Spatial variations in child undernutrition in Ethiopia:

Implications for intervention strategies

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Dissertation for the degree of philosophiae doctor (PhD)

at the University of Bergen

2016

September 16, 2016

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Dedication

I dedicate this work to a mother in Butajira who is always struggling to put something to eat on the table when her children are back from school. She knows that "good food" at this age will decide their future.

Acknowledgements

I would like to extend a special thanks to my primary supervisor Prof. Bernt Lindtjørn, whose supervisory skills are exemplary. I can bear witness to many of these exceptional skills, but will only mention a few of them, such as his ability to build a capacity for independent opinion, self-learning skills and an ability to control complexity. He does not exert a heavy control over one's thoughts and always put forth simple but challenging views. I very much enjoyed his saying: "*One message for a paper and write it in English!*"

I am also indebted to my co-supervisors Prof. Damen Hailemariam and Dr. Tasew Woldehanna, who were both highly instrumental in my PhD work. I cannot forget to mention Prof. Damen's role in my public health teaching and research career since 2006. I would like to give a big thank you to Dr. Tasew for his invaluable input and supervision in this PhD work. Thank you all, without your valuable assistance and input, the process would have been far more challenging.

I am indeed thankful to the Norwegian State Education Loan Fund for funding this PhD work. I am pleased to be one of the products of the Centre for International Health, University of Bergen. This is a place where the faculty is friendly, willing to share their experiences and be supportive for learning. I have never seen such an excellent working environment anywhere else. I shall also mention the hospitality and friendliness of the administrative staff at the Centre for International Health (CIH), in particular Ingvild Hope and Øyvind Mørkedal, for whom I have nothing but respect.

I must also extend my veneration to the Butajira Health and Demographic Surveillance Programme (BRHP) and its staff, particularly to Abiot and Mulugeta, who deserve special recognition. They were very instrumental in helping me during this extensive data collection. I must also thank the mothers in Butajira, who gave me their valuable time, and took part in the interviews with a great deal of patience and enthusiasm.

I would also like to acknowledge the school of Public Health, Addis Ababa University for supporting my PhD work. I must also extend my compliments to my mentor Prof. Mesganaw Fantahun. He is wonderful and exemplary in academics and beyond.

Last but not least as the saying goes, behind every successful PhD work there is always good support from family and parents. Had there been a criterion for an indirect but substantial contribution to a PhD work, I would have made my wife Aster Assefa a co-author. Thank you very much for this.

Summary

Background: Ethiopia is one of the countries with the highest burden of undernutrition, with rates of stunting and underweight as high as 40% and 25%, respectively. National efforts are underway for an accelerated reduction of undernutrition by the year 2030. However, for this to occur, understanding the spatial variations in the distribution of undernutrition on a varying geographic scale, and its determinants will contribute a quite a bit to enhance planning and implementing nutrition intervention programmes.

Objectives: The aim of this thesis was to evaluate the large- and small-scale spatial variations in the distribution of undernutrition indicators, the underlying processes and the factors responsible for the observed spatial variations.

Methods: We used nationally available climate and undernutrition data to evaluate the macro-scale spatial pattern of undernutrition and its determinants. We applied a panel study design, and evaluated the effect of growing seasonal rainfall and temperature variability on the macro-scale spatial variations (Paper I). We conducted a repeated cross-sectional survey to assess the performance of the Household Food Insecurity Access Scale (HFIAS) developed internationally to measure household food insecurity. The results from this validation work were used to modify the HFIAS items for subsequent papers (Papers III and IV). We conducted a census on six randomly selected *kebeles* to evaluate the spatial patterns of undernutrition on a smaller scale (Paper III). For Paper IV, we conducted a cross-sectional survey on a representative sample, and employed a Bayesian geo-statistical model to help identify the risk factors for stunting, thereby accounting for the spatial structure (spatial dependency) of the data.

Results: In Paper I, we demonstrated spatial variations in the distribution of stunting across administrative zones in the country, which could be explained in part by rainfall. However, the models poorly explained the variation in stunting within an administrative zone during the study period. We indicated that a single model for all agro-ecologic zones may not be appropriate. In Paper II, we showed that the internal consistency of the HFIAS' tools, as measured by Cronbach's alpha, was adequate. We observed a lack of reproducibility in HFIAS score among rural households. Therefore, we modified the HFAIS tool, and used it for subsequent surveys in this thesis (Papers III and IV). In Paper III, spatial clustering on a smaller scale (within a *kebele)* was found for wasting and severe wasting. Spatial clustering on a higher scale (inter-*kebele)* was found for stunting and severe stunting. Children found within the identified cluster were 1.5 times more at risk of stunting, and nearly five times more at risk of wasting, than children residing outside this cluster. In Paper IV, we found a significant spatial heterogeneity in the distribution of stunting in the district. Using both the local Anselin Moran's *I* (LISA) and the scan statistics, we identified statistically significant clusters of high value (hotspots) and a most likely significant cluster for stunting in the eastern part of the district. We found that the risk of stunting was higher among boys, children whose mother or guardian had no education and children who lived in a food-insecure household. We showed that including a spatial component (spatial structure of the data) into the Bayesian model improved the model fit compared with the model without this spatial component.

Conclusion: We demonstrated that stunting and wasting exhibited a spatial heterogeneity, both on a large and small scale, rather than being distributed randomly. We demonstrated that there is a tendency for undernourished cases (stunting and wasting) to occur near each other than to occur homogeneously. We demonstrated a micro-level spatial variation in risk and vulnerability to undernutrition in a district with a high burden of undernutrition. Identifying such areas where a population at risk lives is central in assisting a geographical targeting of intervention. We recommend further study, possibly using a trial design or implementation research approach, to help evaluate the feasibility and benefits of geographically targeting nutritional interventions.

List of original papers

This thesis is based on the following papers, which are referred to in the text by their roman numerals.

Paper I: *Seifu Hagos, Torleif Lunde, Damen H Mariam, Tassew Woldehanna and Bernt Lindtjørn*. Climate change, crop production and child undernutrition in Ethiopia: A longitudinal panel study. *BMC Public Health* 2014, **14**:884.

Paper II: *Seifu Hagos Gebreyesus, Torleif Lunde, Damen H Mariam, Tasew Woldehanna and Bernt Lindtjørn:* Is the adapted Household Food Insecurity Access Scale (HFIAS) developed internationally to measure food insecurity valid in urban and rural households of Ethiopia? *BMC Nutrition 2015, 1:2.*

Paper III: *Seifu Hagos Gebreyesus, Damen H. Mariam, Tasew Woldehanna and Bernt Lindtjørn*. Local spatial clustering of stunting and wasting among children under five years: Implications for intervention strategies. *Public Health Nutr 2015.*

Paper IV: *Seifu Hagos Gebreyesus, Damen H Mariam, Tasew Woldehanna and Bernt Lindtjørn*. Spatial heterogeneity and risk factors for stunting among children under age five: A Bayesian geo-statistical model *(under review: PLos One).*

Abbreviations

CSA	Central Statistics Authority
GDP	Gross Domestic Product
EDHS	Ethiopian Demographic and Health Survey
FANTA	Food and Nutrition Technical Assistance
FAO	Food and Agriculture Organization
HFIAS	Household Food Insecurity Assessment
HDSS	Health and Demographic Surveillance System
IYCF	Infant and Young Child Feeding
MDG	Millennium Development Goal
MMP	Multiple Micronutrient Powder
PHCU	Primary Health Care Unit
PoU	Proportion of Undernutrition
SDG	Sustainable Development Goals
TEM	Technical Error of Measurement
UN	United Nations
UNICEF	United Nations International Education Fund
USAID	United States of America International Aid
WHA	World Health Assembly
WHO	World Health Organization
WMS	Welfare Monitoring Survey

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Chapter I: Introduction

Global burden of undernutrition

Malnutrition is a condition resulting from either an insufficient or excessive intake of various nutrients. It is a broad term that includes both undernutrition and overnutrition. This thesis focuses on the undernutrition aspect of malnutrition. Globally, significant numbers of people are affected by malnutrition (undernutrition). The Food and Agriculture Organization (FAO) estimated that undernutrition affected approximately 795 million people in 2014-16 [1,2]. The prevalence of undernourishment (PoU) and underweight among children under age five were primarily used internationally to measure and compare the burden of undernutrition (hunger)[2].

The global trend in undernourishment has shown a substantial improvement [3]. For example, the prevalence of undernourishment (PoU) has decreased globally from 18.6% in 1900-92 to 10.9% in 2014-16. The total number of people undernourished in developing countries significantly decreased from 990 million people in 1990-92 to 789 million people in 2014-16. However, a closer look at the change in the proportion of undernourishment over the years tells us that this has not changed in developing countries. There is a wide variation in PoU among regions. Two regions, southern Asia and Sub-Saharan Africa account for approximately 35.4 % and 27.7% of the shares of global undernourishment, respectively [2]. Next to southern Asia, Sub-Saharan African countries, especially eastern African countries, have the highest burden (share) of undernutrition than any region in the world. The continent of Africa has not shown good progress in terms of reducing the prevalence of undernourishment compared to Asia and Latin America. The prevalence of undernourishment for Africa has only fallen by 14% since 1990–92 compared to a fall of 48% and 62% in Asia and Latin America, respectively.

Globally, the prevalence of stunting (height-for-age Z-score of less than –2SD) has declined by 36%, from 47% in 1985 to 30% in 2011 [1]. Current estimates show that the stunting prevalence is 23.8% globally, with approximately 159 million children affected [4]. Within a similar period, the prevalence of underweight (weight-for-age Z-score of less than –2SD) has decreased by 35%, from 30.1% to 19.4%, with more than 100 million children being underweight [3]. Substantial improvements were documented in Asia, Latin America and the Caribbean. The corresponding estimate for wasting (weight-for-height Z-score of less than –2SD) is approximately 52 million children [3].

Nutrition situation in Ethiopia

Undernutrition and food insecurity, secondarily to poor or untimely rainfall, are significant concerns in Ethiopia, which has been repeatedly affected by famine since the 9th century [5,6]. Most of these famines were preceded by droughts and a failure of rains during the main growing season, as the famines decline after the arrival of rains [7,8]. The major reported famines in Ethiopia in the recent period include the *Wollo* Famine in 1973, the famine of 1984/85 and the emergency crisis in 1999/2000 [6]. Even in 2015, the failure and irregularities of rains during the main growing seasons of June, July, August and September (JJAS) has resulted in an emergency crisis within the country. The government of Ethiopia has appealed for emergency food assistance support for roughly 10 million people residing in certain parts of the country.

Ethiopia has one of the highest number of undernourished people among the countries in eastern African countries, with an estimated 31.4 million people undernourished in 2014 [2]. However, the country has demonstrated a significant decline in the prevalence of undernourishment over the period from 1990-92 to 2014-16. For example, the proportion of undernourished people in Ethiopia had declined by 57.2% percent from 74.8% in 1990-92 to 32% in 2014-16 [2].

Undernutrition is still one of the major public health problems in Ethiopia, particularly affecting a significant number of children and women as the most vulnerable groups. The country faces a high burden of both macro- and micronutrient malnutrition, including high rates of stunting, wasting, underweight, chronic energy deficiency, iron deficiency anaemia (IDA), vitamin A deficiency (VAD) and iodine deficiency disorder (IDD).

The most common macronutrient deficiencies in Ethiopia include stunting, wasting and underweight among children under age five, as well as a chronic energy deficiency among women of a reproductive age group. The rates of stunting and underweight have decreased over the past 15 years [9-12] , but remain high, with 40% of children under age five stunted and 25% underweight. The country has documented a 31% decline in the prevalence of stunting, from 58% in 2000 to 40% in 2014 [9-12]. The prevalence of underweight has decreased by 39%, from 41% in 2000 to 25% in 2014. The progress in the reduction of stunting and underweight prevalence is not uniform across the regions, and pocket studies indicated a significant variability in the magnitudes within the country [13-29].

The existing national and states level prevalence of stunting is still considerable. Based on the WHO recommended criteria for assessing the severity of stunting by prevalence range at the population level, five of the nine regions in the country are classified under a very high severity (>40% prevalence), while the remaining four regions were classified as having a medium to high severity (prevalence range of 20-40%)[30].

Micronutrient deficiencies among children under five are also among the nutritional problems of public health importance. Vitamin A, iron and iodine deficiencies greatly contribute to the burden of childhood morbidity and mortality. The burden of anaemia among children is high in Ethiopia. According to the 2011 Demographic and Health Survey, nearly half (44%) of children under five in Ethiopia are anaemic (Table 3). In the most vulnerable age group from six to 23 months, anaemia rates are as high as 52-73% (Table 1).

Breastfeeding and complementary feeding practices are essential to help meet the nutritional needs of children in the first years of life. In 2008, the World Health Organization (WHO) put a core set of eight indicators (i.e. three breastfeeding and five complementary feeding) to help measure the appropriateness of feeding practices among children six to 23months [31]. The eight core indicators include the initiation of breastfeeding, exclusive breastfeeding and continued breastfeeding for at least one year, the introduction of complementary foods, a minimum dietary diversity, a minimum meal frequency, a minimum acceptable diet and the consumption of iron-rich or iron-fortified foods.

Reports for Ethiopia showed that breastfeeding is nearly universal, with 98% of children being breastfed at some time in their early years. Exclusive breastfeeding has improved slightly from 49% in 2005 to 52% percent in 2011. Breast milk or other liquids alone are not sufficient to meet the energy and nutrient requirements of infants older than six months of age. Hence, only 4% of children from six to 23 months are fed in accordance with infant and young child feeding practices, and 49% are fed at least a minimum number of times a day. It is disconcerting to note that only 5% of children were found to be fed according to minimum standards with respect to food diversity (four or more food groups). In summary, contrary to the WHO recommended criteria of infant and young child feeding practices, the national feeding practices are suboptimal, characterized by inadequate breastfeeding, delayed complementary feeding for infants or an inadequate quality or quantity of complementary feeding, in addition to a poor consumption of vitamin A-rich or vitamin A-fortified foods.

Table 1: Major indicators for maternal and child nutritional status derived from the 2005, 2011 and 2014 Demographic and Health Surveys

Indicator	**2005 DHS**	**2011 DHS**	**2014 EDHS**
Stunting among under-five children	51%	44%	40
Underweight among under-five children	33%	29%	25
Wasting among under-five children	12%	10%	9
Early initiation of breastfeeding	69%	52%	n/a
Exclusive breastfeeding practice	49%	52%	n/a
Continued breastfeeding at one year	n/a	96%	n/a
Introduction of complementary foods	50%	49%	n/a
Minimum dietary diversity	n/a	5%	n/a
Minimum meal frequency	n/a	48%	n/a
Minimum acceptable diet	n/a	4%	n/a
Children consuming iron-rich foods	10%	13%	n/a
Anaemia in children under five	54%	44%	n/a
Children provided with vitamin A	50%	53%	n/a

supplements			
Children consuming vitamin A-rich foods	24%	26%	n/a
Families have access to iodized salt	20%	15%	n/a
Anaemia in women of reproductive age group (14-49 years)	27%	17%	n/a
Post-partum mothers provided with vitamin A supplements	20%	16%	n/a
Chronic Energy Deficiency among women (BMI less than 18.5 kg/m2)	26.5	27	n/a

The Ethiopian government has responded to the existing situation by devising relevant programmes such as the National Nutrition Strategy (NNP) and implementation plans, as well as mobilizing human- and other resources. The Federal Ministry of Health (FMOH) has taken several measures, which include putting in place enabling policies and implementing a range of nutrition programmes aimed at preventing and mitigating the consequences of malnutrition. One of the most recent measures includes the *Seqota* Declaration, and the subsequent health sector transformation plan. The Federal Ministry of Health of Ethiopia, declared on 15th July 2015 that they intended to use all available resources to end child malnutrition by 2030, which was communicated at the launch of the *Seqota* Declaration. The components of this declaration among others includes zero stunting in children less than two years and universal access to adequate food all year round and

The five-year health sector growth and transformation plan for Ethiopia also planned to reduce the prevalence of childhood stunting among children under five from 40% in 2015 to 26% in 2020, wasting from 9% in 2015 to 4.9% in 2020 and underweight from 25% in 2015 to 13% in 2020 [32].

Childhood undernutrition and determinants

The UNICEF conceptual framework dates back to 1990 [33], and remains one of the most extensively used and prominent frameworks for understanding the determinants of undernutrition among children. Recent adaptations of the UNICEF framework have been made by the Lancet Maternal and Child Nutrition Series entitled: "*Framework of the relations between poverty, food insecurity, and other underlying and immediate causes to maternal and child undernutrition and its short-term and long-term consequences*" [3,34], and the WHO conceptual framework entitled: "*Childhood Stunting: Context, Causes and Consequences*" [35]. These frameworks describe how children's nutritional status is influenced by household and family factors, inadequate complimentary feeding and breastfeeding, infections and the interrelationships between these factors and community and societal factors operating at different levels, in addition to the long-term consequences.

Immediate causes

The most important immediate factors contributing to children's undernutrition include dietary intake and diseases. Inadequate breastfeeding and complementary feeding practices in the first two years of life have a profound effect on children's nutritional status (stunting)[36].

Suboptimal breastfeeding, including a delayed initiation of breastfeeding and non-exclusive breastfeeding, are the major problems linked to child undernutrition. Suboptimal breastfeeding, especially the absence of exclusive breastfeeding, is responsible for approximately 10% of disease burden in children under age five [34]. Observational studies have indicated that children who have been breastfed for less than two years, and with pre-lacteal feeding, were more likely to be stunted [18,23,25,26]. The quality and quantity of complementary food that children receive after six months of age negatively impact the linear growth of infants and young children [14,17,19,36,37]. Moreover, dietary diversity and recommended complementary feeding practices were found to be significantly associated with reducing the odds of stunting in younger children [19,38].

Infectious diseases arising from respiratory illnesses [39], malaria [40] and diarrhoea [39-41] during the period of growth and development (6-59months) are also important proximal determinants of growth faltering [34,42]. Black *et al*. quantified the contribution of diarrhoea to the risk of stunting. They found that the risk of stunting attributable to diarrhoea increased by a factor of 1.05 for each episode of diarrhoea in the first 24 months [34]. Checkley *et al.* also estimated that children affected by diarrhoea 10% of the time in the first two years were 1.5cm shorter compared to those children with no diarrhoea [41]. At the individual level, stunting prevalence is higher in boys than girls [3] and in older age groups.

Underlying and basic causes

The underlying factors for child undernutrition include household and family factors, household food security, child care, household environment (access to water and sanitation) and lack of basic health services [3,33-35]. Household food insecurity as one of the underlying factors is associated with stunting, and a larger difference in the prevalence of stunting by household food insecurity status is noted [14,16,21-23,25,43].

Household economic inequalities and its relation to child undernutrition (stunting) is a controversial issue. Some studies have shown the potential of improved household income in improving access and the consumption of goods and services, which in turn improves undernutrition [3,13,22,44] . Others indicate that income at the household level might not necessarily help to improve stunting, and reported a weak relation between income growth and undernutrition at the household level [45-47]. The mother's education, which is a modifiable household factor, is a key predictor of linear growth and stunting [17,23,29,35,48,49]. A better maternal educational status might improve child caring practices related to stunting, or could help to understand and respond to nutrition-based educational messages, as well as helping to adopt optimal complementary feeding and household dietary behaviours [49].

At the basic level, the political economy of nutrition, namely the political, social, economic and ideological factors, play an important role. These factors determine the structural knowledge and power relationships within the community [50]. Good governance, as reflected through a receptiveness to people's needs, priorities and political stability, was shown to create an enabling environment for public services for improved child undernutrition [51].

Climate and undernutrition

In a broader context, the environment, particularly climate change, is an important basic cause that exacerbates childhood undernutrition [35]. With its potential to disrupt weather patterns, change rainfall distribution and increase temperatures, climate change has been one of the critical threats to food security and child undernutrition, and especially for stunting. For example, in a study conducted in Mali, areas with lower precipitation and temperature (arid climates) were found to negatively influence stunting [52].

Recently, a number of studies have attempted to project the impacts of climate change on food and nutritional security, and subsequently on malnutrition and child health [53-56]. Climate change impacts food security through multiple pathways. These include altering the availability of food [57] and influencing the stability of food supplies due to extreme weather events, and through influencing access to food and utilization [58]. Lobell *et al.* indicated that the production of maize would decline by 3.8% globally, while the production of wheat would decline by 5.5%. Furthermore, the impact on global food prices was estimated to cause an increase in the average price of commodities by 18.9% and 6.4%, respectively [57,59]. Climate change will also affect the ability of individuals to use food effectively by altering the conditions for food safety and food security [60]. Fischer et al. estimated that by 2080 the magnitude of undernourished people would increase by 5-26% when compared to a baseline with no climate change under a moderate emissions scenario and by 120-170 million people under a higher emission scenario [53,54]. Funk et al. projected a 23-53% increase in the number of malnourished people between 2000 and 2030 under three different scenarios [61].

Impacts of undernutrition

The impact of childhood stunting later in life is a result of either being a direct consequence of being short in height at adulthood or as a product of the underlying process at childhood leading to adverse octomoms later in life [36]. Victoria *et al.* have reviewed the long-term effect of stunting during childhood. The authors showed that stunting during childhood resulted in poor school performance, cognitive development, short adulthood stature and a poor income at adulthood [62].

Studies from Guatemala and Zimbabwe indicated that poor growth during early childhood is associated with shortness at adulthood [63,64]. Children with better nutrition and linear growth during childhood were 13 times more likely to have better educational achievements [65] and more likely to perform better in terms of the number of grades of schooling completed [64], in addition to improving maternal schooling by 1.2 grades [66]. The role of poor nutrition on economic returns and losses are well understood [36,62,64,67-70], as a shorter status influences productivity at adulthood, thereby affecting the lean body mass [34]. This is particularly true in countries where jobs are highly labour-intensive. Taller men and women were found to earn more as compared to shorter men and women [36], as the impact of undernutrition goes beyond the individual level to affect national income. A report from a study on the cost of hunger from four African countries, Egypt, Ethiopia, Swaziland and Uganda, indicated that Ethiopia is losing more than 2.5 billion USD (in 1999), which is approximately 16.5% of the country's GDP secondary to undernutrition [71]. Further research is needed to examine the pathways (mechanisms) through which stunting in early life brings about long-term problems in productivity , cognitive performance and schooling [36].

Interventions for improved child undernutrition

Currently, the first two years of life (1,000-day approach) is widely accepted as the window of opportunity to combat child undernutrition and its long-term effects. The first such evidence was brought forth from a study in Guatemala by Schroeder *et al*. The authors indicated that the impact of nutritional supplementation was highest for children in the first three years of life [72]. Subsequent research efforts support the idea of the highest growth faltering in the first two years of life, thus suggesting that nutritional interventions need to focus on the first 1,000 days to help avert growth faltering and prevent childhood stunting [73,74]. Recently, Leroy, *et al.* indicated that the window of opportunity for interventions against stunting could possibly go beyond two years [75,76]. This goes against the common understanding that interventions beyond this period do not have an effect on- or a potential for catch-up growth [13,77].

Within the broader approach of the first 1,000 days, interventions aiming at improving child nutrition can be broadly categorized into two namely prenatal and postnatal nutritional interventions. The former is aimed at improving growth faltering occurring in utero, while the latter focuses on beyond the postnatal period [78].

The Maternal and Child Undernutrition Study Group (Bhutta *et al*. 2008; Bhutta *et al*. 2013) reviewed the effectiveness and feasibilities of various interventions that affect both maternal and child nutrition [79,80]. These were interventions to improve general nutrient intake such as balanced energy and protein supplements during pregnancy, the promotion of breastfeeding, complementary feeding interventions, micronutrient interventions such as food fortification with micronutrients, supplementation with iron folate or iron, dispersible micronutrient preparations, Vitamin A, zinc, iodine and Multiple Micronutrient Powder (MMP) supplementation and delayed umbilical cord clamping, disease prevention strategies such as hygiene and sanitation measures and deworming, and general nutrition support strategies such as conditional cash transfers and dietary diversification strategies.

Evidence regarding the impact of optimal breastfeeding practices such as an early initiation of breastfeeding and exclusive breastfeeding up to six months on the linear growth of children is not conclusive [3,79,80]. Complementary feeding (CF) interventions employ multiple approaches, including nutritional education or provision/modification of complementary foods or a combination of these. Evidence indicates that interventions employing only nutritional education strategies with the aim of improving complementary feeding practices in food insecure areas are not successful in relation to their impact on linear growth [78,81]. However, in food-secure areas where access to food is not a major problem, nutritional education has the potential to improve the linear growth of children. This finding was noted from a study in Peru. Penny *et al.* showed that children who were not given nutritional education were three times more likely to be stunted compared to those with educational intervention [82]. In summary, nutritional education has a modest effect on the linear growth of children [81,83,84].

Complementary food provision alone, or with nutritional education, thereby improving the energy density or fortifying them with micronutrients, has also been shown to have a modest effect on the linear growth of the children [81]. The effectiveness results indicated that not all CF interventions, which theoretically seem, plausible, could bring the anticipated results. We affirm that there are still gaps in our collective knowledge regarding proven intervention for improving the linear growth of children in various contexts.

The impact of single or multiple prenatal micronutrient supplementation programmes on the linear growth of children has been examined in different studies [85-94]. Multiple Micronutrient (MMN) supplementations resulted in significant impact of small gestational age and low birth weight [79,95-97]. However, the impact of MMN on the linear growth of children is not well documented.

Child undernutrition in the post-MDG

Globally, four major initiatives and commitments were set by the international bodies (WHO and UN) to reduce hunger and undernutrition. The first one was launched in 1996 in Rome, the second at the United Nations Millennium Summit in 2000, the third in May 2012 at the 65th World Health Assembly (WHA) meeting and the fourth at the UN General Assembly on 25 September 2015. The one launched in 1996 in Rome was at the world food summit, which committed "…*to eradicate hunger in all countries, with an immediate view to reducing the number of undernourished people to half their present level no later than 2015*".

In 2000, the world leaders' assembly at the United Nations Millennium Summit developed a worldwide development agenda against poverty [98], which was subsequently shaped into eight Millennium Development Goals (MDGs). The first MDG goal aimed to: *"Halve, between 1990 and 2015, the proportion of people who suffer from hunger."* Out of the 129 developing countries, only 72 countries reached MDG 1(hunger target)[2,99]. An evaluation of the MDG targets worldwide showed that, despite significant improvements in many of the targets, there is an uneven progress across regions and countries. Targeted efforts might be necessary to avert this uneven progress, and reach the most vulnerable people in both regions and countries [68].

In May 2012, the 65th World Health Assembly (WHA) meeting endorsed *a Comprehensive Implementation Plan (2012–2025) on Maternal, Infant and Young Child Nutrition*[100] (Table 2). This plan adopted six global targets on low birth weight, anaemia, stunting, wasting, overweight and breastfeeding. The global target by the World Health Assembly sets a 40% reduction in the number of children under five who are stunted. de Onis *et al.* indicated that country-level national targets may be needed to be set that take into consideration current levels, demographic trends, the status of the health system functioning and coverage and experiences with interventions [78].

Table 2: World Health Assembly nutrition targets, 2012

Target	Baseline (baseline year)	Target for 2025
40% reduction in the number of children under age five who are stunted	162 million (2012)	100 million
50% reduction of anaemia in women of reproductive age (pregnant and non-pregnant)	29% (2011)	15%
30% reduction in low birth weight	15% (2008-2012)	10%
No increase in childhood overweight	7% (2012)	7%
Increase the rate of exclusive breastfeeding in the first six months up to at least 50%	38% (2008-2012)	50%
Reduce and maintain childhood wasting to less than 5%	8% (2012)	<5%

Sustainable Development Goals

The resolution adopted by the General Assembly on 25 September 2015 sets 17 Sustainable Development Goals (SDG) and 169 targets [99]. These goals and targets are based upon the MDGs, and aimed at fulfilling the gaps that MDGs failed to achieve. The second SDG goal focused on ending hunger achieves food security and improved nutrition, and promotes sustainable agriculture. The two targets within the second goal, which are closely linked to undernutrition include:

- *"By 2030, end hunger and ensure access by all people, in particular the poor and people in vulnerable situations, including infants, to safe, nutritious and sufficient food all year round "*
- *"By 2030, end all forms of malnutrition, including achieving, by 2025, the internationally agreed targets on stunting and wasting in children under 5 years of age, and address the nutritional needs of adolescent girls, pregnant and lactating women and older persons"*

Rationale for this thesis

Developing countries are disproportionately affected by a high burden of childhood undernutrition [2,68,78,101]. Sub-Saharan African countries such as Ethiopia have a larger share of the global burden of undernutrition [2,68,78]. Understanding the spatial distribution of undernutrition in Ethiopia and its determinants are of paramount importance for intervention designing and implementations. Despite this, the spatial structure of undernutrition at varying geographic scales is not well understood.

We used nationally available data to evaluate the large-scale spatial pattern of undernutrition (stunting, wasting and underweight) (Paper I). We also looked at the role of climate variables (rainfall and temperature) on the spatial structure of childhood undernutrition, as children are highly vulnerable to the effects of climate changes [102-107]. Evaluating the role of climate was necessary, particularly for a country like Ethiopia, with a history of repeated famine [6] and food shortages secondary to failure or irregularities in rain [7,8,108]. Therefore, understanding the effects of climate change on children's nutrition will provide important and relevant information for policy actions, and be used to design appropriate programmes for areas impacted by climate change.

Spatial methods have been used in dealing with public health problems [109-117] as input for the geographical targeting of locations and the optimizing of interventions [118-122]. We employed spatial tools (Papers III and IV) and evaluated their applicability in the area of child undernutrition. The result of the spatial analysis would be helpful in improving our understanding of the distribution of undernutrition indicators on different scales, in addition to the applicability of this approach to enhance planning and implementing targeted nutrition intervention programmes.

Food insecurity is among the most important determinants of child undernutrition. Because household food security is a complex, multidimensional measure, assessing household food insecurity is a big challenge. There is lack of a method for differentiating households with varying degrees of food insecurity. We validated the HFIAS tools developed internationally to measure the access component of household food insecurity in order to bridge the gap on the limitations related to the unavailability of the locally valid food security assessment tool (Paper II). Evaluating the applicability of the HFIAS tool is important in order to classify, target and evaluate interventions aimed to improve a given household's food insecurity.

Chapter 2: Objectives

General objectives

The overall aim of this study was to evaluate the spatial (geographic) variation in risk to undernutrition, and to identify factors that influence the spatial distribution of undernutrition among children under age five in Ethiopia.

Specific objectives

Paper I

The aim of Paper I was to examine the large-scale spatial variation of underweight, wasting and stunting, and to evaluate the impact of growing season temperature and rainfall on the spatial distribution of child underweight, wasting and stunting.

Paper II

The aim of Paper II was to evaluate the performance of the Household Food Insecurity Assessment (HFIAS) tool among the rural and urban households of the Butajira District in Ethiopia.

Paper III

The aim of Paper III was to evaluate the clustering of stunting and wasting among children under age five in relation to different scales. Furthermore, it aimed to evaluate whether the observed clustering is due to a non-random distribution of known risk factors or spatial dependence.

Paper IV

The aim of Paper IV was to identify the risk factors for stunting and severe stunting in a rural area of Ethiopia. Furthermore, it aimed to examine the effect of accounting for the spatial structure of the data on the performance of the model.

Chapter 3: Methods

Ethiopia

Ethiopia is located in the horn of Africa, with a total land area of 1.1 million square kilometres. Ethiopia is the second most populous country in Sub-Saharan Africa, with an estimated total population of approximately 100 million, with more than 80% of the population living in rural areas. Ethiopia has one of the world's lowest-incomes, with an estimated per capita income of USD 550 per year [123].

The country is administratively divided into nine regional states and two city administrations. The administrative regions are further divided into zones and districts. Ethiopia's health-care system is currently restructured into a three-tier delivery system (Figure 1). The first level is a primary health-care unit (PHCU) at the district level. The PHUC is composed of a district hospital (covering 60,000-100,000 people), health centres (covering a population of 15000-25,000) and health posts (covering a population of 3000-5000), all of which are linked through a referral system. The country's health extension flagship programme is based within this first level. The second level is composed of a general hospital (covering a population of 1-1.5 million population), while the third level is a specialized hospital (covering a population of 3.5-5 million).

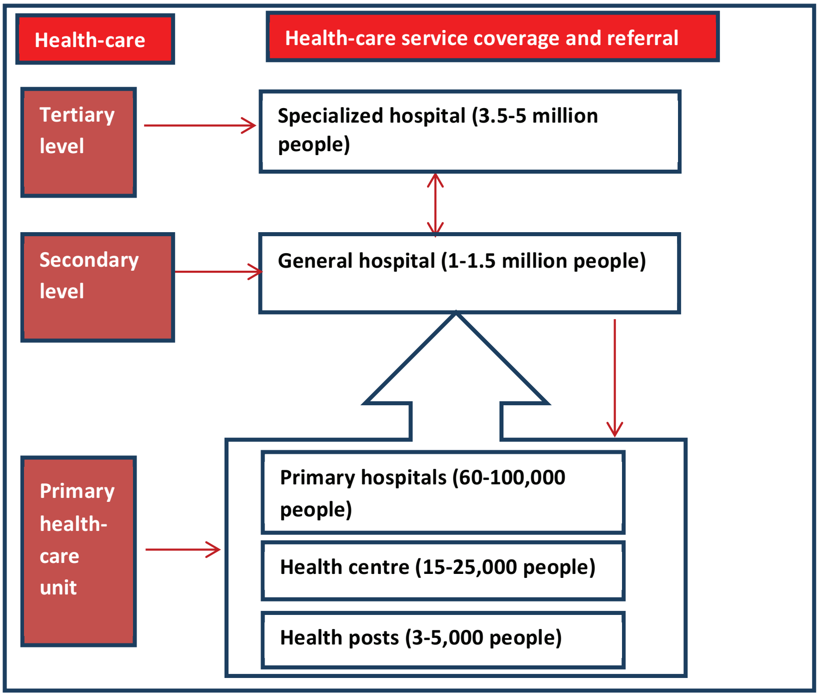

Figure 1: Ethiopia's health-care delivery system (adapted from the Federal Ministry of Health Sector Transformation Plan, 2015)

Study location

Three of the studies in this thesis (Papers II, III, and IV) were conducted in the Meskane Mareko District (38.45763 E, 8.042144 N). The district is located approximately 130 km south of Addis Ababa (the capital city of Ethiopia) and 50 km west of the Rift Valley. The district is part of the *Guraghe* administrative zone within the Southern Nations Nationalities and People's Region (SNNPR). The district covers an area of approximately (Fig. 2) 513·65 km^2. The district has 40 rural and two urban *kebeles* (a *kebele* is the smallest administrative unit in Ethiopia). According to the district office's report, the district had an estimated population size of 199,771 living in approximately 38,933 households, with a crude population density of approximately 390 inhabitants per square kilometre.

The district is characterized by an elevation ranging from approximately 1500 to 3,500 metres above sea level, with an average temperature ranging from 10-24^{o}C and an average annual rainfall ranging from 900 to 1,400 mm. The district's climate is characterized by a rainy season between June and October and a dry season between the months of November and May. The topography of the district is predominantly highland (mountainous). However, dry and semi-arid areas are located in the eastern part of the district.

The main means of livelihood in the district is a rain-fed agriculture, which is characterized by production of subsistence crops (primarily *Enset*, cereals, legumes, vegetables, fruits) and some cash crops such as *Khat* (*Catha edulis*). Most of the households, especially those located in the lowland areas, are affected by a chronic food insecurity and are prone to drought.

The district was served by seven health centres, 40 health posts and two hospitals. As in other parts of the country, the major health problems are infectious diseases, including diarrhoea, malaria and others. In each *kebele,* there is a health post run by two health extension workers (HEWs). These workers are deployed to reach the rural community to deliver health services focusing on health promotion, disease prevention and basic curative services. Through their regular home visits, HEWs provide nutrition-related services such as nutrition education, growth monitoring and promotion, deworming, vitamin A supplementation and Iron folic acid supplementation.

The Butajira Rural Health Programme (BRHP), which is located in this district, was established in 1986 and includes nine rural and one urban kebele, representing three agro-ecological zones (highlands, midlands and lowlands) of the district. The primary aim of the Health and Demographic and Surveillance System (HDSS) is to generate data on vital registrations, fertility and mortality. Moreover, the HDSS is continually used as a study base and research infrastructure for various public health researches and clinical trials.

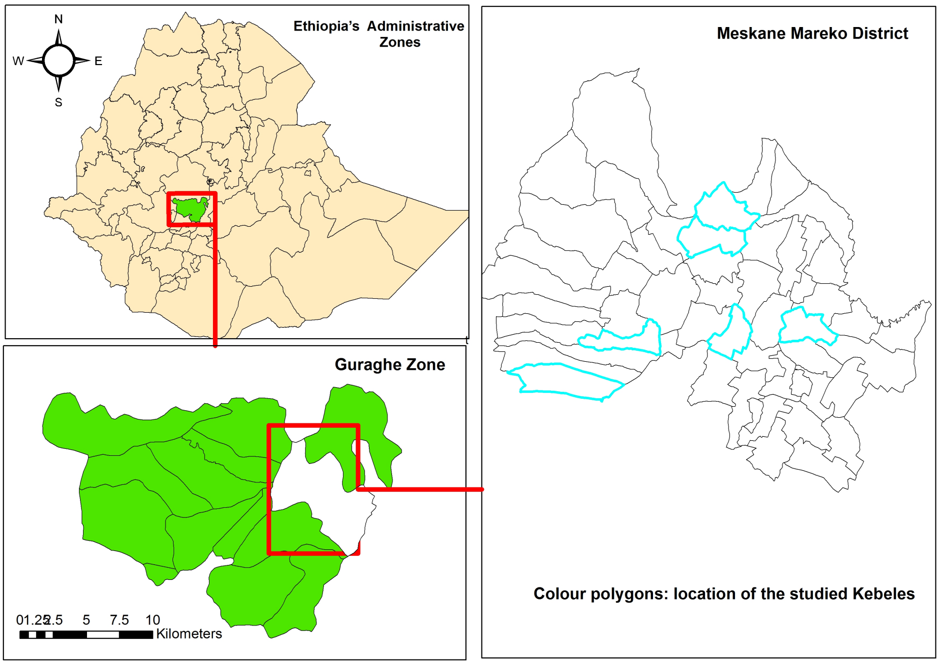

Figure 2: Geographic location of studied kebeles, Meskane Mareko District and the *Guraghe* Zone, Ethiopia, 2014

Study design, sampling and data collection

Table 2 indicates an overview of the study designs, study populations and final sample size used in this thesis. For Paper I, we employed a panel study design otherwise named as a cross-sectional time-series design, which involves observing the attributes (e.g. stunting) of a cross-sectional unit (e.g. administrative zone) over time (e.g. years). In other words, a panel study design has both time and space dimensions.

For Paper I, we constructed a panel data set from 43 locations (administrative zones) in Ethiopia for the years 1996, 1998, 2000 and 2004. The expected sample size was 172 observations (43 locations * 4 years). Nonetheless, the final sample size for Paper I was limited to 145 observations based on the availability of data on the zone-level undernutrition estimates. For example, only 28 zones had complete data for the four years, nine zones had complete data for three of the four years, while the remaining zones were observed for less than- or equal to two of the four years.

We collected secondary data from different sources in the country. Data on zone-level child undernutrition estimates were derived from the Ethiopian Welfare Monitoring Survey (WMS) conducted by the Central Statistical Agency (CSA). The availability of zone-level undernutrition estimates was limited to the period of 1996, 1998, 2000 and 2004. We obtained the amount of crops (cereals and oil seeds) and number of livestock produced in this period from the CSA. Station-based rainfall data for the months of June, July, August and September for the period from 1996-2004 was obtained from the National Metrological Authority. Temperature data for the specified time period was extracted from the Climatic Research Unit (CRU) TS (time-series) datasets. Based on this limitation, a pseudo panel data (unbalanced panel data) set of zone-level estimates for stunting, wasting and underweight, crop, livestock and other variables were extracted and matched by year.

For Papers II, III and IV, a community-based cross-sectional study design was employed. The study area, the Butajira District in southern Ethiopia, was purposively chosen because it houses a Health and Demographic Surveillance System (HDSS). The Butajira HDSS has nine rural *kebeles* and one urban *kebele,* and we collected primary data from households residing in the district. Data were collected between November and December 2013 (Paper II), and continued between December 2013 and April 2014 for Papers III and IV. The data were collected by trained and experienced data collectors who were residents of the district. Moreover, we interviewed mothers or caregivers in the households, since they are culturally responsible for the preparation of foods within a household.

For Paper II, we sampled 767 households found in the 10 *kebeles* under the surveillance system, with households being selected using a simple random sampling. We used the Butajira HDDS as a sampling frame to help recruit households and study participants. The HFIAS tool was administered twice to these randomly selected households in order to evaluate the reproducibility of the HFIAS tool. In the first round we included 767 households. However, the HFIAS tool was administered for the second time for only 749 households.

For Paper III, we applied a simple random sampling method, and selected six *kebeles* out of the nine rural kebeles under the HDSS. The selected *kebeles* represented the three agro-ecologic zones in the district. We identified households that had one or more children under age five in the six *kebeles,* using the HDSS data registry. We then extracted the household's identification number and the names of the household head to help us locate the houses. We visited all households found in the six *kebeles* that had children under age five. The final sample size for Paper III was 2,371 children under age five.

For Paper IV, we applied a simple random sampling method, and selected 1,723 households with children under age five found in 34 *kebeles (*excluding the six kebeles studied for Paper III*)* in the district. Inorder to improve the representativeness of the outcome, we included the 2,371 children who were interviewed for Paper III. The total sample size for Paper IV was 3,975 children under age five.

Table 3: A summary of study designs and sample sizes used in this thesis

Paper	Design	Sample size	Study units	Data type and collection
Paper I: Climate change, crop production and child undernutrition in Ethiopia; a longitudinal panel study: *Hagos et al. BMC Public Health 2014, 14:884*	Panel study/cross-sectional time-series	43 administrative zones found in Ethiopia (145 zone-year of observations)	Administrative zones	Secondary data WMS, CSA
Paper II: Is the adapted Household Food Insecurity Access Scale (HFIAS) developed internationally to measure food insecurity valid in urban and rural households of Ethiopia? *Gebreyesus et al. BMC Nutrition 2015, 1:2*	Repeated cross-sectional study	1,516 households (767 in the first and 749 in the second round)	Households residing in 10 *kebeles* under the HDDS	Primary data collected between November and December 2013
Paper III: Local spatial clustering of stunting and wasting among children under five years: Implications for intervention strategies. *Public Health Nutr 2015*	Cross-sectional study (census)	2,371 children	All children under age five found in six randomly selected *kebeles*	Primary data collected between December 2013 and April 2014
Paper IV: Spatial heterogeneity and risk factors for stunting among children under age five: A Bayesian geo-statistical model	Cross-sectional study	3,975 children	All children under age five in six randomly selected *kebeles* and additionally randomly selected children from 34 *kebeles*	Primary data collected between December 2013 and April 2014

Data collection instrument and measurements

Instrument

For Paper II, we developed a questionnaire adapted from the Ethiopian Demographic and Health Survey (EDHS) and relevant literature that has three sections. The first section covered questions on the mother's or caregiver's socio-demographic characteristics, household conditions and fixed-asset ownership. The second section covered the HFIAS questions (nine items asked with a recall period of four weeks). The third section covered questions for measuring household food diversity (12 food groups that were consumed in the household yesterday during the day and at night)[124]. For Papers III and IV, additional sections on child's demographic, health and morbidity condition, child's weight and height, as well as households' latitudes and coordinates, were added. The questionnaire used in this thesis is appended at the end of this thesis.

Measurements and standardization

A total of 20 trained and experienced research assistants were involved in interviewing and taking anthropometric data. We formed 10 teams, with each team composed of a female measurer and a male supporter. We conducted standardization exercises approximately four times. For each exercise, we calculated the intra, inter, total Technical Error of Measurement (TEM) and the coefficient of reliability (R)[125-127]. We started the actual data collection when the coefficient of reliability (R) reached 86%.

Weight was measured using a digital weighing scale (the Coline brand), which has a capacity of 150 kg and is designed in graduations of 100 grams. Length was measured in a lying (recumbent) position for children who were under two years of age, otherwise in a standing position. All length or height measurements were taken with a precision of 0.1 cm using a locally constructed length or height board (Stadiometer). A local calendar of events was developed to help estimate a child's month and year of birth [128].

Assessment of exposures and outcomes

Tables 4 and 5 show an overview of the outcome and main exposure variables considered in this thesis and their respective definitions. Anthropometric indices (Z-scores) were calculated based on the 2006 WHO reference standard [129]. Household food security was measured using the Household Food Insecurity Access Scale developed by the Food and Nutrition Technical Assistance Project [130].

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Table 4: Definitions of outcome variables used in the thesis

Variable name	Definition/measurement	Paper
Stunting	A child was considered stunted if the Z-score for height-for-age was 2SD (standard deviation) below the WHO 2006 median growth reference.	I, III and IV
Wasting	A child was considered wasted if the Z-score for weight-for-height was 2SD below the WHO 2006 median growth reference.	I and III
Underweight	A child was considered underweight if the Z-score for weight-for-age was 2SD below the WHO 2006 median growth reference.	I and III
Severe stunting	A child was considered stunted if the Z-score for height-for-age was 3SD below the WHO 2006 median growth reference.	I, III and IV
Severe wasting	A child was considered wasted if the Z-score for weight-for-height was 3SD below the WHO 2006 median growth reference	I and III
Severe underweight	A child was considered underweight if the Z-score for weight-for-age was 3SD below the WHO 2006 median growth reference	I and III
Household food insecurity level	Household food security level was evaluated based on nine occurrence questions on the household experience of food insecurity that were asked with a recall period of four weeks preceding the survey. If a respondent responded "yes" to any of the questions, a follow-up frequency-of-occurrence question was asked to determine the frequency of the experience. The frequency of occurrence is classified as rarely (if occurring once or twice), sometimes (3-10 times) or often (more than 10 times). A food-secure household is the one that experienced none of these nine questions (conditions) or just experienced the first condition (worrying about food), though with a frequency of once or twice over the past four weeks (rarely).	II, III and IV
Spatial clustering	Indicates whether a case (stunted or severely stunted) is present within the identified cluster or not (yes/no).	III

Table 5: Definitions of exposure and other variables used in the thesis

Variable name	Level (Aspect)	Definition/measurement	Paper
Per capita crop	Administrative zone	Measured by total amount of crops (cereals and oil seeds) produced during the main harvesting season (October to November) in each administrative zone for the study year. This was converted into per capita crop availability using a projected population for each administrative zone.	I
Rainfall	Administrative zone	Computed from the total amount of rainfall (mm) for the pre harvest seasons of June-July-August-September (JJAS) for each administrative zone and study year.	I
Temperature	Administrative zone	The average temperature for each zone and year was obtained from the Climatic Research Unit (CRU) TS (time-series) datasets (CRU v321)	I
Education level	Parental	Assessed based on a question that asked the highest education level achieved by the mother or caregiver. Three levels of educational status (no education, being able to read and write or primary and above) were used in the analysis.	III and IV
Marital status	Parental	Assessed based on a question that asked about the current maternal or caregiver's marital status. A binary marital-status variable was created in such a way that mothers or caregivers in a marital union at the time of the survey will be under the "married" category, while the other will be under the "single or separated or divorced or widowed" category.	III and IV
Agro ecology	Household	An agro-ecologic zone was generated from the elevation data for each administrative zone. Administrative zones with an elevation less than 500 m.a.s.l. were grouped under the lowland category, zones with an elevation between 500-1,500 m.a.s.l. were grouped under the midland category and those with an elevation above 1,500 m.a.s.l. were grouped under the highland category.	I
Residency type	Household	Defined by either the *kebele* name where the household was located (B*ati, Deobena, Drama, Shershera Bido, Yeteker*) (Paper II) or whether households were located in the Butajira town administration (urban) or not. If a household was located in the Butajira town Administration, it	II and III

		was grouped under urban residency, otherwise rural.	
Household dietary diversity	Household	Based on the reported number of food groups consumed, we classified households into three levels (lowest, medium and high) of dietary diversity. A household with the lowest dietary diversity score consumed three or less food groups. A household with a medium dietary diversity score consumed four or five food groups, while households consuming six or more food groups were grouped as having a high dietary diversity.	III and IV
Household dietary diversity score	Household	Household level mean dietary diversity score was generated using the sum of all foods (food groups) eaten in the respective house during the day and night prior to the date of the survey.	III and IV
Household food insecurity level	Household	Household food security level was evaluated based on nine occurrence questions on the household experience of food insecurity, which were asked with a recall period of four weeks preceding the survey. If a respondent responded "yes" to any of the questions, a follow-up frequency-of-occurrence question was asked to determine the frequency of experience. The frequency of occurrence is classified as rarely (if occurring once or twice), sometimes (3-10 times) or often (more than 10 times). A food-secure household is the one that experienced none of these nine questions (conditions) or just experienced the first condition (worrying about food), though with a frequency of once or twice over the past four weeks (rarely).	III and IV
Household wealth index	Household	A categorical household income level was constructed using information on a household's ownership of fixed assets and housing materials. We used a Principal Component Analysis to create a relative wealth index for the households involved in the study. The household wealth index was constructed independently for rural and urban households.	II,III, and IV
Child's morbidity status	Child	Assessed by a history of morbidity such as respiratory tract infections, diarrhoea and/or fever in the past two weeks preceding the survey.	III and IV
Severity of stunting at village level	Village	Computed based on village-level prevalence of stunting as follows: low severity (below 20%), medium/high severity (20-40%) and very high severity (greater than 40%).	IV

Data management and statistical analysis

Data management

The questionnaires (Papers II, III and IV) were checked for inconsistencies and missing values at the field site by the study supervisors, who used EpiData Version 3.1 for the data entry (Papers II, III and IV). The data was entered by a trained and experienced data entry clerk, who. Data were cleaned for inconsistencies and missing values. We revisited the questionnaire for correcting errors and missing values, and all variables with missing data were reported.

Statistical analysis

The mapping of the spatial distribution of undernutrition (underweight, stunting and wasting) was done using ESRI ® ArcMap™ 10.0 (Redlands, CA, USA) (Papers I, III and IV). In order to identify the factors responsible for the observed trend, a panel data analysis (PDA) with a fixed-effects model (Paper I) was run using Stata 11.0 (StataCorp, College Station, TX). The model aimed to evaluate the effect of climatic variability such as rainfall and temperature on the spatial distribution of child undernutrition. We calculated standardized anomalies for both exposure and outcome variables considered in the panel regression models. The standardization was needed to evaluate the response of undernutrition to weather variability in the same administrative zone. A subgroup analysis was performed by stratifying by the three agro-ecology zones. Three types of R-squared values (within, between and overall) were examined to assess the goodness of fits of the models.

The micro- scale (at the inter- and intra-*kebele* level) spatial analysis was done using SaTScan™ v9.1.1 software http://www.satscan.org (Paper III) [131]. Spatial autocorrelation was visually revealed using a semivariogram and was quantified using spatial methods such as local Moran's I statistics and Kulldorf's spatial scan statistics.We evaluated and established the presence of spatial heterogeneity using Kulldorf's spatial scan statistics (Paper III), as well as local Moran's I statistics and Kulldorf's spatial scan statistics (Papers IV).

A retrospective purely spatial Poisson probability model was applied to help identify the locations of clusters and estimate cluster sizes (Papers III and IV). We applied the local Anselin Moran's *I* (also known as Local Indicator of Spatial Association or LISA) to investigate the spatial autocorrelation and identify potential hotspots of stunting in the study district.

A conditional logistic regression model was fitted using Stata 11.0 (StataCorp, College Station, TX) to identify the underlying process that governed the observed clustering (Paper III).

Subsequently, a spatial and non-Spatial Bayesian modelling was undertaken using WinBUGS version 1.4.3 (MRC Biostatistics Unit, Cambridge and Imperial College London, UK) (Paper IV) to evaluate the risk factors for stunting and severe stunting. A mixed effect logistic regression model was fitted to identify variables for Bayesian modelling, whereas we used the Deviance Information Criterion (DIC) statistics to evaluate the model performance.

The HFIAS tool (Paper II) was evaluated for its internal consistency using Cronbach's alpha, for dose–response relationships, reproducibility and parallelism.

A Principal Component Analysis (PCA) (Papers II, III and IV) was used to construct a relative household wealth index, combining a suite of socio-economic indicators such as a household's ownership of fixed assets, land ownerships, type of houses and building materials.

Table 6: Summary of statistical methods or approaches used in this thesis

Statistical methods/approaches	Paper(s)	Statistical software(s)
Anthropometric analysis (Z-scores)	Papers I, III and IV	WHO Antro software (v3.2.2)
Panel data analysis (fixed effects)	Paper I	Stata 11.0 (StataCorp, College Station, TX)
Spatial visualization and mapping	Papers I, III and IV	ESRI ® ArcMap™ 10.0 (Redlands, CA, USA)
Kulldorf's spatial scan statistics	Paper III	SaTScan™ v9.1.1
local Anselin Moran's *I* (also known as Local Indicator of Spatial Association or LISA)	Paper IV	Spatial statistics tools in ESRI ® ArcMap™ 10.0 (Redlands, CA, USA)
Logistic regression	Paper III	Stata 11.0 (StataCorp, College Station, TX)
Spatial and non-spatial Bayesian modelling	Paper IV	WinBUGS version 1.4.3 (MRC Biostatistics Unit, Cambridge and Imperial College London, UK)
Mixed effect multivariate logistic regression	Paper IV	Stata 11.0 (StataCorp, College Station, TX)
Principal Component Analysis	Papers II, III and IV	Stata 11.0 (StataCorp, College Station, TX)
Descriptive analysis	Papers I, II, III and IV	Stata 11.0 (StataCorp, College Station, TX)
Dose-response analysis	Papers II and IV	OpenEpi

Ethical considerations

The study protocol was approved by the Institutional Review Boards from the Addis Ababa University, College of Health Sciences. We also received approval from the Regional Committee for Medical and Research Ethics, Western Norway (REK Vest) (reference 2014/605/REK vest). A support letter from the School of Public Health, Addis Ababa University and a permission letter from the Butajira District Health Office were written to the local administrators.

For Papers II, III and IV, we obtained verbal consent from the mother, head of the household or guardian in the house. The consent form was signed by the data collector and witnessed by the team member. Interviews, height and weight measurements were conducted in the respective households or within the compound, and information collected from participants was kept in a locked room at the BRHP compound.

For Paper I, since we used secondary data obtained from different sources, consent was not needed. We obtained a support letter from the Institutional Review Board of the Addis Ababa University to facilitate acquisition of the zone-level undernutrition data from the Central Statistics Agency (CSA Ethiopia) and rainfall data from the National Meteorological Authority.

For Papers III and IV, we constructed village-level prevalence maps rather than point maps to depict the specific location of households. This was done to avoid the risk of linking confidential data to the particular spatial location of the households in the study.

Chapter 4: Results

Paper I: Effect of climate variability on large-scale spatial variation in child undernutrition

We aimed to evaluate the effect of growing season rainfall and temperature variability on the large-scale spatial variations in stunting, wasting and underweight. Furthermore, we analysed the variation in effects across different agro-ecological zones in the country.

We had a total of 145 complete observations from 43 administrative zones in Ethiopia for the years 1996, 1998, 2000 and 2004. We found a noticeable spatial and temporal variation in the distribution of growing season rainfall. The mean rainfall in millimetres (mm) for the highlands was 726.8 mm, whereas for the midlands and lowlands it was 680.0 mm and 523.9 mm, respectively. Unlike rainfall, we did not observe a noticeable spatio-temporal variation in the distribution of growing season temperature.

We found that the large-scale spatial variation (trends) in the distribution of stunting between zones was explained in part by weather variable (rainfall). The R-squared values for the models were between 0.81 and 0.95. However, these models poorly explain the temporal variation in stunting within an administrative zone over the years from 1996-2004.

We also demonstrated that the climate models varied in predicting stunting and underweight across the three agro-ecologic zones in Ethiopia. For example, rainfall adequately explained the variation in stunting for the midlands and highlands compared to the variation in the lowlands. This could imply that a single model for all agro-ecologic zones may not be appropriate.

Paper II: Is the Household Food Insecurity Access Scale (HFIAS) valid for measuring food insecurity?

We aimed to evaluate the performance of the Household Food Insecurity Access Scale (HFIAS) developed internationally to help measure Household Food Insecurity. Additionally, we analysed the variation in the performance of the tool among both rural and urban households.

We analysed data from 1,516 households, of which 1,056 were from rural- and460 from urban households. The validation work indicated that four of the nine HFIAS items (questions) needed modifications such as rephrasing and adding examples before application, while the five items were not difficult to understand and were used in their original form.

We showed that the tool had a satisfactory internal consistency and reproducibility, and performed well with minor deviations to the set criteria. The tool's internal consistency, as measured by Cronbach's alpha, was consistent in the two rounds of data collection for urban- (0.79 vs 0.8) than rural households (0.75 vs 0.68). The reproducibility of the HFIAS tool was evaluated by comparing the HFIAS score between the two rounds of data collection. We did not observe a change in the overall HFIAS score between rounds I and II (6.1 vs. 6.3). However, there was a significant difference in HFIAS score among rural households. We found an increase in the overall HFIAS score for the rural sample during the second round of data collection (mean difference: −0.58; 95% CI: −1.07, −0.083).

We recommend that the HFIAS tool can be applied to the study setting. However, the tool needed minor adaptions such as rephrasing the items, using local ways of expressing the questions and adding local examples to the nine items to help improve understanding. The findings described above were used to modify and restructure the nine HFIAS items for subsequent surveys in this thesis.

Paper III: Intra- and inter-*kebeles* clustering of stunting and wasting

In this paper, we aimed to evaluate whether undernutrition indicators (stunting and wasting) for children under age five had a tendency to cluster, and if so, at what geographic scale. Moreover, we evaluated whether the observed clustering is due to the non-random distribution of known risk factors or due to spatial dependence.

We analysed data collected from 2,371 children under age five found in six rural *kebeles*. We demonstrated that undernutrition indicators such as stunting and wasting exhibited a spatial clustering, rather than being distributed randomly over space. Spatial clustering on a smaller scale (within a *kebele)* was only found for wasting and severe wasting. The most likely significant clusters were found in only two of the six *kebele*s. For wasting, a single cluster of 31 cases (18.2 expected) in 129 households was identified (RR=4.83, P< 0.01). For severe wasting, a smaller cluster of seven cases (0.83 expected) in 15 households was identified (RR =10.31, P<0.01).

Spatial clustering on a higher scale (within a *kebele)* was only found for stunting and severe stunting. For stunting, a single large cluster size of 390 cases (304.19 expected) in 756 households was identified (RR=1.28, P<0.01), whereas for severe stunting, a single cluster size of 106 cases (69.39 expected) in 364 households was identified (RR=1.69, P= 0.035)

Unlike for severe stunting, we found no difference with regard to the distribution of known risk factors for stunting between the cases found in the spatial cluster (as identified by the scan statistics) and the cases out of the cluster. This might suggest that the observed clustering for stunting is due a spatial dependency, as we accounted for known influences. We identified the spatial locations of a high-risk area for stunting that could be an input for geographically targeting and optimizing nutritional interventions.

Paper IV: Risk factors for stunting and severe stunting

In this study, we evaluated the spatial variation in the distribution of stunting in the district and identified risk factors, accounting for the spatial structure of the data. Furthermore, we evaluated the effect of including the spatial structure of the data on the performance of the models for stunting and severe stunting.

We analysed a total of 3,975 children under age five residing in in the district. The overall district-level prevalence of stunting and severe stunting was 42.1% [95%CI: 40.6, 43.6] and 20.3% [95%CI: 19.0, 21.5], respectively. We found a significant spatial heterogeneity in the distribution of stunting in the district. The local Anselin Moran's *I* (LISA) result identified statistically significant clusters of high value (hotspots) of stunting in the eastern part of the district and clusters of low values in the western part of the district. Similarly, the scan statistics indicated a most likely significant cluster for stunting in the eastern part of the district. A single large cluster size of 953 stunted cases (844 expected) in 1957 households was identified (Relative risk (RR) =1·29, P <0·01).

The risk of stunting was higher among boys, with an adjusted odds ratio (AOR) =4.74; 95% Bayesian credible interval [BCI]; 3.35–6.58), for children whose mother/guardian had no education (AOR=1.21; 95%BCI: 1.02–1.42), for children born in a health facility (AOR=0.81; 95% BCI; 0.66–0.986) and for children who lived in moderately food-insecure households (AOR=1.26; 95% BCI: 1.04-1.51). The risk of stunting increased as the age of the child increased. Children in the age group between 24-35 months were 4.7 times more likely to be stunted (AOR=4.74; 95% BCI: 3.35–6.58) than children below six months of age. The risk of severe stunting was higher among boys, with an adjusted odds ratio (AOR) = 1.34; 95% BCI; 1.14–1.57), for children whose mother/guardian with no education (AOR=1.30; 95%BCI; 1.08–1.64) and for children who lived in a moderate food-in secure households (AOR= 1.31; 95% BCI; 1.04-1.64). We demonstrated the added benefits of accounting for spatial structure, and also showed how this information can be used to better understand the determinants of stunting in the district. We found that including a spatial component (spatial structure of the data) in the Bayesian model improved the model fit as compared with the model without a spatial component.

Chapter 5: Discussion

In this thesis, we aimed to evaluate the macro- and micro-scale spatial variation in risk due to undernutrition, the underlying process and the factors responsible for the observed spatial variation. We demonstrated a spatial variation (spatial heterogeneity) in the distribution of stunting and wasting on a varying geographic scale. We showed that undernourished cases (stunting and wasting) tend to occur near each other than occurring homogeneously. On a smaller scale, we located significant clusters for wasting and stunting, with a higher risk and vulnerability than the underlying population. Identifying such areas where a population at risk lives is central in assisting a geographical targeting of intervention.

Methodological discussion

Errors faced in the process of conducting a study will lead to incorrect conclusions. These errors could be introduced during the designing of the surveys, collecting information, processing and analysing data. Following this, we will discuss the possible errors and methodological limitation of the studies in the thesis and the implications on the study findings, and further discuss the actions taken to minimize the errors.

Study design

We used two main observational study designs in this thesis, namely a panel study design (Paper I) and a cross-sectional study design (Papers II, III and IV). A panel design (Paper I) is a combination of time-series and cross-section study designs. A time-series design involves observing a given unit for an attribute value over a period of time (e.g. stunting for several years in a district). A cross-sectional design involves observing an attribute value of multiple units at the same point in time. In panel data, the same cross-sectional unit (e.g. district) is surveyed multiple times. A panel study design is advantageous since combining time-series and cross-sectional units would considerably improve the sample size of the study. The time-series component of the panel data will help to study the dynamics of a change in undernutrition over a period [132]. There were two limitations applying to the panel design in this thesis (Paper I): First, the number of observations differed among the panel members (study zones), thereby resulting in an unbalanced panel. Second, the study units of the panel were administrative zones and the link between weather variables and child undernutrition made at the zone level using aggregated estimates.

The attempt to use aggregate data to estimate the individual level association between weather variables and child undernutrition could result in ecological bias. Ecological bias occurs when a group-level analysis is carried out, while at the same time aiming to make an inference for study subjects within the group [133-138]. Aggregation bias and cross-level bias are other terms used to refer to ecological bias in the literature. A group-level analysis commonly fails to correctly apply individual-level relations, and usually leads to ecological fallacy [135,138,139]. One way to help minimize ecological bias would be to decrease within-group exposure variation. In the panel study (Paper I), we assumed that the variation in exposure variables (weather variables such as rainfall and temperature) for households that are found in the same zone (group) would be minimal. This might be true since climate impacts populations rather than individuals [140]. However, we admit that variations in rainfall and temperature can exist within a given zone.

Papers II, III and IV used a community-based cross-sectional study design. Cross-sectional studies are of primary importance to study the prevalence of a disease or condition in a population, and to identify associations that can be further studied, rigorously using other study designs such as case control, cohort and randomized controlled trials [141-143]. However, cross-sectional study designs are limited by the fact that it is difficult to ascertain whether the exposure preceded the onset of the outcome of interest (i.e. temporality). For this reason, it is impossible to assume causality [144].

For example, in this thesis (Paper IV), stunting and the potential risk factors such as household food insecurity were measured simultaneously at one point in time. We found that a household's food insecurity is associated with child stunting. Stunting is a chronic condition, while household food security was measured as a household experience in the last 4 weeks before the survey. This finding does not demonstrate whether a household's food insecurity leads to child stunting, or whether improved household food insecurity prevents child stunting. The cross-sectional nature of the research design may therefore limit us from inferring causality, since we are not certain whether the household food insecurity measured in our study preceded the occurrence of stunting.

Nevertheless, we evaluated the likelihood of a causal association between stunting and household food insecurity in light of Hill's criteria for causality in a biological system [145]. The criteria employed in this thesis include the presence of dose-response relationships (a biological gradient), consistency of the observed relationship by different researchers and under different circumstances in the literature, and the biological plausibility of the relationships [143,145,146].

Sample size and sampling

The importance of having an adequate sample size in a research study lessens the risk of reporting a type II error (false negative findings), and improves the precision of the estimates made [147]. Unpowered studies are more likely to report non-significant associations ("absence of evidence"). However, the absence of evidence does not necessarily imply evidence of absence.

We calculated adequate sample sizes for two of the studies (Papers III and IV) included in this thesis. For the validation work (Paper III), we involved approximately 1,516 households (767 households in the first round and 749 in the second round) found in 10 *kebeles* in the district. For Paper IV, we included a total of 3,975 children under age five. For the above studies, we applied one of the probability sampling methods, namely a simple random sampling (SRS) procedure to select study samples. This sampling method is independent, and less likely to result in a biased sample of study participants. In addition, samples obtained by simple random sampling methods are highly representative of the population under study. The representativeness of the sample helps to make a generalization of study findings to the source population [147].

However, we did not calculate sample sizes for two of the studies (Papers I and III) included in this thesis. For Paper I, the sample size was dependent on the availability of complete data, which we were able to find for almost half of the administrative zones found in the country. We based our analysis on 145 observations from 43 administrative zones.

The absence of statistically significant results in this paper could partly be explained by the lack of enough power in the study.

For Paper III, we included all households who have children under age five, including all eligible samples from a given geographic boundary results in a better spatial resolution for cluster analysis. The underlying assumption in cluster analysis using SaTScan is based on the fact that the spatial locations of all households within the given geographical boundary are included in the scanning window. Hence, we can assume that the sample size was adequate to perform a spatial (cluster) analysis.

Validity of research

Epidemiological studies often face two important questions: 1) Are the findings reported correct?; 2) Can we generalize the results obtained from the study to individuals other than those in the sample? The first question is linked to the internal validity of the research, while the second to the research's external validity. The internal validity of a study is concerned with the study's ability to measure what it sets out to measure [139,148,149]. Studies with a good internal validity have an accurate inference about their study participants, whereas the internal validity of a research study is weakened by systemic errors such as bias and confounding [143]. Bias is any systematic error in the research process leading to incorrect conclusions. There are several forms of bias that affect observational studies, and some are specific to spatial studies [138]. Biases can be broadly grouped into three types: selection, information and confounding.

Selection bias

Selection bias occurs when there is no known or equal chance for individuals to be included in a study [148-150]. Selection bias commonly occurs during the design phase of a study. Non-response bias, a form of selection bias, happens when some individuals who are invited to the study refuse or are not able to take part for any reason [149]. The significance of non-response bias in the studies in this thesis (Papers II, III and IV) was minimal. This is because only a few individuals who are approached refused to participate in the study. Moreover, the response rate in the studies in this thesis (Papers II, III and IV) is high, ranging from 95% to 98%. The Butajira surveillance programme has helped to achieve this high rate in response rate. In addition, the study's enumerators and supervisors were residents in the study district. This has probably improved the trust and relationship with the invited households. We believe that there could be a difference in the characteristics of households included in the study from those who refused or were not able to participate for any reason. We believe that the results reported in the studies are less likely affected by a non-response bias.

Another form of selection bias occurs when the selection of study participants is based on volunteerism. Volunteer bias focuses on the difference between the volunteers and the target population [149]. This bias is heavily dependent on the selection procedure of the participants. For the studies in this thesis (Papers II, III and IV), study participants were selected using a simple random sampling method, and we do not see any potential influence of this bias on the studies in this thesis. The sampling method we employed yielded a sample that is closely similar to the source population. We believe that the characteristics of participants included in the study might not be that much different from the source population.

For the spatial studies involving cluster analysis (Papers III and IV), selection bias could also arise due to the selection of a particular geographic layer, which is termed as boundary shrinkage (modifiable area unit problem). The risk estimate could vary upon the chosen zone (geographic) boundaries during cluster analysis [138], and the observed spatial pattern may not solely be a function of the underlying spatial distribution, but also due to the selected geography boundaries. Since we used the administrative boundaries provided by the local government, the risk estimates might change if the selected village geographic boundaries are changed or modified. Consequently, we therefore admit that this form of selection bias could potentially influence the validity of the results obtained in our cluster analysis (Papers III and IV). The validity is influenced, since selecting alternative geographic boundaries of *kebeles* in the study area could result in identifying a significant cluster(s) located in a different location(s) or clusters with different risk estimates.

Selection bias could also arise due to the selection of only those administrative zones that have data on undernutrition and weather variables. For Paper I, we included only 43 administrative zones, and we were not able to find complete data for almost half the administrative zones in the country. Because of this, we believe that the results reported in Paper I could be affected by selection bias, as the samples used for analysis lack an adequate representation of the administrative zones specifically found in the eastern and lowland parts of the country.

Information bias

Information bias is a distortion arising from measurement error or a difference in the way information is collected from participants. Information bias commonly occurs during the stage of data collection [143,148,149]. The most common types include measurement error, interviewer bias and respondent bias. We acknowledge that the studies in this thesis (Papers II, III and IV) were subjected to measurement errors. Measurement errors (bias) can occur during the measurement of temperature and rainfall, agriculture productivity (Paper I), anthropometric data (Papers III and IV) and other demographic characteristics (Papers II, III and IV). For Paper I, we used secondary data from different sources, and the control we had over the quality of the data and measurement error was minimal. In order to minimize information bias due to measurement errors (Papers II and III), data collectors were trained intensively on anthropometric data collection methods and standard operating procedures. They were also posted for the job when the coefficient of reliability (R) reached 86%. This figure indicates that only 14% of the variation in anthropometric measurement can be explained by measurement error. For Paper II, the HFIAS tool was tested for face validity to improve the problems of misunderstanding, multiple interpretation and flaws in the questionnaire. We validate the tool and found a good internal consistency (Cronbach's alpha for the values of rounds 1 and 2 were 0.76 and 0.73, respectively).

Respondent bias was predominantly observed during a household's food security assessment questions (Papers II, III and IV) and reporting child's age. Households from the rural area were more likely seen to report affirmative responses than their urban counterparts. This was primarily observed due to their expectations of possible food and similar supports. We developed a local calendar of events to minimize respondent bias in reporting a child's age. All research assistants were required to use the calendar for all children to estimate their age. Even though we developed a local events calendar for this purpose, we experienced age heaping during analysis and were therefore forced to report children's age as age categories.

Recall bias in the studies in this thesis (Papers II, III, and IV) was minimized through limiting the recall periods of measurements. For example, the measurement of morbidity was limited to a recall period of two weeks, while the measurement of food insecurity was limited to a recall period of four weeks.

Confounding bias

Confounding is basically a mixing of effects that occur when a variable (confounder) is related with the exposure of interest, and at the same time is an independent risk factor for the outcome of interest [143,148,150]. There are multiple ways of controlling confounding when examining the relationship between an exposure and outcome variable [143,148]. For Paper I, we employed a fixed-effects model, thereby accounting for the potential confounders such as livestock and per capita crop. Furthermore, we run a stratified analysis (Paper I) by agro ecology to evaluate whether the agro-ecology zone had an effect on the modification of the association between weather variables and child undernutrition. We observed that the effect of rainfall and temperature on child undernutrition was modified by the type of agro-ecologic zone where the administrative zone is located. For Paper IV, we employed a Bayesian geostatistical model that adjusts for the spatial structure of the data. Another important source of bias in small area epidemiologic studies (Paper I) is socio-economic confounding [138]. The social economic characteristics of the administrative zones studied in Paper I, such as wealth, dietary pattern, health service distribution, etc., are important predictors for outcomes such as child undernutrition. Due to the unavailability of such type of data locally, we were not able to adjust for this in our small area study.

Chance

Chance is another possible explanation for the observed result if the results cannot be explained by the biases mentioned above [143,148]. The possibility of chance as an alternative explanation for the observed result's in this thesis was evaluated using a statistically significance test at a specific cut-off such as a P-value < 0.05 or a 95% confidence interval not crossing the null hypothesis (Papers I and III), or a 95% credible interval that is not crossing one (Paper IV) [148,151,152].

External validity (generalizability)

The main purpose of a research study is to say something about the population that the sample is supposed to represent. In most research practices, it is impossible to do a total enumeration of the study population; hence, the way forward is to select some participants, study them and extrapolate the study results to the population [143,148]. This is the external validity of a research. Internal validity is a pre-condition for the external validity of a research.

For Paper I, the availability of climate and undernutrition data was limited to highland areas. We were not able to get enough data for lowland parts in the country, as this might compromise the generalizability of the findings for the different agro-ecology zones in the country.

For Paper II, the applicability of the HFIAS tool may be limited to similar groups in southern Ethiopia. Since a household's response to food insecurity could be both culturally and contextually different among the various ethnic groups in Ethiopia, the use of this tool in different cultures might need further validation work.

The studies in this thesis (Papers II, III and IV) were conducted in the Butajira District, which is one of the food-insecure districts in Ethiopia. The findings on the spatial structures of child undernutrition and its subsequent implications could also be applicable to areas that have similar characteristics with regard to socio-demographic and food insecurity, health services and other characteristics.

Discussion of main findings

In this thesis, we used both national- and district-level data to evaluate the large- and small-scale variations in the distribution of undernutrition among children under age five. We identified the explanatory variables for the observed spatial variation in the distribution of undernutrition indicators. Household food insecurity, the important explanatory variable for the existing spatial variation, was measured using a validated HFIAS tool.

Large-scale spatial variation

The total variation in undernutrition (stunting, wasting and underweight) is the result of both macro- and micro-scale variation. The large- and micro-scale variations are also referred as first- and second-order spatial effects, respectively [153,154]. One of these types usually dominates the observed spatial variation in the distribution of undernutrition indicators.

Macro-scale spatial variation expresses itself as a trend across a given geographical region [153,154]. We used aggregated data at the administrative zone level to show the large-scale spatial variation of undernutrition indicators in Ethiopia. We showed that the Ethiopian highlands (in the north and north-western part) exhibited a higher prevalence of stunting and underweight compared to the lowlands (eastern part of Ethiopia). To the contrary, the north and north-western parts of the country that are known for a higher prevalence of stunting documented a higher rainfall compared to areas with a lower prevalence of stunting.

The observed large-scale spatial pattern for stunting was linked to differences in rainfall among administrative zones. The reported models also explained the spatial variations in the prevalence of stunting across the country. However, the large-scale spatial structure for underweight and wasting was poorly captured by climatic variables, thus implying that other factors beyond rainfall and temperature could have an important role for the observed spatial variation. It is also worth noting that the link between growing season rainfall and stunting vary significantly by agro-ecology zone. Conceivably, our results suggest that it may appropriate to develop separate models for highlands, midlands and lowlands to help explain the links between climate variables and stunting in the country. In conclusion, we believe that models aiming at predicting future child undernutrition, especially stunting attributable to climate changes, need to possibly be conducted at the micro level (finer spatial scale). In spite of this, at least in practice, the link between climates and child undernutrition were usually analysed [61,155-158] and modelled on a higher spatial scale level, ignoring the within-country variations.

Small-scale spatial variation

Small-scale spatial variations describe the local dependence of undernutrition indicators and are also called spatial heterogeneity [153,154]. For example, small-scale spatial variations of undernutrition indicator could express themselves as clusters of stunting or wasting within a *village* or across *kebeles* within a given district. We demonstrated that unlike underweight, undernutrition indicators such as stunting and wasting exhibited a spatial heterogeneity, rather than being distributed randomly over space [114,116,159]. Spatial clustering was found both within- and between *kebeles* in the district. This is in contrast to the studies that reported a lack of area-level clustering of undernutrition indicators of children under age five [160,161]. We specifically indicated the maximum distance between villages where we could find spatial relatedness. For example, the maximum distance at which we could a find spatial dependency between villages for stunting and severe stunting was approximately 12 km. This limit indicates that within this range villages are related, and that one can spatially interpolate (predict) the prevalence of stunting in unsampled locations.

More importantly, we showed that within a general at-risk population, there can be differences in risk and defined specific areas at an increased risk to undernutrition. Our finding reinforces the view of not merely relying on district-level averages, but instead simultaneously looking at micro-level variation at risk within an area for programme planning [112]. The identification of areas with a high risk (cluster) within a general at-risk population is not an end in itself. More in-depth analysis of the possible causes of the observed spatial clustering is equally important [153,154]. Two key underlying processes can govern the observed spatial clustering of stunting. Firstly, there can be an overall tendency for stunted cases to occur near other cases, rather than to occur homogeneously among an at-risk population (this is termed as Tobler's First Law of Geography)[162]. Secondly, the underlying aggregation of risk factors might not be distributed randomly within the population at risk, [153] thereby resulting in stunted cases to cluster over a defined area. Although we did not exhaustively measure risk factors of stunting in this study, the observed clustering for stunting could more likely be due to spatial dependency. This means households with stunted children have a tendency to occur near other households with stunted children, which is in contrast to the underlying process of clustering for severe stunting.

Explanatory factors for the observed small-scale spatial patterns

In our studies (Papers III and IV), we observed that the spatial distribution of stunting and severe stunting was not random. We evaluated the added benefits of accounting for spatial dependence, and also showed how this information can be used to better understand the determinants of stunting and severe stunting in a district [110,163,164].

Our results indicated that household wealth did not play an important role as a predictor for stunting in the study district [45-47]. This is in contrast to other studies which reported an increased risk of stunting among poor households [13,22,44]. Conceptually speaking, wealthier households are more likely to have a better economic access for the consumption of good and services. In turn, these conditions could improve the nutritional status of children. We emphasize that for improved stunting among children, household spending behaviour and balancing the allocation of available resources between food and non-food items could be more important than merely bettering a household's income [45,47].

Household food insecurity status played a significant role in the pathway to stunting. We measured a household's food insecurity status with the Household's Food Insecurity Assessment tool (HFIAS) [130,165]. This tool has been used in different settings to measure the access component of household food insecurity [166-170]. We validated the HFIAS tool and made modifications before application in this thesis (Paper II). We showed that the tools have a good internal consistency[171], although the value of the Cronbach's alpha was a bit higher than reports of other similar studies [167-169,172-177].

The role of household food insecurity as a factor influencing the linear growth of children was independent of household wealth [16,21,22]. Some studies document that maternal depression could be one of the pathway through which household food insecurity could impact stunting [22]. As a result, we recommend that interventions targeting food-insecure households might help to strengthen the effort to reduce the burden of stunting.

In addition, of the many predictor variables entered into the spatial Bayesian model, only maternal education, child age and sex, and place of delivery were found as important predictors of stunting. Similar to other works [17,23,29,35], maternal education positively influences stunting in the study area. While the role of gender and the pathway to stunting are still unclear, we found that boys are more likely to be stunted than girls [23,25].

We noted that some of the risk factors selected were statistically insignificant when we accounted for the spatial correlation of stunting in the data. These risk factors were significant when a Bayesian model which did not account for spatial structure was used. We also noted that the inclusion of spatial structure into the Bayesian model has improved the model fit for stunting. This leads us to recommend studies to account for the spatial structure of stunting while performing a risk factor analysis for undernutrition.

Geographically targeting interventions

A geographically targeting intervention(s) requires stratifying a locality according to defined levels of risks [154,178,179]. Identifying areas where a population at risk lives is central in assisting a geographical targeting of intervention. This requirement is partially fulfilled by applying a spatial analytic approach. In this thesis, we showed that the spatial distribution of stunting and wasting are not random, and are further identified areas with a higher risk than the underlying at-risk population. Identifying the physical location and size of the high-risk segment will be an important input for geographically targeting interventions.

The Butajira District is one with a high burden of undernutrition, with a rate of stunting as high as 40% (Papers III and IV). Within this high-burden district, we identified an area (cluster) bordering the lowlands with a higher risk than the expected risk for the underlying at-risk population. The cluster contains more than 32% of the stunted cases (309 out of 954 cases) in the analytical sample. In such a way, geographically targeting a cluster like the one identified in this analysis through the spatial analytic method may bring the added benefits of improving programme coverage and effectiveness, as well as optimizing resources [154,179].

Although the theoretical assumptions described above hold true, geographical targeting is not immune to problems, with the most common of them reported from programme experiences including errors during inclusion, the movement of people to targeted geographic areas and community objections [180].

We believe that this approach could be applicable for district-level planning for nutrition for the following reasons. Health extension workers (HEWs) are expected to have a family register for each household, in which they can document the geographic position of respective households. HEWs are expected to routinely carry out growth monitoring and promotion (GMP), which will help to capture undernutrition data that can help provide policy-relevant information at regular intervals at the district level. Although the approach looks feasible and provides interesting input for the accelerated reduction of the stunting programme in Ethiopia and elsewhere, the lack of practical experience and lessons about its application in nutritional intervention programmes warrants field testing and evaluation.

Chapter 6: Conclusions and Recommendations

Conclusions

Based on the findings of the studies (Papers I, II, III and IV) in this thesis, we conclude the following:

- The spatial variation in undernutrition between administrative zones in Ethiopia can be explained in part by climate variables.
- The impact of climate on child undernutrition is modified by the type of agro-ecologic zone of the study area.
- There is spatial clustering for stunting and wasting on a different scale, thus indicating that within a given area there can be a micro-level variation in risk and burden in undernutrition.
- We found that the HFIAS tool can be used to measure the access component of household food insecurity in southern Ethiopia with minor modifications.
- Household economy is not a major determinant of stunting in this district, while household food security and maternal education played bigger roles.

Recommendations

For further research:

- We recommend further studies, but at the meso- and micro level (preferably at the district or village level, and the household level), to be conducted in order to evaluate the link between climate variables and undernutrition.
- The impact of climate variability on future undernutrition (stunting and wasting) in Ethiopia shall be studied.
- Evidence is required for the validation of HFIAS tool in other parts of Ethiopia, since variations in sociocultural settings might influence the successful application of the tool.
- The nine items in the HFIAS tool are put forth in order to reflect the increasing level of the severity of food insecurity. Further research is needed in order to evaluate the correct sequence of the nine items, as this sequence has its own implications in terms of the assignment of households into different levels of food insecurity.
- We recommend a replication of the spatial analysis of undernutrition indicators in other parts of the country to help validate and strengthen the evidence for its use.
- We recommended developing a risk map of stunting for Ethiopia using a robust statistical technique.
- Further studies are required to evaluate the impact of household's improved income on child undernutrition (stunting) using a robust study design.
- The pathways how household's food insecurity could impact stunting, other than its effect on dietary diversity, shall be further studied.
- Further studies are required to evaluate and compare the applicability and effectiveness of geographically targeting nutritional interventions using the inputs from spatial analysis and mapping.

For programme implementation

- The geographical targeting of nutritional interventions shall be tested by possibly using a trial design or implementation research as an alternative strategy to improve programme coverage and effectiveness for an accelerated reduction of undernutrition in the country.
- Among resource-constrained communities, interventions integrating household food insecurity in nutrition programmes would be effective in averting child undernutrition (stunting).
- Nutrition intervention programmes shall be comprised of women empowerment as part and parcel of their programmes.

Policy recommendations

- We recommend the need for local (district) level planning for nutrition to accommodate the variation in micro-environment vulnerability and the burden of undernutrition.
- Policymakers shall consider the use of the spatial analysis and mapping tool to strengthen the planning and implementation of the accelerated reduction of stunting in the country.
- The policy attention given to improving women's empowerment and improving a household's access to food (food security) shall be strengthened.
- The national Growth and Transformation Plan (GTP) shall give due attention on how national income can be sensitive to children's nutrition in terms of balancing the allocation of resource on items that improves children's nutrition.
- Programme planning based on data obtained from regional averages may mask variations within regions. Hence, national surveys such as the Demographic and Health Survey (DHS), the Welfare Monitoring Survey (WMS) and others shall consider providing district-level estimates of undernutrition indicators.

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Hagos et al. BMC Public Health 2014, 14:884
http://www.biomedcentral.com/1471-2458/14/884

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RESEARCH ARTICLE Open Access

Climate change, crop production and child under nutrition in Ethiopia; a longitudinal panel study

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Abstract

Background: The amount and distribution of rainfall and temperature influences household food availability, thus increasing the risk of child under nutrition. However, few studies examined the local spatial variability and the impact of temperature and rainfall on child under nutrition at a smaller scale (resolution). We conducted this study to evaluate the effect of weather variables on child under nutrition and the variations in effects across the three agro ecologies of Ethiopia.

Methods: A longitudinal panel study was conducted. We used crop productions (cereals and oilseeds), livestock, monthly rainfall and temperature, and child under nutrition data for the period of 1996, 1998, 2000 and 2004. We applied panel regression fixed effects model.

Results: The study included 43 clusters (administrative zones) and 145 observations. We observed a spatio temporal variability of rainfall, stunting and underweight. We estimated that for a given zone, one standard deviation increase in rainfall leads to 0.242 standard deviations increase in moderate stunting. Additionally, a one standard deviation increase temperature leads to 0.216 standard deviations decrease in moderate stunting. However, wasting was found to be poorly related with rainfall and temperature. But severe wasting showed a positive relationship with the quadratic term of rainfall.

Conclusions: We conclude that rainfall and temperature are partly predicting the variation in child stunting and underweight. Models vary in predicting stunting and underweight across the three agro ecologic zones. This could indicate that a single model for the three agro ecologies may not be not applicable.

Keywords: Temperature, Rainfall, Climate change, Under nutrition

Background

Ethiopia has experienced repeated famine since the 9th century [1]. Drought due to failure of rains often precedes Ethiopian famines. The failure of rain results in crop failure, impact food productions and usually results in food shortages in vulnerable parts of the population. Historical accounts showed that famine declines after the arrival of rains [2]. Rainfall is hence, one of the most important factors influencing livelihoods of subsistence farmers and pastoralists. Failures or irregularities of the rainy season have a direct link to reduced household food availability [3]. Therefore, in some parts of the country the pattern of rainfall during the main growing season of June-July-August-September (JJAS) has grave consequences on crop availability and child nutrition.

The spatio temporal distribution as well as the amount of rain and temperature influence human health [4]. The influence is substantial in developing countries, such as Ethiopia, which are largely dependent on rain fed agriculture [5]. Climate change impacts food security through multiple pathways. These include altering the availability of food that depends on the agricultural production [6] and influencing the stability of food supplies due to extreme weather events. Moreover, climate impacts are observed through influencing access to food and utilization [7].

There is a marked improvement in children's anthropometric status in Ethiopia over the past 10 years, as seen by the downward trend in the proportion of children stunted and underweight over the three successive Ethiopian Demographic and Health Survey (EDHS) [8-10]. Although

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the trend is showing a decreasing pattern, the proportion of under-five stunting, underweight and wasting are still high and more efforts are needed to reach the MDG goals [11]. Climate change is one of the challenges against the efforts undergoing to combat child under nutrition through improved household food security. Ethiopia recently (1999–2000) experienced the effect of low and untimely rainfall [12].

Children are vulnerable to the effects of climate change and examples of these effects are reviewed and reported [13-18]. However, few studies examined the local spatial variability and the impact of climate on stunting, underweight and wasting of under-five children despite the fact that children are considered vulnerable. The purpose of this study was to: (i) evaluate the spatial distribution of rainfall, temperature, per capita crop availability and under nutrition; (ii) characterize the pattern and interrelationship of rainfall, temperature and under nutrition; and (iii) analyze the variations in effects across different agro ecological zones of Ethiopia.

Hence this paper builds on the links between climate variables and under-five children under nutrition and could be used to design appropriate programs for areas impacted by climate change.

Methods

Study design and period

We employed a longitudinal panel study design to estimate the effect of growing season temperature and rainfall on child under nutrition for the period of 1996–2004.

Data and data sources

The dataset constituted a panel of observations of multiple variables. Crop productions (cereals and oil seeds) and livestock data for administrative zones included in the study were obtained from the Central Statistics Agency (CSA Ethiopia) for the period of 1996, 1998, 2000, and 2004. We converted the total amount of crops produced during the main harvesting season (October to November) in each zone into per capita crop availability. We used projected population for each administrative zone. The projected population of zones was estimated by CSA using the ratio method based on the projected population of each region.

We obtained monthly rainfall data for the months of JJAS for each studied zones from the respective weather station(s). The data were made available by the Ethiopian Malaria Prediction System Research Project and the National Meteorological Authority. The main harvest season in most of the study locations is during the months of October and November. We assumed that crop yield is predominantly affected by the amount of rain during the growing seasons of JJAS. Hence we computed the total amount of rainfall for the pre harvest seasons of JJAS and used in this analysis.

The main outcomes of interest for this study were both moderate and severe forms of stunting, wasting, and underweight in children under five years of age. Children were considered moderately malnourished if one of the three forms of under nutrition are 2 SDs (standard deviations) below the median expected height-for-age, weight-for-height and weight-for-age. Children were considered severely malnourished if one of the three forms of under nutrition is 3 SDs below the median expected height-for-age, weight-for-height and weight-for-age.

We used data sets of Agricultural Sample and the Demographic Health Survey (DHS) Surveys collected by the Central Statistics Agency (CSA) that cover all Ethiopian administrative zones from 1996 to 2004. Out of these successive data sets, we created a pseudo panel data set of under nutrition, crop, livestock and other variables at zonal level. The zonal level panel data sets of under nutrition, crop, livestock and other data were matched by year.

Altitude data at 30 arc-seconds (~1 km) resolution data were downloaded by a tile from the world climate data source website (http://www.worldclim.org/bioclim.). The altitudes were then extracted from the raster data set for each study zone. Temperature data were obtained from the Climatic Research Unit (CRU) TS (time-series) datasets (CRU v321) available at http://badc.nerc.ac.uk/view/badc.nerc.ac.uk__ATOM__ACTIVITY_0c08abfc-f2d5-11e2-a948-00163e251233.

Data processing and analysis

We used Stata (version 11, Stata Corporation, College Station, TX) for panel data analysis. Spatial visualization, extraction of altitude data and mapping was done using Arc GIS version 10 (ESRI).

We applied panel data regression techniques and used the variables per capita crop arability, livestock, rainfall (both linear and quadratic) and temperature in the model to estimate the effect of climate variability on child wasting, underweight and stunting.

Before applying regression, multiple steps were followed. We took logs of crop per capital availability to achieve normality. Based on altitude, we classified the study areas (administrative zones) into three agro ecological zones. A separate model was fit to see the variations in response to climate across the three agro ecological zones. We calculated standardized anomalies for all the variables and used the same in the model. By standardizing we ask if wetter/warmer conditions in any zone leads to more/less under nutrition in the same zone.

Hausman test was conducted in order to choose between fixed or random effects models. The test basically examines whether the error terms are correlated with the regressors. The null hypothesis was that the preferred model is a random effect, while the alternative is the fixed effects. If the error terms are correlated with the one or more of the regressors (such as rainfall), the estimated coefficients are biased and hence the preferred model is the fixed effects.

We used both the linear and quadratic terms for standardized rainfall assuming that stunting, underweight and wasting could be worsened by extreme low and high rainfall. However, we did not check for serial correlation of the residuals as the data set constructed had a shorter timer series.

Goodness of fits of models

We reported three types of R-square values for each regression model. These are the within, between, and overall R-squares. The within R-square value indicates how much of the variation in child under nutrition with in a zone over the study period is explained by weather variables. The between R-square values indicates how much of the variation in child under nutrition between zones is explained by weather variables. The overall R-square values indicates how much of the overall variation in child under nutrition is explained by climatic variables.

Non-technical summary of the methods

We constructed a panel dataset using the following steps. For each study zone, data on rainfall, temperature, per capita crop availability and livestock was compiled for the years 1996, 1998, 2000 and 2004. We then matched child under nutrition estimates of each zone with the respective study year. This made a panel data set consisting of a total of 145 observations. A panel data set consists of a cross sectional time series data in which attributes (e.g. Rainfall) of many units (e.g., Zones) are observed over time (e.g. Years). From this data we computed standardized anomalies in order to capture the effects of climate within a given zone. The data were then analyzed using a fixed effects model. We chose the fixed effects model over random effects because each study zone can have a peculiar feature or characteristics that can prevent (e.g. higher productivity) or worsens child nutrition condition and this must be accounted in the analysis.

Results

Sample characteristics

The study included 43 clusters (administrative zones) and 145 observations for the period of 1996–2004. This period was one of the recent periods that Ethiopia experienced the effect of low and untimely rainfall [12]. There were on average 3.5 observations per cluster (zone) in the data set. A descriptive summary of the panel data set used for the present analysis is presented (Table 1).

Summary of the model parameters

The average growing season rainfall of the study locations was 645.2 mm. The overall amount of growing season rainfall ranges from 41.2 to 1378 mm. The average minimum and maximum amount of rainfall with in zones was 64.4 and 1225.4 mm respectively. However, the average minimum and maximum amount of rainfall documented between zones was 258 and 1055 mm respectively. We observed a comparatively higher variability of rainfall between zones compared to within zones.

We found an average growing season temperature of 19.9°C for the study period. The overall minimum and maximum temperatures for the study locations were 15.5°C and 29.9°C respectively. Unlike rainfall, we observed a smaller variability of temperature within zones over the study period.

Low amount of rainfall during the growing season is expected to affect crop production and availability. Data on total per capita crop availability in the studied zones indicated that the overall mean total per capita crop availability during the study period was 206.9 kg. Per capita crop availability in the study ranged from 10.8 kg to 1022.3 kg.

The overall average prevalence of underweight over the study period was 42.5% (range: 19, 62.5%). About 15.4% had a severe degree of underweight. The overall average stunting during the study period was 55.2% (range: 20.4, 78.6%). About 32.8% of the children had severe stunting. The mean wasting prevalence over the study period was 10.1%. We observed a higher variability in the prevalence of moderate stunting, wasting and underweight. The variability was consistent between as well as within the zones over the study period.

Spatial and temporal pattern

The average growing season rainfall shows marked variation over the study period as well as agro-ecologies. The average growing season rainfall showed a decreasing pattern between the highlands to the lowlands. The highlands had an average rainfall of 726.8 mm, while the midlands and lowlands had 668.0 mm and 513.9 mm respectively. The average growing season temperature didn't show a marked variation over the study period. We observed a relatively higher temperature in lowland compared to the midlands and highlands (Table 2).

We observed a decreasing pattern on stunting, wasting and underweight over the study periods. The highlands and midlands documented a relatively higher prevalence of stunting and underweight compared to the lowlands. The average prevalence of underweight and stunting among highlands was 45.3 and 59.5% respectively, while the average prevalence of underweight and stunting among lowlands was 38.7 and 51.0% respectively. However, the prevalence of severe forms of stunting, underweight and

Table 1 Summary of panel data used in the study, Ethiopia, 1996–2004

Variable		Mean	Std. dev.	Min	Max	Observations*
Rainfall (mm)	Overall	645.2	317.4	41.2	1377.9	N = 145
	Between		306.5	64.4	1225.4	n = 41
	Within		122.3	258.8	1055.0	T-bar = 3.5
Temperature (°C)	Overall	19.92	3.12	15.5	29.9	N = 142
	Between		3.56	15.8	29.9	n = 41
	Within		0.19	19.44	20.3	T-bar = 3.6
Per capita crop (kg)	Overall	206.9	166.9	10.8	1022.3	N = 127
	Between		123.6	22.9	528.6	n = 34
	Within		115.5	−106.5	872.6	T-bar = 3.73529
Wasting (%)	Overall	10.1	3.7	2.8	24.6	N = 145
	Between		2.9	3.4	17.9	n = 41
	Within		2.6	2.7	16.8	T-bar = 3.5
Severe wasting (%)	Overall	3.3	2.1	0.0	16.3	N = 143
	Between		1.5	0.0	9.2	n = 41
	Within		1.6	−0.7	10.4	T-bar = 3.4
Underweight (%)	Overall	42.5	9.5	19.0	62.5	N = 145
	Between		7.4	27.6	57.9	n = 41
	Within		6.3	23.5	57.7	T-bar = 3.5
Severe underweight (%)	Overall	15.4	5.6	3.4	30.3	N = 145
	Between		4.1	7.5	21.8	n = 41
	Within		4.0	5.2	24.9	T-bar = 3.5
Stunting (%)	Overall	55.2	11.2	20.4	78.6	N = 145
	Between		7.4	38.3	70.6	n = 41
	Within		8.8	28.2	73.8	T-bar = 3.5
Severe stunting	Overall	32.8	10.0	8.0	54.2	N = 145
	Between		6.8	18.5	45.9	n = 41
	Within		7.5	15.4	50.9	T-bar = 3.5

*N = total number of observations, n = the number of clusters (zones), T-bar = average observation per cluster (zone).

wasting did not vary over the three agro ecologic zones (Table 2).

Figure 1 shows the spatial pattern of average growing season rainfall, per capita crop availability, stunting and underweight in the study zones. The choropleth map indicates zones in the north and northwestern part of the country documented higher rainfall. Higher per capita crop availability is documented in some zones with high rainfall. We noted that zones with higher rainfall documented a higher prevalence of stunting and underweight compared with zones with lower rainfall. However, zones with higher per capita crop availability had a relatively lower prevalence of child under nutrition rates.

Panel regression results

We observed the following relationships from the panel regression models for moderate and severe stunting (Tables 3 and 4). First, stunting was found to be strongly and negatively correlated with growing season temperature for the three agro ecologies. For a given zone, one standard deviation increase in temperature resulted in 0.216 standard deviation decrease in moderate stunting. This relationship is statistically significant for the all zone and the lowland models. Second, stunting is positively associated with the amount of rainfall, indicating that an increase in rainfall resulting in an increas. For a given zone, one standard deviation increase in rainfall resulted in 0.242 standard deviation increase in moderate stunting. This relationship is statistically significant for the all zone and midlands model. We did not find any significant result on the relationship between rainfall and stunting when the quadratic terms instead of the linear form of rainfall was used. However, the direction of the coefficients indicates that extreme forms rainfall is leading to a higher prevalence of moderate stunting. Similar results were documented on the relationship between severe form of stunting and weather variables.

Table 2 Distribution of rainfall, temperature, per capita crop and child under nutrition status by agro ecologies and study period, Ethiopia, 1996–2004

Agro ecology	Year	Rainfall (mm) (mean, SD)	Temperature (°C) (mean, SD)	Per capita crop (kg)	wasting (%) (mean, SD)		Underweight (%) (mean, SD)		Stunting (%) (mean, SD)	
					Moderate	Severe	Moderate	Severe	Moderate	Severe
Lowland	1996	547.3(335.9)	21.42.0)	391.1(210.5)	8.1(2.7)	3.9(0.7)	41.6(7.9)	16.7(5.3)	63.1(6.3)	42.4(8.3)
	1998	540.8(401.3)	23.1(3.0)	130.6(121.8)	9.5(3.8)	2.9(1.8)	41.0(8.0)	14.0(4.9)	55.8(7.6)	32.2(6.5)
	2000	512.0(414.7)	23.6(3.4)	162.5(154.8)	11.2(4.5)	3.7(3.9)	38.4(9.8)	13.9(6.6)	47.6(9.7)	27.0(8.0)
	2004	464.6(374.0)	22.5(2.3)	138.2(136.3)	9.8(5.4)	2.8(2.5)	34.7(10.1)	12.4(6.9)	41.7(10.5)	21.3(7.9)
	Total	513.9(377.2)	22.8(2.6)	202.3(185.1)	9.9(4.3)	3.3(2.6)	38.79(9.2)	14.0(6.0)	51.0(11.5)	29.6(10.3)
Midlands										
	1996	721.1(165.4)	18.5(2.3)	259.4(129.1)	9.7(2.6)	4,2(1.1)	43.0(6.3)	17.9(4.6)	65.0(6.0)	43.7(6.8)
	1998	751.8(304.1)	19.7(2.7)	187.3(197.6)	11.6(4.4)	2.9(1.4)	48.4(8.0)	16.3(4.9)	57.3(7.4)	32.8(7.2)
	2000	646.4(263.5)	19.5(2.9)	224.8(167.3)	12.0(2.5)	4.7(2.2)	45.7(10.7)	18.6(5.7)	56.8(7.6)	33.4(7.3)
	2004	645.3(292.9)	19.7(2.8)	278.2(271.8)	10.8(4.2)	3.1(1.8)	35.7(4.6)	10.3(3.1)	43.9(10.9)	22.2(7.7)
	Total	688.0(281.9)	19.4(2.7)	233.9(198.0)	11.2(3.6)	3.7(1.9)	43.2(9.1)	15.6(5.7)	54.8(11.0)	32.2(9.8)
Highlands										
	1996	733.0(165.4)	17.5(1.4)	217.1(160.6)	9.6(2.5)	4.1(1.5)	45.9(7.6)	19.5(5.3)	64.7(6.4)	43.9(7.4)
	1998	744.2(194.5)	18.1(1.5)	163.5(111.9)	9.9(3.3)	2.3(1.0)	49.3(8.0)	15.3(4.1)	62.3(8.7)	35.0(7.3)
	2000	739.1(340.3)	17.9(1.6)	186.9(100.2)	10.5(2.7)	3.3(1.5)	38.4(9.8)	18.9(3.6)	61.8(6.7)	37.8(6.80
	2004	691.2(274.0)	18.1(1.5)	182.2(271.8)	7.0(2.6)	2.1(1.2)	36.1(7.5)	12.8(3.7)	49.5(9.4)	28.6(7.8)
	Total	726.8(247.3)	17.9(1.5)	186.99118.0)	9.26(3.0)	2.9(1.5)	45.3(9.1)	16.6(4.9)	59.5(9.8)	36.2(9.0)
All zones		645.2(317,4)	19.92(3.11)	206.9(167.0)	10.1(3.7)	3.3(2.1)	42.5(9.5)	15.4(5.6)	55.2(11.2)	32.8(10.0)

Tables 5 and 6 shows results from the models where moderate and severe underweight is regressed on growing season rainfall and temperature. The results across the agro ecological zones consistently showed inverse relationships between growing season temperature and moderate form of underweight, although the relationship was not statistically significant. A severe form of underweight, however, showed a statistically significant inverse association with temperature. We observed that the quadratic term for rainfall is significantly related with underweight in the highland models indicating that a very small as well as high amount of rainfall leading to higher prevalence of underweight. This relation might indicate a nonlinear relationship between rainfall and underweight in the highlands of Ethiopia.

In the present study wasting was found to be poorly related with rainfall and temperature (Table 7). None of the models resulted a significant relationship with rainfall and temperature. But severe wasting showed a positive relationship with the quadratic term of rainfall in the all zone as well as the midland models (Table 8).

Goodness of fits of models

Except for the lowlands, the variation in moderate and severe stunting between study zones is adequately explained by climatic variables in the model (between R square values; 0.81-0.95). However, the variation in stunting with a study zone over the study period is poorly explained by the present model. The R-square values for models on underweight were very small and vary over the three agro ecologies. The overall R-square values indicated that these models capture smaller aspects of the variation in child underweight between as well as within the study zones over the study period.

Discussion

We used existing data to explore spatio temporal patterns and further to estimate the impact of growing season temperature and rainfall on child underweight, wasting and stunting before, during and after the crisis period of 1999–2000 [12].We found that unlike temperature, rainfall showed a marked variation over the study periods as well as agro-ecologies. Although, there is a decreasing pattern of stunting, wasting and underweight over time , a higher prevalence of stunting and underweight were found in the highlands and midlands compared to the lowlands. We found that the amount and direction of the effect of rainfall vary among the different ecologies. Additionally, sometimes the quadratic terms of rainfall rather than the linear forms were significant predictors for underweight and stunting. Moreover, the results of the study demonstrate that temperature has a significant effect on child underweight and stunting.

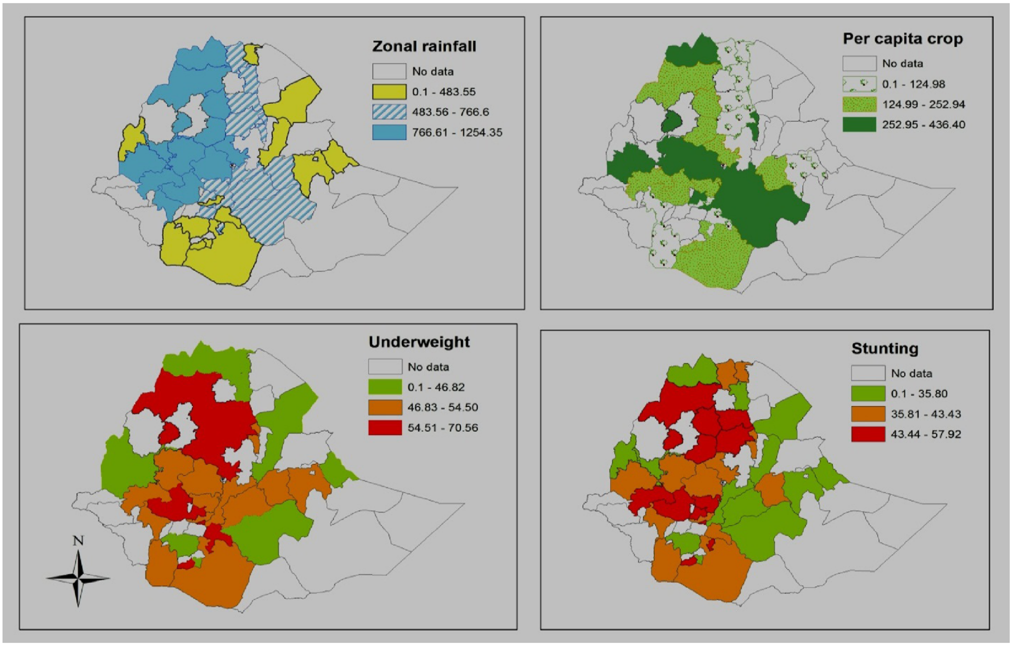

Figure 1 Choropleth maps showing spatial distribution of rainfall, per capita crop availability and under nutrition for the study locations, Ethiopia,1996-2004.

Table 3 Panel regression results on the effect of rainfall and temperature on stunting, Ethiopia, 1996–2004

	All zone model		Lowlands		Midlands		Highlands	
	coef†	se‡	coef	se	coef	se	coef	se
Rainfall during growing season	0.242***	0.91	0.06	0.17	0.495**	0.16	0.22	0.16
Temperature	−0.216*	0.12	−0.55**	0.26	−0.09	0.17	−0.23	0.22
Quadratic term for rainfall	0.060	0.14	−0.33	0.27	0.30	0.22	0.23	0.27
Per capita crop	−0.53	0.000	0.003	0.18	0.12	0.16	−0.000	0.17
Livestock	−0.02*	0.068	−0.27*	0.24	−0.52	0.21**	0.06	0.18
Number of observations	121		32		39		50	
Within R^2	0.28		0.53		0.49		019	
Between R^2	0.81		0.07		0.95		0.87	
Overall R^2	0.30		0.53		0.5		0.19	

Note: ***p < 0.01, **p < 0.05, *p < 0.1 , †model coefficients, ‡standard errors of the coefficient.

The reported prevalence of stunting, wasting, and underweight from this study are relatively higher when compared with successive EDHS [8-10]. However, a similar result was observed with regard to the decreasing trend in stunting and underweight over the study years. Moreover when the prevalence of stunting and underweight of the present study is compared with EDHS survey of the same year, we found a comparable figure All these taken might suggest that the sample could be represent significantly major parts of Ethiopia.

A similar approach was used to provide evidence on the association between climate change and child under nutrition in Mali, Africa. [19]. Stunting is found to be highly influenced by arid climate even when controlled for livelihoods. However, the effect of climate on underweight is found to be not significant. Some argue that underweight is a short term response to climate seasonal flux or shocks and these shocks can be absorbed and modified by livelihood adaptation capabilities. Moreover, sometimes the effects of decline in rainfall (and crop failure) on child hood anthropometries indices may not be visible as it could be prevented through public health measures [20]. Our study also documented that the

Table 4 Panel regression results on the effect of rainfall and temperature on severe stunting, Ethiopia, 1996–2004

	All zone model		Lowlands		Midlands		Highlands	
	coef†	se‡	coef	se	coef	se	coef	se
Rainfall during growing season	0.225***	0.81	−0.01	0.17	0.51**	0.16	0.17	0.13
Temperature	−0.24*	0.11	−0.64**	0.26	−0.28	0.18	−0.13	0.17
Quadratic term for rainfall	0.52	0.12	−0.39	0.27	0.26	0.22	0.27	0.21
Per capita crop	0.13	0.85	0.99	0.18	0.23	0.16	0.13	0.13
Livestock	−0.39***	0.10	−0.15	0.22	−0.36	0.21**	−0.46***	0.15
Number of observations	121		32		39		50	
Within R^2	0.43		0.56		0.50		0.47	
Between R^2	0.82		0.03		0.81		0.97	
Overall R^2	0.44		0.56		0.51		0.48	

Note: ***p < 0.01, **p < 0.05, *p < 0.1 , †model coefficients, ‡standard errors of the coefficient.

model for underweight showed non-significant association with rainfall as compared to models for stunting.

The finding that rainfall and temperature predicting child stunting has important implications over future child under nutrition attributable to climate change. A relative increase on moderate and severe forms of stunting is estimated due to climate change in sub-Saharan African countries [21]. However, uncertainties still remain on the pattern of future rainfall in Eastern African countries including Ethiopia. Studies done by Christensen et al. reported a higher probability of an increase in the annual mean rainfall in East Africa extending to the Horn of Africa [22]. The growing seasons of countries such as Ethiopia would be benefited due to a combination of increased rainfall as well as temperature indicating that not all changes in climate variability would be negative [23]. In contrary, Funk et al. [24] indicated that warming of the Indian Ocean would lead to a decrease in rainfall and hence can threaten Eastern Africa. Some argue that the precipitation simulation by IPPC did not consider the complex terrain nature of the Eastern Africa [24].

Assessing the effect of climate variability on health poses methodological challenges. The common challenges

Table 5 Panel regression results on the effect of rainfall and temperature on underweight, Ethiopia, 1996–2004

	All zone model		Lowlands		Midlands		Highlands	
	coef†	se‡	coef	se	coef	se	coef	se
Rainfall during growing season	0.19*	0.10	−0.17	0.21	0.36*	0.20	0.23	0.16
Temperature	−0.12	0.14	−0.29	0.34	0.07	0.23	−0.21	0.23
Quadratic term for rainfall	0.12	0.16	−0.32	0.35	0.21	0.27	0.49*	0.26
Per capita crop	−0.07	0.11	0.10	0.23	−0.21	0.20	−0.05	0.16
Livestock	−0.08	0.12	−0.16	0.28	−0.31	0.24	0.15	0.18
Number of observations	121		32		39		50	
Within R^2	0.09		0.22		0.22		0.25	
Between R^2	0.80		0.03		0.45		0.25	
Overall R^2	0.09		0.22		0.22		0.25	

Note: *p < 0.1 , †model coefficients, ‡standard errors of the coefficient.

Table 6 Panel regression results on the effect of rainfall and temperature on severe underweight, Ethiopia, 1996–2004

	All zone model		Lowlands		Midlands		Highlands	
	coef†	se‡	coef	se	coef	se	coef	se
Rainfall during growing season	0.14	0.10	−0.27	0.20	0.42**	0.18	0.19	0.15
Temperature	−0.26**	0.13	−0.35	0.30	−0.26	0.21	−0.32	0.17
Quadratic term for rainfall	0.16	0.15	−0.39	0.31	0.02	0.25	−0.03	0.24
Per capita crop	0.17*	0.01	0.37*	0.21	0.14	0.18	0.14	0.15
Livestock	−0.18	0.12	0.09	0.25	−0.27	0.22	−0.27	0.17
Number of observations	121		32		39		50	
Within R^2	0.24		0.36		0.35		0.35	
Between R^2	0.06		0.01		0.07		0.97	
Overall R^2	0.24		0.36		0.34		0.35	

Note: **p < 0.05, *p < 0.1 , †model coefficients, ‡standard errors of the coefficient.

Table 7 Panel regression results on the effect of rainfall and temperature on wasting, Ethiopia, 1996–2004

	All zone model		Lowlands		Midlands		Highlands	
	coef†	se‡	coef	se	coef	se	coef	se
Rainfall during growing season	−0.06	0.10	−0.04	0.17	0.01	0.20	−0.03	0.18
Temperature	−0.14	0.14	0.33	0.26	−0.32	0.24	−0.21	0.23
Quadratic term for rainfall	0.09	0.16	−0.37	0.27	0.31	0.28	0.37	0.29
Per capita crop	−0.04	0.11	0.33	0.18	−0.22	0.20	−0.02	0.18
Livestock	0.11	0.13	0.16	0.22	0.15	0.25	−0.04	0.20
Number of observations	121		32		39		50	
Within R^2	0.02		0.2		0.50		0.47	
Between R^2	0.17		0.00		0.81		0.97	
Overall R^2	0.02		0.2		0.51		0.48	

Note:, †model coefficients, ‡standard errors of the coefficient.

Table 8 Panel regression results on the effect of rainfall and temperature on severe wasting, Ethiopia, 1996–2004

	All zone model		Lowlands		Midlands		Highlands	
	coef†	se‡	coef	se	coef	se	coef	se
Rainfall during growing season	0.04	0.10	0.09	0.18	0.29	0.20	−0.14	0.15
Temperature	−0.11	0.13	0.05	0.28	−0.17	0.23	−0.11	0.2
Quadratic term for rainfall	0.26*	0.14	0.19	0.29	0.49*	0.26	0.26	0.25
Per capita crop	0.26**	0.1	0.62	0.19**	0.09	0.19	0.23	0.15
Livestock	−0.26**	0.12	−0.10	0.23	−0.32	0.23	−0.41**	0.17
Number of observations	121		32		39		50	
Within R^2	0.27		0.45		0.22		0.35	
Between R^2	0.05		0.02		0.45		0.91	
Overall R^2	0.26		0.45		0.22		0.35	

Note: **p < 0.05, *p < 0.1 , †model coefficients, ‡standard errors of the coefficient.

include exposure assessment, ecological fallacies, the complexity of relationships, and scale of the study [25,26]. First, in this study we assumed that the exposure (rainfall and temperature) will be similar for households that are found in the same zone (group) as climate impacts populations rather than individuals [25]. Hence we interpreted the link between rainfall, temperature and child under nutrition at zonal (group) level using aggregated estimates. However, in the absence of individually collected data, it is somehow difficult to exclude totally the role of ecological fallacy in the relationship. Moreover, we cannot rule out the local variation in the exposures such as rainfall and temperature within a given zone. Second, we used the UNICEF conceptual framework [27] to develop a biologically plausible model. Immediate and underlying causes of child under nutrition are captured with model variable such illness prevalence, livestock and per capita crop availability. However, the actual relationship can be more complex than assumed, and can be nonlinear requiring multiple pathways.

The findings of the current study shall be interpreted within the context of the following limitations. Due to the limitation of the availability of complete data for such work, the sample sizes for a stratified analysis based on agro-ecological zones were small. This has likely resulted in the absence of significant results. We were not also able to quantify and characterize threshold limits of rainfall which would have been beneficial to model child under nutrition risks. Despite these limitations, we believe that the present study involved more than half of the administrative zones of Ethiopia and was able to generate important information on the variation in effects of weather variables on child under nutrition.

Conclusions

We conclude that rainfall and temperature are partly predicting the variation in stunting and underweight in Ethiopia. Moreover, the models vary in predicting stunting and underweight across the three agro ecologic zones. This could indicate that a single model for all the three agro ecologies may not be not applicable. We recommend further work but at a micro level using similar analysis methods to assess the effect of rainfall and temperature on stunting, wasting and underweight.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

SH conceived the study, collected, analyzed and prepared the draft manuscript (as partial requirement for his PhD degree at University of Bergen, Norway). TL helped to analyze and interpret the data. BL, as a primary advisor for SH, conceived the study, advised and supervised the conception, the conduct as well as the analysis and write-up of the study. DH advised and supervised the analysis and write-up of the study. TW advised and supervised the conception, the analysis and write-up of the study. All authors helped in drafting the manuscript. All authors have read and approved the manuscript.

Acknowledgement

We would like to thank the Ethiopian Central Statistics Agency (CSA Ethiopia) for providing data on crop production, cattle production and population size. We would also like to thank the National Meteorological Authority (NMA) for providing station based rainfall data.

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Received: 3 January 2014 Accepted: 15 August 2014
Published: 27 August 2014

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doi:10.1186/1471-2458-14-884
Cite this article as: Hagos *et al.*: Climate change, crop production and child under nutrition in Ethiopia; a longitudinal panel study. *BMC Public Health* 2014 **14**:884.

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Gebreyesus *et al. BMC Nutrition* 2015, **1**:2
http://www.biomedcentral.com/bmcnutr/content/1/1/2

BMC Nutrition

RESEARCH ARTICLE Open Access

Is the adapted Household Food Insecurity Access Scale (HFIAS) developed internationally to measure food insecurity valid in urban and rural households of Ethiopia?

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Abstract

Background: The concept of food insecurity encompasses three dimensions. One of these dimensions, the access component of household food insecurity is measured through the use of the Household Food Insecurity Access Scale (HFIAS). Despite its application in Ethiopia and other similar developing countries, its performance is still poorly explored. Our study aims to evaluate the validity of the HFIAS in Ethiopia.

Methods: We conducted repeated cross-sectional studies in urban and rural villages of the Butajera District in southern Ethiopia. The validation was conducted on a pooled sample of 1,516 households, which were selected using a simple random sampling method. The HFIAS was translated into the local Amharic language and tested for face validity. We also evaluated the tool's internal consistency using Cronbach's alpha and factor analysis. We tested for parallelism on HFIAS item response curves across wealth status and further evaluated the presence of a dose-response relationship between the food insecurity level and the consumption of food items, as well as between household wealth status and food insecurity. Additionally, we evaluated the reproducibility of the tool through the first and second round of HFIAS scores.

Results: The HFIAS exhibited a good internal consistency (Cronbach's alpha for the values of rounds 1 and 2 were 0.76 and 0.73, respectively). A factor analysis (varimax rotation) resulted in two main factors: the first factor described a level of mild to moderate food insecurity, while the second factor described severe food insecurity. HFIAS item response curves were parallel across wealth status in the sample households, with a dose-response trend between food insecurity levels and the likelihood of previous day food consumption being observed. The overall HFIAS score did not change over the two rounds of data collection.

Conclusions: The HFIAS is a simple and valid tool to measure the access component of household food insecurity. However, we recommend the adaptation of questions and wordings and adding examples before application, as we found a discrepancy in understanding of some of the nine HFIAS questions.

Keywords: HFIAS, Food security, Validity

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Background

In its *Plan of Action*, the 1996 World Food Summit adopted a working definition on food security. This definition was redefined in 2001 by the Food and Agricultural Organization (FAO): "*Food security* [*is*] *a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life*" [1]. According to a recent estimate by the FAO, approximately 870 million people worldwide are undernourished, with 27% of these affected people residing in sub-Saharan African countries [2].

Food security is a complex issue with a multi-dimensional concept, which is based on multiple dimensions such as physical, social, and economic access, availability, amount, preferences for certain foods, security, and time [3]. The measurement of food insecurity at any given time captures one if not more of the three dimensions of food security: availability, utilization, and access. The food insecurity assessment based on the availability dimension is widely used and for the most part guides the responses to food insecurity [4]. However, it fails to capture the unequal distribution of food and is also unable to guarantee the utilization of food in a given population. An assessment of food insecurity based on the second dimension, utilization, is well captured through various anthropometric indicators, e.g., underweight, stunting, and wasting. Nonetheless, measurements based on the access dimension of food insecurity are not yet well established.

Food access, which reflects the demand side of food security, has recently been designated as one of the major contributors to food insecurity [5]. In 2006, the USAID-funded Food and Nutrition Technical Assistance Project, through the Academy for Educational Development, published a tool that measures the access component of household food insecurity. The tool was developed to be simple, easy to use, and applicable, with only minor adaptations to different sociocultural contexts. The tool captures three domains: i) anxiety and uncertainty about food access, ii) insufficient quality (variety, preferences, and social acceptability), and iii) insufficient food intake and the physical consequences [6].

The HFIAS has been shown to measure food insecurity with an acceptable standard in a few developing countries [7-10]. Even so, a lot has been done on measurements of the access component of food insecurity in developed countries such as the US [11]. The Core Food Security Module (CFSM), which has a similar structure with that of the HFIAS, is currently being used to measure the access component of food insecurity in the US. The CFSM is based on a set of 18 questions for households with children and 10 questions for households without children, and the frequencies of affirmative responses to these questions are used to discriminate households into three levels of food insecurity [12].

Maes and colleagues have attempted to validate the HFIAS among volunteer AIDS caregivers in Addis Ababa, Ethiopia [9]. The authors reported that the tool performed well in capturing the access component of food insecurity among the study participants, who were special groups of people and may not represent the general population.

However, despite the increasing application of the tool in Ethiopia, its performance remains underexplored. The results of this study will help to strengthen the applicability of the tool and its performance for measuring progress and to monitor and evaluate different programs focusing on household food insecurity.

Methods

Study setting

The study was conducted in the Butajera District of southern Ethiopia, which is located approximately 130 km from Addis Ababa (the capital city of Ethiopia) in the *Guraghe* Zone in the Southern Nations Nationalities and People's Region (SNNPR). The district houses a Rural Health Program (BRHP) (owned and operated by Addis Ababa University), which is a health and demographic surveillance system (HDSS) with a continuous registration of vital and migratory events among ten selected villages. The studied district was purposely selected for the benefit of a better sampling frame and research infrastructure.

Study design and period

A community-based, cross-sectional study design was employed between November and December 2013. We administered the survey questionnaire twice to the study participants, and the second survey questionnaire was administered to the study participants after 7 days of the first administration. This repeated survey was used to determine the reproducibility of the household food insecurity assessment tool (HFIAS).

Study population and sampling

The study included a total of ten HDSS villages, of which nine were rural and one was urban, and the study population included households residing in these villages.

The sample size for the study was estimated using the formula for a single population proportion. Assuming an 80% prevalence of household food insecurity [13], a 95% confidence level, a 4% margin of error, and a design effect of 2, the calculated sample size was 768 households. With an expectation of a 5% non-response rate, the final sample size required was approximately 800 households.

The final sample size was allocated to the ten HDSS villages proportionate to the number of households in each village. We then used BRHP data set as a sampling frame and applied a simple random sampling method to select study households within a given village.

Data collection

The HFIAS is composed of nine items, which are asked with a recall period of 1 month. For each item, there was a follow-up of the frequency of the occurrence question. The tool was also translated into the Amharic (local) language by one of the authors (SHG) and initially reviewed with research assistants who were residents in the study area.

Face validity

We discussed all nine questions independently with four urban and four rural households in the neighboring villages, basically aiming at whether the questions were clear, easily understandable, and had a minimal amount of multiple interpretations. We read the nine questions to the women, and the responses were recorded. This was followed by a question about how the women understood each question. For example, we asked: "*What do you understand when I ask you the question*: *In the past four weeks*, *were you or any household member not able to eat the kinds of foods you preferred because of a lack of resources*?" We compared their understanding with that of the primary aim of the questions, and when there was a difference between what they understood and what we were actually looking for, a discussion followed on how that question could best be framed to make it clearer and contextually appropriate. Lastly, together with these women, the nine questions were adapted through modification, rephrasing, and adding examples when necessary.

We collected food groups that a household had consumed over the preceding 24 h [14], with the household food intake structured using the consumption of 12 food groups/item. The food groups included meat, fish, vegetables, fruits, eggs, potatoes, and other roots/tubers, beans, cereals/breads, oil, fat or butter, sugar or honey, as well as other types of foods such as coffee and tea.

Moreover, a range of sociodemographic data about the respondents such as age, education, religion, marital status, and occupation was collected, in addition to household-level data such as ownership and size of land, type of house and construction materials, availability of fixed assets such as radio, television, phone, bed and chair, and other household items, possession of domestic animals, type of water source for drinking and cooking, and availability and type of latrine.

Interviews were conducted by 20 trained and experienced junior nurses who are residents of the local district and had similar data collection experiences. The work was monitored by six supervisors, and interviews were primarily conducted with women in the household, as women are commonly responsible for food preparation in the study area. If women were unavailable, another adult who was present and ate in the household the previous day was asked.

Quality control

Questionnaires were controlled for completeness and logical errors, and where errors were found, the questionnaires were redone. Consistency checks were done to improve the quality of the data, and inconsistent entries and responses were crosschecked with the questionnaires and corrected accordingly.

Ethical clearance

The study protocol was approved by institutional review boards from the Addis Ababa University, College of Health Sciences. The study was also approved by the Regional Committee for Medical and Research Ethics, Western Norway (REK Vest). Information on the research objective was read to the participants, verbal informed consent was received, and the privacy and confidentiality of respondents was also maintained.

Data entry and analysis

We used EpiData Version 3.1 for the data entry, and the data was exported to Stata 11.0 (StataCorp, College Station, TX) for cleaning and further analysis.

Household wealth was constructed through a principal component analysis (PCA) of the household-level data described above. The PCA was done independently for urban and rural samples, and the score was then used to assign sampled households into quintiles that indicate poorest, poor, medium, rich, and richest.

The results from HFIAS delineate households across the four levels of food insecurity, including food secure, mild food insecure, moderate food insecure, and severely food insecure. The procedure and steps used to assign households to one of the levels is described elsewhere [3].

Factor analysis

An exploratory analysis was conducted on the nine items, using a Horn's parallel analysis (PA) to determine the number of factors to retain. PA is a Monte Carlo-based simulation method that compares observed eigenvalues with that obtained from uncorrelated normal variables.

Validation

We evaluated the validity of the nine-item food insecurity assessment tool based on the following recommended criteria employed by a few similar studies [9,15,16].

The first criterion is the value of the Cronbach's alpha, which is a measure for internal consistency, approaching 0.85 for the two rounds of surveys. Secondly, we tested for parallelism on HFIAS item response curves across

Table 1 Sample characteristics of households by rounds of data collection, Ethiopia 2013

Variable	Round I (%)	Round II (%)
N	767	749
Residency, %		
Urban	30.4	30.3
Rural	69.6	69.7
Respondent status, %		
Household head	13.3	12.7
Spouse	62.1	56.1
Other adult male	5.8	5.6
Other adult female	18.8	25.6
Missing		
Reported age, %		
14–29 years	33.0	-
30–45 years	45.2	-
46–61 years	14.2	-
61+ years	7.6	-
Mean age	36.9	
Marital status, %		
Single	15.3	-
Married	65.1	-
Separated	1.7	-
Divorced	2.0	-
Widowed	14.7	-
Missing	1.3	-
Religion		
Orthodox Christian	18.6	-
Muslim	73.7	-
Protestant	7.2	-
Catholic	0.5	-
Missing	0.4	-
Occupation		
Housewife	32.5	-
Farmer and housewife	31.3	-
Merchant	14.3	-
Students	9.0	-
Daily laborer	4.3	-
Employee	4.2	-
Others	4.4	-
FI level, %		
Food secure	11.9	9.6
Mild FI	21.6	23.1
Moderate FI	50.3	58.1
Severe FI	16.2	9.2
HFIAS score	6.1 ± 4.5[a]	6.3 ± 4.2
Dietary diversity score (0–12)	5.2 ± 1.5[a]	5.2 ± 1.6

[a]Mean and standard deviations.

wealth status, which was done by comparing the likelihood of affirmative responses to the nine items across households' wealth quintiles.

Thirdly, we evaluated the presence of a dose-response relationship between food insecurity level and the previous day consumption of certain food items. We also tested for a dose-response relationship between household wealth status and food insecurity levels and used the extended Mantel-Haenszel chi square for linear trend to check for dose-response relationships.

Additionally, the reproducibility between the first and second HFIAS scores (HFIAS overtime) was estimated by means of a paired *t*-test.

Results

Sample characteristics

A total of 1,516 households (767 in the first round and 749 in the second round) were studied across the two rounds of data collection. The response rate for the first and second round of data collection was 96% and 98%, respectively, and we included 1,056 and 460 households from rural and urban villages, respectively.

The sample characteristic of the study population is shown in Table 1, and the mean age (year) of the respondents was 36.9 years. The age distribution indicated that 33% and 45.2% of respondents were in the age group between 14–29 and 30–45, respectively, and the great majority were Muslims (73.7%), rural residents (69.6%), and married (65.1%). Occupationally, 32.5% were housewives and 31.3% were a combination of a housewife/farm worker.

Responses to the nine HFIAS items

As seen in Table 2, affirmative responses for the items ranged from 2.0% to 76.1% and 0.1% to 80.3% among urban and rural samples, respectively. We found that affirmative responses were highest for items showing mild to moderate forms of food insecurity such as worry about food, unable to eat preferred foods, eating a limited variety of food items, and eating smaller or fewer meals a day. Among urban samples, the item that received the highest affirmative response was item 3: "…*Did you or any household member have to eat a limited variety of foods*?" For the rural samples, item 2:"*Were you or any household member not able to eat the kinds of foods you preferred*?" received the highest affirmative response. Affirmative responses for items 7, 8, and 9, which indicates severe forms of food insecurity, were low. Of the nine items, the

Table 2 Affirmative responses to items on the Household Food Insecurity Access Scale (HFIAS) in urban and rural settings, Ethiopia, 2013

HFIAS questions	Urban		Rural		Total	
	n	(% yes)	*n*	(% yes)	*n*	(% yes)
Q1. Worry about food	308	66.96	549	51.99	857	56.5
Q2. Unable to eat preferred foods	355	71.17	848	80.3	1203	79.35
Q3. Eat a limited variety of foods	350	76.09	728	68.94	1078	71.11
Q4. Eat foods that you really did not want to eat	9	1.96	7	0.09	10	0.66
Q5. Eat a smaller meal	284	61.74	540	51.14	824	54.35
Q6. Eat fewer meals in a day	277	60.22	586	55.49	863	56.93
Q7. No food to eat of any kind in the household	40	8.7	39	3.69	79	5.21
Q8. Go to sleep at night hungry	75	16.3	74	7.01	149	9.83
Q9. Go a whole day and night without eating anything	27	5.87	28	2.65	55	3.63

item: "*Eat food that I really did not want to eat*" received the lowest affirmative responses in both the urban and rural samples.

Face validity

We conducted a total of eight interviews (four each among rural and urban households), with the main aim of these interviews being to get the wording right for the specific context of the use of the HFIAS. We found that four of the nine questions were not straightforward and needed to be modified in either way for a better understanding. We discussed with these nine women how to best frame these questions to help make them clearer and contextually appropriate without losing the main aim of these questions. The questions that needed modifications, rephrasing, or adding examples were items 2–4 and item 6 (Table 2). The remaining five questions were kept in their original form since they were not difficult to understand and did not have multiple interpretations.

According to these interviews, we found a higher likelihood of affirmative response to the item "*unable to eat preferred food*." This item was restructured, and examples were necessary to reflect a preferred food according to the respondent's own economy, rather than a general preference. Interviewees better understood the item "*… limited variety of foods*" if the item was translated with a core meaning of "monotonous diet" or "almost the same meal every time." The item "*…eat food that you really don't want to eat*" was also rephrased as food items that are not eaten under normal circumstances, but could be eaten during times of hardship, such as during a severe food crisis or a severe drought. Two to three meals per day were considered as a normal meal frequency in the study district. Hence, the item "*…eat fewer meals a day*" was modified as "*…eat less than two-three meals per day*." In summary, the key adaptations we made included rephrasing, adding local (context-specific) examples, as well as specifying the name of the previous month. Furthermore, the importance of explaining the objective of the study in detail prior to initiating the interview process was found to be vital in obtaining a correct response.

Exploratory analysis

A factor analysis (varimax rotation) of the nine HFIAS questions resulted in two main factors for both urban and rural samples (in fact, the analysis resulted in nine factors, though the PA indicated to retain two factors). The first factor loaded most highly on the first five HFIAS items (except for item 4), while the second factor loaded most highly on the last three items (Table 3). The first factor seems to describe the level of a mild to moderate form of food security, while the second factor seems to describe the level of a severe form of food insecurity. Factors 1 and 2 together explained 56.7% and 54.3% of the nine questions' combined variance for rural and urban samples, respectively.

Internal consistency

The internal consistency analysis showed that the Cronbach's alpha values for the overall sample (both rural and urban samples) for rounds 1 and 2 were 0.73 and 0.73, respectively (Table 4), whereas the Cronbach's alpha values were relatively higher among urban residents compared to those among rural residents in the two rounds of data collection.

Parallelism

Figures 1 and 2 show HFIAS item response curves across household wealth status in the urban and rural villages of the study district. HFIAS item response curves were parallel across wealth status in urban households, and with the exception of HFIAS item 4, we observed that the likelihood of affirmative responses decreased as the household wealth status increased. When compared to

Table 3 Factor loadings for rotated component matrix for households' responses to nine questions by residency, Ethiopia, 2013

HFIAS questions	Factor loading					
	Rural		Urban		Total	
	Factor 1	Factor 2	Factor 1	Factor 2	Factor 1	Factor 2
Q1. Worry about food	0.6861	0.1336	0.7042	0.0951	0.6916	0.1384
Q2. Unable to eat preferred foods	0.6817	−0.0504	0.7833	0.0852	0.7089	−0.0079
Q3. Eat a limited variety of foods	0.5618	0.1296	0.6832	0.0486	0.6061	0.1084
Q4. Eat foods that you really did not want to eat[a]	-	-	0.2427	−0.0984	0.1664	−0.0186
Q5. Eat a smaller meal	0.7874	0.1954	0.7782	0.2547	0.7846	0.2166
Q6. Eat fewer meals in a day	0.7578	0.1978	0.8157	0.1708	0.7769	0.1853
Q7. No food to eat of any kind in the household	0.0766	0.7384	0.1245	0.7295	0.0973	0.7416
Q8. Go to sleep at night hungry	0.2104	0.8220	0.2346	0.8188	0.2285	0.8184
Q9. Go a whole day and night without eating anything	0.0616	0.8352	0.0506	0.7623	0.0584	0.8065

Extraction method: principal component analysis, rotation method: Varimax. Kaiser-Meyer-Olkin measure of sampling adequacy = 0.80.
[a]Unwanted food dropped in because of zero variance.

the urban sample, a similar but less clear pattern is observed for rural households.

Food insecurity level and food intake

Among rural sample households, a dose-response trend between the food insecurity level and the likelihood of the previous day's consumption of food items such as eggs, milk, fish, cereals, and beans was observed. For example, the likelihood of the previous day's consumption of milk among food-secure households was 39.8% compared with 11.6% for severely food-insecure households. Similarly, the likelihood of the previous day's consumption of eggs among food-secure households was 10.2% as compared with 2.1% for severely food-insecure households. The observed trend between food-secure and food-insecure households was significant for eggs ($p < 0.018$), milk ($p < 0.01$), fish ($p < 0.01$), cereals ($p < 0.01$), and pulses ($p < 0.01$), with the result also indicating that some food items such as vegetables and roots were less sensitive to household food insecurity levels. These food items are common staples in the diet for the rural parts of the studied district.

Among urban sample households, with the exception of the consumption of fish, dose-response trends between food insecurity level and the likelihood of the previous day's consumption of other food items were observed. Additionally, the observed trends between food-secure and food-insecure households were also significant for all the food items that showed a dose-response trend.

Table 4 Internal consistency (Cronbach's alpha) by rounds of data collection and residency, Ethiopia 2013

Residency	Rounds	
	I	II
Urban	0.79	0.80
Rural	0.75	0.68
Total	0.76	0.73

FI severity and household wealth status

We found a significant and positive dose-response trend ($p < 0.01$) between household wealth status and levels of food security among rural and urban samples. With the exceptions of minor deviations between the two lowest (poorest and poor) strata, an increase in household wealth has been accompanied by an improved household food security.

An inverse but significant dose-response trend between ($p < 0.01$) household food insecurity level and wealth status was found among the urban samples (Figure 3). In the urban samples, a decrease in household wealth is accompanied by a higher household food insecurity level, though we did not find a significant dose-response trend between the household wealth and food insecurity level among rural households.

FI over time (reproducibility)

The overall HFIAS score did not change over the two rounds of data collection. The HFIAS scores for the first and second round of data collection were 6.1 ± 4.5 and 6.3 ± 4.2, respectively (Table 1), while the HFIAS score for the urban sample did not show a statistically significant difference across the two rounds of data collection. However, we found an increase in the HFIAS score for rural samples during the second round of data collection, and the difference in HFIAS score between the two rounds was also statistically significant (mean difference: −0.58; 95% CI: −1.07, −0.083).

Discussion

In this study, we validated an adapted version of the HFIAS developed to measure the access component of

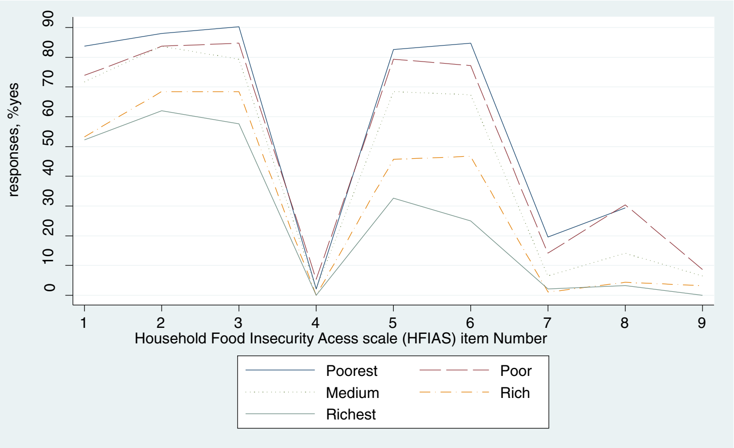

Figure 1 HFIAS item response curves across household wealth quintile strata among 233 urban households. In the town of Butajera, Ethiopia, 2013. Observations across two data collection rounds are pooled (combined *n* = 460).

food insecurity among both rural and urban households of the Butajera District in Ethiopia. We evaluated the tool for its internal consistency, criterion validity, and reproducibility through two rounds of data collection, and our results indicate that the tool had a satisfactory internal consistency and reproducibility and performed well with minor deviations to the set criteria. The HFIAS required minor modifications such as rephrasing words, the use of local ways of expressing the questions, and adding local examples to the nine items. Most importantly, we found that providing information during the consent process on the objectives of the administration of the instruments (surveys) helped modify the respondent's expectations and get the nearest accurate responses.

A factor analysis of the nine HFIAS items discriminated between two main components, which indicate the degrees of household food insecurity level. Similar to our study, a validation study from Iran [10] reported two components. The main difference was that in our

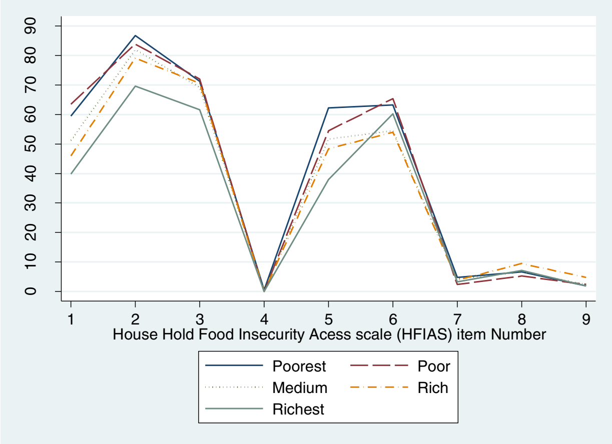

Figure 2 HFIAS item response curves across household wealth quintile strata among 534 households. In the rural villages of Butajera, Ethiopia, 2013. Observations across two data collection rounds are pooled (combined *n* = 1,056).

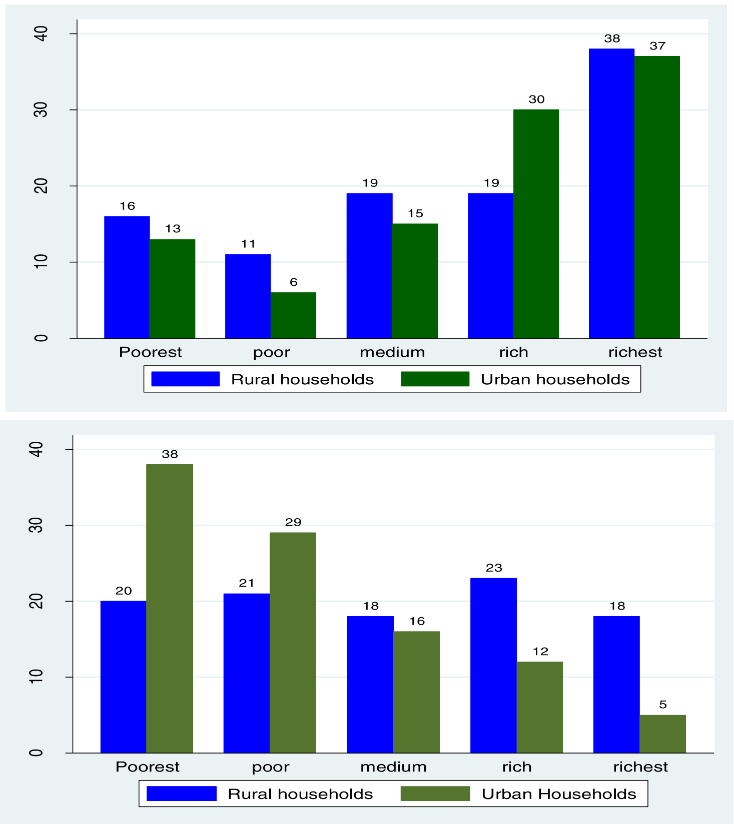

Figure 3 Food security and severe FI as a function of wealth quintile strata. Among 534 rural and 233 urban households in the Butajera, Ethiopia, 2013. Observations across two data collection rounds are pooled (combined *n* = 1,516).

study, the second factor loaded on the last three items, which indicates severe forms of food insecurity, while the study from Iran reported that the second factor loaded on the last four items. Knupeel et al. [8] also reported (i) insufficient food quality and (ii) insufficient food intake as the two main factors that emerged after a rotated principal component factor analysis. Unlike the domain described by Coates et al. [3], our study showed that the first item does not appear to form a separate domain and was loaded to the first principal component. In addition to this, the fourth item does not appear to represent any specific domain.

The items that indicate a moderate food insecurity (FI) are experienced more frequently than those that indicate severe forms of FI on the HFIAS. The nine HFIAS items are sequenced in order of an increasing severity of household food insecurity [6]. In this scale, the first and ninth items are the least and most severe indicator of food insecurity, respectively. However, we found a lack of this sequential pattern on some of the nine items, e.g., for item 1: “Did you worry about having enough food?”, which according to the scale should receive the highest percentage of affirmative response. Even so, the item actually only received the third highest percentage of affirmative responses. Although we cannot totally rule out the possibility of the respondent’s difficulties in understanding the items, households in FI areas could adapt themselves to the existing food shortage, and “worrying” may not be the immediate response to household food shortages. Knupeel et al. [8] similarly documented a reduction in the quality and quantity of food as a first response, rather than expressing a worry about food shortage. The authors suggest that the severity of FI in these areas could alter a household’s response to the item.

Another example is that the percentage of households with an affirmative response on the item “…eating fewer meals?" was higher than that for the item "…eating smaller meals?", which was documented among rural samples. Households in the rural areas may respond to food insecurity primarily through eating fewer meals, followed by eating smaller meals. This lack of order could indicate the contextual differences in responses to the level of FI in the households [17]. Hence, a further investigation on the order of experience of the nine items in the scale in response to the progression of household FI is warranted.

Cronbach's alpha values reported by other similar studies were relatively higher (α >0.80) than those by ours [8-10,16,18-22]. However, the internal consistency of HFIAS in this study is satisfactory for its application [23], and minor deviations of parallelism on the last three items were observed among the rural samples. We think that these deviations might indicate that the poor and poorest strata may have employed different coping mechanisms than the relatively rich strata. Similar deviations were also reported elsewhere [9], with the authors explaining that income strata may not necessarily translate into access to diet, as there could be less significant practical differences across the income strata.

The mean HFIAS score did not change over the two rounds of data collection for the overall sample, which shows in part that the HFIAS has a very good reproducibility to measure and capture household FI. Nevertheless, we observed a lack of reproducibility among rural samples. We do not think that changes in the HFIAS could be a real phenomenon since the interval between the administration of the first and second questionnaire was shorter (7 days), and changes related to FI are not expected. Moreover, we did not observe a significant change in household dietary diversity scores between the two rounds. Households' expectations of support after the survey and respondent's change during the second survey might be possible explanations for the lack of reproducibility among the rural samples.

Limitations and strengths of the study

Our study has some limitations that warrant consideration. The study was done in one of the nine regions of Ethiopia where the applicability of the findings may be limited to similar groups in southern Ethiopia. Respondent understanding of the nine items and expectations of possible support may have also influenced the results, and respondents could lean towards affirmative responses. Furthermore, in the absence of an established gold standard for household food insecurity, it becomes difficult to discuss the external validity of the HFIAS.

Among the main strengths of this study are the inclusion of urban and rural residents, the employment of a relatively larger sample size, and the application of a simple random sampling method to recruit households. These could help strengthen the generalizability of the findings and its application to similar contexts. We also administered two rounds of surveys in the same households to evaluate the repeatability of the HFIAS. However, this validation study was done at the household level, so further work might be needed to evaluate whether the tool can perform well if applied at the individual level (e.g., with adolescents) to help measure FI.

Conclusions

We conclude that the HFIAS is a simple and valid tool to measure the access component of household FI in urban and rural settings. However, we recommend a modification of the questions before application because we found a discrepancy in understanding on some of the nine HFIAS questions. We recommend further studies in other parts of the country, as variations in sociocultural settings could influence the successful application and validity of the tool. Moreover, we recommend that further works should also focus on identifying the correct sequence of the nine items in response to the severity of household FI. The order of progression of the nine items in the HFIAS (in the context of the level of household food insecurity) will have its own implications for the assignment of households to the different categories of food insecurity.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

SHG and BL designed the study. All authors participated in the data analysis and drafting of the manuscript. All authors read and approved the final manuscript.

Acknowledgements

We would like to acknowledge the Center for International Health at the University of Bergen for funding the study, and we are very thankful to all the study participants for their willingness to participate in the study. Lastly, we declare that the funding body had no role in the design of the study, the collection, analysis and interpretation of the data, the writing of this manuscript, and in the decision to submit it for publication.

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Received: 13 June 2014 Accepted: 20 November 2014
Published: 21 January 2015

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doi:10.1186/2055-0928-1-2
Cite this article as: Gebreyesus *et al.*: Is the adapted Household Food Insecurity Access Scale (HFIAS) developed internationally to measure food insecurity valid in urban and rural households of Ethiopia? *BMC Nutrition* 2015 1:2.

Study instruments

HOUSEHOLD FOOD INSECUIRTY AND SPATIAL PATTERN STUDY QUESTIONNAIRE

INTERVIEW INFORMATION

DATE OF INTERVIEW	|__|__| Day |__|__| Month |__|__||__|__| Year
TIME STARTED	|__|__| Hour |__|__| Minutes
TIME ENDED	|__|__| Hour |__|__| Minutes
RESULT *	|__|
INTERVIEWER NAME	______________________________________
SUPERVISOR	______________________________________
CHECKED BY	______________________________________
ENTERED BY	1) ____________________________________
	2) ____________________________________

*RESULT CODES:

1=COMPLETED	4=REFUSED	7=OTHER (SPECIFY)
2=NOT AVAILABLE	5=PARTLY COMPLETED	
3=POSTPONED	6=INCAPACITATED	___________________

NAME OF THE VILLAGE	__________/___________
NAME OF ENUMERATION AREA (SUB VILLAGE)	__________/___________
ENUMERATION AREA (SUB VILLAGE) ID	|__|__|
NAME OF THE HOUSEHOLD HEAD	__________/___________
HDSS HOUSE NO	|__|__||__|__|

INTERVIEWER: INTRODUCTION AND CONSENT. May I begin the interview now?

NO	QUESTIONS AND FILTERS	CODING CATEGORIES	SKIP
Section One: I would like to start the interview asking a few questions about you, your partner and the household condition.			
101.	Date of interview	Monday ....1 Tuesday ....2 Wednesday ....3 Thursday ....4 Friday ....4 Saturday....4 Sunday....4	
102.	Respondent's relationship/status	Head....1 Spouse of head ....2 Other adult male....3 Other adult female....4 Other (specify) ....99 ______________________________	
103.	Sex of the household head?	Male ....1 Female 2	
104.	How old are you now?	______________________years	
105.	What is the highest level of school you attended?	Primary (1-8) ....1 Secondary(9-12) ....2 College/university....3 Read and write ....4 Illiterate 5	
106.	What is your marital status?	Currently married ....1 Separated ....2 Divorced ....3 Widowed ....4 Never married 99	
107.	What is your religion?	Orthodox Christian ....1 Islam ....2 Protestant ....3 Catholic Widowed....4 Other (specify) ....99 ______________________________	

108.	To which ethnic group do you belong?	Oromo ....1 Amhrara ....2 Gurage ....3 Tigray ....4 Afra....5 Silete ....6 Other (specify) ....99 ______________________________	
109.	What is your occupation?	Farmer and housewife....1 Housewife ....2 employee/private ....3 Student....4 Merchant ....5 Local drink seller ....6 Commercial sex worker ....7 Maid servant....8 Daily laborer ....9 Unemployed ....10 Other (specify) ....99 ______________________________	
110.	What is your partner/husband occupation?	Farmer ....1 employee/private ....2 Student....3 Merchant ....4 Daily laborer ....5 Unemployed ....6 Other (specify) ....99 ______________________________	
111.	What is your partner/husband educational status? (highest level of school attended)	Primary (1-8) ....1 Secondary(9-12) ....2 College/university....3 Read and write ....4 Illiterate 5	
112.	Who usually decides how the money you earn will be used: you, your husband/partner, you and your husband/partner jointly?	Respondent ....1 Husband/partner ....2 Respondent and Husband/partner jointly ....3 Other (specify) ....99 ______________________________	
113.	Who usually makes decisions about health care for yourself ?	Respondent ....1 Husband/partner ....2 Respondent and Husband/partner jointly ....3 Other (specify) 99	
114.	Who usually makes decisions about making major household purchases?	Respondent ....1 Husband/partner ....2 Respondent and Husband/partner jointly ....3 Other (specify) 99	
115.	Does your husband help you with household chores like looking after the children, cooking,	No....1	

	cleaning the house, and doing other work around the house?	Yes 2	
INTERVIEWER: PLEASE SUPPLY THE FOLLOWING INFORMATION ABOUT RESPONDENT'S HOME			
116.	Main construction material used for the floor: CIRCLE ALL THAT APPLY	Natural floor Earth /sand ....11 dung ....12 Rudimentary floor Wood planks ....21 Bamboo...22 Finished floor Polished wood or parquet.......................31 Vinyl or Asphalt strips ....32 Ceramic tiles ....33 Cement ....34 Carpet ....35 Other (specify)...99 ______________________________	
117.	Main construction material used for the roof: CIRCLE ALL THAT APPLY	Natural roofing No roof ....11 Thatch/leaf/mud ....12 Rudimentary roofing Rustic mat/plastic sheet ....21 Reed/Bamboo ....22 Wood planks ....23 Cardboard ....24 Finished roofing Corrugated iron/metal.............................31 Wood ....32 Asbestos/cement fiber............................33 Cement/concrete ....34 Roofing/shingles.....................................35 Other (specify)...99 ______________________________	
118.	Main construction material used in exterior walls: CIRCLE ALL THAT APPLY	Natural walls No walls ....11 Cane/Trunks/Bamboo/Reed ....12 Dirt ....13 Rudimentary walls Bamboo/wood with Mud ....21 Stone with mud ....22 Uncovered adobe ....23 Plywood ....24 Card board ....25 Reused wood ....26 Finished walls Cement ....31 Stone with lime/cement ....32 Bricks ....33 Covered adobe......................................34 Wood planks/shingles ....35 Other (specify)...99 ______________________________	
119.	Will you please describe your family's household structure?	We rent a room ....1 We rent an apartment.................................2 We rent a house ....3 We rent part of a house..............................4 We live in a dormitory.................................5	

		We live in an apartment that we own..........6 We live in a house that we own..................7 We live in part of a house that we own........8 Other (specify)..99 ________________________________	
120.	Does any member of the household own any agricultural land?	No..1 Yes..2	**Q122**
121.	How many (LOCAL UNITS) of agricultural land do members of this household own? LOCAL UNITS ___________ (SPECIFY) IF 95 OR MORE CIRCLE 'B'	Local units(*Tlimad*) |__|__| Don't know 88	
122.	Does the household own any livestock, herds, other farm animals, or poultry?	No..1 Yes..2	**Q124**
123.	How many of the following animals do you keep? (INTERVIEWER: IF HOUSEHOLD DOES NOT OWN A PARTICULAR ITEM, RECORD "00" AGAINST THAT ITEM.)	a) Milk cows, oxen or bulls .... |__|__| b) Chickens .... |__|__| c) Goats... |__|__| d) Sheep.. |__|__| e) Horses ,donkey, or mule .... |__|__| f) Camels...................................... |__|__| g) Beehives .... |__|__|	
124.	Does any member of the hold have a bank or microfinance saving account	No..1 Yes..2	
125.	What is the main source of water used by your household for other purposes such as cooking and hand washing? [INTERVIEWER: BE SURE OF THE SOURCE OF "PIPED WATER". IF THE ANSWER IS "PIPED WATER" CHECK THE SOURCE AND CIRCLE THE APPROPRIATE CODE]	<u>Piped water/supply water</u> Piped inside dwelling .... 11 Piped to yard/plot............................. 12 Public tap .... 13 <u>Water from spring</u> Protected well/spring .... 21 Unprotected well/spring .... 22 <u>Water from Dug well</u> Protected well .... 31 Unprotected well .... 32 <u>Water form borehole</u> Borehole in yard/plot........................ 41 Public borehole .... 42 <u>Surface water</u> Pond/lake/River/stream/spring/Dam . 51 <u>Rain water</u>.. 61 <u>Tanker truck</u>.. 71 <u>Vendor</u> .... 81 <u>Bottled water</u>....................................... 91 No fixed facility.................................... 96 Other (specify) .... 99 ________________________________	
126.	What kind of toilet facility does your household	<u>Flush toilet</u> Flush to Piped sewer system 11	

	have? [INTERVIEWER: LIMIT TO ONE RESPONSE; IF TWO TYPES ARE MENTIONED, RECORD THE TYPE CLOSEST TO THE TOP OF THE LIST]	Flush to septic tank ....12 Flush to Pit latrine ....13 Flush to somewhere else....14 Flush , Don't know where ....15 Pit latrine Traditional pit toilet ....21 Pit latrine with slab ....22 Pit latrine with without slab ....23 Ventilated improved pit latrine ....24 Bucket toilet....25 Composting toliet....26 Hanging toilet/hanging latrine ....27 No facility/bush/field ....31 Other (specify)....99 ______________________________	
127.	Tell me, please, if your home has: [INTERVIEWER: CIRCLE ALL THAT APPLY]	Electricity....1 Watch/clock....2 Radio....3 Television ....4 Mobile Telephone....5 House Phone ....6 Refrigerator ....7 Chair....8 A bed with cotton/Sponge/Spring mattress .9 Electric Mitad....10 Kerosene Lamp/pressure ....11 None 12	

Section Two: Household Food Insecurity Access Scale (HFIAS) Measurement: Now I would like to ask you few question regarding your household food security situation in the past four weeks.			
NO	**QUESTIONS AND FILTERS**	**CODING CATEGORIES**	**SKIP**
201.	In the past four weeks, did you worry that your household would not have enough food?	No....1 → Yes....2	**Q203**
202.	How often did this happen in the past four weeks?	Rarely (once or twice in the past four weeks) ....1 Sometimes (three to ten times in the past four weeks) ....2 Often (more than ten times in the past four weeks)....3	
203.	In the past four weeks, were you or any household member not able to eat the kinds of foods you preferred because of a lack of resources?	No....1 → Yes....2	**Q205**
204.	How often did this happen in the past four weeks?	Rarely (once or twice in the past four weeks) ....1 Sometimes (three to ten times in the past four weeks) ....2 Often (more than ten times in the past four weeks)....3	
205.	In the past four weeks, did you or any household member have to eat a limited variety of foods due to a lack of resources?	No....1 → Yes....2	**Q207**
206.	How often did this happen in the past four weeks?	Rarely (once or twice in the past four weeks) ....1 Sometimes (three to ten times in the past four weeks) ....2 Often (more than ten times in the past four weeks)....3	
207.	In the past four weeks, did you or any household member have to eat some foods that you really did not want to eat because of a lack of resources to obtain other types of food?	No....1 → Yes....2	**Q209**
208.	How often did this happen in the past four weeks?	Rarely (once or twice in the past four weeks) ....1 Sometimes (three to ten times in the past four weeks) ....2 Often (more than ten times in the past four weeks)....3	
209.	In the past four weeks, did you or any household member have to eat a smaller meal than you felt you	No....1 → Yes....2	**Q211**

	needed because there was not enough food?		
210.	How often did this happen in the past four weeks?	Rarely (once or twice in the past four weeks) ....1 Sometimes (three to ten times in the past four weeks) ....2 Often (more than ten times in the past four weeks) 3	
211.	In the past four weeks, did you or any other household member have to eat fewer meals in a day because there was not enough food?	No...1 → Yes 2	**Q213**
212.	How often did this happen in the past four weeks?	Rarely (once or twice in the past four weeks) ....1 Sometimes (three to ten times in the past four weeks) ....2 Often (more than ten times in the past four weeks) 3	
213.	In the past four weeks, was there ever no food to eat of any kind in your household because of lack of resources to get food?	No...1 → Yes 2	**Q215**
214.	How often did this happen in the past four weeks?	Rarely (once or twice in the past four weeks) ....1 Sometimes (three to ten times in the past four weeks) ....2 Often (more than ten times in the past four weeks) 3	
215.	In the past four weeks, did you or any household member go to sleep at night hungry because there was not enough food?	No...1 → Yes 2	**Q217**
216.	How often did this happen in the past four weeks?	Rarely (once or twice in the past four weeks) ....1 Sometimes (three to ten times in the past four weeks) ....2 Often (more than ten times in the past four weeks) 3	
217.	In the past four weeks, did you or any household member go a whole day and night without eating anything because there was not enough food?	No...1 → Yes 2	**End**

218.	How often did this happen in the past four weeks?	Rarely (once or twice in the past four weeks) ....1 Sometimes (three to ten times in the past four weeks) ....2 Often (more than ten times in the past four weeks)..............................3	
219.	Have you received any food support in the past month?	No...1 Yes..2	
220.	How do you cope at times when you are running out of food in the house?	Reduce number of meals……………………….1 Reduce meal size…………………………………2 Borrowing…………………………………………3 Petty trade ………………………………………4 Consume stored food (seed) ……………………5 Migration for labour………………………………6 Sell of farm tools…………………………………7 Sale charcoal/fire wood…………………………8 Daily labor …………………………………………9 Safety Net…………………………………………10 Sell of farm animals……………………………11 Other(specify) ……………………………………99	

Section Three: (a)Household dietary diversity

Now I would like to ask you about the types of foods that you or anyone else in your household ate ***yesterday during the day and at night*** *either separately or combined with other foods.*

301.	Were there any foods that were not prepared for the in the house because it was a fasting day?	No ....1 Yes..2	
302.	Could you tell me the types of foods that were prepared in the house and that you or anyone else in your household ate?	Breakfast………………………………………… Lunch…………………………………………… Dinner…………………………………………… Others……………………………………………	
303.	Any bread, rice, pasta, biscuits, or any other foods made from millet, sorghum, maize, rice, wheat ?	No ....1 Yes..2	
304.	Any potatoes, bulla, *kocho* or any other food made from roots or tubers?	No ....1 Yes..2	
305.	Any vegetables?	No ....1 Yes..2	
306.	Any fruits?	No ....1 Yes..2	
307.	Any beef, pork, lamb, goat, rabbit wild game, chicken, duck, or other birds, liver, kidney, heart, or other organ meats?	No ....1 Yes..2	
308.	Any eggs?	No ....1 Yes..2	

309.	Any fresh or dried fish or shellfish?	No ....1 Yes..2	
310.	Any foods made from beans, peas, lentils, or nuts?	No ....1 Yes..2	
311.	Any cheese, yogurt, milk or other milk products?	No ....1 Yes..2	
312.	Any foods made with oil, fat, or butter?	No ....1 Yes..2	
313.	Any sugar or honey?	No ....1 Yes..2	
314.	Any other foods, such as condiments, coffee, tea?	No ....1 Yes..2	
(b) Child's dietary diversity: N*ow I would like to ask you about the types of foods that your child ate* ***<u>yesterday during the day and at night</u>*** *either separately or combined with other foods.*			
315.	Was the food that your child ate yesterday during the day and at night from foods prepared to the family?	No ....1 Yes..2	**Q330**
316.	Were there any foods that were not prepared for the child because it was a fasting day?	No ....1 Yes..2	
317.	Before i ask what foods your child ________________ (name) ate yesterday. Was yesterday a usual day? for example was he sick? etc	No ....1 Yes..2	
318.	Could you tell me the types of foods that were prepared in the house and that the child________________ (name) ate yesterday?	Breakfast…………………………………………… Lunch…………………………………………… Dinner…………………………………………… Others……………………………………………	
319.	Any bread, rice, pasta, biscuits, or any other foods made from millet, sorghum, maize, rice, wheat?	No ....1 Yes..2	
320.	Any potatoes, bulla, *kocho* or any other food made from roots or tubers?	No ....1 Yes..2	
321.	Any vegetables?	No ....1 Yes..2	
322.	Any fruits?	No ....1 Yes..2	

323.	Any beef, pork, lamb, goat, rabbit wild game, chicken, duck, or other birds, liver, kidney, heart, or other organ meats?	No .... 1 Yes 2	
324.	Any eggs?	No .... 1 Yes 2	
325.	Any fresh or dried fish or shellfish?	No .... 1 Yes 2	
326.	Any foods made from beans, peas, lentils, or nuts?	No .... 1 Yes 2	
327.	Any cheese, yogurt, milk or other milk products?	No .... 1 Yes 2	
328.	Any foods made with oil, fat, or butter?	No .... 1 Yes 2	
329.	Any sugar or honey?	No .... 1 Yes 2	
330.	Any other foods, such as condiments, coffee, tea?	No .... 1 Yes 2	
Now I am going to read out a list of crops. Please try to recall whether you have harvested any of these on your land in the last year.			
	list of crops	What was the harvest in kilograms?	
331.	Sorghum?	|__|__||__|__|K.g	
332.	Wheat?	|__|__||__|__|K.g	
333.	Corn?	|__|__||__|__|K.g	
334.	Teff?	|__|__||__|__|K.g	
335.	Potatoes?	|__|__||__|__|K.g	
336.	Tomatoes?	|__|__||__|__|K.g	
337.	Squash/Pumpkin?	|__|__||__|__|K.g	
338.	Carrots?	|__|__||__|__|K.g	
339.	Cabbages?	|__|__||__|__|K.g	
340.	Onions?	|__|__||__|__|K.g	

341.	Pepper??\	|__|__||__|__|K.g	
342.	Banana?	|__|__||__|__|K.g	
343.	Other vegetables?	|__|__||__|__|K.g	
344.	Other fruits?	|__|__||__|__|K.g	

Section Four: Child health and nutrition conditions
(INTERVIEWER: ASK ABOUT ALL LIVING CHILDREN UNDER 5 YEARS OF AGE LIVING IN THE HOUSEHOLD;
Now I would like to ask your few questions about your children's health.

NO	QUESTIONS AND FILTERS	CODING CATEGORIES	SKIP
401.	How many times were you pregnant? (including those that did not end with a live births), record "00" if none	|__|__| times Don't know …….99	
402.	Now I would like to ask about all the births you have had during your life. How many times have you given live birth? [I mean, to a child who ever breathed or cried or showed other signs of life – even if he or she lived only a few minutes or hours], record "00" if none	|__|__| times Don't know …….99	
403.	How many sons or daughters do you have?	|__|__| Sons |__|__| Daughters |__|__| Total	

404.	**QUESTIONS AND FILTERS**	**Last birth/CHILD** **Child name** _____________	**Second-to-last CHILD** **Child name**_____________
405.	How old is [name]?	_____________ months	_____________ months
406.	Sex of [name]?	Male……………………...1 Female …………………2	Male……………………...1 Female …………………2
407.	How long (months) was the interval between the last child and second-to-last birth?	_____________ months	_____________ months
408.	Where did you give birth? PROBE TO IDENTIFY THE PLACE OF DELIVERY	Hospital ....….1 Health center..............…2 Health post.................….3 Private Hospital/clinic…………..4 Home ....….5 TBA home ....….6 Other (specify)__________________ Don't remember…………….99	Hospital.................. ….1 Health center .... …..2 Health post............ …..3 Private Hospital/clinic…….4 Home .... …..5 TBA home............. …..6 Other (specify)_______________ Don't remember……….99
409.	Did you give colostrum to [name]?	Yes............... 1 No .... 2 Don't know 99	Yes .... 1 No .... 2 Don't know 99
410.	How long after birth did you first put [name] to the breast?	Within one hour ………..1 Within a day…………2 After a day..............3 Don't know…….…….99	Within one hour ………..1 Within a day…………2 After a day ....3 Don't know……..…..99
411.	For how long did you breastfeed [name]?	Weeks ……….1 Months………2 Years………...3 Currently breastfeeding 77 Don't know………...99	Weeks ……….1 Months………2 Years………..3 Currently breastfeeding 77 Don't know……… ..99

412.	During this time (or until the baby was 6 months of age), what did you give the baby to eat or drink?	Only breast milk…………..1 Mostly breast milk………..2 Milk other than breast milk………………………...3 Infant formula…………….....4 Local semi-solid food…...5 Don't remember………....99	Only breast milk…………..1 Mostly breast milk………..2 Milk other than breast milk………………………...3 Infant formula…………….....4 Local semi-solid food…...5 Don't remember………....99
413.	How old was [child name] when he/she got anything else other than breast milk to eat or drink?	Days……………....1 |__|__| Weeks …………....2 |__|__| Months…………....3 |__|__| Years…………….4 |__|__| Don't know……….............99 Still on only breast milk…..88	Days……………....1 |__|__| Weeks …………....2 |__|__| Months…………....3 |__|__| Years…………….4 |__|__| Don't know……….............99 Still on only breast milk…..88
414.	Did (NAME) eat any solid, semi-solid, or soft foods yesterday during the day or at night?	No……………….1 Yes………………2	No……………….1 Yes………………2
415.	How many times did (NAME) eat solid, semisolid, or soft foods yesterday during the day or at night?	___________(times) Don't know………88	___________(times) Don't know………88
416.	Do you have a card where [name]'s vaccinations are written down?	Yes…………...1 No…………….2 Don't know…..8	Yes…………...1 No…………….2 Don't know…..8
417.	**INTERVIEWER: ASK FOR THE CARD FOR EACH CHILD; RECORD VACCINATION DATE FOR EACH VACCINE FROM THE CARD; WRITE "44" IN "DAY" COLUMN IF CARD SHOWS THAT VACCINATION WAS GIVEN BUT NO DATE IS RECORDED. WRITE "99" IN "DAY" COLUMN IF CARD IS NOT SHOWNBUT VACCINATION IS GIVEN.**		
	Immunizations	Day Month Year	Day Month Year
	BCG	|__|__| |__|__| |__|__|	|__|__| |__|__| |__|__|
	Polio 0 (at birth)	|__|__| |__|__| |__|__|	|__|__| |__|__| |__|__|
	Polio 1 (OPV)	|__|__| |__|__| |__|__|	|__|__| |__|__| |__|__|
	Polio 2 (OPV)	|__|__| |__|__| |__|__|	|__|__| |__|__| |__|__|
	Polio 3 (OPV)	|__|__| |__|__| |__|__|	|__|__| |__|__| |__|__|
	DPT 1	|__|__| |__|__| |__|__|	|__|__| |__|__| |__|__|
	DPT 2	|__|__| |__|__| |__|__|	|__|__| |__|__| |__|__|
	DPT 3	|__|__| |__|__| |__|__|	|__|__| |__|__| |__|__|
	Measles	|__|__| |__|__| |__|__|	|__|__| |__|__| |__|__|
	HepB 1	|__|__| |__|__| |__|__|	|__|__| |__|__| |__|__|
	HepB 2	|__|__| |__|__| |__|__|	|__|__| |__|__| |__|__|
	HepB 3	|__|__| |__|__| |__|__|	|__|__| |__|__| |__|__|
	Hib 1	|__|__| |__|__| |__|__|	|__|__| |__|__| |__|__|
	Hib 2	|__|__| |__|__| |__|__|	|__|__| |__|__| |__|__|
	Hib 3	|__|__| |__|__| |__|__|	|__|__| |__|__| |__|__|
	HepB-Hib1	|__|__| |__|__| |__|__|	|__|__| |__|__| |__|__|
	HepB-Hib2	|__|__| |__|__| |__|__|	|__|__| |__|__| |__|__|

	HepB-Hib3	|__|__| |__|__| |__|__|	|__|__| |__|__| |__|__|
	Yellow Fever	|__|__| |__|__| |__|__|	|__|__| |__|__| |__|__|
	Vitamin A (most recent)	|__|__| |__|__| |__|__|	|__|__| |__|__| |__|__|
	Vitamin A (2nd most recent)	|__|__| |__|__| |__|__|	|__|__| |__|__| |__|__|
418.	Has [name] had diarrhea in the last 2 weeks?	Yes………………1 No ………………2 →**Q420** Don't know ……8 →**Q420**	Yes………………1 No ………………2 →**Q420** Don't know ……8 →**Q420**
419.	Now I would like to know how much [name] was given to drink during the diarrhea (including breast milk)? Was he/she given less than usual to drink, about the same amount, more than usual to drink or nothing? IF LESS, PROBE: Was he/she given much less than usual to drink or somewhat less?	Much less……………….1 Somewhat less………..2 About the same………..3 More……………………..4 Nothing…………………..5 Don't know……………..88	Much less……………..1 Somewhat less ……….2 About the same……….3 More ……………………4 Nothing ………………..5 Don't know……………..88
420.	Has [name] been ill with a fever at any time in the last 2 weeks?	Yes…………………………1 No …………………………2 Don't know ………………88	Yes ……………………1 No ………………………2 Don't know ……………88
421.	Has [name] had an illness with a cough at any time in the last 2 weeks?	Yes…………………………1 No …………………………2 Don't know ………………88	Yes ……………………1 No ………………………2 Don't know ……………88
422.	Within the last six months has (NAME) received a vitamin dose like this?	Yes…………………………1 No …………………………2 Don't know ………………88	Yes ……………………1 No ………………………2 Don't know ……………88
423.	In the last seven days, was (NAME) given iron pills like this?	Yes…………………………1 No …………………………2 Don't know ………………88	Yes ……………………1 No ………………………2 Don't know ……………88
424.	Have you heard of or do you know about the health extension worker?	Yes…………………………1 No …………………………2	
425.	Did the HEW visit your household during the past 6 months to talk about health related issues?	Yes…………………………1 No …………………………2	
426.	What are the services provided by the health extension workers? (Multiple Responses Possible)	Yes No a)Message on Immunization……………… 1 2 b)Information on child feeding…………….1 2 c) Message on diarrhea treatment………..1 2 d)Information on pregnancy care………….1 2 e) Information on Breastfeeding …………1 2 f) Information on hygiene………...............1 2 g) Promotion pit latrine construction……...1 2 h) promote latrine use…………………….1 2 i)promote safe water use…………………..1 2 j) Information/discussion on Family planning ……………………….…1 2 Other, specify____________________	
427.	Have you heard about a Model family	Yes ……1 No ……2	
428.	Is this family graduated as a Model Family?	Yes, graduated (Certificate seen)……1 Yes, graduated (Certificate not seen)…..2 No, working towards…..3 Not at all…..4	

Section Five: Now I am going to ask you few questions related to your health. How often have you been bothered by any of the following problems over the past 2 weeks		
QUESTIONS AND FILTERS		**CODING CATEGORIES**
501.	little interest or pleasure in doing things	Not at all………………….0 Several days …………..1 More than half the days….2 Nearly every day ………3
502.	feeling down, depressed or hopeless	Not at all………………….0 Several days …………..1 More than half the days….2 Nearly every day ………3
503.	trouble falling asleep, staying asleep, or sleeping too much	Not at all………………….0 Several days …………..1 More than half the days….2 Nearly every day ………3
504.	feeling tired or having little energy	Not at all………………….0 Several days …………..1 More than half the days….2 Nearly every day ………3
505.	poor appetite or over eating	Not at all………………….0 Several days …………..1 More than half the days….2 Nearly every day ………3
506.	feeling bad about yourself- or that you are a failure or have let yourself or your family down	Not at all………………….0 Several days …………..1 More than half the days….2 Nearly every day ………3
507.	trouble on concentrating on things	Not at all………………….0 Several days …………..1 More than half the days….2 Nearly every day ………3
508.	Moving or speaking so slowly that other people could have noticed-or the opposite being fidgety or restless that you have been moving a lot more than usual	Not at all………………….0 Several days …………..1 More than half the days….2 Nearly every day ………3
509.	Thoughts that you would be better off dead or of hurting yourself in some way	Not at all………………….0 Several days …………..1 More than half the days….2 Nearly every day ………3

Section six: Child and mother's anthropometric measurement, and Household's GPS data				
601.	-- Name : Last Child	Child mother pair . K.g	Child weight . K.g	Child's height/length .
602.	-- Name : Last Child	Child mother pair . K.g	Child weight . K.g	Child's height/length .
603.	-- Mother's name	weight . K.g	Height(cm) .	MUAC (cm) .
604.	Longitude and latitude	N .	E .	
605.	Altitude (elevation)			

INFORMATION SHEET

Greetings!

We are conducting a study entitled **"Food security, climate variability and spatial pattern in Ethiopia**" which is a PhD research project of the Department of Reproductive and Family Health and Nutrition, School of Public Health, College of Health Sciences, Addis Ababa University and University of Bergen, Center for international health , Norway.

The study aims to quantify the effect of climate change on food security, malnutrition vulnerability, and child health in Ethiopia, Moreover, the study will assess the validity and dependability of the Household Food Insecurity Access Scale (HFIAS), which was developed for international use and further analyses the spatio-temporal pattern and spatial dependability of food security and child and maternal malnutrition.

We do not expect any considerable risks to be associated with participation in this study and would like to assure you that whatever information you provide will be kept confidential and anonymous. The results from this study will only be used for the purpose of further improving mothers' and children's health and nutrition.

You have the right to refuse from participating in this research, if you do not wish to. You also have full right to withdraw at any time without explaining the reason why and all these decisions will not affect your right to get health services or in any other way.

Experienced and trained data collectors conduct interviews at your residence. The interview will take about 1 hour.

Should you need any further explanation at any point, you can contact Mr. Seifu Hagos or Prof Damen Haile Mariam (mobile 251911613577, 0911228981 respectively).

Do you have any questions?

Do you agree to participate in the study?

If yes, read the consent form to the participant, date and sign it. If no, thank and proceed to the next participant.

CONSENT FORM

I have been informed about the objectives, risks and benefits of the study. I have also been informed about my rights not to participate in the study and withdraw any time without any consequences. I was also given opportunity to ask questions.

Based on the information provided above, I have agreed to participate in the study.

Name of data collector ________________________

Signature ……………….

Date:

Name of literate witness _____________________

Signature……………………………..

Date:

Ethical approvals

Region:	Saksbehandler:	Telefon:	Vår dato:	Vår referanse:
REK vest	Øyvind Straume	55978496	22.05.2014	2014/605/REK vest
			Deres dato:	Deres referanse:
			08.04.2014	

Vår referanse må oppgis ved alle henvendelser

Bernt Lindtjørn
University of Begen

2014/605 Klima, matsikkerhet og underernæring i Etiopia

Body responsible for the research: University of Bergen
Project manager: Bernt Lindtjørn

With reference to your application about aforementioned project. The Regional Committee for Medical and Health Research Ethics, Western Norway (REK vest) reviewed hte application in the meeting 08.05.2014, pursuant to The Health Research Act § 10.

Description of the project
This study aims to develop statistical model to quantify the impact of climate change on food security, to validate household food insecurity and to analyse the spatial pattern of food insecurity and malnutrition in Ethiopia. Both statistical and panel data modelling methods will be used to quantify the effect of climate variability on child malnutrition. A repeated household survey using community based cross sectional study design will be used to validate and analyse the spatial patterns of food insecurity.

The Committee`s considerations

Application/Study protocol
The Committee finds the project to be very interesting with potential for great scientific importance.

Data Collection
The Committee remarks that to include variable such as religion and ethicity does not seem necessary to answer the research question. However, since this is part of a standardised test battery the Committee finds that their inclusion is justifiable.

Consent
Consent will be obtained orally due to illiteracy. The consent form will be signed by the data collector and a literate witness. The Committee has no objections to this.

Timeframe
Project start is set to 1.6.2013 and project end is 31.12.2015. REC West assumes that the start date implies planning and that the interviews or any use of personal data have not started yet.

The attached approval from Addis Ababa University College of Health Science Institutional Review Board has a timeframe from 8.11.2012 to 7.11.2014. Approcal by REC will be conditioned by that the project is approved again in Ethiopia.

Condition

- Approval must be obtained from the Ababa University College of Health Science Institutional Review Board

Decision
REC Western Norway approves the project in accordance with the submitted application as long as the aforementioned condition is met.

Final Report and Amendments
The Project Manager shall submit a final report to the REC Western Norway no later than 01.07.2017., according to Health Research Act § 12. The Project Manager shall submit an application of approval to REC Western Norway if there is significant changes in the project protocol, according to Health Research Act § 11.

Appeal
The Project Manager may appeal the committee's decision, see the Administration Act § 28. The appeal must be sent to the REC Western Norway within three weeks of receiving this letter. If the decision is upheld by REC Western Norway, the appeal will be forwarded to the National Research Ethics Committee for Medical and Health Research for a final assessment.

Sincerly

Ansgar Berg
Prof. Dr.med
Committee Chairman

Øyvind Straume
Head of Office

Kopi til: post@uib.no

	Addis Ababa University College of Health Science Institutional Review Board	SOP# AAUMF 008 Version 2.0 Effective date: 1 Feb. 2009 Page 13 of 13
	Title: **3.2. Use of Study Assessment Form**	

ANNEX 3

Form AAUMF 03-008

IRB's Decision

Meeting No: 047/2012 | Date (D/M/Y): November 07/2012

Protocol number: 036/12/SPH | Assigned No.………………

Protocol Title: Food Security, Climate variability and pattern: Modeling the impact of climate variability on food security and analyzing the spatial pattern in Ethiopia.		
Principal Investigators:	Seifu Hagos	
Institute:	AAU-School of Public Health	
Elements Reviewed (AAUMF 01-008)	☑ Attached	☐ Not attached
Review of Revised Application ☐ Yes ☐ No	Date of Previous review:	
Decision of the meeting:	☑ **Approved** ☐ Resubmission	☐ Approved with Recommendation ☐ Disapproved

I. Elements approved-
1. Protocol Version No. ………………………………
2. Protocol Version Date……………………………
3. Informed consent Version No. ……………………
4. Informed Consent Version Date ……………………

II. Obligations of the PI-
1. Should comply with the standard international & national scientific and ethical guidelines
2. All amendments and changes made in protocol and consent form needs IRB approval
3. The PI should report SAE within 10 days of the event
4. End of the study, including manuscripts and thesis works should be reported to the IRB

III. **TO ESTM** ☐

Institution Review Board (IRB) Approval: Period from **08/11/2012** to **07/11/2014**

Follow up report expected in

3 Months ___ 6 months ___ 9 months_______one year____

Chairperson, IRB
Dr. Yimtubezenash W/Amanuel
Signature ______________
Date: 08/11/12

Associate Director of Research and Technology Transfer
Signature ______________
Date ______________

Institutional Review Board Office (IRB) Faculty of Medicine ADDIS ABABA UNIVERSITY