, however they identified barriers to accessing personalised education and implementing behaviour changes recommended through group education.
	Primary caretakers highlighted social structures which, in different instances, served as barriers or facilitators to clinically recommended behaviour changes.

Trends and Inequalities in Childhood Undernutrition in 51 African Countries

The first research objective of this thesis was to examine trends and inequalities in the prevalence of childhood undernutrition in African countries over the last 19 years. In 2012, the World Health Assembly (WHA) introduced six global targets for maternal and child nutrition - two of which focused on the reduction of childhood undernutrition (4). Consequently, a UNICEF, WHO, and World Bank Group inter-agency team (JME group) was formed and began releasing estimates of the levels and trends of childhood malnutrition annually (5). Specifically, the JME group estimates the levels of childhood stunting, wasting, and overweight; and the trends of childhood stunting and overweight from 2000 onwards. Estimates are provided globally, within geographical regions, and according to different country level income group classifications. The JME group's most recent publication also includes estimates of whether countries are on track to meet the child malnutrition targets, detailed in the Sustainable Development Goals, by 2030 (5).

Critically, previous JME group research has not examined how childhood undernutrition trends vary in subpopulations and how inequalities in the prevalence of childhood undernutrition have changed over time. Similar studies examining trends of childhood undernutrition in LMICs have also been conducted for regions other than Africa, with limited subgroup analysis, and for varying child age groups (6-8). In addition to the above limitations, with the exception of a few studies that have mapped the prevalence of child malnutrition in LMICs (9, 10), multinational studies examining trends of childhood undernutrition do not commonly report subnational estimates.

Preliminary analysis of the prevalence of childhood undernutrition in 51 African countries revealed three key findings. First, between 2000 and 2019 the prevalence of childhood wasting and stunting decreased regionally. Second, significant inequalities existed in the prevalence of

childhood undernutrition. The prevalence of childhood stunting was highest in the poorest wealth quintiles, males, rural regions, and children 2-5 years old. The prevalence of childhood wasting was highest in the poorest wealth quintiles, males, rural regions, and children under two years old. The prevalence of childhood undernutrition was also higher in countries with levels of household air pollution above the mean or countries whose prevalence of household air pollution either increased or did not change between 2000 and 2019. Third, minimal improvements were made to the levels of inequalities of childhood undernutrition in African countries over the last 19 years.

Secondary analysis using multilevel linear regression models controlling for UN subregions and country level fixed effects revealed two additional key findings. First, the average annual rate of reduction of childhood wasting and stunting in the African continent was slow. Should present trends continue, the African continent will be unable to meet the 2025 Global Nutrition Targets for both childhood stunting and wasting. Second, there is significant heterogeneity in the rate of reduction of childhood undernutrition according to area of residence, wealth quintiles, child sex, child age, and levels of HAP.

The above findings exist within the context of increased financial investments in nutrition-specific interventions in African countries and continued implementation of current approaches to address childhood undernutrition. Current approaches to address childhood undernutrition in LMICs have identified separate programmes for childhood wasting and stunting. Programmes targeting childhood wasting focus on the treatment of severe acute malnutrition. Programmes targeting childhood stunting focus on the prevention of stunting by improving infant and young child feeding and water, sanitation, and hygiene infrastructure and behaviour. The following studies and associated research objectives identified opportunities for nutrition

action to go beyond current approaches and further accelerate the reduction of childhood undernutrition in Sub-Saharan Africa.

Exposure to Household Air Pollution from Solid Cookfuels and Childhood Undernutrition in 59 LMICs: A Population-Based Cross-Sectional Study

The second research objective of this thesis was to examine the association between exposure to household air pollution from solid cookfuels and childhood undernutrition in LMICs. A recent systematic review and meta-analysis identified 34 studies examining the association between ambient air pollution and small for gestational weight (SGA) or intrauterine growth restriction (IUGR), and 11 studies examining the association between household air pollution from solid fuels and childhood stunting in LMICs (11). Pooled estimates suggested a modest association between exposure to ambient air pollution and SGA/IUGR, and a modest association between exposure to household air pollution from solid fuels and childhood stunting. However, previous research was limited by small sample sizes and limited subgroup analysis.

Although there is a small body of literature examining the association between exposure to household air pollution and childhood undernutrition in LMICs, presently, air pollution is still excluded from nutrition policy. Nutrition action has largely centred around treating severe acute malnutrition, improving WASH behaviour and infrastructure, growth monitoring and promotion, and where feasible, the provision of supplementary food (12). However, within the field of public health, there have been growing calls to further examine household air pollution, especially as an approach to accelerating the reduction of childhood undernutrition in LMICs (13, 14).

This chapter builds on the key findings of the first analytical chapter, which highlight a need to strengthen current approaches to address childhood undernutrition, by examining the association between cooking energy infrastructure and childhood stunting, wasting, and concurrent stunting and wasting. Multilevel logistic regression models, controlling for a priori confounders, were used to analyse cross-sectional Demographic and Health Survey data from 59 LMICs.

Four key findings were identified through this study. First, children living in households using solid fuels for cooking were more likely to be stunted, wasted, and concurrently stunted and wasted than children living in households using cleaner fuels. Second, changes in the cooking fuel type according to the energy ladder were associated with incremental changes in the odds of stunting and wasting. Third, solid cooking fuel use was associated with disturbances in both linear and ponderal child growth. Fourth, there was heterogeneity in the association between exposure to household air pollution and child undernutrition within subpopulations. Children living in households cooking with solid fuels were more likely to be stunted if they were in the Americas, the poorest households, had a mother who smoked, were older, or lived in rural regions.

To date, household air pollution, has been excluded from nutrition action. The findings of this study underscore the potential value of addressing household air pollution on the rates of childhood undernutrition. In order to accelerate the reduction of childhood undernutrition in Sub-Saharan Africa, wider determinants of child undernutrition should be further researched and where relevant incorporated into nutrition action.

Attributions of Causality for Childhood Undernutrition Among Primary Caretakers and Healthcare Providers: A Qualitative Analysis in Lusaka District, Zambia

The third research objective of this thesis was to explore and compare attributions of causality for childhood undernutrition among primary caretakers of children under five years old and healthcare providers. Previous research has highlighted the importance of stakeholders' explanatory models of disease – how a disease presents itself, what causes it, and how it can be treated (15). Within the context of other illnesses, studies have shown that divergent explanatory models of disease among healthcare providers and primary caretakers/patients can impact health seeking behaviour, the quality of healthcare services, and healthcare practices implemented within households (16). Previous research has examined primary caretakers' perceived causes of childhood undernutrition and the explanatory models in which they are embedded (17, 18), highlighting the perceived impact of finances, cultural beliefs, social-cultural feeding norms, and gender on infant and young child feeding (19, 20). However, critically, previous studies have not compared primary caretakers' and healthcare providers' explanatory models of childhood undernutrition. Consequently, potential divergences have not been accounted for in nutrition policy or interventions.

The third study of this thesis was a qualitative study conducted in Lusaka district, Zambia. One-to-one and group semi-structured interviews with primary caretakers of children under five years old and healthcare providers were used to gather interview data. Interview data was transcribed and analysed using thematic analysis.

While the previous analytical chapter examined a potential risk factor associated with childhood undernutrition, this chapter explored which risk factors key stakeholders attributed childhood undernutrition to. Additionally, this chapter examined explanatory models of childhood undernutrition, and their implications for household and clinical practice in Zambia.

Six perceived causes of child undernutrition, according to primary caretakers and healthcare providers, were identified.

Three key findings were identified through this study. First, primary caretakers and healthcare providers conceptualised child undernutrition differently. Primary caretakers perceived child undernutrition as a result of the intake of an inadequate *quantity* of food and healthcare providers perceived child undernutrition as a result of the intake of low *quality* food. Second, primary caretakers and healthcare providers had divergent explanatory models of child undernutrition, perceived parental agency differently, and attributed causality differently. Primary caretakers largely highlighted structural factors where they perceived themselves as having limited or no agency - children's food preferences, child health, and household finances as determinants of child undernutrition. Healthcare providers attributed causality for child undernutrition to improper feeding practices and wider economic constraints, factors where they perceived primary caretakers as having more agency than they acknowledged. Primary caretakers and healthcare providers also both identified inadequate mothering as a perceived cause of child undernutrition. Third, healthcare providers' explanatory models of child undernutrition did not reflect the biosocial approach employed by updated versions of the UNICEF conceptual framework for undernutrition or the local context described by primary caretakers.

Divergent explanatory models of child undernutrition have implications for how healthcare providers disseminate nutrition education to primary caretakers, primary caretakers' compliance with recommended practices to prevent undernutrition, and the prevalence of child undernutrition in Zambia. The findings of this study underscore a need to introduce and/or strengthen interventions which address key stakeholders' perceived causes of undernutrition,

and address divergences between healthcare providers' and primary caretakers' explanatory models.

Primary Caregivers' Experiences of Nutrition Education for the Prevention of Childhood Undernutrition in Zambia: Barriers and Facilitators of Behaviour Change

The fourth research objective of this thesis was to explore primary caretakers' experiences with nutrition education in Lusaka district, Zambia. The Zambian government identified nutrition education as a key intervention to improve infant and young child feeding, and address high rates of childhood malnutrition (21, 22). Although nutrition education is widely implemented in Zambia and other LMICs, evidence about its effectiveness is inconsistent (23). Studies suggest that nutrition education may be associated with improvements in infant and young child feeding and child growth (24-26), however, findings vary across studies. Previous research examining the variable effectiveness of nutrition education has largely focused on how different levels of food security or the provision of supplementary food may impact the effectiveness of nutrition education.

Within the Zambian context, research from nearly two decades ago highlighted significant inadequacies in the provision of nutrition healthcare services (27). In an attempt to strengthen and standardise the provision of nutrition education, the Zambian Ministry of Health disseminated revised guidelines in 2008. However, to date, the implementation of nutrition education in Zambia has only resulted in marginal improvements to infant and young child feeding practices and rates of childhood malnutrition (28).

This chapter examined data from the qualitative study described in the previous chapter. This chapter went beyond the previous analytical chapters to identify primary caretakers' perceptions and experiences of nutrition education. This study identified significant limitations

in the implementation of nutrition education in Lusaka district and subsequent opportunities to improve the impact of nutrition education on child undernutrition in Zambia.

Four key findings were identified through this study. First, primary caretakers valued and actively sought out nutrition education from healthcare providers. Second, primary caretakers identified three barriers to accessing personalised nutrition education – delayed delivery of personalised education, poor clinical communication, and disrespectful delivery of personalised education by healthcare providers. Third, primary caretakers highlighted two barriers to implementing behaviour changes recommended through group education – limited household finances, and socio-cultural feeding norms. Fourth, primary caretakers identified social structures through which they also accessed nutrition information informally and detailed how these structures acted as barriers or facilitators to behaviour change. In spite of the mentioned barriers, primary caretakers still sought out nutrition education from healthcare providers through informal avenues, highlighting the value that they placed on healthcare providers and opportunities to improve both the delivery and impact of nutrition education.

This study revealed significant discrepancies between nutrition education policy and the way in which nutrition education is implemented. Additionally, this chapter underscores the need to improve the delivery of personalised education and address the wider socio-cultural factors curtailing behaviour change.

6.3. POLICY IMPLICATIONS

There is a need to accelerate progress in the reduction of childhood undernutrition. Current approaches to address childhood undernutrition in Sub-Saharan Africa have not resulted in significant improvements in the reduction of childhood stunting and wasting in African countries. Most African countries are not on track to meet the 2025 Global Nutrition

Targets for childhood stunting and wasting. It is vital that relevant stakeholders identify how to maximise the effectiveness of existing nutrition programmes, and identify nutrition programmes which go beyond present approaches to address determinants of childhood undernutrition other than infant and young child feeding and WASH, and the treatment of severe acute malnutrition.

Additionally, significant inequalities persist in both the prevalence and reduction of childhood undernutrition in subpopulations in Africa. Additional policy and clinical attention needs to be directed toward these vulnerable populations. More detailed opportunities for policy and/or practice to accelerate the reduction of childhood undernutrition in Zambia are detailed below.

Wider determinants of childhood undernutrition may play a significant role in the reduction of childhood undernutrition. Traditionally, nutritional policy has largely centred around the immediate and underlying causes of childhood undernutrition. While these policies and programmes are important, this thesis underscores a need to identify and incorporate wider determinants of childhood undernutrition into existing policy. Particularly, the findings point towards a potentially significant positive effect of infrastructure interventions, specifically cooking energy infrastructure, on childhood growth, undernutrition, and associated mortality and morbidity. In addition to building on the policy implication detailed above, it is important to identify and direct additional policy attention towards subpopulations who are disproportionately affected by distal determinants of childhood undernutrition.

Within the Zambian context, existing clinical practice needs to be reflective of nutrition policy, robust and well established knowledge, and the local context. Existing nutrition policy addresses the role of social, economic, and cultural factors on childhood undernutrition. However, in practice, this conceptualisation of undernutrition was not reflected in healthcare

providers' explanatory models of childhood undernutrition and consequent clinical practice. There is a need to ensure that healthcare providers' conceptualisations of undernutrition and clinical practice account for the potential impact of social, economic, and cultural factors on childhood undernutrition. Additionally, healthcare providers' conceptualisations of child undernutrition and clinical practice need to be reflective of the local context in which primary caretakers operate. Furthermore, in countries where childhood undernutrition persists, it is important to identify and address potential divergences in conceptualisations of child undernutrition among key stakeholders and the associated implications on the effectiveness of nutrition services and ultimately the reduction of childhood undernutrition.

Within the Zambian context, there is a need to strengthen policy addressing the impact of economic constraints on childhood undernutrition. Although social protection and school feeding programmes exist, the findings of the thesis underscore the fact that these programmes have not sufficiently addressed the impact of economic constraints on household food security. It is vital that within populations where severe financial limitations exists, economic constraints are sufficiently addressed alongside programmes addressing more proximal determinants of childhood undernutrition such as health literacy.

6.4. OPPORTUNITIES FOR FUTURE RESEARCH

Strengths and Limitations

Although the studies included in this thesis were conceptualised, designed, and conducted both thoroughly and systematically, the findings of this thesis must be interpreted within the context of existing limitations. The strengths and limitations of each individual study and paper are discussed in detail within each analytical chapter, however, this section will briefly discuss strengths and limitations of the thesis as a whole. The studies included in this thesis are fairly

new research areas. Consequently, nearly all of the studies are exploratory and will require additional research. The research conducted as part of this thesis has critically identified opportunities for improvements in child undernutrition research, policy, and clinical practice. However, due to the exploratory aims and subsequent designs of each study, the findings of this thesis were unable to quantify the exact impact of addressing the policy recommendations highlighted within this thesis.

As a result, the findings of this thesis provide four key insights for future research. First, a significant research gap identified through the research conducted for this thesis is the limited body of work examining the impact of distal determinants on childhood undernutrition. Second, once an association is identified, there is a need to examine the impact of associated wider interventions on childhood growth, undernutrition, and associated morbidity and mortality. Particularly, the findings of this study suggest a significant association between exposure to household air pollution from solid cooking fuels and childhood undernutrition in LMICs. However, a robust study examining the impact of household air pollution interventions on childhood growth and undernutrition is required to further confirm this association and quantify the impacts of said interventions on child undernutrition.

Third, as it pertains to the findings of the qualitative study discussed in chapters four and five, future studies should examine the impact of the recommended modifications to policy and clinical practice on child growth, childhood undernutrition, infant and child feeding practices, and clinical practice in Lusaka district, Zambia. Four, similar quantitative and qualitative studies can be conducted in other LMICs to examine whether conceptualisation of undernutrition among key stakeholders, and experiences with existing nutrition programmes and policies may be impacting progress in the reductions of childhood undernutrition within other settings.

In spite of the above limitations, this thesis is strengthened by the robust and systematic study designs. This study has gone beyond current approaches to address undernutrition to provide a breadth of knowledge and highlight opportunities for the global community to further accelerate the reduction of childhood undernutrition in African countries, increasing the number of African countries on track to achieve the 2025 Global Nutrition Targets for childhood stunting and wasting. Furthermore, the use of multiple study methods has provided a robust body of work from which future research can be conducted and appropriate policy, clinical practice, and programmatic modification can be identified.

6.5. CONCLUSION

The aim of this thesis was to influence the development of policies and programmes targeted towards the reduction of childhood undernutrition in Sub-Saharan African countries and similar developing settings. Although current approaches to address childhood undernutrition in Sub-Saharan Africa are critical and have positively impacted childhood undernutrition outcomes, the findings of this thesis highlight the need to further accelerate progress. Notably, this thesis has identified opportunities to further accelerate reduction of childhood undernutrition in Sub-Saharan Africa through additional research, and modifications to clinical practice and existing nutrition policies.

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APPENDIX

APPENDIX ONE: ETHICS, RESEARCH, AND PUBLICATION APPROVALS

UNIVERSITY OF BIRMINGHAM

FINANCE OFFICE

11th March 2019

Dear Dr Anna Lavis & Dr Semira Manaseki-Holland,

Re: "The Role of Infrastructure Development in the Reduction of Multiple Forms of Child Undernutrition in Sub-Saharan Africa: A Case Study of Child Undernutrition in Zambia"
Application for Ethical Review ERN_18-1428

Thank you for your application for ethical review for the above project, which was reviewed by the Science, Technology, Engineering and Mathematics Ethical Review Committee.

On behalf of the Committee, I am pleased to confirm a favourable ethical opinion for your project, subject to your adherence to the following conditions:

- A Health and Safety risk assessment is completed and approved prior to travel.
- Approval is gained from the Zambian National Health Research Authority, and the Lusaka Provincial Medical Office.

For clarification, as long as the conditions above are met and the details of the proposed work do not change, your project has ethics approval and no further action is necessary.

I would like to remind you that any substantive changes to the nature of the study as described in the Application for Ethical Review, and/or any adverse events occurring during the study should be promptly bought to the Committee's attention by the Principal Investigator and may necessitate further ethical review.

Kind regards,

Ms Sam Waldron
Deputy Research Ethics Officer
Research Support Group
University of Birmingham
B15 2TT
Tel:
Email:

ERES CONVERGE

Plot No. 1, Cnr Joseph Mwilwa & Great East Road
Rhodes Park, Lusaka - Zambia
Tel: +260 955 155 633
+260 955 155 634
Cell: +260 977 493220
Email: eresconvergeltd@gmail.com

I.R.B. No. 00005948
F.W.A. No. 00011697

30th May, 2019

Ref. No. 2019-Mar-022

The Principal Investigator
Ms. Nakawala L. Lufumpa
Institute of Applied Health Research
University of Birmingham (UK), B15 2TT
UNITED KINGDOM.

Dear Ms. Lufumpa,

RE: THE ROLE OF INFRASTRUCTURE DEVELOPMENT IN THE REDUCTION OF MULTIPLE FORMS OF CHILD UNDERNUTRITION IN SUB-SAHARA AFRICA: A CASE STUDY OF CHILD UNDERNUTRITION IN LUSAKA AND KAFUE DISTRICTS, ZAMBIA.

Reference is made to your corrections dated 21st May, 2019. The IRB resolved to approve this study and your participation as Principal Investigator for a period of one year.

Review Type	**Ordinary**	Approval No. **2019-Mar-022**
Approval and Expiry Date	Approval Date: 30th May, 2019	Expiry Date: 29th May, 2020
Protocol Version and Date	Version - Nil.	29th May, 2020
Information Sheet, Consent Forms and Dates	• English.	29th May, 2020
Consent form ID and Date	Version - Nil	29th May, 2020
Recruitment Materials	Nil	29th May, 2020
Other Study Documents	Interview Guide.	29th May, 2020
Number of participants approved for study	60	29th May, 2020

Specific conditions will apply to this approval. As Principal Investigator it is your responsibility to ensure that the contents of this letter are adhered to. If these are not adhered to, the approval may be suspended. Should the study be suspended, study sponsors and other regulatory authorities will be informed.

Conditions of Approval

- No participant may be involved in any study procedure prior to the study approval or after the expiration date.
- All unanticipated or Serious Adverse Events (SAEs) must be reported to the IRB within 5 days.
- All protocol modifications must be IRB approved prior to implementation unless they are intended to reduce risk (but must still be reported for approval). Modifications will include any change of investigator/s or site address.
- All protocol deviations must be reported to the IRB within 5 working days.
- All recruitment materials must be approved by the IRB prior to being used.
- Principal investigators are responsible for initiating Continuing Review proceedings. Documents must be received by the IRB at least 30 days before the expiry date. This is for the purpose of facilitating the review process. Any documents received less than 30 days before expiry will be labelled "late submissions" and will incur a penalty.
- Every 6 (six) months a progress report form supplied by ERES IRB must be filled in and submitted to us.
- A reprint of this letter shall be done at a fee.

Should you have any questions regarding anything indicated in this letter, please do not hesitate to get in touch with us at the above indicated address.

On behalf of ERES Converge IRB, we would like to wish you all the success as you carry out your study.

Yours faithfully,

Dr. Jason Mwanza
Dip. Clin. Med. Sc., BA., M.Soc., PhD
CHAIRPERSON

NATIONAL HEALTH RESEARCH AUTHORITY

Paediatric Centre of Excellence, University Teaching Hospital, P.O. Box 30075, LUSAKA

Tell: +260211 250309 | Email: znhrasec@gmail.com | www.nhra.org.zm

Ref No:..... **Date: 12th June, 2019**

The Principal Investigator
Ms. Nakawala Lufumpa
Institute of Applied Health Research
University of Birmingham
United Kingdom

Dear Ms. Lufumpa,

Re: Request for Authority to Conduct Research

The National Health Research Authority is in receipt of your request for authority to conduct research titled **"The Role of Infrastructure Development in the Reduction of Multiple Forms of Child Undernutrition in Sub-Saharan Africa: A Case Study of Child Undernutrition in Lusaka and Kafue Districts, Zambia".**
I wish to inform you that following submission of your request to the Authority, our review of the same and in view of the ethical clearance, this study has been **approved** on condition that:

1. The relevant Provincial and District Health Director(s) where the study is being conducted are fully appraised;
2. Progress updates are provided to NHRA quarterly from the date of commencement of the study;
3. The final study report is cleared by the NHRA before any publication or dissemination within or outside the country;
4. After clearance for publication or dissemination by the NHRA, the final study report is shared with all relevant Provincial and District Health Director(s) of where the study was being conducted, University leadership, and all key respondents.

Yours sincerely,

Dr. Godfrey Biemba
Director/CEO
National Health Research Authority

All correspondence should be addressed to the
Provincial Health Director
Telephone: +260 211 256813
Fax: +260 211 256814
Telephone: +260 211 256815
Cell: +260 956 399643
+260 963 908260

REPUBLIC OF ZAMBIA
MINISTRY OF HEALTH

In Reply please quote:

PMOLSK/10/23/1
File No.....

Lusaka Provincial Health Office
P.O. Box 32573
LUSAKA

27th June, 2019

Ms. Nakawala Lyapa Lufumpa
Ph.D Student
Institute of Applied Health Research
University of Birmingham, U.K. B15 2TT
Telephone : [redacted]
Email :

Dear Sir/Madam,

RE: REQUEST FOR AUTHORISATION TO CONDUCT RESEARCH IN LUSAKA DISTRICT

Reference is made to above subject matter.

Lusaka Provincial Health Office is in receipt of your letter requesting to conduct research on ***"The Role of Infrastructure Development in the Reduction of Multiple Forms of Child Undernutrition in Sub-Saharan Africa: A Case Study of Child Undernutrition in Lusaka and Kafue Districts, Zambia "***.

My office is glad to inform you that it has no objection to your request provided that;

1. The relevant District Health Director where the study is being conducted are fully appraised;
2. Progress updates are provided to Lusaka Provincial Health Office and the District Health Office biannually from the date of commencement of the study;
3. The final study report is cleared by NHRA before any publication or dissemination within or outside the country;
4. After clearance for publication or dissemination by NHRA, the final study report is shared with all relevant Provincial and District Directors of Health where the study was being conducted, University Leadership and all key respondents.

Kindly ensure minimum interruption in health service delivery to the selected health facilities you will undertake your research.

By copy of this letter, District Health Offices is advised to allow you undertake the above mentioned research and provide you with the relevant support.

Dr Collsity Mwale
Provincial Health Director
Lusaka Province

cc. District Health Office - Kafue
cc. District Health Office – Lusaka

All correspondence should be addressed to the District Medical Officer

Tel: +260-211-235554
Fax: +260-211236429

In reply please quote
No:.....

REPUBLIC OF ZAMBIA
MINISTRY OF HEALTH

LUSAKA DISTRICT HEALTH OFFICE
P.O. BOX 50827
LUSAKA

5th July, 2019

Nakawala Lyapa Lufumpa (Ms)
Institute of Applied Health Research
University of Birmingham
United Kingdom

Dear Ms. Lufumpa,

RE: AUTHORITY TO CONDUCT RESEARCH IN LUSAKA DISTRICT

We are in receipt of your letter over the above subject.

Please be informed that Lusaka District Health Office has no objection for you to conduct research entitled **"The role of infrastructure development in the reduction of multiple forms of child undernutrition in Sub-Saharan Africa: A case study of child undernutrition in Zambia"** as per list attached.

Kindly ensure that your findings are shared with the health facility and District Health Office and that the normal operations of the facility are not disrupted.

By copy of this letter, the Medical Superintendents and In-Charges for Lusaka District Health Facilities are kindly requested to facilitate accordingly.

Yours sincerely

REPUBLIC OF ZAMBIA
MINISTRY OF HEALTH
LUSAKA DISTRICT MEDICAL OFFICE
05 JUL 2019
PRINCIPAL CLINICAL CARE OFFICER
P.O. BOX 50827
LUSAKA, ZAMBIA

Dr. Chota Chishimba
Acting/PRINCIPAL CLINICAL CARE OFFICER
For/DISTRICT HEALTH DIRECTOR

C.C: The In-Charges: All Lusaka District Health Facilities
C.C: The Medical Superintendents: All Lusaka District 1st Level Hospitals
C.C: The Public Health Specialists: All Lusaka District 1st Level Hospitals
C.C: Deputy Research Ethics Officer: Ms. Sam Waldron – University of Birmingham

NATIONAL HEALTH RESEARCH AUTHORITY
Paediatric Centre of Excellence, University Teaching Hospital, P.O. Box 30075, LUSAKA
Tell: +260211 250309 | Email: znhrasec@gmail.com | www.nhra.org.zm

Ref No: NHRA0005/25/11/2020 **Date: 25th November, 2020**

Ms Nakawala Lyapa Lufumpa
Institute of Applied Health Research
University of Birmingham (UK), B15 2TT.

Dear Ms. Lufumpa,

Re: Request for Authority to Publish Manuscript

The National Health Research Authority is in receipt of your request for authority to publish a manuscript from your study titled **"THE ROLE OF INFRASTRUCTURE DEVELOPMENT IN THE REDUCTION OF MULTIPLE FORMS OF CHILD UNDERNUTRITION IN SUB-SAHARAN AFRICA: A CASE STUDY OF CHILD UNDERNUTRITION IN LUSAKA AND KAFUE DISTRICTS, ZAMBIA."**

I wish to inform you that following submission of your request to the Authority and our review of the same and in view of ethical clearance, your manuscript has been **approved** for publishing.

Notwithstanding the fact that your request to publish has been approved however, the Health Research Act in section 32 subsection (1) requires that any health research conducted in Zambia shall first be disseminated locally before being disseminated outside Zambia. This approval is therefore conditional to you abiding by this legal provision. Should you require assistance in facilitating local dissemination of your results, kindly let us know.

Yours sincerely,

Prof. Godfrey Biemba
Director/CEO
National Health Research Authority

APPENDIX TWO: DATA COLLECTION FORMS

Participant Information Sheet: Family Caretakers

Study Title: The Role of Infrastructure in the Reduction of Child Undernutrition in Sub-Saharan Africa: A Case Study of Child Undernutrition in Lusaka and Kafue District

Researcher: Nakawala Lufumpa (PhD Student, University of Birmingham)
Under the supervision of Dr Anna Lavis at the University of Birmingham; and
Through a research attachment at the National Food and Nutrition Commission of Zambia

I want to invite you to join my study. I believe that you can be an important part of my research. I want to give you some information about this study, what your participation would involve and your rights. Take your time to read this paper and make a decision. Please ask me any questions if any of the information is not clear or brings up concerns.

STUDY PURPOSE

This study is part of my research for a PhD course in Public Health. I will use the information from this study to explore child undernutrition in Lusaka and Kafue district.

The purpose of this study is to understand the views of decision makers (within a household and a community) around the feeding and health of children aged five or younger. My aim is to understand why we are observing the most recent child nutritional outcomes in Zambia.

PARTICIPANT INVOLVEMENT

If you choose to participate in this study, you will be asked to take part in a **one-to-one interview**. I will ask you for your thoughts about child health, what your child eats, and what you think impacts that within your household and your community.

CONFIDENTIALITY/ANONYMITY AND DATA STORAGE

I will keep the information collected through this study confidential. Only the research team (myself, research assistants, and my research supervisors) will have access to this information in its raw form.

While I am collecting data, I will store our recorded interviews on a password-protected hard drive. I will do this to avoid anyone except the research team from getting access to the data. When I return to the University of Birmingham, names and locations will be changed to make sure that no participants can be identified by anyone other than myself. I will then move this data to the University drive. I will store the data on University storage for ten years. Long-term storage allows for transparency when data is included in published documents.

I will analyse the data and include it in my thesis and papers for publication. I will anonymise any data included in my thesis or papers. This means that nothing you say will be linked back to you.

POSSIBLE BENEFITS AND RISKS OF TAKING PART IN THIS STUDY

I will use the data from all interviews to write papers that I hope will add to the current knowledge about child undernutrition in African countries. I hope to encourage a change in how we understand and prevent poor child health outcomes in Zambia and other African countries. As a participant, your experiences and thoughts will give me important information that will strengthen my research.

I do not think that there are any risks to taking part in this study. But, please let me know if you feel that being part of this study could be dangerous to you.

COMPENSATION

As a participant in this study, you will receive a small form of compensation for your time. Additionally, for your valuable time and participation, you will be provided with refreshments during the interview.

RIGHTS

It is completely up to you whether or not you would like to participate in this study. You have the right to, at any point during or before the interview, conclude the interview and ask the research investigator to delete your data collected during the interview.

When the interview is finished, you will have **until September 2019** to contact me if you want to remove all or any part of your interview data. If you want to remove your whole interview, your audio recording and transcript will be deleted. If you want to remove a section of the interview that you do not feel comfortable including in the research, that section will be deleted from the transcript.

Please find included below the contact information for two research team members and ERES Converge Zambia.

CONTACT INFORMATION FOR CONCERNS REGARDING THE STUDY

If you are worried about any part of the study once your interview has ended, please contact one of the people detailed below. If you were interviewed at a formal or informal health care facility and you are unable to directly contact any of the people detailed below, please inform your relevant health care facility and they will contact the research investigator for you.

Name, Study Involvement: Nakawala Lufumpa, Researcher
Telephone Number:
Email:
Address:

Name, Study Involvement: Anna Lavis, Doctoral Research Supervisor
Email:
Address:

Name, Study Involvement: ERES Converge Zambia, Research Ethics Board
Telephone Number:
Address:

APPROVED
30 MAY 2019
ERES CONVERGE
P/BAG 128 LUSAKA

Participant Information Sheet: Healthcare Professionals

Study Title: The Role of Infrastructure in the Reduction of Child Undernutrition in Sub-Saharan Africa: A Case Study of Child Undernutrition in Lusaka and Kafue District

Researcher: Nakawala Lufumpa (PhD Student, University of Birmingham)
Under the supervision of Dr Anna Lavis at the University of Birmingham; and
Through a research attachment at the National Food and Nutrition Commission of Zambia

I want to invite you to join my study. I believe that you can be an important part of my research. I want to give you some information about this study, what your participation would involve and your rights. Take your time to read this paper and make a decision. Please ask me any questions if any of the information is not clear or brings up concerns.

STUDY PURPOSE

This study is part of my research for a PhD course in Public Health. I will use the information from this study to explore child undernutrition in Lusaka and Kafue district.

The purpose of this study is to understand the views of decision makers (within a household and a community) around the feeding and health of children aged five or younger. My aim is to understand why we are observing the most recent child nutritional outcomes in Zambia.

STUDY DESIGN AND PARTICIPANT INVOLVEMENT

If you choose to participate in this study, you will be invited to take part in a **focus group**. This is a group discussion in which you will be asked questions about how you view child undernutrition in your community; what you believe influences child undernutrition at the household, community, and/or country level; and your professional experiences with children under five who suffer from undernutrition.

CONFIDENTIALITY/ANONYMITY AND DATA STORAGE

I will keep the information collected through this study confidential. Only the research team (myself, research assistants, and my research supervisors) will have access to this information in its raw form.

While I am collecting data, I will store our recorded interviews on a password-protected hard drive. I will do this to avoid anyone except the research team from getting access to the data. When I return to the University of Birmingham, names and locations will be changed to make sure that no participants can be identified by anyone other than myself. I will then move this data to the University drive. I will store the data on University storage for ten years. Long-term storage allows for transparency when data is included in published documents.

I will analyse the data and include it in my thesis and papers for publication. I will anonymise any data included in my thesis or papers. This means that nothing you say will be linked back to you.

POSSIBLE BENEFITS AND RISKS OF TAKING PART IN THIS STUDY

I will use the data from all interviews to write papers that I hope will add to the current knowledge about child undernutrition in African countries. I hope to encourage a change in how we understand and prevent poor child health outcomes in Zambia and other African countries. As a participant, your experiences and thoughts will give me important information that will strengthen my research.

I do not think that there are any risks to taking part in this study. But, please let me know if you feel that being part of this study could be dangerous to you.

COMPENSATION

No compensation will be provided for your participation in this research. However, for your valuable time and participation, you will be provided with refreshments during the focus group.

RIGHTS

Your participation in this study is entirely voluntary. You have the right to, at any point during or before the interview, conclude your participation in the focus group. If you decide to stop participating in the study during or after the focus group it will not be possible to discard your data. But, you will be able to withdraw **specific** parts of what you have said in the focus group discussion. This is described in additional detail below.

Following the completion of the focus group, you will be unable to completely withdraw all of your data from this study. However, if, on reflection, you do not want a specific part of what you said in the focus group to be included in the research, please contact me and I will delete that section from the transcript and it will not be included in any write-ups of the research. You will have **until September 2019** to contact me should you wish to withdraw any specific part of your discussion in this way from the transcript.

Please find included below the contact information for two research team members and ERES Converge Zambia.

CONTACT INFORMATION FOR CONCERNS REGARDING THE STUDY

If you are worried about any part of the study once your interview has ended, please contact one of the people detailed below. If you were interviewed at a formal or informal health care facility and you are unable to directly contact any of the people detailed below, please inform your relevant health care facility and they will contact the research investigator for you.

Name, Study Involvement: Nakawala Lufumpa, Researcher
Telephone Number:
Email:
Address:

Name, Study Involvement: Anna Lavis, Doctoral Research Supervisor
Email:
Address:

Name, Study Involvement: ERES Converge Zambia, Research Ethics Board
Telephone Number:
Address:

APPROVED
30 MAY 2019
ERES CONVERGE
P/BAG 125, LUSAKA.

APPROVED
30 MAY 2019
ERES CONVERGE
P/BAG 125. LUSAKA.

Revised Consent Form: Family Caretakers

One-to-One Interview

Study Title: The Role of Infrastructure in the Reduction of Child Undernutrition in Sub-Saharan Africa: A Case Study of Child Undernutrition in Lusaka and Kafue Districts

Researcher: Nakawala Lufumpa (PhD Student, University of Birmingham)

Please check the boxes below if you agree with the statements.

I read the information sheet or had it read to me, and understand the information. I have also asked Nakawala to explain all that was unclear.	☐
I know that at any point before or during the interview, I can stop the interview with no explanation. I can ask for my data to be erased at this point.	☐
I know that if I am interviewed, I have **until September 2019** to contact Nakawala if I do not want to be part of the study. I can ask for my data to be erased at this point.	☐
I know that a sound recording device will be used to record this interview. The recording will then be transcribed.	☐
I know who to contact with concerns about the research.	☐
I know that all of the data will be kept confidential. The data will also be kept anonymous, where relevant.	☐
I freely agree to participate in this study.	☐

Please sign below if you agree with all the statements.

Please include your email address if you want to get the results of this research.

Participant Name: _____

Date: _____

Signature or Thumb Print: _____

Email Address: _____

I believe the participant is freely partaking in this study.

Researcher Name: _____

Date: _____

Signature: _____

Revised Consent Form: Healthcare Professionals

Focus Group

Study Title: The Role of Infrastructure in the Reduction of Child Undernutrition in Sub-Saharan Africa: A Case Study of Child Undernutrition in Lusaka and Kafue Districts

Researcher: Nakawala Lufumpa (PhD Student, University of Birmingham)

Please check the boxes below if you agree with the statements.

I read and understand the information sheet. I have also asked Nakawala to explain all that was unclear. ☐

I know that at any point before or during the interview, I can stop the interview. I can also ask for my data to be erased at this point. ☐

I know that if I am interviewed, I cannot withdraw *all* my data. But, I can contact Nakawala **until September 2019** to remove *a part* of my data from the transcript. ☐

I know that a sound recording device will be used to record this interview. The recording will then be transcribed. ☐

I know who to contact with concerns about the research. ☐

I know that all of the data will be kept confidential. It will also be kept anonymous, where relevant. ☐

I freely agree to be in this study. ☐

Please sign below if you agree with all the statements.

Please write your email address if you want to get the results of this research.

Participant Name: .....

Date: .....

Signature or Thumb Print: .....

Email Address: .....

I believe the participant is freely partaking in this study.

Researcher Name: .....

Date: .....

Signature: .....

APPROVED
30 MAY 2019
ERES CONVERGE
P/BAG 126, LUSAKA

Nakawala Lufumpa
May 2019

Topic Guide: Caretakers

Opening

Hello, my name is Nakawala and I am researching child health in Zambia. I would like to ask you a few questions about your perspective as a caretaker of a child five years old or younger. I would like to learn more about how you care for your child's health, and specifically your child's nutritional status.

This interview should take about one hour but the exact time is up to you. I have a list of questions in front of me but you do not need to answer any questions that you don't want to and we are interested in hearing your perspective so please do talk about any aspects of the topics that you feel are important. Can I confirm that you freely choose to participate in this interview?

I will begin by asking you questions about yourself and your background.

Respondent Background

1. Age
2. Where are you from (province and district)?
3. Who do you live with?
4. Does anyone in the household work? If so, what are their jobs?

I am now going to ask you a little bit about the children you care for, if that's okay…

1. Number of children (ages)
2. Who takes care of the children and what is your support system?
3. How would you describe the health of your children?
   Prompt: Specifically those children 5 years or younger - walk me through their health from birth up until now
   Be alert to any accounts of children having died – causes described in terms of illness/undernutrition etc. but also in terms of impact of infrastructure/health resources. Sensitively follow the participant's discussion.

Feeding and Food

1. Where do you get your food from?
   Prompt: How do households access food? I.e. markets or farming
   Prompt: A new road has recently been introduced in your community how has that affected the above? If you're a farmer, how has this affected your job?
2. Who makes the decisions in your household regarding what everyone eats?
3. What kind of food do you usually eat?
4. What kinds of things affect what everyone eats?
   Prompts: i.e. finances or time

5. Could you tell me a little bit about how you feed your children?
6. Walk me through how you prepare food for your children
    Prompt: Access to electricity, how is food stored?
    Prompt: Cooking fuel, stove type, and location of kitchen?
    Prompt: Location of child while food is being prepared
    Prompt: In terms of what your children eat, are there different feeding practices for different ages? If so, what are they?
7. How many times a day do your children (five years old and younger) eat? Who makes the decision?
8. How do you know if your child is hungry?

Child Undernutrition

1. Have you heard about child undernutrition? If so, what is your understanding of this?
2. How might you know if a child is suffering from undernutrition?
3. What do you do when someone is undernourished?
4. Where in your life have you encountered child undernutrition?
    Prompt: Have you ever been undernourished or known someone else to be undernourished? If so, what did it do to them and did it change them in any way?
5. Are any of your children (five years old younger) currently, or ever been undernourished?
6. How did you know the child was undernourished?
7. Walk me through what you did when you found out the child was undernourished?
    Explore who/what was sought out, and how is child undernutrition treated?

Information, Communication, and Technology

1. How do you receive health information about what different diseases, how to care for yourself, and how to care for your children?
    Prompt: Community programmes, access to radio, phone, or the internet
2. Do you have access to the following at home or in your community (specific level of access)?
    Prompt: TV, Radio, Mobile Phone, Electricity
    Explore information about how the above is used and which areas of life are most impacted by it?
    Prompt: How has it impacted the health of the household and the children?
    Explore specific infrastructure in the region

Closing

Thank you very much for giving me the opportunity to speak with you and understand your story and perspective a little better. The information you have provided me with will be very important in helping me understand how we can ensure that children throughout Sub-Saharan Africa are as healthy as possible.

As the interview has now come to a close, can I confirm that you still wish for your data to be included in this study?

Nakawala Lufumpa
April 2019

Focus Group Topic Guide: Healthcare Professionals

Opening

Hello, my name is Nakawala and I am researching child health in Zambia. I would like to ask you all a few questions about your perspectives as health professionals of children five years old or younger.

This focus group should take about one hour but the exact time is up to you. I have a list of questions in front of me but you do not need to answer any questions that you don't want to and we are interested in hearing your perspective so please do talk about any aspects of the topics that you feel are important. Can I confirm that you freely choose to participate in this interview?

I will begin by asking questions about yourselves and your backgrounds

Respondent Background – Could each person answer the following in turn

1. What kind of health care professional are you?
2. How long have you been in this profession?
3. Could you describe the kind of work that you do as an 'x' in this clinic

Patient Profiles

1. Please describe to me your regular patients and/or your most common kind of patients
   Prompt: Age, symptoms presented, diseases
2. When a child comes into the clinic, who are they usually accompanied by?
   Prompt: Age, relation to child, support system for caring for the child

Transportation

1. What size geographical area does this healthcare facility look after?
   Prompt: How many people?
2. How accessible do you feel that this health care facility is for the people in this area?
   Explore mode of transportation, time to reach the health care facility, and specific infrastructure in the region
   Prompt: How has accessibility changed over time? How has this impacted you?

Information, Communication, and Technology

1. Once patients have left the hospital, how do you communicate with caretakers?
   Prompt: Use of phones, internet, and radio
2. How do you communicate to caretakers what good health practices are and when to bring children to a health care facility for treatment?
   Explore: Public health structures in the region, use of community level programmes (designed and implemented by clinics or involving clinic participation)
   Prompt: Phones, internet, and radio

3. Have other health entities promoted good health within communities?
   Prompt: Known government and NGO programmes
4. How do you store patient information?
   Prompt: How do you monitor growth?
5. *General Prompt: Specific infrastructure in the region & impact on child health*

Now I'm going to ask you some more detailed questions about child health

1. In your opinion, what is the health status of children under five in this community?
2. What usually prompts caretakers to bring children (five years old or younger) to the clinic?

Child Undernutrition

1. How do you determine if a child is suffering from undernutrition?
   Prompt: What tests do you do?
2. What are the different forms of undernutrition and their symptoms?
3. How do you treat a child suffering from undernutrition?
4. How prominent is child undernutrition in this community?
5. What do you believe are the main factors impacting child undernutrition?
   Prompt: Access to health information once the caretaker is at home/knowledge; financial; infrastructure; cultural
6. Have you encountered child undernutrition in your personal life?
   Prompt: If so, please tell me about it
7. What are the impacts of child undernutrition – at the household and community level?

Child Feeding

1. Walk me through the role of child feeding in overall child health
   Prompt: What are harmful feeding practices and how do caretakers know of what is harmful and what isn't?
   Prompt: Access to electricity

Closing

Thank you very much for giving me the opportunity to speak with you all and understand your perspective a little better. The information you have all provided me with will be very important in helping me understand how we can ensure that children throughout Sub-Saharan Africa are as healthy as possible.

As the focus group has now come to a close, can I confirm that you all still wish for your data to be included in this study?

APPENDIX THREE: PAPER BASED ON THE WORK IN CHAPTER THREE

Paper Under Review

Caleyachetty, R.*, **Lufumpa, N.***, Kumar, N., Mohammed, NI., Bekele, H., Kurmi, O., Wells, J., Manaseki-Holland, S. Exposure to Household Air Pollution from Solid Cookfuels and Childhood Stunting.

* Contributed equally

Authors' Contributions

RC conceptualized and designed the study, interpreted the results, drafted the initial manuscript, and revised it critically for important intellectual content. **NL designed the study, acquired the data, analysed and interpreted the results, drafted parts of the initial manuscript, and revised it critically for important intellectual content.** NK acquired the data, carried out the initial statistical analysis, interpreted the results, and reviewed and revised the manuscript. JW, NIM, HB, OK and SMH contributed to the design of the study, interpreted the data and critically reviewed the manuscript for important intellectual content. All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

Title:

Exposure to household air pollution from solid cookfuels and childhood stunting: a population-based cross-sectional study of half a million children in low-income and middle-income countries

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Abstract

Background: Household air pollution from the incomplete combustion of solid cookfuels in low-income and middle-income countries (LMICs), has been largely ignored as a potentially important correlate of stunting. Our objective was to examine the association between solid cookfuel use and stunting in children under five years.

Methods: We used data from 59 LMICs population-based cross-sectional Demographic and Health Surveys. 557,098 children under five years were included in our analytical sample. Multilevel logistic regression was used to examine the association between exposure to solid cookfuel use and childhood stunting, adjusting for child sex, age, maternal education and number of children living in the household. We explored the association across key subgroups.

Results: Solid cookfuel use was associated with child stunting (adjusted odds ratio: 1.58, 95% CI: 1.55 to 1.61). Children living in households using solid cookfuels were more likely to be stunted if they were lived in rural areas, the poorest households, had a mother who smoked tobacco, or were from the Americas.

Conclusion: Focused strategies to reduce solid cookfuels exposure might contribute to reductions in childhood stunting in LMICs. Trial evidence to assess the effect of reducing solid cookfuel exposure on childhood stunting is urgently needed.

Introduction

While significant progress has been made toward reducing the global prevalence of childhood stunting, the prevalence of childhood stunting in many countries remains unacceptably high with negative consequences for those children affected (1). Three large new trials of unprecedented scale and cost found no effect of basic water, sanitation and hygiene (WASH) interventions on childhood stunting, and only mixed effects on childhood diarrhoea (2, 3). This possibly highlights that other risk factors are likely to be important for reducing childhood stunting.

Approximately 2.8 billion people, mostly in low-income and middle-income countries (LMICs), are exposed to household air pollution from the incomplete combustion of solid fuels traditionally used for cooking (e.g. wood, agricultural residue, dung, charcoal and coal) (4). Household members, particularly young children, are exposed to pollutants including particulate matter (PM), carbon monoxide (CO), black carbon and polycyclic aromatic hydrocarbons (5). Children under five years old are uniquely vulnerable to exposure to household air pollution for several reasons. They stay indoors spending a large proportion of the time in the kitchen (6), and are often carried on their mother's back or lap while cooking (7). Young children also inhale more air than adults each day on a per-kilogram body-weight basis (8).

Household air pollution has recently been suggested to affect child's growth (9). This may be through several mechanisms that reflect either a direct effect of airborne particulate exposure on growth or indirectly through increased morbidity (10-12). Children in LMICs are regularly exposed to household air pollution from burning solid cookfuels (4). A systematic review and meta-analysis has demonstrated that children exposed to household air pollution from cooking with solid fuels are more likely to be stunted (13). However, this was based on only three

studies - two were based on data from India and the other using Demographic and Health Survey (DHS) data for seven countries. Using nationally representative and comparable DHS in 557,098 children aged < 5 years from 59 LMICs, we examined the association between solid cookfuel use and childhood stunting.

Materials and Methods

Data Source

We use DHS which are nationally representative cross-sectional household surveys conducted in approximately five-year intervals in LMICs. We assessed the most recent DHS data, from January 2000 to date, with available data on the use of cookfuel and height-for-age. Standardised methodology and measurement tools have been developed for the collection of DHS data in each country.

The DHS uses a stratified two-stage random sampling approach. Census enumeration areas are identified based on a probability proportional to the sampling area. Within each of the selected enumeration areas, a random selection of households is identified from a complete listing of households. In each sampled household, all consenting women aged 15–49 years are interviewed, and their children aged 0-60 months undergo anthropometric measurements including height, from which stunting can be assessed. Our analytical sample included alive children under age five years with valid height measurements and living with their mother who is a de jure resident.

All the women included in the DHS provided written consent for themselves and their children. The DHS received ethical approval centrally by ICF International (Calverton, MD, USA) institutional review board and locally by individual review boards within every participating country.

Stunting

DHS include data about each child's age (in months and years) and measured length/height. We measured stunting according to the WHO reference anthropometric measurements for children (14). Height-for-age z-scores (HAZ) were used to measure whether a child was stunted or not. HAZ indicate the number of standard deviations a child's height is from the median height-for-age in the reference population. A child with a z-score less than – 2 was categorised as stunted.

Solid Cookfuel Use

Each respondent was asked 'What type of fuel does your household mainly use for cooking?'. Responses included electricity, electricity from other source, liquefied petroleum gas (lpg), natural gas, biogas, kerosene, coal lignite, charcoal, wood, straw shrubs, agriculture crop, animal dung, cardboard/paper, and solar power. Solid cookfuel use was defined as using the following fuels coal lignite, charcoal, wood, straw shrubs, agriculture crop, animal dung, cardboard/paper. Additionally, we constructed a three category variable based on the cleanliness of the cookfuel: clean (electricity, electricity from other source, lpg, natural gas, biogas and solar), moderately clean (kerosene), and not clean (coal lignite, charcoal, wood, straw shrubs, agriculture crop, animal dung, and cardboard/paper) (15).

Confounders

Based on *a priori* subject matter knowledge and the literature, we adjusted for the following confounders: child sex, child age in months, maternal education, and the number of children in the household (16, 17). Child sex was recorded as either male or female. Child age in months was calculated from the date of birth. Maternal education was self-reported and categorised in three groups: none (no formal education); primary (any primary education, including

completed primary education); and secondary or higher (any secondary education, including complete secondary).

We hypothesised the pre-specified variables including residence type, location of kitchen, household wealth, exclusive breastfeeding for 6 months, maternal tobacco smoking, birth weight, and WHO region may alter the magnitude of the association between solid cookfuel use and child stunting. Urban or rural residence was categorised according to country-specific delimitations at the time of the survey. The location of the kitchen was categorised as outdoors or indoors. The household wealth index was derived using principal component analyses of household assets and characteristics of the building, presence of electricity, water supply and sanitary facilities, in addition to other variables associated with wealth (18). The score is provided with the original survey datasets and calculated according to a standard methodology (18). Household wealth was categorised into quintiles (poorest, poorer, middle, richer, or richest). Exclusive breastfeeding was defined for all children in the first 6 months and was assessed from the question: "Are you currently breastfeeding (name of the child)?". A "yes" response led to further questions on additional food and liquid given to the child in the past 24 hours. We categorised children as exclusively breastfed if they had been breastfed in the 24 hours preceding the survey and had not been fed any other type of food. Maternal smoking in the DHS is assessed via questionnaire. Participants were asked four questions which are answered either "yes" or "no" regarding current cigarette, pipe or other country specific tobacco usage. We classified any "yes" response to the use of smoking products as "maternal smoking", creating a binary variable. The DHS recorded birth weight in kilograms according to health card records or mother's recall. As per WHO classification, birth weight was categorised as LBW (<2500 g) and NBW (≥2500 g). Regions, according to WHO categorisations, are the following: the Americas, African, European, Eastern Mediterranean, South-East Asian and Western Pacific.

Statistical Analysis

We pooled individual-level data from the DHS and created a sample grouped into a 3-level hierarchical structure. Children formed level 1, nested within communities at level 2 and countries at level 3. In order to account for the complex survey design, we used multilevel logistic regression models to estimate the association between solid cookfuel use and childhood stunting. The association between cleanliness of cookfuels (clean, moderately clean, not clean) and childhood stunting was also examined. We present adjusted odds ratios (AOR) and 95% confidence intervals (95% CI). All our models adjusted the following a priori confounders: child age, child sex, maternal education, and number of children living within the household. Random effects at level 2 and level 3 were controlled.

Interaction tests between solid cookfuel use and the subgroup (residence type, kitchen location, household wealth, exclusive breastfeeding, maternal smoking, birth weight and WHO regions) were performed by including a solid cookfuel use solid cookfuel use × subgroup interaction term in the model. We report p-values for tests of interaction as well as present subgroup specific adjusted AOR estimates. All models were adjusted for child age, child sex, maternal education, and number of children living within the household.

Our multilevel models did not weight the data, since DHS sample weights are country specific and not suitable for multilevel analysis. However, we repeated analyses using a two-stage individual participant data (IPD) meta-analysis approach (19), preserving country-specific sample weights and obtained similar OR estimates and 95% CIs.

Stata/SE version 16.1 (StataCorp, College Station, TX) was used for data cleaning and preparation. Multilevel models were run in MLwiN 3.05 using the runmlwin program in Stata 16.1 Multilevel model parameters were estimated using iterative generalised least squares and marginal quasi-likelihood algorithms.

Results

Datasets from 2000 to 2018 DHS were available for 69 LMICs. Of these, 59 (86%) country datasets included data on self-reported primary fuel used for cooking and HAZ, and were included in our analysis. According to WHO regions, the following number of LMICs were included in our analysis, 41 out of 45 in Africa; 3 out of 16 in Eastern Mediterranean; 3 out of 20 in Europe; 7 out of 25 in the Americas; 4 out of 11 in South-East Asia; and 1 out of 18 in Western Pacific.

577,348 children were eligible for inclusion in our analysis (Fig 1). Of these children, 20,233 (3·5%) were excluded due to missing (n=12,959) or implausible (n=6,761) data on height-for-age, and missing data on reported cookfuel type (n=513). A further 17 children were excluded due to missing values for maternal education. The analytic sample was based on the remaining 557,098 children (96% of the total eligible population).

The mean child age was 29 months (range 0-60) and 51·2% (n=285,188) were boys (Table 1). A total of 34% of children were stunted (ranging from 7·9% in the Dominican Republic to 54·6% in Burundi). The most common cookfuel used in households was wood (55·0%) (Supplemental Table 1). The majority of children (72·0%) lived in households using solid cookfuels (Fig 2) ranging from 0·0% in Jordan to 99·9% in Sierra Leone (Supplemental Table 1 and Supplemental Table 2). Regionally, the proportion of children living in households using solid cookfuels was highest in Africa (46·8%) and lowest in Europe (0·9%) (Fig 2).

Children living in households using solid cookfuels were more likely to be stunted (AOR: 1·58, 95% CI: 1·55 – 1·61; p<0.0001) than children living in household not using solid cookfuels (Fig 3). Less clean cookfuels were associated with increasing odds of childhood stunting in a monotonic and linear manner ($p_{trend} < 0·0001$) (Fig 3).

Analyses were repeated for subgroups according to urban/rural residence, location of kitchen,

household wealth, exclusive breastfeeding, maternal smoking, birth weight, and WHO regions (Figs 4 and 5). Children living in households using solid cookfuels were more likely to be stunted if they were living in rural areas (p-interaction=0·004), lived in the poorest household (p-interaction=0·019), belonged to a mother who smoked tobacco (p-interaction=0·0001), were low-birth weight babies (p-interaction=0·010), and living in the Americas (p-interaction=0·003).

Discussion

To the best of our knowledge, this is the largest analysis of solid cookfuel use and child stunting to date, covering over half a million children in 59 LMICs. Our findings demonstrated that children who lived in households primarily using solid cookfuels were more likely to be stunted, with an increased likelihood of stunting with increasing exposure to solid cookfuels.

The evidence base on the association between solid cookfuel use and stunting in children aged 0-5 years has been limited and inconsistent (13, 20). Bruce et al's (13) systematic review and meta-analysis indicated that children exposed to household air pollution from solid cookfuels were more likely to be stunted. However, this was based on only three studies - two were based on data from India and the other using Demographic Health Survey data for seven countries. Vilcins et al's (20) systematic review identified the same three studies with an additional study the review identified conducted in Swaziland (21). This analysis reported no association between exposure to solid cookfuel use and child stunting. Using cohort data from the first (2002) and second waves (2006–07) of the Young Lives Study in Ethiopia, India (Andhra Pradesh), Peru and Vietnam, Upadhyay et al (22) examined the association between use of solid cookfuels and child growth among children aged 5–76 months. This analysis demonstrated a significant reduction in the average height-for-age z-score (HAZ) score

between the two waves in all countries except Ethiopia. However, the YLS sampling populations were not representative, and their measures of association should be interpreted with caution. None of these studies have comprehensively examined how the association between solid cookfuel use and stunting in young children might vary. This is important because the mix of solid cookfuels varies by household socioeconomic characteristics and location (17), and maternal tobacco smoking or poor breastfeeding practices may also influence young children's growth (23).

Our analyses showed consistently that solid cookfuel use increased the likelihood of childhood stunting in LMICs. However, the subgroup analyses suggested the magnitude of association varied according to subgroups. For example, we found children living in households belonging to the lowest wealth quintile or households in rural areas using solid cookfuels were more likely to be stunted. Poorer households or those in rural areas, are known to heavily rely on solid fuels for cooking (24). This is associated with a variety of reasons, including the cost of transitioning from solid cookfuels to modern, safe, and efficient cookfuels (i.e. moving up the “energy ladder") (25). Our analysis also found that children who lived in households using solid cookfuels and had mothers who smoked tobacco were more likely to be stunted. Second-hand tobacco smoke is known to contain harmful pollutants which are reported to delay skeletal development (26). Therefore, solid cookfuel use and tobacco smoke combined could lead to a greater likelihood of child stunting. Stratified estimates of the association by birth weight were very similar and not viewed to be clinically significant.

Solid cookfuel use may impede children's growth through several mechanisms that reflect either a direct effect of airborne particulate exposure on growth or indirectly through increased morbidity. Household solid-fuel combustion produces relatively high levels of polycyclic aromatic hydrocarbons which have been recognized as endocrine-disrupting chemicals,

compromising endocrine system processes involving growth hormone and insulin-like growth factors (12). Children living in households using solid cookfuels are also more likely to develop acute respiratory infections (10). Repeated episodes of respiratory infections can impair growth, through increased metabolic requirements, anorexia and reduced dietary intake, increased catabolism and deranged metabolism of key nutrients (9).

This analysis has several limitations, which should be considered when interpreting our findings. First, DHS are cross-sectional and therefore it was not possible to establish a temporal relationship between solid cookfuel use and child stunting. Second, while reporting solid cookfuels is a good proxy for exposure to smoke from cooking (27), future studies should be designed to conduct complex exposure assessments. Better quantification of exposure to solid cookfuel combustion products will be necessary for an improved understanding of the exposure–response relationships. Third, there is also the possibility of exposure misclassification from household air pollution to outdoor air pollution through cross-ventilation. However, use of solid cookfuel stoves in the household are typically for hours and result in higher exposure to household air pollution than from outdoor sources (28). Fourth, several of the subgroup analyses should be viewed with caution due to missing confounder data. Finally, although our analysis controlled for several confounders, there is always potential for residual confounding. A few of the variables (such as birth weight and maternal smoking), included in the subgroup analyses, may be subject to measurement error, reducing the statistical power of these analyses. In particular, the measurement of birth weight in the DHS is either from health card records or mother's recall. Due to an increased likelihood of non-facility births in LMICs, most birth weight data are from mother's recall. There is a risk of misreporting from mothers due to heaping or an inability to recall the exact birth weight. However, in the absence of more complete and accurate data, the variable included in this analysis is the most appropriate measure of birth weight. The DHS does not have appropriate measures for dietary

intake and disease. We were therefore unable to examine whether these modify the association between solid cookfuel use and child stunting.

Despite these limitations, our analysis has several strengths. First, our estimates for the associations between solid cookfuel use and child stunting are based on a large and diverse sample of children from 59 nationally representative household surveys that followed standardised procedures for reporting use of solid cookfuels. Second, we had unprecedented power and precision to examine solid cookfuel use and child stunting in LMICs and additionally examine how the association varies by subgroups.

The World Health Assembly (WHA) in 2012 adopted Resolution 65/6 on the Comprehensive Implementation Plan on Maternal, Infant and Young Child Nutrition, called for combined actions in nutrition, water, sanitation, and hygiene conditions to reduce childhood stunting (29). So far, stunting has been largely intractable to targeted interventions on complementary feeding, elimination of all diarrhoea in the first two years of life and water, sanitation and hygiene (WASH) (2, 3). This indicates not only the complexity of stunting but a need for a wider approach to the causes and interventions to substantially reduce the burden of childhood stunting. The WHO recent report (Air pollution and child health: prescribing clean air) highlights that the majority of children under the age of five are exposed to household air pollution in LMICs (30), however solid cookfuel use has been largely ignored by the global health community as a potentially important cause of stunting (9). Determining the causal role of solid cookfuel use on childhood stunting with randomised controlled trials will ultimately be needed to inform the national action frameworks to address the burden of childhood stunting.

Conclusion

Solid cookfuel use is associated with childhood stunting in LMICs. There is an urgent need to make policy makers in the health sector, health professionals, and communities aware of the deleterious association between solid cookfuel use and child stunting. To strengthen the available evidence, it is crucial that the evaluation of cookfuel intervention studies are extended to include child stunting.

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Table 1: Characteristics of Demographic Health Surveys

Country	Year	Children < 5 years (n)	Analytic sample (n)	Mean age, month	Living in urban area (%)	Lowest household wealth quintile (%)	No maternal education (%)	Stunting (%)
Albania	2017-18	2,762	2,459	26.2	40.6	32.9	0.9	12.9
Angola	2015-16	14,322	6,296	27.1	54.8	23.8	34.8	37.5
Armenia	2015-16	1,724	1,573	27.0	55.6	20.5	5.4	10.6
Azerbaijan	2006	2,297	1,957	27.1	46.8	25.9	1.2	27.6
Bangladesh	2014	7,886	6,416	27.3	31.8	22.3	16.1	37
Benin	2017-18	13,589	11,477	27.7	40.7	21.3	65.1	31.7
Bolivia	2008	8,605	7,685	27.7	51.4	27.9	5.5	26.5
Burkina Faso	2010	15,044	6,582	27.6	21.9	20.1	82.8	34.4
Burundi	2016-17	13,192	6,021	27.8	15.6	20.2	45.7	54.6
Cambodia	2014	7,165	4,331	28.8	27.2	24.2	14.1	32.7
Cameroon	2018	9,733	4,254	28.2	45.4	19.9	23.7	28.4
Chad	2014	18,623	9,893	29.9	20.7	19.5	72	42.8
Colombia	2010	17,756	15,935	28.2	62.9	37.4	3	14.5
Comoros	2012	3,149	2,526	28.8	33.4	27.3	46.5	28.9
Congo	2011-12	9,329	4,272	28.1	25.3	45	9.6	26.9
Cote d'Ivoire	2011-12	7,776	3,151	28.1	33.5	26.3	67.5	30.1
Dominican Republic	2013	3,714	3,067	28.3	70.1	29.5	3.4	7.9
DR Congo	2013-14	18,716	8,080	28.0	28.9	27.4	21.7	44.2
Ethiopia	2016	10,641	8,767	28.4	18.3	36	64	36.3
Gabon	2012	6,067	3,343	28.4	60.8	46.7	6.6	23.9
Gambia	2013	8,088	3,155	28.4	31.4	25.9	64.2	25.9
Ghana	2014	5,884	2,669	28.4	40.4	33	36.2	19.2
Guatemala	2014-15	12,440	11,603	28.5	34.2	27.2	18.3	46.6
Guinea	2018	7,951	3,405	28.4	28.3	25	77.4	31.1
Guyana	2009	2,178	1,616	28.5	19.1	41.8	3.4	23.8
Haiti	2016-17	6,530	5,531	28.6	28.4	30.9	20.8	21.5
Honduras	2011-12	10,888	9,656	28.5	32.9	33.8	5.9	25.6
India	2015-16	259,627	219,908	28.7	23.8	26.2	31.2	38.1
Jordan	2012	10,360	6,074	28.7	68.9	26.9	2.8	8.9
Kenya	2014	20,964	18,403	28.8	31.5	34.8	22	27.3
Kyrgyz Republic	2012	4,363	3,869	28.8	25.1	22	0	18.4
Lesotho	2014	3,138	1,248	28.9	22.6	27.2	1.4	35
Liberia	2031	7,606	3,163	28.9	31.6	35.7	47.9	31.5
Madagascar	2008-9	12,448	5,198	29.1	17.9	28.9	28.3	48
Malawi	2015-16	17,286	5,116	29.2	16.1	21.8	12.5	35.3

Maldives	2016-17	3,106	2,344	29.1	7.7	28.8	1.5	15.1
Mali	2018	9,940	8,234	29.1	24.4	19.6	72.5	26.7
Moldova	2005	1,552	1,295	29.1	51	16.5	0.6	10.5
Morocco	2003-4	6,180	5,421	28.9	43.1	27.5	65.5	23.8
Mozambique	2011	11,102	9,334	29.4	31.4	18.5	35	39.8
Namibia	2013	5,046	1,787	29.5	40.7	24.2	8.8	22.4
Nepal	2016	5,038	2,180	29.5	56.4	25.4	34	36.4
Nicaragua	2001	6,986	5,939	29.4	43.6	N/A	24.9	27.1
Niger	2012	12,558	4,896	29.4	21.7	18.2	83.3	41.8
Nigeria	2018	33,924	11,160	29.4	39	19.9	38.3	36.3
Pakistan	2017-18	12,708	3,997	29.6	45.3	21.2	52	38
Peru	2012	9,620	8,897	29.6	57.9	29	3.7	20.7
Rwanda	2014-15	7,856	3,532	29.7	21.7	24.5	14	37.8
Sao Tome and Principe	2008-9	1,931	1,585	29.9	38.6	24.2	5.7	28.8
Senegal	2018	18,904	5,856	29.8	28.9	33.3	67.2	20.7
Sierra Leone	2013	11,938	4,300	29.8	28.8	23.3	69.3	37.8
South Africa	2016	3,548	1,079	30.5	46.8	26	2	26
Eswatini	2006	2,812	2,010	29.9	21	22.3	9.5	27.1
Tajikistan	2017	6,195	5,707	30.0	32.9	17.9	2.4	18.5
Tanzania	2015-16	10,233	8,619	30.1	22.6	23.5	22.1	33.8
Timor-Leste	2016	7,221	5,851	30.0	29.4	20.2	24.8	45.7
Togo	2013	6,979	3,143	30.0	27	31.8	46	28.4
Uganda	2016	15,522	4,308	30.3	16.8	27.1	13.1	28.4
Yemen	2013	16,093	13,580	30.3	22.8	22.3	56.2	46.2
Zambia	2018	9,959	8,572	30.6	29.4	28.5	10.6	35
Zimbabwe	2015	6,132	4,773	31.5	35.9	21.9	1.1	25.9

Figure 1: Sample Selection

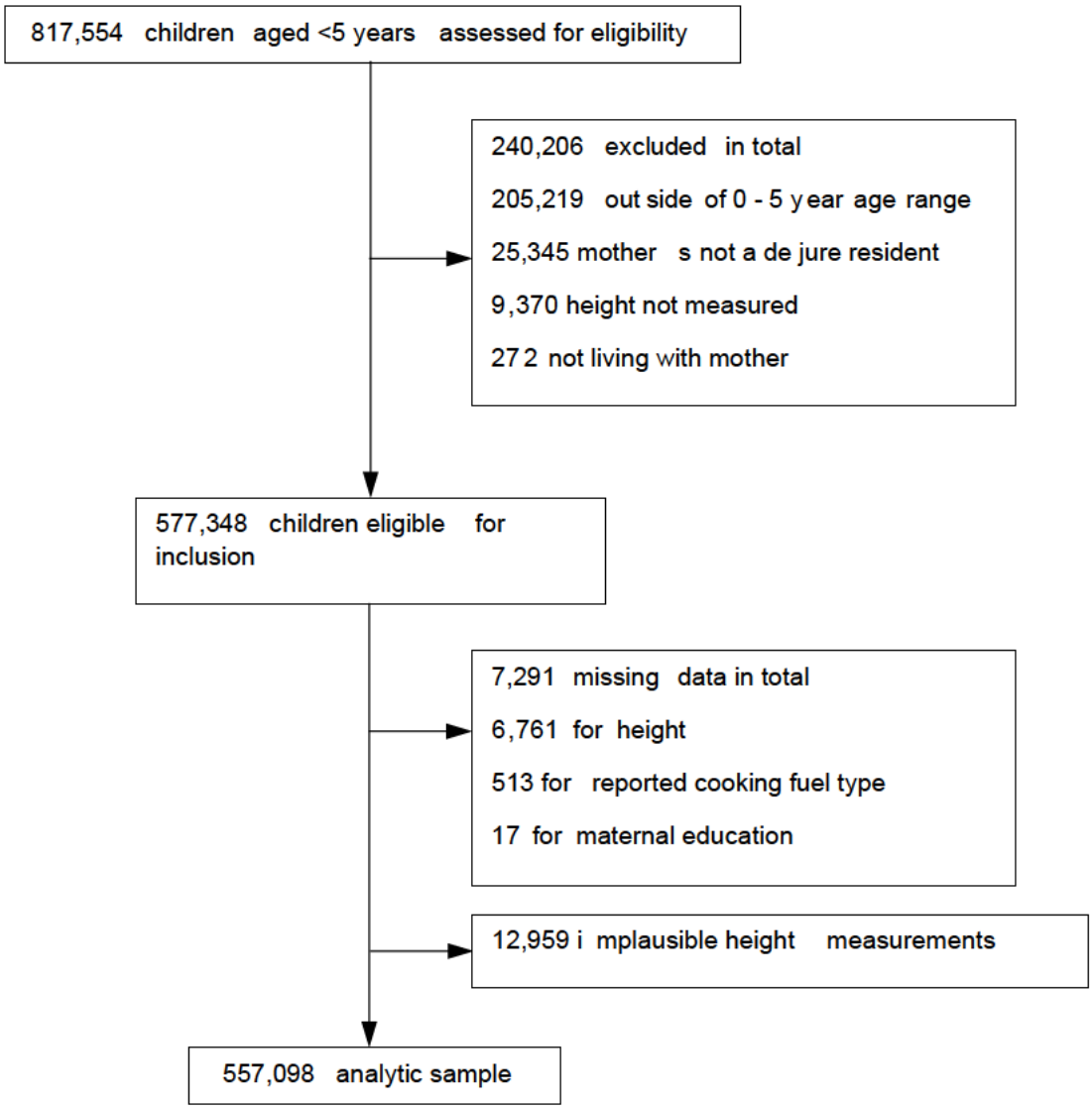


Figure 2: Proportion of children living in households using clean cookfuels by WHO Region

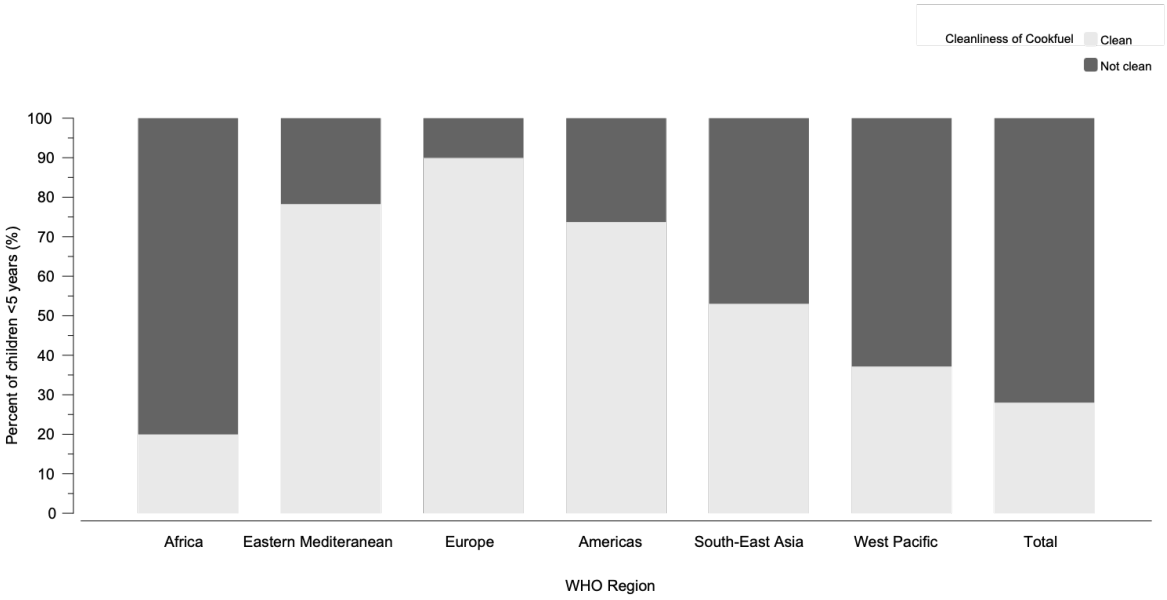


Figure 3: Association of use of solid cookfuel use and cleanliness of cookfuels with childhood stunting. Models were adjusted for child age, child sex, maternal education, and number of children living within the household. AOR, adjusted odds ratio; CI, confidence interval; HAP, household air pollution

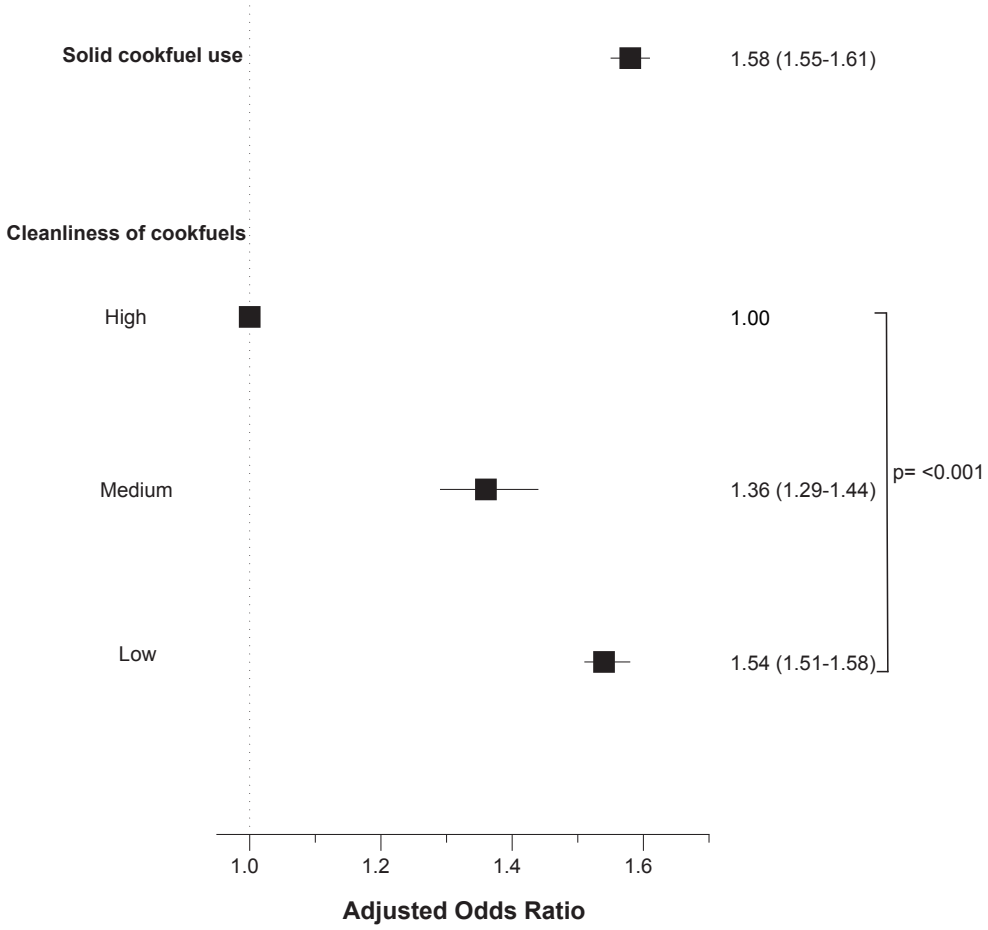


Figure 4: Association of use of solid cookfuel use with child stunting by residence type, location of kitchen and household wealth. Models were adjusted for child age, child sex, maternal education, and number of children living within the household. AOR, adjusted odds ratio; CI, confidence interval

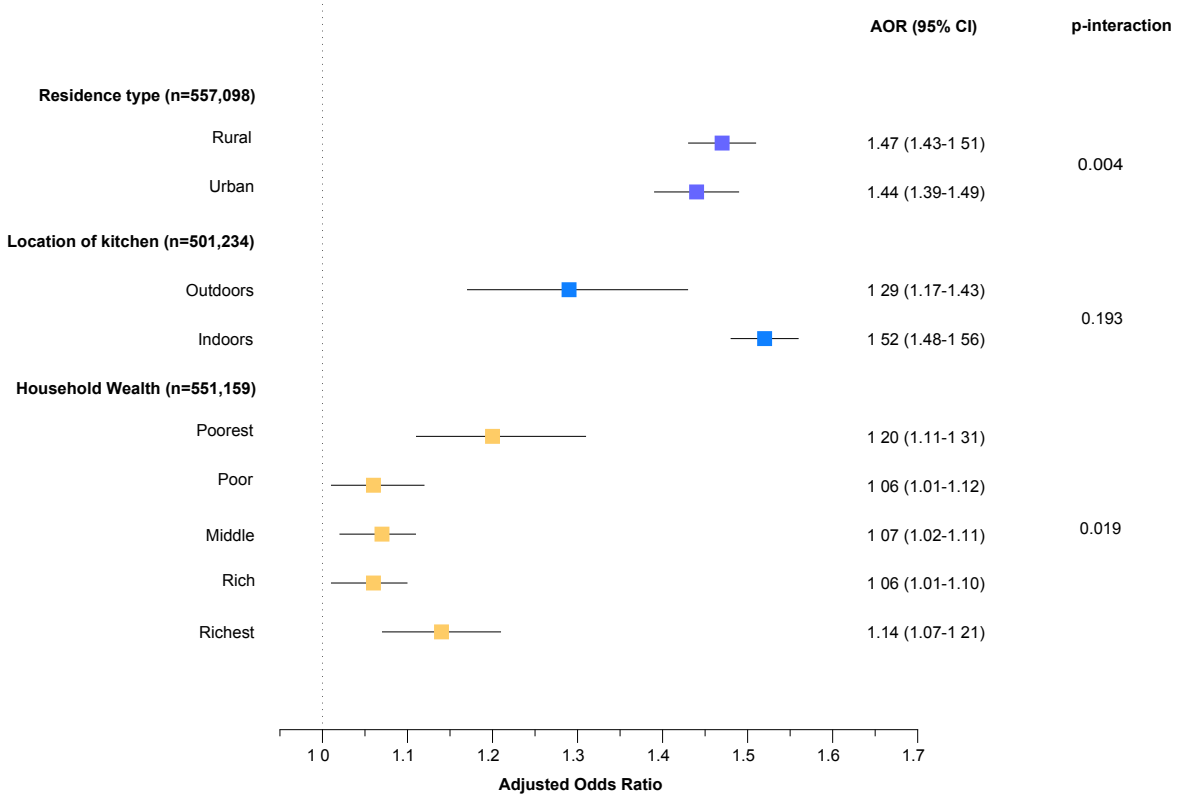
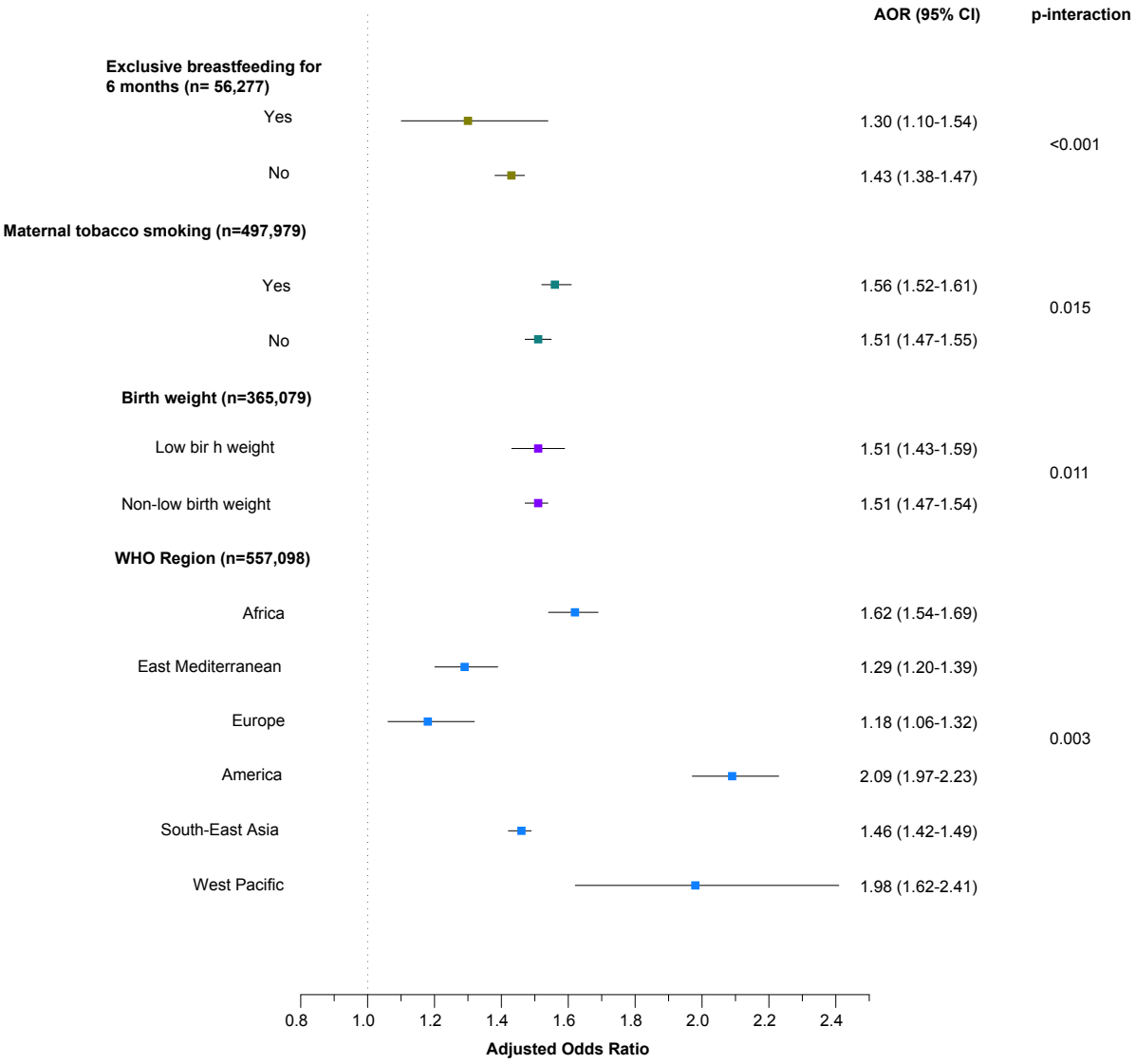


Figure 5: Association of use of solid cookfuel use with child stunting by breastfeeding status, maternal tobacco smoking status, birth weight, and region. Models were adjusted for child age, child sex, maternal education, and number of children living within the household. AOR, adjusted odds ratio; CI, confidence interval; WHO, World Health Organization



S1 Table: Primary cookfuels used in LMICs

Cookfuel type	N	(%)
Electricity	19,695	3.5
Liquefied petroleum gas (LPG)	106,953	19.2
Natural gas	8,744	1.6
Biogas	10,447	1.9
Kerosene	10,081	1.8
Coal lignite	8,252	1.5
Charcoal	45,113	8.1
Wood	306,544	55.0
Straw shrubs	8,272	1.5
Agricultural crop	8,745	1.6
Animal dung	24,100	4.3
Cardboard/paper/sawdust/woodchips	150	0.0
Other electrical source	2	0.0

S2 Table: Proportion of children exposed to household air pollution from cookfuels by country

Country	Solid cookfuel use (N, %)
Albania	952 (38.7)
Armenia	46 (2.9)
Angola	3770 (59.9)
Azerbaijan	300 (15.3)
Bangladesh	5529 (86.2)
Burkina Faso	6479 (98.4)
Benin	110.94 (96.7)
Bolivia	3071 (40.0)
Burundi	6010 (99.8)
DR Congo	7991 (98.9)
Congo	3840 (89.9)
Cote D'Ivoire	2942 (93.4)
Cameroon	3517 (82.7)
Colombia	46 (0.3)
Dominican Republic	481 (15.7)
Ethiopia	8298 (94.7)
Gabon	1164 (34.8)
Ghana	2299 (86.1)
Gambia	3145 (99.7)
Guinea	3363 (98.8)
Guatemala	8712 (75.1)
Guyana	388 (24.0)
Honduras	6805 (70.5)
Haiti	5405 (97.7)
India	153207 (69.7)
Jordan	0 (0.0)
Kenya	17204 (73.5)
Cambodia	3514 (81.1)
Comoros	2090 (82.7)
Kyrgyz Republic	1364 (35.3)
Liberia	3163 (100.0)
Lesotho	901 (72.2)
Morocco	4659 (85.9)

Moldova	151 (11.7)
Madagascar	5184 (99.7)
Mali	8151 (99.0)
Maldives	22 (0.9)
Malawi	5059 (98.9)
Mozambique	9063 (97.1)
Nicaragua	4608 (77.6)
Nigeria	8917 (79.9)
Niger	4824 (98.5)
Namibia	1263 (70.7)
Nepal	1701 (78.0)
Peru	3954 (44.4)
Pakistan	2298 (57.2)
Rwanda	3527 (99.9)
Sierra Leone	4297 (99.9)
Senegal	5211 (89.0)
Sao Tome and Principe	1319 (83.2)
Eswatini	1518 (75.5)
Chad	9649 (97.5)
Togo	3030 (96.4)
Tajikistan	944 (16.5)
Timor-Leste	5112 (87.4)
Tanzania	8462 (98.2)
Uganda	4293 (99.7)
Yemen	5177 (38.1)
South Africa	310 (28.7)
Zambia	8108 (94.6)
Zimbabwe	3285 (68.8)