Epidemiology and Social Determinants of Chronic Diseases Attributed Adult Mortality and its Influence on Maternal and Young Child Nutrition in Tigray, 2009-2015: Evidence from Kilte Awlaelo- Health and Demographic Surveillance Site

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Dedicated to

- mom and dad,
- my daughter: Mariamawit Semaw Ferede, and
- my sister: Mamitey Ferede Abera.

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"The LORD is good, a strong hold in the day of trouble;

and He knoweth them that trust in Him." Nahum 1: 7

"እግዚአብሔር፡ መልካም፥ ነው፥ በመከራ፡ ቀንም፡ መሸሸጊያ፡ ነው፤

በእርሱ፡ የሚታመኑትንም፥ ያውቃል።" ናሆም ፩፥ ፯

Contribution to publications

Mr. Semaw Ferede Abera conceived the research ideas; designed the methods; developed the research project; secured ethical clearance; extracted, managed, and analyzed the data; interpreted the results and drafted the manuscripts; incorporated comments from co-authors, and corresponded all the publications.

The datasets underlying the thesis project were based on Kilte Awlaelo-Health and Demographic Surveillance Site (KA-HDSS). The Ph.D. student was a research team member of this surveillance project since September 2012. As a research team member, he actively worked in designing KA-HDSS survey tools; leading overall data collection activities including training of data collectors and supervision of the data collection process; cleaning and analysis of data; preparation of reports and writing manuscripts as well as participation in management of the surveillance site. His appointment to the part-time project responsibility was following a competitive announcement while he was working as a lecturer at the School of Public Health, College of Health Sciences of Mekelle University.

PD, Dr. Veronika Scherbaum, who is the main supervisor of the Ph.D. student, contributed to conception and design of the research project; participated in the interpretation of results; critically revised and approved all manuscript submissions; and supervised the doctoral thesis.

Prof. Dr. med. Eva Johanna Kantelhardt contributed to conception and design of the research project; critically revised and approved all manuscript submissions.

Adjunt Prof. Dr. Andreas Wienke contributed to statistical analyses plans; reviewed all statistical analyses; critically revised and approved all manuscripts submissions.

Prof. Dr. Jan Frank participated in the interpretation of results, critically revised and approved submission of the manuscript in chapter 4.

Prof. Dr. med. Hans Konrad Biesalski critically revised and approved submission of the manuscript in chapter 3.

Prof. Ejeta Gebisa critically revised and approved submission of all manuscripts.

Mr. Alemseged Aregay Gebru helped in securing ethical clearance; critically revised and approved submission of all manuscripts.

Prof. Afework Mulugeta critically revised and approved submission of the manuscripts in chapters 4 and 5.

Dr. Mache Tsadik critically revised and approved the manuscript in chapters 4.

Dr. Judith Lauvai critically revised and approved the manuscripts in chapters 4 and 5.

List of publications

1. Abera SF, Gebru AA, Biesalski HK, Ejeta G, Wienke A, Scherbaum V, Kantelhardt EJ. Social determinants of adult mortality from non-communicable diseases in northern Ethiopia, 2009-2015: Evidence from health and demographic surveillance site. PLoS One. 2017; 12(12): e0188968. doi: 10.1371/journal.pone.0188968. https://pubmed.ncbi.nlm.nih.gov/29236741/
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3. Abera SF, Kantelhardt EJ, Bezabih AM, Gebru AA, Ejeta G, Lauvai J, Wienke A, Scherbaum V. Nutrition-specific and sensitive drivers of poor child nutrition in Kilte Awlaelo-Health and Demographic Surveillance Site, Tigray, Northern Ethiopia: implications for public health nutrition in resource-poor settings. Glob Health Action. 2019;12(1):1556572. doi: 10.1080/16549716.2018.1556572. https://pubmed.ncbi.nlm.nih.gov/31154991/

Summary

In Ethiopia, the burden of disease related to communicable diseases has recently decreased significantly, while morbidity and mortality due to non-communicable diseases (NCDs) have increased. At the same, maternal and child malnutrition remained a major public health problem of Ethiopia. In developing countries, where health insurance is largely unavailable, individual medical conditions can also affect the overall and nutritional well-being of household members. In particular, the occurrence of disease and adult mortality in households can affect the nutritional well-being of the most vulnerable household members, especially lactating mothers and their young children. If the diseases are of chronic nature, which usually are costly and adult household members die from it in the long-term, this can be devastating for the family.

The aim of this Ph.D. project was to investigate the epidemiology and social determinants of NCDs-attributed adult mortality, and to examine the association of chronic diseases attributed adult mortality with undernutrition of lactating mothers and their young children in rural population of Kilte Awlaelo-Health and Demographic Surveillance Site (KA-HDSS), Eastern Zone of Tigray, Ethiopia.

During the data analysis, causes of death in adults were classified into chronic and non-chronic causes. The category of adult mortality due to chronic diseases refers to all causes that may be characterized by a long duration of illness. This group includes all deaths caused by NCDs and chronic communicable diseases such as tuberculosis and HIV/AIDS.

The thesis has three articles, all published in peer-reviewed journals. The first article reports findings on the epidemiology and social-determinants of adult mortality caused by NCDs among 45,982 adult residents of KA-HDSS using population-based longitudinal data collected from 2009 to 2015. The second article tested whether the burden of undernutrition was higher among lactating mothers who were living in households with adult mortality from chronic diseases than among lactating mothers living in households with no adult mortality from chronic diseases. The third article examined whether there was an association between undernutrition of children and adult mortality from chronic diseases. Both longitudinal and cross-sectional data were used in the second and third articles. To our knowledge, this study showed for the first time that adult mortality caused by NCDs varied according household members' relationship to their household head: extended family and non-family members of the household head had higher hazard of mortality compared to the household heads. In addition, this work can be considered as the first study from a low-income setting to examine whether mortality of an adult household member from chronic diseases is associated with undernutrition of lactating mothers and their young children.

The results of the first study indicate a double mortality burden from both communicable diseases and NCDs in the study population. Between 2009 and 2015, the leading causes of NCDs-attributed adult

mortality were cardiovascular diseases, cancer and renal failure. Compared to heads of households, extended family and non-family co-residents had an increased hazard of mortality from NCDs. Literacy and younger age were protective factors against adult mortality caused by NCDs. However, the protective role of literacy against adult mortality from NCDs decreased with increasing age.

Next, we assessed the level of undernutrition among the lactating mothers and examined its association with household-level occurrence of adult mortality from chronic diseases by controlling the effect of a wide range of epi-demographic and agro-ecological variables. Nearly two-fifths (38%; 95% CI: 36.1, 40.1%) of the mothers were undernourished. We found an increased risk of maternal undernutrition for lactating mothers who were living in households which experienced adult mortality from chronic diseases. In addition, maternal undernutrition was strongly associated with recent history of household-level morbidity, poor health-seeking practice, lack of diverse food crops, and a low index score for housing and environmental factors.

In the third article, we determined the burden of undernutrition among children of complementary feeding age (6 to 23 months) and its factors within the context of nutrition-specific and -sensitive drivers of young child undernutrition. Here, mortality from chronic diseases were constructed as a nutrition-specific factor. We found high prevalence of wasting (13.7%; 95% CI: 12.1, 15.5%) and inadequate child dietary diversity (81.3%; 95%CI: 79.2, 83.1%). Adult mortality history from chronic diseases was not associated with young child undernutrition and child dietary diversity. However, child undernutrition was strongly associated with recent history of household-level morbidity, maternal undernutrition, low child dietary diversity, poverty, larger family size, insecure employment of household heads, and living in highland areas. Poor household wealth status and lack of diverse food crops production, particularly in highland areas, were also strongly associated with lower child dietary diversity.

Overall, this thesis has shown that an epidemiological transition is ongoing in the surveillance population. Population-based intervention measures are recommended that aim to reduce NCD-related adult mortality by targeting the leading causes of death and focusing on vulnerable population subgroups, such as the extended family and nonfamily household members. In this study, there was no association between the occurrence of chronic diseases attributed adult mortality and young child undernutrition. However, adult mortality from chronic diseases was associated with maternal undernutrition. Our findings appear to call for multi-sectoral interventions, mainly by the agriculture, nutrition and health sectors, to promote nutritional well-being of lactating mothers and their dyads in the long-term.

Zusammenfassung

In Äthiopien ist die Krankheitslast im Zusammenhang mit übertragbaren Erkrankungen zuletzt deutlich zurückgegangen, während die Morbidität und Mortalität aufgrund nicht übertragbarer Krankheiten (NCDs) angestiegen ist. Gleichzeitig blieb die Unterernährung von Müttern und Kindern weiterhin ein großes Problem der öffentlichen Gesundheit in Äthiopien. In Entwicklungsländern, in denen es größtenteils keine Krankenversicherung gibt, können individuelle Erkrankungen auch das allgemeine Wohlbefinden und das Ernährungswohl der Haushaltsmitglieder beeinträchtigen. So kann das Auftreten von Krankheiten und die Erwachsenensterblichkeit in Haushalten insbesondere das Ernährungswohl der am stärksten gefährdeten Haushaltsmitglieder beeinträchtigen – vor allem stillende Mütter und ihre kleinen Kinder. Wenn es sich um chronische Erkrankungen handelt, die meist hohe Kosten verursachen und erwachsene Haushaltsmitglieder langfristig daran versterben, kann dies für den Familienverband bedrohlich werden.

Das Ziel dieses Ph.D. Projekts war es, die Epidemiologie und die sozialen Determinanten der durch nichtübertragbare Krankheiten verursachten Erwachsenensterblichkeit zu untersuchen und den Zusammenhang zur Unterernährung stillender Mütter und ihrer Kinder in der ländlichen Bevölkerung von Kilte Awlaelo – der Gesundheits- und demografischen Überwachungsstelle (KA-HDSS) in der Ostzone von Tigray, Äthiopien - zu untersuchen.

Während der Datenauswertung wurden die Todesursachen bei Erwachsenen in chronische und nichtchronische Ursachen eingeteilt. Die Kategorie der Erwachsenensterblichkeit aufgrund chronischer Todesursachen bezieht sich auf alle Ursachen, die durch eine lange Krankheitsdauer gekennzeichnet sein können. Diese Gruppe umfasst alle Todesfälle, die durch nichtübertragbare Krankheiten und chronisch übertragbare Krankheiten wie Tuberkulose und HIV/AIDS verursacht werden.

Die Dissertation umfasst drei Artikel, die alle in peer-reviewten Fachzeitschriften veröffentlicht wurden. Der erste Artikel berichtet über Erkenntnisse zur Epidemiologie und den sozialen Determinanten der durch nichtübertragbare Krankheiten verursachten Erwachsenensterblichkeit bei 45.982 erwachsenen Einwohnern von KA-HDSS unter Verwendung bevölkerungsbasierter Längsschnittdaten, die von 2009 bis 2015 gesammelt wurden. Im zweiten Artikel wurde untersucht, ob die Prävalenz von Unterernährung bei stillenden Müttern, die in Haushalten leben, in denen eine durch chronische Krankheiten verursachte Erwachsenensterblichkeit auftrat, höher war als bei Müttern, in deren Haushalten keine Erwachsenensterblichkeit durch chronische Krankheiten erhoben wurde. Im dritten Artikel wurde der Frage nachgegangen, ob es einen Zusammenhang gab zwischen der Unterernährung von Kleinkindern und der durch chronische Krankheiten verursachten Erwachsenensterblichkeit. Im zweiten und dritten Artikel wurden sowohl Längsschnitt- als auch Querschnittsdaten verwendet. Unseres Wissens nach hat diese

Studie zum ersten Mal gezeigt, dass die durch nichtübertragbare Krankheiten verursachte Sterblichkeit je nach Beziehung der Haushaltsmitglieder zu ihrem Haushaltsvorstand variiert: Erweiterte Familienangehörige und Nicht-Familienmitglieder hatten im Vergleich zum Haushaltsvorstand selbst ein höheres Sterberisiko. Darüber hinaus kann diese Arbeit als die erste Studie aus einem Umfeld mit niedrigem Einkommen betrachtet werden, in der untersucht wurde, ob die Sterblichkeit erwachsener Haushaltsmitglieder aufgrund chronischer Krankheiten mit der Unterernährung stillender Mütter und ihrer jungen Kinder zusammenhängt.

Die Ergebnisse der ersten Studie weisen auf eine doppelte Sterblichkeitsbelastung sowohl durch übertragbare Krankheiten als auch durch nicht übertragbare Krankheiten in der Untersuchungspopulation hin. Zwischen 2009 und 2015 waren Herz-Kreislauf-Erkrankungen, Krebs und Nierenversagen die häufigsten durch nichtübertragbare Krankheiten verursachten Todesfälle bei Erwachsenen. Im Vergleich zum Haushaltsvorstand hatten Großfamilien- und familienfremde Mitbewohner ein erhöhtes Risiko, an NCDs zu sterben. Alphabetisierung und jüngeres Alter waren schützende Faktoren gegen die durch nichtübertragbare Krankheiten verursachte Mortalität. Allerdings nimmt die schützende Rolle der Alphabetisierung bei der Erwachsenensterblichkeit aufgrund nichtübertragbarer Krankheiten mit zunehmendem Alter ab.

Als nächstes analysierten wir den Grad der Unterernährung bei stillenden Müttern und untersuchten den Zusammenhang zwischen mütterlicher Unterernährung und Sterblichkeit auf Haushaltsebene aufgrund chronischer Todesursachen bei Erwachsenen, indem wir ein breites Spektrum epidemiografischer und agrarökologischer Variablen anwandten. Knapp zwei Fünftel (38%; 95% KI: 36,1, 40,1 %) der Mütter waren unterernährt. Wir fanden ein erhöhtes Risiko für mütterliche Unterernährung bei stillenden Frauen, die in Haushalten lebten, in denen es in der Vergangenheit zu einer Erwachsenensterblichkeit aufgrund chronischer Krankheiten kam. Darüber hinaus war die Unterernährung der Mütter stark mit der Morbidität auf Haushaltsebene in der jüngeren Vergangenheit, unzureichender Inanspruchnahme von Gesundheitsdiensten, Mangel an Zugang zu vielfältigen Nahrungsmittelpflanzen und einem niedrigen Indexwert für Wohnverhältnisse und Umweltfaktoren verbunden.

Im dritten Artikel haben wir die Belastung durch Unterernährung bei Kindern im Beikostalter (6 bis 23 Monate) und ihre Faktoren im Kontext ernährungsspezifischer und ernährungssensibler Indikatoren ermittelt. Dabei wurde die Erwachsenensterblichkeit aufgrund chronischer Todesursachen als ernährungsspezifischer Faktor konstruiert. Wir fanden eine hohe Prävalenz von Auszehrung (13,7%; 95% KI: 12,1, 15,5 %) und eine unzureichende Ernährungsvielfalt bei Kindern (81,3%; 95% KI: 79,2, 83,1 %). Die Sterblichkeit aufgrund chronischer Todesursachen war nicht mit der Unterernährung und der

mangelhaften Ernährungsvielfalt für Kinder assoziiert. Die Unterernährung von Kindern war jedoch stark mit der Morbidität auf Haushaltsebene in der jüngeren Vergangenheit, Unterernährung der eigenen Mutter, geringer Ernährungsvielfalt für Kinder, Armut, umfangreicher Familiengröße, unsicherer Beschäftigung der Haushaltsvorstände und dem Leben im Hochland verbunden. Ein ungenügender Wohlstandsstatus der Haushalte und der Mangel an vielfältigem Nahrungsmittelanbau, insbesondere in Hochlandgebieten, waren ebenfalls stark mit einer geringeren Ernährungsvielfalt bei Kindern assoziiert.

Insgesamt hat diese Arbeit gezeigt, dass der epidemiologische Wandel in der Untersuchungsbevölkerung noch nicht abgeschlossen ist. Bevölkerungsbezogene Interventionsmaßnahmen sind zu empfehlen, die darauf abzielen, die NCD-bedingte Erwachsenensterblichkeit zu senken, indem sie auf die führenden Todesursachen abzielen und den Schwerpunkt auf die gefährdeten Bevölkerungsuntergruppen legen, wie die Großfamilie und die familienfremden Haushaltsmitbewohner. In dieser Studie gab es keinen Zusammenhang zwischen Unterernährung bei Kleinkindern und der Erwachsenensterblichkeit aufgrund chronischer Krankheiten. Die Erwachsenensterblichkeit aufgrund chronischer Krankheiten war jedoch mit der Unterernährung der Mütter verbunden. Unsere Ergebnisse erfordern offenbar sektorübergreifende Interventionen, vor allem in den Bereichen Landwirtschaft, Ernährung und Gesundheit, um das Ernährungswohl stillender Mütter und ihrer Kinder langfristig zu fördern.

List of abbreviations

AAMSP	Addis Ababa Mortality Surveillance Program
adjPR	Adjusted Prevalence Ratio
CBTP	Community-Based Training Program
CDC	Center for Disease Control
CDDS	Child Dietary Diversity Score
CI	Confidence Interval
CoD	Causes of Death
COPD	Chronic Obstructive Pulmonary Disease
CVDs	Cardiovascular Diseases
CVRS	Civil Registration and Vital Statistics
DALYs	Disability Adjusted Life Years
DDS	Dietary Diversity Score
DHS	Demographic Health Survey
DM	Diabetes Mellitus
EDHS	Ethiopian Demographic and Health Survey
EPHA	Ethiopian Public Health Association
ERC	Ethics Review Committee
FMoH	Federal Ministry of Health
GPS	Geographic Positioning System
HAEFI	Housing and Environmental Factors Index
HDL	High Density Lipoprotein
HDSS	Health and Demographic Surveillance Site
HIV/AIDS	Human Immunodeficiency Virus/ Acquired Immunodeficiency Syndrome
HR	Hazard Ratio
HRERC	Health Research Ethics Review Committee
ICD-10	International Classification of Diseases 10th Revision
IDR	Incidence Density Rate
IGTP	Intergenerational Transmission of Poverty

INDEPTH	International Network for the Demographic Evaluation of Populations and Their Health
IQR	Interquartile Range
JMP	Joint Monitoring Program
KA-HDSS	Kilte Awlaelo- Health and Demographic Surveillance Site
LMICs	Low and Middle Income Countries
MDGs	Millennium Development Goals
mHSP	Maternal Health-seeking Practice
MUAC	Mid Upper Arm Circumference
MUACZ	Mid Upper Arm Circumference Z-score
NCDs	Non-communicable Diseases
OR	Odds Ratio
POM	Proportional Odds Model
PPOM	Partial Proportional Odds Model
PR	Prevalence Ratio
SD	Standard Deviation
SDGs	Sustainable Development Goals
SSA	Sub-Saharan Africa
TB	Tuberculosis
UHC	Universal Health Coverage
UN	United Nations
UNICEF	The United Nations Children's Fund
VA	Verbal Autopsy
VIF	Variance Inflation Factor
WHO	World Health Organization
WHZ	Weight for-Height/Length Z-score

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Chapter 1: General introduction

1.1 Introduction

Worldwide, health loss due to non-communicable diseases (NCDs) is enormous. The share of deaths attributed to NCDs was estimated to rise from 59% in 2002 to 69% in 2030 [1]. At a global level, NCDs are responsible for 41 million deaths each year, which accounts for about 74% of all deaths; low and middle income countries (LMICs) share more than three-fourths of these death estimates [2]. NCDs were not yet addressed in the Millennium Development Goals (MDGs). However, the Sustainable Development Goals (SDGs) mention NCDs as one of its priority issues. SDG target 3.4 aims to reduce premature mortality from NCDs by a third by 2030, compared to the baseline levels in 2015, and to promote mental health and well-being [3–5]. Achieving this specific goal also has a vital synergistic role on achieving other SDGs [6]. During the MDG era (2000 to 2015), Ethiopia's focus was predominately on addressing communicable diseases and nutritional problems, while NCDs were not taken seriously until very recently. Since 2015, however, NCDs have gained attention with a high political commitment by incorporating them into the phase-based implementation of the Health Sector Transformation Plan [7,8]. Despite the encouraging progress made, there are still major implementation and service delivery gaps- including a lack of NCDs service integration into primary health care units, limited diagnostic facilities, poor treatment quality and underfunding of NCDs [9–11]. Such has been the challenges regarding NCD intervention in the country and currently it is unlikely that SDG 3.4 will be achieved by 2030 [5,12].

LMICs, especially Sub-Saharan Africa region, had the highest risk of dying prematurely from NCDs [13]. Reports of the World Health Organization (WHO) for Ethiopia revealed an increase of the share of NCD-attributed mortality from 30% in 2012 to 43% in 2019 [14,15]. Evidence showed that Ethiopia is experiencing epidemiologic transition [16–18]. Fueled by the increasingly prevalent risk-factors, and unprepared health system, Ethiopia is likely to face increasing NCD-ascribed morbidity and mortality burden [18–23]. On account of the high burden of child malnutrition, rapid urbanization, and nutrition transition in Ethiopia, NCDs will more likely be of crucial public health significance especially to future generations [24–27]. On the other hand, the burden of disease from chronic communicable causes, which can also interact with unfavorable NCD outcomes and share a common feature of long illness period, such as tuberculosis (TB), still has a substantial impact to the public health situation [18,28–31].

In LMICs, chronic diseases can negatively impact well-being of affected households in different ways. Since chronic diseases (NCDs and chronic communicable diseases) are characterized by a long duration of illness, affected individuals may need long-term care both from their family members and health service providers. Medical expenses and income loss due to illness or death can jeopardize household's economic welfare, even under conditions of free treatment policy [32,33]. Chronic-disease-affected households could become impoverished, exposed to food insecurity, and malnutrition [34–38]. Taking care of a chronically sick member can also negatively influence physical and mental health of caregivers thereby exposing them to increased risk of

poor dietary intake and malnutrition [39,40]. The effect of such deleterious household experiences can be worse for the nutritionally vulnerable household members, especially lactating mothers and their breastfeeding children [41].

In this dissertation, the concept of "chronic diseases" generally refers to diseases characterized by long-duration of illness that includes both NCDs and chronic communicable diseases, such as HIV/AIDS and TB, whereas "NCDs" refers to diseases that are non-infectious and non-transmissible between people [42]. In a previous study, Geubbels et al. combined NCDs, HIV/AIDS, and TB into chronic diseases [43]. This dissertation aims to determine the burden and social determinants of NCD ascribed adult mortality and then examines whether adult mortality from chronic diseases was associated with undernutrition of lactating mothers and their young offsprings.

The thesis has been divided into seven chapters. *Chapter 1* presents up-to-date background information on the epidemiology of NCDs, the context of transitions relevant to NCDs, the burden of NCDs-attributed adult mortality and its social determinants, and the association of chronic diseases with household well-being including maternal and child undernutrition. In addition, it also presents the relevance, hypotheses and objectives of the thesis. *Chapter 2* starts with a description of the study setting and continues to present detailed overview of the tools and methods used for implementing the dissertation project. *Chapter 3* presents results on the epidemiology and social determinants of NCD-attributed adult mortality. The key issue addressed in *chapter 4* will be determining the prevalence of undernutrition among lactating mothers and its associated factors- the focus of interpretation being on the association of chronic-diseases-attributed adult mortality with undernutrition of lactating mothers. *Chapter 5* deals with the burden of child malnutrition and drivers of undernutrition among 6- to 23-month-old children. Also in chapter 5, the association of adult mortality from chronic diseases and young child undernutrition is presented as part of the wider scope of nutrition-specific and sensitive drivers. In *chapter 6*, synthesis and interpretation of the thesis findings will be made and *chapter 7* draws key conclusions and implications.

1.2 Background

1.2.1 Non-communicable diseases globally

Non-communicable diseases (NCDs) are a range of diseases that are non-infectious and non-transmissible among people [42], which tend to be of long duration and are the result of a combination of genetic, physiological, environmental and behavioral factors [2]. The issue of NCDs has received considerable critical attention as one of the leading global health agenda in the SDGs [3].

NCDs constitute the greatest share for the global disease burden [44]. In 2016 alone, NCDs were responsible for 80.6% of years lived with disability and 61.4% of disability adjusted life years (DALYs) globally [45]. DALYs due to NCDs increased by 13.1% between 1990 and 2019, while that of injuries and communicable diseases declined by substantial proportions [46]. Similarly, the share of mortality due to NCDs is increasing at a global level with one person under the age of 70 dying from NCDs every two seconds and NCDs account for 7 out of 10 world's top causes of death [6]. Cardiovascular diseases (CVDs), cancer, diabetes mellitus (DM), and chronic obstructive pulmonary disease (COPD) are the leading causes of death and represent 74% of global NCD deaths [2]. In 2011, the UN in its first High-level General Assembly Meeting on NCDs identified these four diseases, which also share four amenable behavioral risk factors (unhealthy diet, physical inactivity, harmful consumption of alcohol, and tobacco use), as primary focus for interventions to combat NCDs [47]. The third UN Meeting on NCDs updated its priorities of interventions to include addressing environmental risk factors of NCDs (such as air pollution) and the treatment of mental illnesses [48].

Although NCDs were regarded as problems of high-income countries, as a matter of epidemiologic fact, this is a misconception [49,50]. NCDs and their risk factors have rather grown to a level of serious public health concern in LMICs. More than 80% of the total NCD deaths were in these countries [6,51,52]. Slightly higher than two-thirds of the DALYs, and more than 85% of premature mortality due to NCDs occur in LMICs [2,53]. Moreover, Coates et al. showed that age-specific DALY rates were higher for the world's one billion poorest population than for those in high-income regions [54].

Morbidity and mortality caused by NCDs is increasing in Sub-Saharan Africa (SSA), and it has been shown that this region experienced the highest probability of dying from NCDs [55–57]. For instance, the number of CVDs has increased significantly since 1990 and the age-adjusted mortality rate for CVD has not decreased in SSA, unlike what has been observed in other regions of the globe [58]. The increase in the NCDs is largely driven by population growth, ageing, and epidemiological transition [58,59]. Behavioral (physical inactivity, unhealthy diet, tobacco use, harmful consumption of alcohol, unsafe sex), metabolic (obesity, high blood pressure, hyperglycemia, hyperlipidemia), and environmental (such as air pollution) risk factors should be the main focus of prevention efforts in order to control the growing burden and impacts of NCDs [52,60,61].

1.2.2 NCDs in Ethiopia: Prevalence, risk factors and driving transitions

As opposed to the declining trend of communicable diseases, NCDs and their risk factors are becoming more prevalent in Ethiopia [46,62–66]. Kibret and Mesfin found a pooled hypertension prevalence of 19.6%, with a marked difference by urban and rural population [67]. A slightly higher pooled prevalence of hypertension (20.6%) was reported by a more recent meta-analysis, and the prevalence varied from 7.7% in Amhara region to 41.9% in Harari region [68]. It was shown that hypertension is the most common risk factor for stroke in Ethiopia [69]. A pooled ischemic stroke prevalence of 51.4% and hemorrhagic stroke prevalence of 46.4% were estimated, although the precision of these estimates are questioned [70,71]. According to a population-based study conducted in northwest Ethiopia, the prevalence of CVDs was 32.2% in 2014 [72]. Pooled prevalence of DM was 6.3%, showing a clear temporal variation with increased prevalence of 7.5% for studies implemented after 2017 [62]. A meta-analysis, which covered the study period 2013 to 2021, found high prevalence of undiagnosed DM (5.7%) and impaired fasting glucose (8.9%) [73].

A study conducted in southcentral Ethiopia (Gurage Zone) found a 17.8% prevalence of chronic obstructive pulmonary disease, and a study from northwestern Ethiopia found a 27.7% prevalence of Asthma [72,74]. The cancer prevalence in the study conducted in northwestern Ethiopia was 3.2% [72]. Prevalence of NCDs in Ethiopia varied widely [22,75]. The most up-to-date synthesis revealed that nearly a third of Ethiopians have NCDs, the most prevalent being CVDs [22]. A study which used the global burden of disease data showed that ischemic heart disease, rheumatic heart disease and stroke were the three most common CVDs in Ethiopia in 2017 [64]. According to the latest meta-analytic study, two in five older Ethiopians had depression [76]. Morbidity data from a facility-based study in southern Ethiopia showed that 29.7% of the 22,320 attending patients were due to NCDs [77]. In the same study, digestive disorders, CVDs, and DM were the most prevalent NCDs [77]. Infectious diseases contributed a substantial portion of NCDs burden, particularly in LMICs [78]. Occurrence of NCDs can even become more pronounced when individuals are also affected by infectious diseases. Belay et al. showed a higher pooled prevalence of DM (16%) among HIV/AIDS patients who were on Highly Active Anti-retroviral Therapies [79]. Two-fifths of type 2 DM patients were affected by CVDs in Eastern Ethiopia [80].

The prevalence of the classical NCD risk factors is increasing in Ethiopia. For the first time, a nationwide population-based data regarding metabolic risk factors and their determinants in Ethiopia was conducted in 2015 [19]. Prevalence rates of high blood pressure and DM at 15.8% and 3.2%, respectively. A high prevalence of hypercholesterolemia (5.2%), hypertriglyceridemia (21%), low HDL cholesterol (68.7%) and impaired fasting glucose (3.8% with WHO criteria) were also reported [19]. More than three-fourths of adults were found to have at least one modifiable cardiovascular risk factor in Southern Ethiopia and almost all study (95.8%) participants had at least one NCD risk factor in Eastern Ethiopia [81,82]. Exposure to biomass smoke, cigarette smoking, khat chewing, and harmful alcohol consumption are other relevant risk factors of NCDs in Ethiopia [74,83].

NCDs and their risk factors are also likely to increase in Ethiopia as a result of other driving factors: epi-demographic and nutrition transitions. The currently young population (<15 years), 47% of the Ethiopian population in 2019, is projected to decline whilst the working and elderly population is expected to increase [8,84,85]. Demographic transition can be associated with increased risk of NCDs [86,87]. Another crucial driver to consider is the growing rate of urbanization, which may be associated with increased physical inactivity, stress, slummy residential areas, air pollution, increased risk of processed food consumption, and obesity. In Ethiopia, unplanned urbanization was observed to reduce peri-urban agricultural land use resulting in the decline of crop and livestock production [88–92]. Although Ethiopia is one of the least urbanized country (20%), it is experiencing the fastest urbanization due to natural growth and various push and pull factors [93,94]. A projection of a 31.1% increase in urban population by 2037, with an annual growth rate of 3.8%, was made by the Central Statistics Agency of Ethiopia [25]. As has been shown elsewhere, despite the benefits of urbanization to LMICs in terms of improving access to better health services, it can also be a relevant driver of NCD-related risk factors such as higher body mass index and total cholesterol [26,95].

Urbanization can facilitate nutrition transition [26], a globally growing characteristic shift in dietary intake toward lower intake of complex carbohydrates and higher intake of simple and refined carbohydrates [96]. This specific transition was shown to be associated with an increased risk of nutrition-related NCDs [97–99], which needs to be addressed as an amenable factor of NCDs [100]. In this regard, Ethiopia is still in its early stage of nutrition transition (77,78). Nevertheless, the speedy urbanization, in combination with the ongoing effort of industrialization, calls for urgent nutritional intervention with timely policy formulation that takes into account the health dangers of sugar-sweetened beverages [97,101–103]. In Ethiopia, intake of added sugars was shown to increase by 35% during 2006 and 2013 for cohorts born in 2011/2012 [27]. Therefore, the government of Ethiopia may consider taxing sugar-sweetened beverages. Leveraging the policy experience gained through the control of smoking and alcoholic drinks (although gaps in law enforcement were later identified) could be helpful in formulating and implementing such policy effort [8,104]. With a major focus on the volume of sugary drinks, excise taxation of these beverages could reduce incidence of morbidity and mortality from nutrition-related NCDs in developing countries like Ethiopia [105,106]. Population subgroups of a lower socio-economic profile may especially benefit from such a fiscal policy [107].

1.2.3 Adult mortality from NCDs and NCD health service in Ethiopia

A high mortality burden from communicable diseases indicate poor socio-economic status and low health service coverage of a country [108]. However, Ethiopia has made remarkable progress in improving health of its citizens and most of the health-related MDGs were achieved. There was a 67% decline in mortality of children under 5 years of age, a 71% reduction in maternal mortality ratio (close to the 75% target), a 90% reduction in new HIV infections, a 73% decline in malaria-related mortality, and a more than 50% decline in mortality from TB [109]. Due to improved economic development and decline in communicable, neonate-maternal and nutrition

problems, life expectancy has improved significantly [30,109,110]. On the other hand, the proportion of mortality attributable to NCDs is increasing [86,111].

A study from a predominantly rural population in Butajira-HDSS, in Southcentral Ethiopia showed that NCDs were responsible for 25.4% of the deaths in adults of 15 to 49 age groups in the second half of 1990s [112]. Recent data (2008-2019) from the same study site showed that 58.9% of all adult deaths were due to NCDs [111]. There was a significant increase in the upward trend of adult mortality from NCDs, from 48.3% in 2008 to 72% in 2019 [111]. Another more recent analysis from the same site revealed that TB (13.6%), hypertension (6.6%) and chronic liver disease (5.9%) were the leading causes of death during 2008 to 2017, whereas digestive neoplasms (17.3%), TB (12.1%), and stroke (9.4%) were the leading causes of death during 2017 and 2020 [113].

During 2008 to 2013, NCDs caused 26.4% of all adult deaths in Kersa HDSS, in eastern Ethiopia [114]. Contrasting with this, data collected over eight years (2009 to 2017) from Arba Minch HDSS in southern Ethiopia reported that 35% of the deaths were attributed to NCDs [115]. In southwest Ethiopia, the share of NCDs-attributable mortality was 34.8% between 2007 and 2013 [31]. The first study in Kilte Awlaelo-HDSS by Weldearegawi et al. revealed that 28.4% of the 190 adult deaths that occurred between 2009 and 2011 were caused by NCDs [116]. While infectious and parasitic diseases accounted for about a third of adult deaths in the East of Ethiopia, TB (16.8%), malaria (9.7%), and infectious intestinal diseases (9.6%) were the top three causes of adult death in Southern Ethiopia [114,115].

A characteristic increase in NCD-attributed adult mortality, with a decline in adult mortality from communicable diseases was observed in the urban population of Addis Ababa. Analysis of data from 73 sites of the Addis Ababa Mortality Surveillance Program (AAMSP) revealed a 31% increase in NCDs-attributed mortality over a ten-year period [17]. During the same time period, there was a 31% decline in adult mortality from communicable diseases, as well as maternal and nutritional disorders [17]. According to this study, the overall NCDs-ascribed adult mortality was 62.8%, and cerebrovascular disease (12.8%), DM (8.1%), chronic liver disease (6.3%), hypertension (5.7%), ischemic heart disease (5.7%) and neoplasms (5.2%) were the leading NCDs causing adult mortality [17]. A study based on older data from the same population found that NCDs were responsible for 51% of adult deaths between 2006 to 2009 [117]. Cancer, DM, hypertension, stroke, and genitourinary diseases were the main contributors of death among adults younger than 65 years [117]. A more comprehensive analysis of the data showed that cancer accounted for 11% of the adult deaths in Addis Ababa, and the leading causes were cancers of the stomach, breast, and liver [118].

Taken together, the literature showed that mortality burden from NCDs has been increasing with a clear pattern of epidemiologic transition. The burden of adult mortality from NCDs widely varied by geographies, urban/rural residence, and distribution of NCD risk factors. For instance, deaths from chronic liver disease was prevalent among 15-49 years old adults in Eastern and Southern parts of Ethiopia compared to northern and northwestern Ethiopia, mainly due to a differentially high khat consumption habit in the eastern and southern

regions of Ethiopia [31,108,114,116,119–121]. Khat consumption was also associated with increased risk of psychiatric symptoms, stroke, and death [122,123].

Despite the growing burden of NCDs, the coverage and quality of health service delivery related to prevention and treatment of NCDs is generally limited in Ethiopia. Although there has been an organized attempt to respond to the emerging NCD problem, and some progress has already been made [7,8,11], there are serious policy and implementation gaps [9] that could translate to increased NCD mortality. For example, chronic under-resourcing, shortage of NCD essential drugs and diagnostic facilities, absence of standard and quality treatment guidelines, and limited availability of NCD prevention and treatment services at primary health care level were reported as major gaps [10]. A nationwide assessment on service availability and readiness in 2016 identified suboptimal NCD service delivery [23]. On the other hand, proper integration of NCDs into existing health care systems was not made, and this can be associated with increased risk of mortality from NCDs [124–126].

Aside from patient- and health system-related factors, mortality from NCDs can be affected by man-made problems like civil war [127–130]. While war by itself can lead to increased mortality risk, it can also indirectly expose patients to adverse outcomes due to the sadden collapse of health services [131] leading to displaced health professionals, cut drug supply chains, reduced patient flow, and increased patient death. Such damage was documented in the study region during the ongoing conflict in Tigray [132–136], although a critique regarding impartiality of the authors and the scientific rigor of the data sources was raised for one of the research works [133,137]. Although the short-term and long-term impacts of this catastrophic and bloody conflict is not yet systematically quantified, it is obvious that health status of Ethiopians, particularly in the north (Tigray, Afar and Amhara), has been severely impacted [30]. Therefore, ensuring peace and security is of tremendous importance to public health and such measures should be addressed from a scientific perspective. Underscoring the relevance of preventing war and enhancing peace through the three classical levels of disease prevention in epidemiology, Rezaeian suggested a novel challenge: "war and peace epidemiology" to be established as a new branch of epidemiology [138].

1.2.4 Social determinants of NCDs-attributed adult mortality

According to the World Health Organization (WHO), social determinants of health are "the non-medical factors that influence health outcomes. They are the conditions in which people are born, grow, work, live, and age, and the wider set of forces and systems shaping the conditions of daily life. These forces and systems include economic policies and systems, development agendas, social norms, social policies and political systems" [139]. It is critical that improvement in population health be viewed from a wider and multifactorial perspective and with this in mind, social determinants of health should be addressed [140]. It was estimated that 30-55% of health outcomes were attributable to social determinants of health [139]. For instance, lack of education and wealth status were shown to have a profound effect on premature mortality in Iran, accounting for 37% of the premature deaths [141]. Understanding how health outcomes, such as mortality, are socially patterned and

quantifying the magnitude of such effects could help to identify disadvantaged population subgroups and associated disparities with respect to health outcomes, both of which in turn could guide potential interventions [142–144].

It can be expected that higher likelihood of morbidity and mortality from NCDs is associated with increasing age, especially with older age groups [87,145,146]. Advanced age was associated with multi-morbidity and disability [147,148]. In northwestern Ethiopia, the odds of dying from NCDs was 1.8 times higher for those aged ≥50 years compared to the 15 to 24 years old group [31]. NCD-ascribed mortality was associated with increasing age in slums of Nairobi, with older age groups revealing a strong and steady pattern of association [149]. Streatfield et al., in their analysis of multisite longitudinal data, documented highest NCD-mortality rate for the ≥65 years adults and lowest rate for the 15 to 49 years group [150]. Data from Burkina Faso and India showed significantly increased NCDs-attributed mortality at ages 50 and 44 years, respectively [151,152]. Studies from clinical settings also showed advancing age as a strong predictor of mortality from colorectal cancer and hemorrhagic stroke [153,154].

Data from several studies have established that mortality caused by various NCDs varied by educational attainment [155–159]. Evidence synthesis of 72 studies from Asia, Europe, and the United States found that people with low and medium education had a 21% higher risk of CVD death than those with a high education [160]. Analysis of population-based cohort data Japan showed a significantly lower risk of mortality from CVD and all-causes for those with higher education [161]. Similarly, evidence from a cohort of 303,036 people revealed lower mortality from cancer, CVD, and all-causes for those with tertiary level education compared to those with primary level education [162]. A meta-analysis study suggested that low educational attainment, compared to high educational attainment, was associated with significantly increased mortality risk from cancer, CVD, and all-causes [163]. Even attaining a primary level education was beneficial in terms of lowering CVD mortality [164]. Authors related lower educational attainment with CVD mortality to higher occurrence of risk factors in the less educated; but, the effects of education on mortality were independent of age and the classical risk factors [161,162,165]. Mortality differentials by educational status were also noted for cervical and liver cancers. Patients with the lowest educational attainment had the highest mortality from cervical cancer, and this was for all age groups [166]. In the United States, liver cancer ascribed mortality was more confined to the less educated group [167].

Deaths were patterned not only by educational level, but also with respect to income (wealth status) and occupation. Analysis of 24-year cohort data from Matlab HDSS revealed that poorer households suffered more deaths from NCDs [168]. Likewise, a population-based verbal autopsy implemented in five SSA countries, including Ethiopia, showed that the poorest group had consistently higher death rates for NCDs [169]. For example, there was survival disadvantage concomitant with area-level socioeconomic deprivation in stage I endometrial cancer patients and with socio-economic status in breast cancer patients [170,171]. According to the evidence synthesis

by Khaing et al, low- and middle-income groups had a 76% and 34% higher risk of dying from cardiovascular disease, respectively, than the high-income groups [160].

Analysis of population-based prospective cohort data in the US revealed increased adult mortality from cancer, CVD, COPD, DM and kidney diseases for the never or temporarily employed compared to the employed participants [172]. Unemployed young women had increased odds of mortality from NCDs in Georgia [173]. In addition, data from Kenya showed that unemployment increased the hazard of CVD mortality [164]. Previous research works reported survival disadvantages due to NCDs and all-causes by unemployment status [158,174–177], but the effect could vary by career level and sex [176,177]. After controlling the effect of age, all-cause mortality was strongly and inversely associated with education, income, and occupation [178]. However, mortality differences resulting from educational inequality were larger than those resulting from differences in material wealth [179]. It was demonstrated that education, income, and employment are strongly correlated and education stands as the most powerful and consistent predictor of adult mortality [158,180,181]. The effect of education on adult mortality is also evident when the absence of an educated household member was associated with increased adult mortality [182]. Moreover, a study from slums of Nairobi showed achieving universal primary level education could have averted 39% of CVD mortality, and association of education with some NCDs like CVD was believed to be partly causal [159,164].

Further, studies have also shown that there were substantial differences in adult mortality from NCDs by urban/rural residence, marital status, presence of spouses and sons in the family, male household headship, and attendance of religious services [113,183–187].

1.2.5 Chronic diseases and household well-being

Diseases do not only affect the suffering individuals, it can also affect the wellbeing of household members and close friends [188]. Mortality from chronic diseases is often preceded by long duration of illness of the affected individuals [2]. The occurrence of a chronic-diseases-affected household member in Ethiopia, where health insurance is largely unavailable, can be considered as a sustained shock to affected households. The loss of a working adult can have far-reaching and devastating consequences for household members [189]. Economic welfare of affected households can be endangered because of income loss and medical expenditure [34,190]. Datta et al. found a 59% higher medical expenditure for NCDs-affected households than NCDs-unaffected households, and NCD-affected households had lower expenditure shares on food, clothing, hygiene, and energy [191]. And, the odds of household impoverishment due to medical expenditure was higher for NCDs than communicable diseases [192].

In Ethiopia, the cost of illness is high and the poorest households were disproportionately affected [36,193–196]. According to recent evidence synthesis, Ethiopian households were significantly impacted by high medical expenditure, especially when affected by chronic diseases [197]. Interestingly, patients suffering from TB incurred a catastrophic level of medical expenditure although anti-TB drugs were available free of charge in Ethiopia [198].

Similarly, a study in Malawi revealed that patients suffering from chronic diseases incurred catastrophic level out-of-pocket expenditure and providing free health care services did not sufficiently translate to financial protection especially for the vulnerable population subgroups [199]. Households affected by chronic diseases can become impoverished due to high medical expenses and income loss [192]. Studies have shown that households that experienced adult mortality from chronic diseases were dragged into poverty, and the impact was greater for the poorer households [200,201]. Sales of household assets, reductions in off-farm income, rental or sales of farm lands, increases in work load, increases in non-working (dependent) household members, and reductions in staple food production could be common in affected households [189,197,202–207]. These adverse conditions can lead to increased risk of household food insecurity and undernourishment of affected households members, especially the vulnerable lactating mothers and children [205,208–211].

Diseases do not only influence the overall well-being of the suffering individual, but their effects could also spillover and affect other household members. Sick household members usually receive care from their household members in the context of rural population of Ethiopia. Similar to elsewhere in Africa, women are more likely to give care to sick household members and children in the study community [212]. The need for care can be more pronounced and prolonged if the diseases are of chronic duration. Due to such likely adverse household situations, including household resource depletion, care-giving household members can be exposed to mental health problems, such as chronic stress and depression [39]. Using data from LMICs, Bhan et al. reported women had extreme difficulty of accomplishing their life tasks when they had someone sick at home, even though they were not taking the responsibility of care giving to these sick members [213]. Another study revealed that 8 years after the initial diagnosis of cancer in the family, quality of life of care-giving family members remained greatly impacted [214]. Several other researches have also shown that care burden can affect physical and mental health of care givers [215–217]. Depression, a common problem observed among caregivers, in turn can have detrimental negative effect on dietary quality and nutritional wellbeing of lactating mothers and their young offspring [41,218].

Maternal and child undernutrition is a chronic public health problem in Ethiopia [24,219–223]. The increasing burden of chronic diseases attributed adult morbidity and mortality can exacerbate maternal and child undernutrition due to bereavement, high funeral expenses and increased workload following deaths of adult household members [213,224–227]. Such a stressful household environment and associated care burden can reduce the attention and time the mothers dedicate to themselves and their young children, an adverse situation which can increase their exposure to undernutrition.

1.3 Study relevance

The available evidence showed that risk factors, morbidity, and mortality from NCDs are increasing rapidly in Ethiopia (chapter 1). According to the WHO, there were 271,300 NCD-related deaths in Ethiopia in 2019 alone; this translates to a 43% share of all deaths during that year being from NCDs [15]. This was a 13% increase

in the share of NCD-ascribed mortality compared to the estimation for 2012 [14]. Despite the growing burden and the efforts made to combat NCDs, Ethiopia's performance regarding NCDs was insufficient and NCDs were the leading causes of premature mortality and death rates in 2015 [228]. NCD treatment centers, especially for cancer, are very limited, and treatment quality is low [23,229,230]. This could be partly due to resource constraints; NCD treatments have to compete with the chronically prevailing public health challenges of communicable diseases and other problems, although improvement has been made for these groups of disorders [23,110,111,228].

Efforts to address NCDs would play a vital synergistic role in advancing other SDGs [231]. It is hoped that the current project has contributed to this global effort. With the commitment of achieving universal health coverage (UHC) for all its citizens, Ethiopia is actively working to realize this goal by revising its essential health services package in 2019 [232]. In contrast to the previous version, the revised version was relatively responsive to interventions regarding NCDs [233]. However, only about a third of the expenses related to NCDs interventions are free and patient-side expenses could still be substantial [232]. Identifying population subgroups who cannot afford to cover their expenses and who are at increased risk of NCDs-ascribed mortality may effectively facilitate improving the efficiency and focus of the efforts to achieve UHC. For instance, poorer households are particularly vulnerable to these financial constraints, often experiencing the worst effects and cost-related medication non-adherence was higher for women in low income countries [234,235]. Although it has been evident that socio-economically disadvantaged adults had increased risk of mortality from NCDs [163,169,172], this has not been supplemented by data from the local context. In this regard, our study has an important contribution to make by identifying adult groups at increased risk of dying from NCDs who should be eligible for social protection interventions to be implemented alongside UHC [236]. Moreover, this study reveals the need for targeted nutritional screening and support for lactating mothers and their young dyads living in NCD-affected households, although addressing other examined determinants remains important.

Without appropriate action and appropriate optimization of limited resources, adult mortality caused by NCDs would inevitably increase, while communicable diseases and other health problems remain the prevailing public health problems. This requires understanding the burden of NCDs and associated household-level impacts [237]. It is clear that combating NCDs with evidence-based preventive and therapeutic interventions is of utmost importance. To this end, the role of evidence from systematically collected data, especially mortality information, is tremendously important for NCD-related health policy planning and priority setting [238]. However, NCD evidence based on population-based longitudinal data has been scarce in the study region. To the knowledge of the authors, information on social determinants of adult death from NCDs has not been well investigated in Ethiopia, and whether adult deaths from chronic diseases are linked to maternal and child malnutrition has not yet been studied. Focusing on this hitherto unexplored research theme, the current project is poised to fill a critical gap in the literature by 1) providing evidence on the burden and social determinants of adult mortality from NCDs and 2) offering evidence on the association of adult mortality from

chronic diseases with nutritional status of lactating mothers and their young children using KA-HDSS data. Furthermore, the results of this thesis have the potential to guide better implementation of future research efforts by taking into account the strengths and limitations of the current project (Chapter 6). This research work could also inspire researchers from different backgrounds to come together and shed more light on the link between adult mortality and nutritional wellbeing of household members, which in turn can enhance a more holistic understanding of this overlooked research topic.

1.4 Research hypotheses

This dissertation has tested the following research hypotheses.

1. Social determinants, such as educational status and household wealth status, are associated with increased hazard of adult mortality from NCDs.
2. Maternal undernutrition is higher for mothers living in households that experienced adult death from chronic diseases, as compared to those living in the households that experienced no adult death or adult death from all other causes of death.
3. Undernutrition among children of complementary feeding age (6 to 23 months) is higher for those living in households that experienced adult death from chronic diseases, as compared to those living in the households that experienced no adult death or adult death from all other causes.

1.5 Objectives of the study

- To investigate the burden and social determinants of NCDs-attributed adult mortality in KA-DSS population between 2009 to 2015 (Paper 1).
- To assess the level of undernutrition among lactating mothers and its association with adult mortality from chronic diseases in KA-DSS (Paper 2).
- To examine the prevalence of undernutrition among children of complementary feeding age (6 to 23 months) and its association with adult mortality from chronic diseases in KA-DSS (Paper 3).

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Chapter 2: General methodology

2.1 Study area and setting

The role of data for monitoring progress of nationally and internationally agreed goals, evidence-based decision making and sound policy formulation is enormous [1,2]. One acknowledged source of such data is civil registration and vital statistics (CRVS) [3]. However, no CRVS system was present in Ethiopia until it was officially issued in August 2012, and enforced legally in mid-2016 [4]. The responsible office still has several challenges- including poor institutional capacity, lack of resources and low public awareness of the benefits of CRVS [5]. Because of lack of complete CRVS and strong electronic health management information system, there has been chronic unmet need for data in the health sector. With the aim of minimizing this deficit to some extent and providing locally generated epi-demographic data, Health and Demographic Surveillance System (HDSS) sites were established, year of establishment varies from site to site, to provide information on core vital events: birth, death, and in- and out-migration [6,7]. In addition, data on pregnancy status and pregnancy outcomes, marital status changes, and cause of death for deceased cases are also collected on a continuous basis (Figure 2).

This thesis used data from Kilte Awlaelo- Health and Demographic Surveillance System (KA-HDSS), a community-based longitudinal study project located in Eastern Zone of Tigray regional state (Figure 1). It lies 835 kilometers north of the capital city of Ethiopia, Addis Ababa. The Federal Republic of Ethiopia has four administrative levels; and mentioned in descending hierarchical order are *Region*, *Zone*, *Wereda*, and *Kebelle*. Kebelle, the smallest and the lowest level administrative unit, is estimated to have an average of 5,000 to 6,000 population. With a total of 9 rural Kebelles from Kilte-Awlaleo and Atsbi-Wemberta Weredas and 1 urban Kebelle from Wukro town, KA-HDSS was established in Eastern Zone of Tigray region and has been generating data since September 2009 (Figure 1). At baseline (in 2009), KA-HDSS defined 14, 453 households with a total of 66, 438 residents living in these households. Most recently, it has expanded to include more than 113, 000 individuals [8].

This surveillance site is the only project that can provide longitudinal epi-demographic, socio-economic, housing and agricultural data in Tigray since September 2009. It is affiliated with Mekelle University, College of Health Sciences. Its central office (mainly comprising research members, a data manager, record officers and data clerks led by the project director) is home-based at Ayder college of Health Sciences, and its field office (composed of enumerators, field supervisors led by the field coordinator) is in Wukro town of Kilte Awlaelo Wereda. KA-HDSS is a member of both the intra-country surveillance sites and the International Network for the Demographic Evaluation of Populations and Their Health (INDEPTH) network [9].

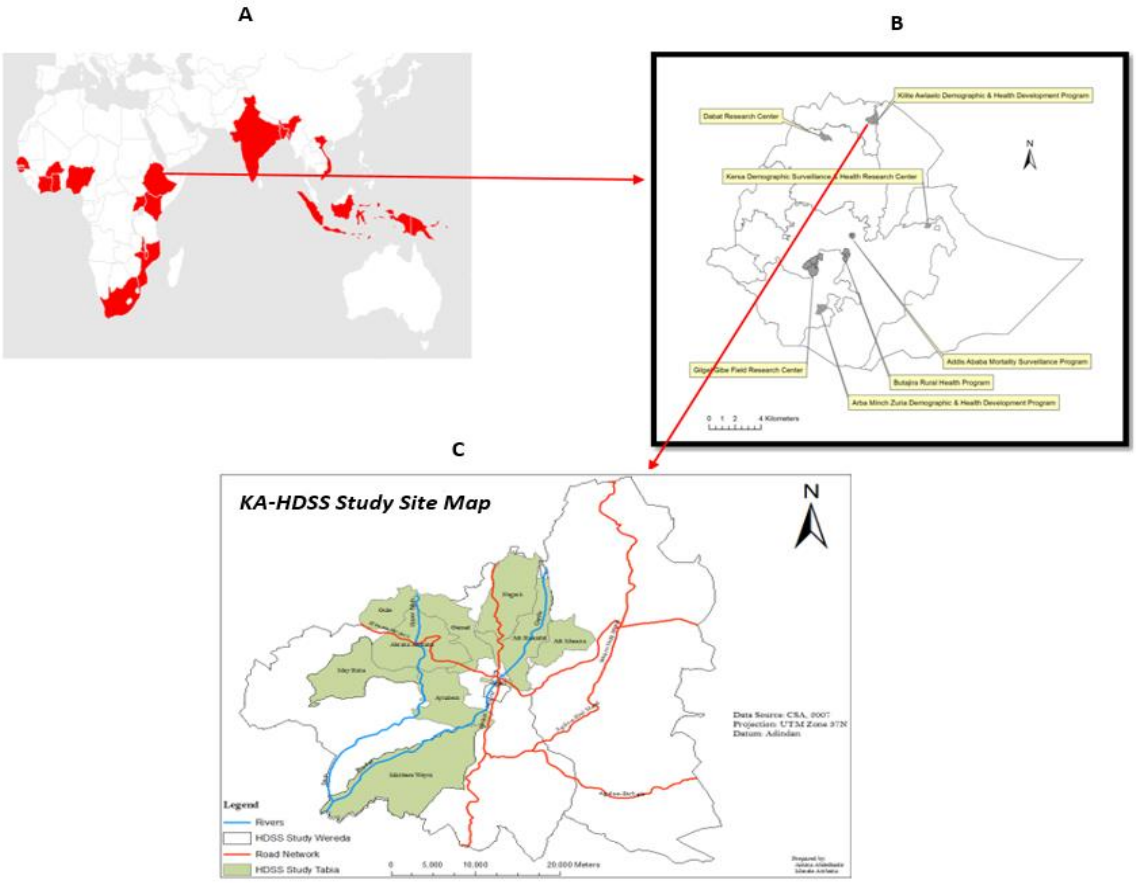

Figure 1C. Location of study site (Source: KA-HDSS)

(Figure 1A. Location of Ethiopia and INDEPTH Network member HDSS sites, accessed from http://www.indepth-network.org/member-centres; Figure 1B. Location of HDSS sites, including Addis Ababa Mortality Surveillance Program, in Ethiopia[10]; Figure 1C, location of KA-HDSS)

The author of this thesis, a research member of the surveillance site from September 2012 to October 2015, was intensively involved with all aspects of the KA-HDSS tasks. Together with his colleagues, he actively worked on planning and implementation of census updates and surveys, providing supportive field supervision, designing research tools, cleaning data and preparing reports, and delivering trainings. Moreover, he was involved in the dissemination of results to different stakeholders, participation in annual nationwide HDSS data pooling and analysis workshops, authorship and approval of critically reviewed manuscripts, and management aspects of the surveillance project.

Photo 1. Research team members delivering training to KA-HDSS colleagues in Kilte Awlaelo town

Source: KA-HDSS

Photo 2. KA-HDSS: Central office and a part of its site while the field coordinator was going for a supervision (top right) and a data collector was interviewing a mother (bottom right)

2.2 Study period and population

For the first study (Chapter 3), the observation period ran from 11 September 2009 to 26 April 2015, and the study population was made up of all adults residing in KA-HDSS at the time. For both the second and third studies, the nutrition and baseline recensus survey data were collected during July 2015 to December 2015. All lactating mothers aged 18 years and above who gave their informed consent for participation in the study, and who were residing in KA-HDSS were the study population for the second study (Chapter 4), whereas all

infants and young children (aged 6 to 23 months) born from those mothers were the study participants for the third study (Chapter 5).

2.3 Study design

In line with KA-HDSS's design, community-based dynamic (open) cohort design was used for the first paper, which included in chapter 3. For both the first and the second studies, cross-sectional study design was used to collect baseline nutrition and dense recensus data. Later, the survey datasets were merged with the longitudinal data to assess the association of chronic diseases attributed adult mortality with burden of undernutrition among lactating mothers and their infants and young children. Figure 2 shows a summary of the study design and period.

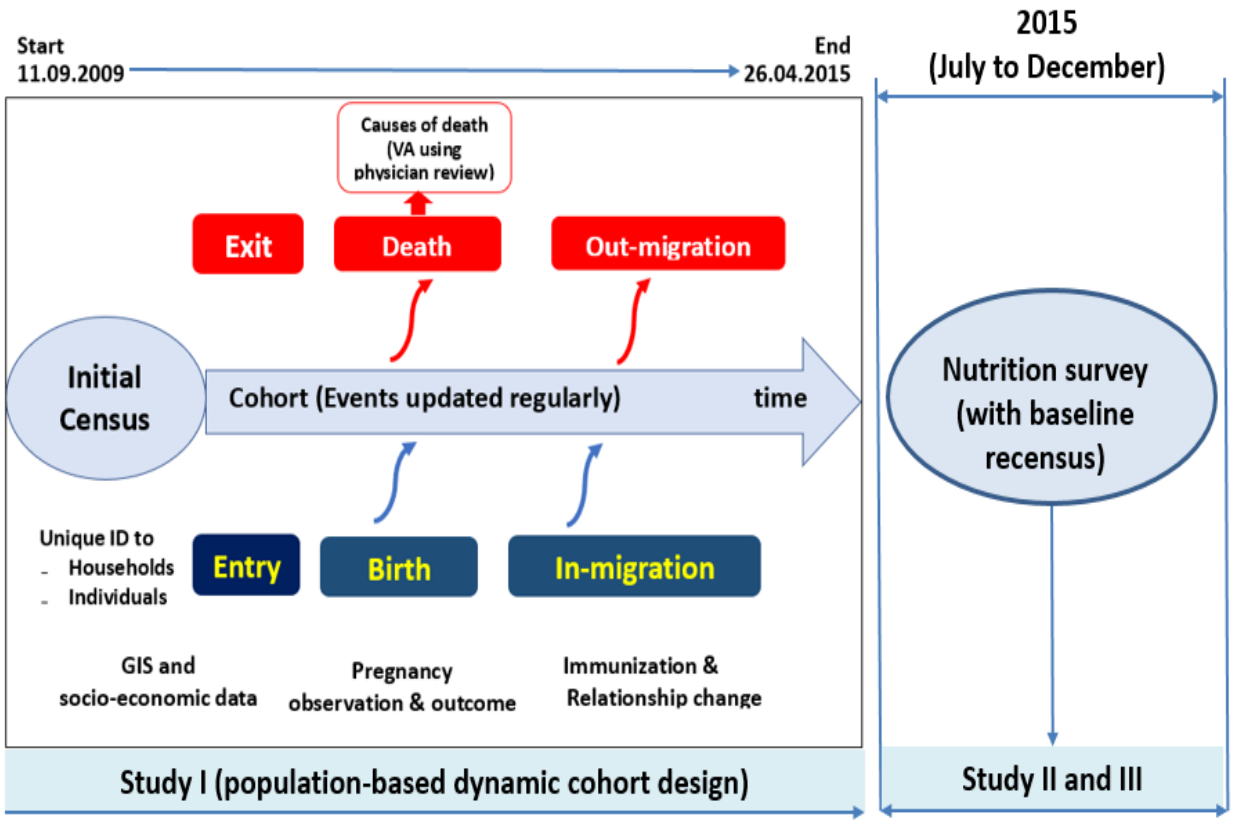

Figure 2. Study design and period, diagrammatic representation adapted from INDEPTH Network

2.4 Data collection and data quality control

In KA-HDSS, mortality is one of the core outcome of interest. The focus of the first paper (Chapter 3) is related to adult mortality, and occurrence of mortality events (updated biannually) was continually monitored and recorded by full-time data collectors of the surveillance site. Data on causes of deaths were collected by full time verbal autopsy interviewers using verbal autopsy questionnaires. The most likely causes of death were

determined using the physician review method. The baseline nutrition and recensus surveys were also collected by these fulltime project data collectors. Mid upper-arm circumference (MUAC) was used to measure nutritional status of lactating mothers and their complementary feeding (6 to -23 month) children. Child dietary diversity score was measured using a 24-hour dietary recall method.

The data underlying this study are of high quality. The experienced enumerators were at least high-school-completed residents of the surveillance population. They were thoroughly trained and were familiar with the standardized KA-HDSS data collection tools and ethical standards therein, including the nutrition survey questionnaire. A one-week long refresher training was given to the data collectors every six month, before each update enumeration cycle. The research team members of the surveillance site provided frequent supportive supervisions to the field data collectors in addition to the strict supervision made by the field supervisors and field coordinator. The data reconciliation process was also highly rigorous when implausible values were identified by the data clerks or data manager during data entry, or by the research team during cleaning and analysis.

2.5 Ethical consideration

KA-HDSS was ethically approved by the Ministry of Science and Technology with ethical approval identification number IERC 0030. Additional ethical approvals were also given by the Health Research Ethics Review Committee (HRERC) of College of Health Sciences in Mekelle University and also endorsed by CDC-Ethiopia.

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Chapter 3: Social determinants of adult mortality from non-communicable diseases in northern Ethiopia, 2009-2015: Evidence from health and demographic surveillance site

PLOS ONE

RESEARCH ARTICLE

Social determinants of adult mortality from non-communicable diseases in northern Ethiopia, 2009-2015: Evidence from health and demographic surveillance site

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Data Availability Statement: The dataset of this study was extracted from an ongoing surveillance research named Kilte Awlaelo-Health and Demographic Surveillance Site (KA-HDSS) where the principal investigator is a research member of the study. The dataset underlying this research, which also contains detailed sensitive information such as the household location (as measured by GPS) of deceased individuals and their causes of death, is exclusively a property of KA-HDSS. In

Abstract

Introduction

In developing countries, mortality and disability from non-communicable diseases (NCDs) is rising considerably. The effect of social determinants of NCDs-attributed mortality, from the context of developing countries, is poorly understood. This study examines the burden and socio-economic determinants of adult mortality attributed to NCDs in eastern Tigray, Ethiopia.

Methods

We followed 45,982 adults implementing a community based dynamic cohort design recording mortality events from September 2009 to April 2015. A physician review based Verbal autopsy was used to identify the most probable causes of death. Multivariable Cox proportional hazards regression was performed to identify social determinants of NCD mortality.

Results

Across the 193,758.7 person-years, we recorded 1,091 adult deaths. Compared to communicable diseases, NCDs accounted for a slightly higher proportion of adult deaths; 33% vs 34.5% respectively. The incidence density rate (IDR) of NCD attributed mortality was 194.1 deaths (IDR = 194.1; 95% CI = 175.4, 214.7) per 100,000 person-years. One hundred fifty-seven (41.8%), 68 (18.1%) and 34 (9%) of the 376 NCD deaths were due to cardiovascular disease, cancer and renal failure, respectively. In the multivariable analysis, age per 5-year increase (HR = 1.35; 95% CI: 1.30, 1.41), and extended family and non-family household members (HR = 2.86; 95% CI: 2.05, 3.98) compared to household heads were associated

addition to the sensitive nature of the data, sharing this dataset publicly can deter other ongoing researches run by the research site. Due to these conditions, the dataset will not be shared publicly. However, all interested researchers can access to the underlying data by sending an e-mail request to the data holder, Semaw Ferede Abera, through semawfer@yahoo.com.

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with a significantly increased hazard of NCD mortality. Although the difference was not statistically significant, compared to poor adults, those who were wealthy had a 15% (HR = 0.85; 95% CI: 0.65, 1.11) lower hazard of mortality from NCDs. On the other hand, literate adults (HR = 0.35; 95% CI: 0.13, 0.9) had a significantly decreased hazard of NCD attributed mortality compared to those adults who were unable to read and write. The effect of literacy was modified by age and its effect reduced by 18% for every 5-year increase of age among literate adults.

Conclusion

In summary, the study indicates that double mortality burden from both NCDs and communicable diseases was evident in northern rural Ethiopia. Public health intervention measures that prioritise disadvantaged NCD patients such as those who are unable to read and write, the elders, the extended family and non-family household co-residents could significantly reduce NCD mortality among the adult population.

Introduction

Non-communicable diseases (NCDs) are medical conditions or diseases that are, by definition, non-infectious and non-transmissible between people [1]. Major NCDs include cardiovascular diseases, cancer, chronic respiratory diseases, diabetes, rheumatologic diseases and mental disorders, which contribute to about 80% of all NCD-attributed deaths [1–4].

Studies have demonstrated that the burden and sequelae of NCDs are increasing considerably worldwide [5–10], and that NCDs constitute a quadruple burden in developing countries in addition to communicable, neonato-maternal and nutritional diseases, injuries and road traffic accidents [11–13]. NCDs account for the largest share of mortality globally [14, 15], and 82.4% of the total deaths occur in low and middle income countries [15].

In recent years, global attention and the commitment to address NCDs has grown rapidly. Sustainable Development Goal 3 (SDG 3) target 3.4 [16] of the WHO states "By 2030, reduce by one third premature mortality from NCDs through prevention and treatment and promote mental health and well-being" to ensure that global development is sustanable [17–19]. If health policies are not shaped by reliable evidence for the purpose of optimizing disease interventions, the achievement of this target will likely be an ambition particualrly in low and middle income countries (LMICs) due to the fact that health sectors in LMICs are also strained by the existence of other resource-intensive competing priorities [13]. In 2012, a study conducted by Weldearegawi et al. in northern Ethiopia, from the same study area, indicated that NCDs accounted for 28.6% of the total deaths [20]. However, the aim of the study was merely descriptive and did not attempt to inferentially identify the factors associated with NCD-attributed mortality.

Health or illness status of individuals are determined by social structures through micro level processes, and the quality of these social structures are in turn shaped by macro level processes like the political ideology of governments [21]. Nowadays, effective reduction in population and individual level health inequality should be viewed from the philosophical and holistic perspective of integrating interventions that could address social and economic inequalities between and within population [21–25].

According to the World Health Organization (WHO)'s Commission on Social Determinants of Health analytical framework for priority public health conditions, social and economic factors have a vital public health importance. These factors influence exposure to several downstream factors, vulnerability to disease development, utilization of health care services, health outcomes and consequences [26].

Several studies have consistently showed that attaining higher education is observed as the strongest indicator of social determinant of good health [27–30]. Low educational attainment was reported to predict increased risk for and mortality from NCDs [31–38], low longevity [39, 40], and poor health service utilization [40, 41]. The consistently strong association of education with the risk of developing NCDs and dying from NCDs, even after controlling the effect of lifestyle factors, may indicate its causal relationship [28, 31, 33]. In one large cohort study, having a less educated partner was associated with higher risk of mortality [42]. On the other hand, studies have shown that unemployed individuals had higher NCD risk factor profile [43], differential odds of developing and dying from some NCDs and all-cause mortality [44–46], and these effects remained persistent after adjusting for the use of preventive medications, clinical and lifestyle factors. In addition, employment insecurity was also associated with a decrease in preventive health service utilization [47].

The relationship of income inequality and poor health was extensively studied [48, 49]. Higher risks of morbidity and mortality from NCDs were also associated with income status [50–53]. However, the adverse effect of income inequality on health becomes more pronounced if the inequality exists at national level than in small areas [54]. In the literature, three main hypotheses (social capital, status anxiety and neo-materialist hypotheses) are widely mentioned to explain the mechanisms income inequality follows to result in poor health [21, 49]. Some other studies, however, showed that wealth status may not be an important factor in relation to mortality for some NCDs like acute myocardial infarction [55]. Several research works have also established that household composition and structure, marital status, age and ethnicity could be germane factors in epidemiological investigations focusing on mortality [7, 32, 40, 56–60]. In general, the mechanisms of the socio-economic and demographic determinants of NCD attributed mortality are shown in the conceptual framework customized from the WHO's Commission on Social Determinants of Health analytical framework for priority public health conditions [26], as described in the supplementary document (S1 Fig).

Evidence on social determinants of NCD attributed mortality is essential for evidence based public health actions against NCDs. Despite such importance, to the best of our knowledge, there has been no detailed systematic quantification of the effect of such factors on the risk of mortality from NCDs using population-based prospective data in Ethiopia. Consequently, our understanding of how socio-demographic and economic determinants drive NCD-attributed mortality is very limited.

Bearing these factors in mind, the present paper presents the adult mortality burden due to NCDs and its socio-demographic and economic determinants in northern Ethiopia using population-based data from Kilte Awlaelo-Health and Demographic Surveillance Site (KA-HDSS). A description of the broad and specific causes of death by the study population's characteristics is also provided.

Methods

Study setting

Complete civil registration and vital statistics (CRVS) systems provide essential information for public health policy and prevention [61, 62]. Nevertheless, complete CVRS is absent in sub-Saharan Africa including Ethiopia. In countries where CVRS is absent, an alternative

effective way of generating reliable and accurate vital events data, although not fully representative, could be made through health and demographic surveillance systems (HDSS)[62]. HDSS collect data on vital events, causes of death, and socio-economic data based on a geographically defined population ranging from tens of thousands to around a quarter of million [63]. Such longitudinal research systems have been implemented in Africa, Asia and Oceania and have been jointly organized by a cross-continental organization called The International Network of field sites with continuous Demographic Evaluation of Populations and Their Health in developing countries (INDEPTH Network) [63]. Under this research network, there are over 3.8 million surveillance population, and KA-HDSS is one of the contributing member sites of this organization [64].

Our current study used data from KA-HDSS, which is located 835 kilometres (KMs) north of Addis Ababa, the capital city of Ethiopia. KA-HDSS was established in 2009 home-based under the School of Public Health in Mekelle University. It is led by the university's Research and Community Services Directorate and College of Health Sciences with the central research motivation of generating population-based health and demographic-related longitudinal information to support evidence-based decision making. It started its surveillance by enumerating and recording data from 66,438 individuals who were living in 14,453 households. These households were located in 10 kebelles, and only one of the 10 kebelles is urban. According to the Ethiopian government administrative structure, kebelles are the smallest administrative units with an average population of 5,000–6,000.

KA-HDSS collects data on vital events (birth, death, and migration in and out), pregnancy outcome, causes of death and marital status, which change on a continuous basis. Moreover, update data are collected biannually from the entire population and accordingly the surveillance database is updated twice a year. The data collectors are fulltime workers, from among the community, who are intensively trained on the different data collection tools, skills and preparations for interviewing by the research team academics. In addition, refresher training of a similar content is delivered to the data collectors twice a year before the start of each update. Generally, the study area is characterised by low fertility and mortality [20, 60] and high external outmigration of adults to the Arab world.

Verbal autopsy data

Information on mortality and its causes is critical to public health planning and action. Such public health information is non-existent in developing countries where complete vital registration is not available and most deaths occur at home [65]. Collecting cause-specific mortality information using the verbal autopsy (VA) method is the most feasible, comprehensive and appropriate approach to narrow mortality information gaps in resource-limited settings [66–68]. VA is a research tool used to assign probable causes of death by interviewing a close caregiver about the signs and symptoms of the deceased's terminal illness [68].

In KA-HDSS, mortality data are collected from the closest adult care givers who took care of the deceased individuals, within 45–55 days after each death event, considering the mourning period of the community, by trained high school completed residents. The surveillance research project collects VA data using standard VA questionnaires for neonates, post-neonates and children and adults [69]. The current study used the VA data set for adults, whose age was greater than 15 years at the time of death, collected from September 2009 to April 2015.

We applied the physician review method to identify the most probable cause of death. The reviewing physicians are trained for the use of International Classification of Diseases (ICD-10) [69]. The collected questionnaire-based VA data were submitted to two blinded physicians

for their independent review to assign the probable cause of death. If the two physicians concluded a specific cause of death, say tuberculosis (TB), then the cause of death was considered to be TB. If the two blinded physicians assigned two different causes of death, then a third blinded physician was invited to review and assign a cause of death which served as a tie breaker. If the third physician assigned a cause of death different from assigned causes by either of the first two physicians, the cause of death was classified as "indeterminate".

In this study, premature mortality from NCDs was defined as the relative proportion of NCD death in the 15–64 age group. The cut-off of age 65 years was used in accordance with the estimated life expectancy for Ethiopia [15]. A similar definition was also used by Streatfield et al. [58]. Moreover, in each household, one person was defined as the head of a given household. In the context of the study area, the husband is usually the head of the household. If the husband is dead, then the husband's wife, the mother, is usually the head of the household. The relationship of household members to the household head can be either close or extended family members or non-family member. Geographic locations of households, derived from the altitudinal measurements obtained using GPS, were classified as located in midland or highland.

The WHO defines social determinants of health as "The conditions in which people are born, grow, work, live, and age, and the wider set of forces and systems shaping the conditions of daily life. These forces and systems include economic policies and systems, development agendas, social norms, social policies and political systems" [70]. In this study, social determinants such as education, occupation, marital status, residence, geographic location, wealth index, intra-household relationships, household headship, sex of household head, health seeking practice during terminal illness were considered. The effects of demographic factors (age and sex) were also examined in the analysis. Data on these variables were collected using KA-HDSS data collection tools.

Data management and statistical analysis

The dataset was cleaned and checked for the plausibility of the data values. Principal component analysis (PCA) was used to generate wealth index variable reproducing the principles and methods of Demographic and Health Survey (DHS) [71]. The wealth index variable was constructed from the attributes of goods and resources owned by the households (for instance, ownership of radio/tape), construction material and characteristics of the houses (types of floor, roof and wall), and access to resources and services (like access to electricity, land ownership, size of land owned as measured in hectare, drinking water sources, toilet availability, functionality and type). Indicator variables, coded as 0 for "No" or 1 for "Yes", were computed from each category of the included categorical variables before PCA was applied. However, the dummied variables that showed no variation were excluded from the analysis. Socio-economic data were not collected for the households which were established after the start of the surveillance because such data should be collected at baseline and every 5 year from the baseline. Consequently, the wealth status of the adult cohort members (18.9%) who lived in those households was unknown. The main outcome was time to death from NCDs and the incidence density was calculated by dividing the number of new NCD attributed mortality events by the person-years of all observations that were at risk of dying from NCDs. Causes of death were classified using the international disease classification system [69]. Accordingly, NCD related mortality includes all adult deaths caused by neoplasms, nutritional and endocrine disorders, diseases of the circulatory system, respiratory disorders, gastrointestinal disorders, renal disorders, mental and nervous system disorders which have VA codes of VA-02, VA-03, VA-04, VA-05, VA-06, VA-07, and VA-08, respectively. Additionally, VA-01 and VA-11 were classified

as communicable diseases and external causes of death, respectively. All deaths which had the code VA-09 were classified as pregnancy-, childbirth- and puerperium-related deaths.

The starting point of the surveillance project was 11 September 2009. Entry of new members into the surveillance project was possible by enumeration, external immigration or birth. Corresponding dates for these initiating events were accurately recorded. Moreover, the end point of this study was 26 April 2015. Exit of residents from the surveillance project was possible by outmigration and death. Entries of new members into the cohort population or exits of existing members could happen at any time. So, epidemiologically, this study followed a community based dynamic cohort study design. In such design contexts, the length of the follow-up time contributed by each adult could not be the same due to different enrolment time, censoring or competing interests [72], but the time contribution by each cohort member, measured per person-unit time, should be taken into consideration and must be accurately quantified. The 376 NCD-attributed deaths, of the total 45, 982 cohort members, were events of our interest whereas outmigration and mortality from non-NCD causes were treated as censored cases. The exact dates for these censored events were also recorded. Moreover, all of the observed cases that were alive by 26 April 2015 were also considered as administratively censored cases. More than a quarter, 28.7%, of the adults were externally out-migrated, and these adult residents were loss to follow-up cases.

Cox's proportional hazards regression model was used to analyse the survival-type data thatinclude censored observations [72, 73]. A Log rank test was used to assess the equality of the survival patterns. The incidence density rates of NCD-attributed mortality and 95% confidence intervals were calculated. A key assumption of the Cox proportional hazards regression model is the proportional hazards assumption which claims that the effect of a given a covariate, quantified in hazard ratio, does not change over time [73–75]. Adherence to this assumption was checked using the plots of scaled and smoothed Schoenfeld residuals with the reference value of zero slope along the survival time [74,75]. Hence, each fitted covariate had a plot approximately parallel to the reference line, a line that depicted a zero slope with no significant departure, proving that the proportional hazards assumption of the model is fulfilled. In order to build a more pragmatic model with improved inference, interaction effects were also checked by forming a set of biologically plausible interaction terms from the main effects in the model. The significance of each separate interaction was assessed by adding each interaction term to the main effects model and using the partial likelihood ratio test [73]. Assessment of the problem of multicollinearity was checked at variance inflation factor (VIF) of greater than 10 and multicollinear variables were dropped from fitting into the model [76].

All of the variables with a p-value less than 0.25 in the univariate analysis were eligible for inclusion into the multivariable Cox proportional hazards regression [73]. Adjusted hazards ratio (HR) was used to estimate the degree of independent effect of each fitted predictor on the time to NCD attributed death. We also performed a sensitivity analysis to assess the impact of lost to follow-up on our estimates and generally, we found no difference in the results (S1 Table). All the analyses were performed in stata 13.0.

Ethical statement

The Ethiopian Science and Technology Agency has ethically approved KA-HDSS with the identification number IERC-0030. Moreover, an ethical approval of the consent procedure was also obtained from the Health Research Ethics Review Committee (HRERC) in Mekelle University. Since a large proportion of the study population had no formal education, verbal consent was preferred to appropriately inform the interviewee. In addition, the VA data collectors were trained on how to implement the verbal consent and they collected the data from the

primary caregivers of the deceased individuals only if they consented for the interview. KA-HDSS data is also highly protected to avoid potential access by third parties. For this purpose, the target dataset was extracted de-identifying personal identifiers to make that the dataset anonymous and maintain the confidentiality of the study participants.

Results

Characteristics of the study population and incidence of NCD mortality

This study was based on 45,982 adult KA-HDSS cohort members who contributed 193,758.5 person-years. The population resided in 16,247 households and the mean number of persons per household, including children, was 4. More than four-fifths (n = 37,549; 81.7%), and about three quarters, (n = 32,962; 74.5%), of the population were living in rural residences and midland geographic locations, respectively.

The median age was 32 years, with an interquartile range of 24 years. The age-dependency ratio was 14 per 100 working-age population. Although 53% of the external out-migrants were female, the female population was 3.6% higher than the male population.

As shown in Table 1, about half of the population (n = 22,928; 49.9%) were unable to read and write and more than one third (n = 17,701; 38.5%) were unemployed. More than a third (n = 16,247; 35.4%) and a quarter (n = 13, 350; 29%) of the participants were heads of households and economically poor, respectively (Table 1).

Across 193,758.7 person-years, the incidence density rate (IDR) of NCD mortality was 194 deaths (IDR = 194.1; 95% CI = 175.4, 214.7) per 100,000 person-years. The IDR of NCD mortality increased as age increased. The rate was 937 NCD deaths per 100,000 person-years for those who were 65 years and above. The IDR ratio of NCD mortality between 15–64 years to over 64 years was 1:12. On the other hand, the proportion of NCD deaths in the 15–64 years age group, which is interpreted as premature mortality from NCD, was 32.3%. There was a differential occurrence of NCD attributed mortality IDR with most of the other socio-demographic characteristics (Table 1).

Mortality rate of cancer, 37.4 vs. 32.1 deaths per 100,000 person-years, and cardiovascular diseases (CVDs), 83.6 vs. 78.7 deaths per 100,000 person-years, was slightly higher for males compared to females. Contrary to this, the mortality rate of renal failure was higher for females compared to males, 19 vs. 14 deaths per 100,000 person-years, respectively.

Broad causes of death

During the surveillance period, a total of 1,091 adult deaths were observed. About four-fifths (n = 872; 79.9%) of those died at home. Moreover, causes of death were assigned for 908 (83.2%) deaths. Of the total deceased cases, NCDs accounted for more than one-third (n = 376; 34.5%) of all deaths. Comparable to NCDs, communicable diseases caused 360 (33%) deaths. The third leading causes of death were deaths from external causes (n = 126; 11.5%) (Table 2).

Nearly two-thirds of the NCD attributed deaths were among those who were 65 years and above. Observably, deaths from communicable diseases were higher by about 4% for females, but about three-fourths of the deaths from external causes occurred among males. In addition, nearly three-fourths of the undetermined causes and 87.2% of the unspecified causes were among those age 65 years and above (Table 2).

Specific NCD types as causes of death

Of the 376 NCD deaths, cerebrovascular event, cancer and renal failure were the leading causes of adult death, accounting for 83 (22.1%), 68 (18.1%) and 34 (9%) deaths, respectively.

Table 1. Socio-demographic, economic and geographic characteristics and NCD deaths per 100,000 person-years of adult KA-HDSS cohort members from September 2009 to April 2015, northern Ethiopia (n = 45,982; 376 NCD deaths).

Characteristics	Frequency by sex		Total, n (%)	person-years	NCDs attributed deaths	IDR (95% CI)
	Female	Male				
Age						
15–49 years	18,747	15,944	34,691 (75.4)	138,249.8	63	45.6 (35.6, 58.3)
50–64 years	3,163	2,604	5,767 (12.5)	29,251.6	67	229.1 (180.3, 291)
≥65 years	2,715	2,809	5,524 (12.0)	26,257.3	246	936.9 (826.8, 1061.6)
Marital status						
Married	9,728	11,054	20,782 (45.2)	81,081.8	53	65. 4 (49.9, 85.6)
Single	10,354	9,552	19,906 (43.3)	91,207.8	187	205 (177.7, 236.6)
Widowed	2,214	409	2,623 (5.7)	9,732.2	28	287.7 (198.7, 416.7)
Divorced	2,320	334	2,654 (5.8)	11,694.0	104	889.3 (733.8, 1077.8)
Education						
Unable to read and write	13,566	9,362	22,928 (49.9)	107,829.8	312	289.4 (259, 323.3)
Primary	6,773	7,298	14,071 (30.6)	57,578.7	44	76.4 (56.9, 102.7)
Secondary and above	4,286	4,697	8,983 (19.5)	28,350.1	20	70. 6 (45.5, 109.4)
Occupation						
Unemployed	8,110	9,591	17,701 (38.5)	57,258.9	19	33.2 (21.2, 52)
Farmer	3,515	7,880	11,395 (24.8)	55,555.0	247	444.6 (392.5, 503.7)
Government employee and Others	13,000	3,886	16,886 (36.7)	80,944.9	110	135.9 (112.7, 163.8)
Residence						
Rural	19,509	18,040	37,549 (81.7)	167,039.8	331	198.2 (177.9, 220.7)
Urban	5,116	3,317	8,433 (18.3)	26,718.9	45	168.4 (125.8, 225.6)
Wealth index						
Poor	7,494	5,856	13,350 (29.0)	57,273.7	109	190.3 (157.7, 229.6)
Medium	4,152	3,759	7,911 (17.2)	37,969.6	90	237 (192.8, 291.4)
Wealthy	7,855	8,166	16,021 (34.8)	78,188.2	146	186.7 (158.7, 219.6)
Unknown	5,124	3,576	8,700 (18.9)	20,327.2	31	152.5 (107.3, 216.9)
Relation to household head						
Head of household	5,972	10,275	16,247 (35.4)	69,699.5	237	340 (299.4, 386.2)
Wife/children	17,079	9,951	27, 030 (58.8)	115,365.6	66	57.2 (45, 72.8)
Extended and non- family members	1,565	1,115	2,680 (5.8)	8,622.5	68	788.6 (621.8, 1000.2)
Household headship						
No	18,653	11,082	29,735 (64.7)	124,059.2	139	112 (94.9, 132.3)
Yes	5,972	10,275	16,247 (35.3)	69,699.5	237	340 (299.4, 386.2)
Sex of household head						
Female	5,972	0	5,972 (36.8)	23,420.7	84	358.7 (289.6, 444.2)
Male	0	10,275	10,275 (63.2)	46,278.8	153	330.6 (282.2, 387.4)
Geographic location						
Midland	17,599	15,363	32,962 (74.5)	140,823.7	267	189.6 (168.2, 213.8)
Highland	6,016	5,252	11,268 (25.5)	50,330.5	107	212.6 (175.9, 257)
Total	24,625	21,357	45,982 (100)	193,758.7	376	194.1 (175.4, 214.7)

CI: Confidence interval, IDR: Incidence density rate, NCDs: Non-communicable diseases.

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Moreover, 6.9% and 6.6% of the total NCD deaths were shared by ischaemic heart disease and congestive heart failure, respectively. We also found that diabetes mellitus, epilepsy, hypertensive disease, chronic liver disease and Alzheimer's disease were the next top NCDs causing

Table 2. Broad causes of death, stratified by age and sex, among adult KA-HDSS cohort members from September 2009 to April 2015, northern Ethiopia.

Broad category of cause of deaths	Frequency by sex, n (%)		Frequency by age group, n (%)			Total, n (proportion; 95% CI)
	Female	Male	15–49 years	50–64 years	≥65 years	
Non-communicable diseases	182 (48.4)	194 (51.6)	63 (16.8)	67 (17.8)	246 (65.4)	376 (34.5; 31.7–37.2)
Communicable diseases	194 (53.9)	166 (46.1)	75 (20.8)	59 (16.4)	226 (62.8)	360 (33.0; 30.3–35.8)
External causes of death	34 (27.0)	92 (73.0)	67 (53.2)	15 (11.9)	44 (34.9)	126 (11.5; 9.8–13.6)
Unspecified causes of death	24 (61.5)	15 (38.5)	2 (5.1)	3 (7.7)	34 (87.2)	39 (3.6; 2.6–4.9)
Other causes (pregnancy, child birth and puerperium related causes)	7 (100)	0 (0.0)	7 (100.0)	0 (0.0)	0 (0.0)	7 (0.6; 0.3–1.3)
Undetermined causes	104 (56.8)	79 (43.2)	36 (19.7)	11 (6.0)	136 (74.3)	183 (16.8; 14.7–19.1)
Total deaths	544 (49.9)	547 (50.1)	248 (22.7)	155 (14.2)	688 (63.1)	1,091

CI: Confidence interval.

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high numbers of death in the KA-HDSS adult population (Fig 1). It is particularly important to mention that cardiovascular diseases (cerebrovascular event, ischaemic heart disease, congestive heart failure, hypertension and chronic rheumatic heart disease) accounted for 41.8% of all NCD-attributed mortality. Furthermore, gastrointestinal cancers contributed more than half (n = 37; 54.4%) of the deaths caused by all types of cancer. Of the total deaths due to all cancer types, for both men and women, nearly half of the deaths (n = 33; 48.5%)

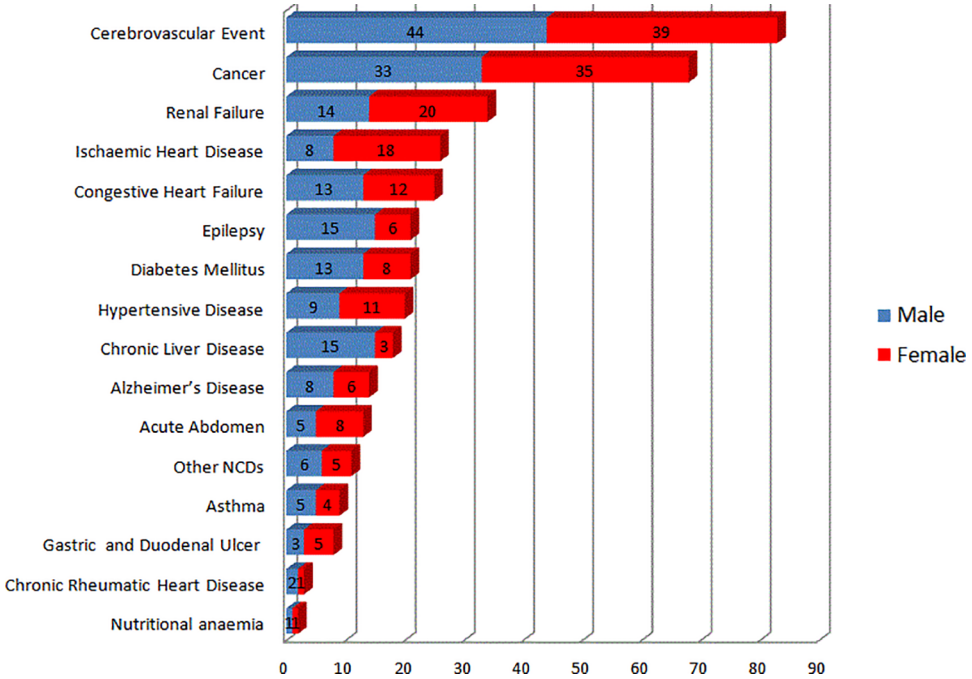

Fig 1. The absolute number of deaths by specific NCD types and sex among the adult KA-HDSS cohort members from September 2009 to April 2015, Tigray region, northern Ethiopia (n = 376).

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were caused by oesophageal cancer (22.1%), stomach cancer (13.2%), and malignant neoplasm of the large and small intestines (13.2%). Moreover, differential mortality of specific NCDs was observed by sex. Generally, listed according to their rank, chronic liver disease (83.3%), epilepsy (71.4%), diabetes mellitus (61.9%), Alzheimer's disease (57.1%), cerebrovascular events (53%) and congestive heart failure (52%) were more common causes of death among male adults, whereas renal failure, ischaemic heart disease (69.2%), gastric and duodenal ulcer (62.5%), renal failure (58%), hypertensive disease (55%) and cancer (51.5%) were more frequent causes of death among female adults (Fig 1).

Predictors of NCD attributed mortality

Age, sex, marital status, education, occupation, wealth index, relation to household head and the interaction of education with age were included in the multivariable Cox proportional hazards regression model. The variables residence and geographic location were not accounted for in the multivariable model because these two variables were not significant in the bivariate analysis. Sex of head of the household was also not fitted in to the model because it created a severe multicollinearity problem with the relation to household variable. Therefore, interpretation of the model was done considering the controlled effect of the remaining seven variables in addition to the interaction of age and education.

Age, education, relation to head of household and the interaction of education with age were significantly associated with NCD attributed mortality.

There was a 35% excess hazard of mortality from NCDs for every 5-year increase of age. The mortality hazard from NCDs was also significantly different by educational status. Compared to those who were unable to read and write, the hazard of NCD attributed mortality was 65% lower for those who were literate. However, the reduced NCD mortality for literate individuals was significantly modified by age in that the observed positive effect was reduced by 18% for every 5-year increase in the age of the cohort.

Another striking finding was that extended family and other non-family members, such as servants, had a 2.9 times higher hazard of NCD attributed mortality compared to their respective head of household (Table 3).

On the other hand, the hazard of mortality from NCDs was not significantly different according to the wealth index of adults. However, it was observed that individuals from medium and wealthy households had a 3% and 15% lower hazard of NCD mortality, respectively, compared to individuals from poor households. Similarly, there was not a statistically significant difference in the mortality hazard from NCD by sex, occupation and marital status (Table 3).

Discussion

Determining the mortality burden of NCDs was one of the main objectives of this study. We found that, out of the total cause ascertained deaths, NCDs accounted for a higher proportion of death (41.4%) in the predominantly rural community of northern Ethiopia.

The other primary objective of the study was to identify the socio-demographic and economic determinants of NCD mortality. In summary, age, education, relation to head of household and the interaction effect of education and age were the significant determinants of mortality from NCD. In contrast, there was no statistically different NCD mortality by sex, wealth index, occupation and marital status. However, the hazard of NCD mortality decreases with increasing wealth status.

One of our key findings is that the mortality burden from NCDs was slightly higher than infectious causes of death accounting for more than one-third of the total deaths. This clearly

Table 3. Predictors of NCD mortality among adult KA-HDSS cohort members from 11 September 2009 to 26 April 2015, northern Ethiopia (n = 45,982).

Variables	Crude HR (95% CI)	Adjusted HR (95% CI)
Age (for 5-year increase)	1.41 (1.37, 1.45)***	1.35 (1.30, 1.41)***
Sex		
Female	1.00	1.00
Male	1.21 (0.99, 1.48)	0.97 (0.73, 1.30)
Marital status		
Married	1.00	1.00
Single	3.19 (2.35, 4.33)**	0.8 (0.55, 1.19)
Widowed	4.44 (2.81, 7.01)**	0.94 (0.57, 1.54)
Divorced	13.81 (9.92, 19.23)**	1.03 (0.69, 1.53)
Education		
Unable to read and write	1.00	1.00
Literate	0.25 (0.19, 0.33)***	0.35 (0.13, 0.91)*
Occupation		
Unemployed	1.00	1.00
Farmer	13.7 (8.58, 21.82)***	1.3 (0.61, 2.80)
Others	4.14 (2.55, 6.74)***	0.63 (0.30, 1.29)
Residence		
Rural	1.00	
Urban	0.85 (0.62, 1.16)	
Wealth index		
Poor	1.00	1.00
Medium	1.25 (0.94, 1.65)	0.97 (0.73, 1.31)
Wealthy	0.98 (0.77, 1.26)	0.85 (0.65, 1.11)
Unknown	0.79 (0.53, 1.17)	1.08 (0.72, 1.62)
Relation to household head		
Head of household	1.00	1.00
Wife/children	0.17 (0.13, 0.22)***	1.23 (0.82, 1.84)
Extended family & other members	2.30 (1.76, 3.02)***	2.86 (2.05, 3.98)***
literate#age_5year		1.18 (1.10, 1.27)***
Household headship		
No	1.00	
Yes	3.06 (2.48, 3.77)***	
Sex of household head		
Female	1.00	
Male	0.92 (0.71, 1.20)	
Geographic location		
Midland	1.00	
Highland	1.12 (0.90, 1.4)	

CI: Confidence interval, HR: Hazard ratio.

*p<0.05.

** p<0.01.

*** p<0.001.

https://doi.org/10.1371/journal.pone.0188968.t003

indicates that the double mortality burden from both NCDs and communicable diseases is evident in the community. The proportion of mortality burden shared by NCDs, which falls between 31.7% and 37.3% at 95% CI, is higher than in previous studies from Ethiopia [20, 77–

79], Africa [80–82] and another cross-continental study conducted in similar research settings located in Africa and Asia [58]. The current finding is also higher than the 30% NCD mortality mentioned in the 2014 WHO mortality report for Ethiopia [83]. However, it is lower than the finding of 56.8% from the Global Burden of Disease (GBD) estimation for 2015 [84]. This study has illuminated the hidden consequences of NCDs, the most severe being mortality. It has uncovered that mortality burden of NCDs has slightly prevailed over communicable diseases or injuries and this substantiates the fact that epi-demographic transition [20, 85–87] is emerging in the community. One of the possible explanations for the slightly higher proportion of NCD-attributed mortality in our population could be due to the significant decline in communicable diseases increasing the life expectancy of Ethiopians. From 1990 to 2015, the age-standardised national annual percentage drop of communicable, neonato-maternal and nutritional diseases was 4.2% [84]. This decrease in communicable diseases could merely be a result of the functional relevance of the investment in public infrastructures such as public health centres particularly during the past decade [88, 89].

The 2015 World Health Statistics release indicated that life expectancy at birth of Ethiopians between 1990s and 2013 increased by about 20 years [15]. Similarly, according to the United Nations Development Report (UNDP), Ethiopia gained a life expectancy of 20.4 years between 1980 and 2014 [88]. Although lower than the above-mentioned results, a more recent global health study by Wang et.al showed that male and female Ethiopians gained a life expectancy of 7.6 and 10.7 years, respectively [90]. Generally, the results show a gain in life expectancy for Ethiopia although there exists variation in the estimated years of gain. Additionally, based on our data, the median age of the deceased individuals was 70 years with an IQR of 59.5–80 years compared to the median age of 31 years with an IQR of 23–46 years for the alive and migrated cohorts. Accordingly, it seems reasonable that we can think of increased life expectancy as one of the partially explaining demographic phenomenon for the comparably high NCD mortality observed in our population [87].

On the other hand, despite Ethiopia's reportedly significant achievement in economic growth, the country is still one of the poorest nations with a HDI of 0.442, which falls below the average HDI of 0.505 for countries in the low human development group, ranking 174 out of 188 countries [88]. Even though the Federal Ministry of Health (FMoH) has recently started to pay attention and respond to the emergence of NCDs [91], the large burden of communicable diseases, especially among younger age groups, seems to influence much of the operational focus of the ministry office. Moreover, patients' poor use and access to early diagnosis and treatment, aggravated by the poor health insurance coverage in the study area, may also have contributed to the high NCD attributed mortality. In addition to these factors, the high population-to-health workforce ratio and extremely low density of well-equipped hospitals to population could have exacerbated the mortality from NCDs [15, 41, 88]. Moreover, the healthcare-seeking practice of NCD patients might also be low, as revealed in Malawi [92], eventually leading to premature mortality. Another explanation for this is that only 14.4% of the NCD patients died at health facilities, which can further elucidate the fact that the healthcare services utilization of NCD patients might have been poor assuming death at health facilities, from the context of developing countries, as a proxy indicator of access to and utilization of healthcare services during a terminal illness [41].

In this study, CVDs, cancer and renal failure were the leading NCDs accounting for more than two-thirds, one-fifth and one-tenth of NCD-ascribed deaths respectively. This result is in line with earlier research findings from Ethiopia [20, 77, 79]. The epidemiological fact behind the disproportionate observation of renal failure and ischaemic heart disease attributed deaths among females and oesophageal cancer and chronic liver disease among males is worth investigating. However, our observation of higher occurrence of oesophageal cancer and chronic

liver disease as causes of death among males could be related to the higher alcohol consumption among the male population, similar to the study from Sri Lanka [93]. Furthermore, in this study, a large share of the NCD deaths were caused by CVDs. This is consistent with other studies which demonstrated that CVDs are the single most important cause of mortality and disability in low and middle-income countries [14, 18, 80, 94–97].

In this study, a 5-year increase in age was associated with 35% higher hazard of mortality from NCDs. In 2015, aging was reported to be the most important factor for the increased occurrence of NCD morbidity and mortality [7]. This might be justified by the fact that NCD risk factors are likely to accumulate with increasing age [58, 98].

Our study provides strong insight into the inverse effect of education on NCD-attributed mortality. Adjusting the effects of the fitted covariates, adults who were unable to read and write were at a higher hazard of mortality from NCDs compared to those who were literate. Our finding substantiates several previous prospective study findings which demonstrated that lower educational attainment is associated with higher cardiovascular, cancer and other NCD-related mortality [31–33, 38, 99–101]. The significant effect of education on reducing NCD attributed mortality may partly be explained by lower healthcare utilisation and disparity in the severity of disease prognosis among the non-literate group [33, 41]. Moreover, education could promote the adoption of healthy behaviours more easily and the avoidance of unhealthy habits which could finally avert mortality from NCDs such as diabetes mellitus and enhance healthcare-seeking behaviour during terminal illness [32, 102]. Although our observation of a strong association of literacy with reduction of NCD mortality is not adjusted for the established lifestyle NCD risk factors, in two largest prospective cohort studies, that had 303,036 and 39, 228 study participants, it was reported that lower education remained a significant predictor of mortality from CVDs or premature mortality, even after adjustment for these factors [31, 33]. This finding may have an important public health implication with respect to preventing adult mortality from NCDs. The possibly higher health service utilization by the literate group, as shown in previous studies, could partly account for the observed difference among the cohorts [41]. However, further research needs to be undertaken to decode the details of different pathways on how education could mediate or causally influence NCD mortality in the rural setting of the population. This could be of paramount importance for designing effective interventions to address NCD mortality. In this study, the protective effect of literacy was strongly modified by increasing age. This significant attenuating effect of age on the protective effect of education may highlight the reality that aging stands as a dominant risk factor to NCD-attributed mortality.

One of the interesting findings of our study was that NCD-attributed mortality was significantly different depending on the type of relationship household members have with their respective head of household. Extended family and non-family household members were at a significantly increased hazard of NCD mortality compared to the household head. As to our update, published research works linking adult mortality from NCDs and household headship are unavailable. Yet, one study found that being head of household significantly reduced elderly mortality for both sexes. Nonetheless, this effect was found to decline with increasing age of the household heads [57]. The relationship of family members to the head of households has also a vital implication to the survival of children. There is supporting evidence which shows that children who lived in households headed by persons other than their parents faced a relative survival disadvantage [56]. It has been reported that NCDs pose a significant economic burden to households by means of catastrophic hospitalization expenditure and productivity loss [9, 10]. In developing countries, where the health care costs are mostly covered by the patients, the adverse economic effect of catastrophic out of pocket expenses disproportionately affects the poor and vulnerable segments of the population [10]. As such, it is possible

that the healthcare-seeking practice and access to medicines by these vulnerable household members might have been excessively impeded which could have led to the significantly excess hazard of NCD ascribed mortality among these co-residents. Moreover, extended family and non-family members are less likely to access household resources since, in the cultural context of the study area, household related decisions, such as spending decisions, are primarily made by the heads of the households. Similarly, in one longitudinal study, it was explained that joint household resources were allocated differentially and accessed greatly by household heads and their wives [57]. Furthermore, illness from NCDs is generally characterised by long-term morbidity compared to communicable diseases, which could also predispose NCD patients who were not closely related to the household heads, to poorer care-seeking behaviour. This could evidently be aggravated by lifelong medical expenditures and the probable family fatigue as a result of long-term care [10, 103]. Conclusively, we observed that intra-household structure and relationships have significance in terms of excess NCD-related mortality among extended family and non-family co-residents within households. Therefore, we strongly recommend that public health interventions, such as community-based health insurance, should consider the intra-household structure and relationships, particularly giving focus to vulnerable co-residents, to significantly prevent NCD-attributed mortality.

Our study did not find a statistically significant difference in NCD mortality by wealth index. Nevertheless, the study demonstrated that individuals who had wealthy asset status had a lower hazard of NCD mortality compared to those who were poor individuals. This may show the positive survival gain of higher economic status in relation to reducing the hazard of adult mortality from NCDs. Similar to our study, other groups did not find a statistically significant difference between wealth and acute myocardial infarction mortality (AMI) [104], wealth and cancer mortality [55]. In contrast, several other studies showed a statistically significant association of wealth with all-cause and NCD mortality [52, 53, 55, 105]. The reason for the finding of insignificant association of wealth with NCD mortality is unclear, but it could be partially attributed to the fact that non-governmental micro-lending service is commonly practiced in the study area, which could have diluted the effect of wealth status on NCD mortality. On the other hand, for some reasons, it is mentioned that wealth status of individuals estimated from household wealth measures, such as household wealth index, could be an unreliable measure of individual economic position [106]. Controlling the effect of education and all other fitted covariates, unemployment was not a significant factor for NCD mortality. This finding is rather contradictory to the evidence from previous research works [44, 46]. This could be explained by the strong correlation of education, income and occupation; however, education is consistently the strongest indicator, proofing its causal effect, compared to the two parameters [27–30].

The results of this study could be generalizable to many developing countries taking in to account the mostly similar situations of low literacy level and patricentric household headship, which is a proxy indicator of differential individual access to within household resources [57], in most rural areas of such countries. One should, however, notice that the results should be utilized with great prudence because NCD patients living in these different countries are exposed to different health system, social and cultural contexts, where the generalization may not be applicable. Contrary to this, we expect that our findings may not be generalized to NCD patients living in developed countries due to the likely better survival resulting from better health insurance coverage. Moreover, the higher literacy level and different family composition and structure in developed countries may also create distinctive contexts where the results of the current study may not be directly inferred. Nevertheless, this does not imply that the results will not have relevance to such economically thrived part of the world.

Our study is based on highly trained and experienced enumerators who collected the population-based longitudinal data using standardized data collection tools and procedures. An

additional strength of the study is that it is based on a large number of participants followed over long period of time. However, the study is not without limitations. One major limitation of the study is that undetermined and unspecified causes of death, 16.8% and 3.6% respectively, accounted for about one-fifth of the total causes of death. This may be due to the fact that physician review based verbal autopsy is less accurate in determining causes of death as compared to other methods [65, 107]. It could be difficult to clearly determine how this has already impacted our results; however, assuming aging as a principal factor for the occurrence of NCDs among elderly adults [98], we think that this might have reduced the burden of NCD mortality because 76.6% of the undetermined and unspecific causes were among adults aged 65 years and above. The second limitation is that the absence of data for some important variables such as the classical NCD risk factors, which may further explain the disparity in NCD mortality, should also be mentioned as a limitation of our study.

Conclusion

In summary, our study has found a high mortality burden from NCDs. The evidence from this study indicates that older age, non-literacy, and being an extended family or non-family member of the household head, show a disparity of significantly higher NCD attributed adult mortality in the project area. This study has enhanced our understanding of social determinants in the context of a predominantly rural community of Ethiopia. Future public health interventions should integrate these findings to plan interventions in those vulnerable groups to meaningfully reduce adult NCD mortality. Further research, combining quantitative and qualitative approaches, needs to be implemented to disentangle the different possible pathways education and intra-household composition and relationships follow to result in differential adult mortality from NCDs.

Supporting information

S1 Fig. A conceptual framework of the social determinants of NCD attributed adult mortality.
(TIF)

S1 Table. Predictors of NCD mortality based on sensitivity analysis.
(RTF)

S1 Data Collection tools.
(ZIP)

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Chapter 4: What factors are associated with maternal undernutrition in eastern zone of Tigray, Ethiopia? Evidence for nutritional well-being of lactating mothers

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What factors are associated with maternal undernutrition in eastern zone of Tigray, Ethiopia? Evidence for nutritional well-being of lactating mothers

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Abstract

Background: Maternal undernutrition is a pervasive health problem among Ethiopian mothers. This study aims at identifying the level of maternal undernutrition and its associated factors in Kilte Awaleo-Health and Demographic Surveillance Site (KA-HDSS), Tigray region, Ethiopia.

Methods: Nutritional status of 2260 lactating mothers was evaluated using the mid-upper-arm circumference (MUAC). Data from the vital events and verbal autopsy databases were linked to the survey and baseline recensus data to investigate the association of adult mortality from chronic causes of death (CoD) on maternal undernutrition. We employed a generalized log-binomial model to estimate the independent effects of the fitted covariates.

Results: The overall prevalence of maternal undernutrition based on MUAC < 23 cm was 38% (95% CI: 36.1, 40.1%). Recent occurrence of household morbidity (adjusted prevalence ratio (adjPR) = 1.49; 95%CI: 1.22, 1.81) was associated with increased risk of maternal undernutrition. In addition, there was a 28% higher risk (adjPR = 1.28; 95%CI: 0.98, 1.67) of maternal undernutrition for those mothers who lived in households with history of adult mortality from chronic diseases. Especially, its association with severe maternal undernutrition was strong (adjusted OR = 3.27; 95%CI: 1.48, 7.22). In contrast, good maternal health-seeking practice (adjPR = 0.86; 95%CI: 0.77, 0.96) and production of diverse food crops (adjPR = 0.72; 95%CI: 0.64, 0.81) were associated with a lower risk of maternal undernutrition. Relative to mothers with low scores of housing and environmental factors index (HAEFI), those with medium and higher scores of HAEFI had 0.81 (adjPR = 0.81; 95%CI: 0.69, 0.95) and 0.82 (adjPR = 0.82; 95%CI: 0.72, 0.95) times lower risk of maternal undernutrition, respectively.

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Conclusions: Efforts to ameliorate maternal undernutrition need to consider the influence of the rising epidemiology of adult mortality from chronic diseases. Our data clearly indicate the need for channeling the integrated intervention power of nutrition-sensitive development programs with that of nutrition-specific sectoral services.

Keywords: Chronic diseases, Adult mortality, Maternal undernutrition, KA-HDSS, Tigray, Ethiopia

Background

In Ethiopia, recent analyses revealed that most of the millennium development goals were achieved [1], but not the goal for reducing maternal mortality. Although maternal mortality significantly declined, it is still high, especially in rural areas of Ethiopia [1, 2], with maternal nutritional deficiencies being one of the underlying causes [3, 4]. It was estimated that for every maternal death, 1000 women suffer from stunting and/or anemia [5]. These nutritional disorders act synergistically with multiple other factors leading to nutrition-related adverse pregnancy outcomes [5, 6]. Low hemoglobin concentrations, for instance, are associated with postpartum hemorrhage, the leading cause of maternal death [7], due to its attenuating effect on uterine contraction [8, 9]. Apart from its impact on maternal morbidity and mortality, taking into account that the mother and her fetus or newborn are an inseparable dyad, nutritional deficiencies of mothers can cause undernutrition to fetuses and children [5, 10–12]. This in turn can affect their survival and well-being even later during adulthood [13, 14]. Thus, ensuring maternal nutritional well-being plays a critical role for preventing morbidity and mortality of mothers and their children [6].

Maternal undernutrition, however, has remained one of the most serious public health problems to Ethiopian mothers [2, 15–17]. Even though the level of maternal short stature (height less than 145 cm) reported in 2000 was reduced by 41.7% in 2016 in Tigray regional state, there was almost no reduction in the burden of maternal undernutrition [2, 15]. Added to this existing challenge is the paradoxically rising phenomenon of maternal overweight and obesity both nationally and in the regional state, making the efforts of addressing maternal nutritional problems even more complex [2, 18]. Hence, unless maternal undernutrition is alleviated, the health problems resulting from both under- and over-nutrition, which were associated with an increasing burden of non-communicable diseases and intergenerational transmission of poverty [14, 19–21], will be an increasing challenge to public health in the future.

Family planning, antenatal care visit, in-facility delivery, skilled birth attendance and preventing nutritional deficiencies are key inputs to enhancing the survival and well-being of women of reproductive age and their children [22–24]. In contrast, morbidity and mortality of adults from chronic diseases could impose high and regressive costs that could significantly cause household poverty [25–29], thereby influencing maternal nutritional status.

This study was carried out to examine factors associated with undernutrition among lactating mothers using epi-demographic, socio-economic and agricultural datasets from Kilte Awlaelo-Health and Demographic Surveillance Site (KA-HDSS), eastern Tigray, Ethiopia.

Methods

Study setting, study period and data sources

Due to poor quality or absence of complete civil registration systems (CVRS), evidence-based health policy formulation and decision-making is challenging in most sub-Saharan Africa [30]. To date, complete and quality CVRS system has not been available in Ethiopia. However, there are other health data sources despite their limitations. In addition to the periodic and routine data sources (censuses, demographic and health survey, routine health information reports), selecting geographically defined populations, and generating longitudinal vital events (birth, migration, and death), causes of death (CoD), and marital status information could also be an alternative systematic approach. Such population-based and ongoing longitudinal health and demographic projects are known as health and demographic surveillance sites (HDSS), and are linked through The International Network for the Demographic Evaluation of Populations and their Health (INDEPTH) network [30, 31]. Pooling data from multiple HDSS, in a given country, may help to narrow the chronic data gaps in low and middle income countries [31], although this approach cannot be a replacement for a fully functional and quality CVRS. In Ethiopia, there are six HDSS projects home-based at their respective local university and networked by the support of Ethiopian Public Health Association (EPHA) and Center for Diseases Control (CDC-ETHIOPIA). Health and demographic data are pooled from these six sites and disseminated for public use on annual basis. KA-HDSS, which is located 835 km north of Addis Ababa in the Eastern Zone of Tigray, was established in 2009 with a total baseline population of 66,438 residents. The current study is based on data extracted from the

KA-HDSS longitudinal data, and the nutrition and baseline recensus survey data, which was collected from July to December in 2015. The nutrition survey was conducted as a baseline for the installment of longitudinal nutrition project to the already existing main surveillance project.

Participants

Our study population included all the 2260 breastfeeding mothers of KA-HDSS, who were at least 18 years old.

Data collectors and data collection procedure

The data collectors were high school completed permanent employees of the surveillance project (KA-HDSS). They were chosen to ensure the overall sustainability of the project and its collateral contribution to the community. They were rigorously trained, and experienced on the standard data collection tools and procedures, including on how to consent the study participants properly. Before the start of the data collection, the data collectors introduced themselves to the study participants, and gave information on the purpose of the study. The data collection started after consent from the participants was given. Furthermore, the interviewers were residents of the surveillance population, with better knowledge about the culture of their community, thus facilitating the proper implementation of the consent procedures. Face-to-face interviews were conducted together with direct observations and measurements. KA-HDSS data collection supervisors led by the field manager (from the field KA-HDSS office) and academic research members (from the KA-HDSS central home office at Mekelle University, College of Health Sciences) strictly monitored the data collection process.

Assessment and study variables

Maternal nutritional status was assessed using the mid-upper-arm circumference (MUAC) measurement. The midpoint between the tip of the shoulder and the tip of the elbow of the left arm was measured using a flexible, inelastic MUAC tape. Circumferential measurements were taken after making sure that the tape had a proper tension, not too loose or too tight, around the midpoint and all values were recorded to the nearest 0.1 cm. Lactating mothers with a MUAC below 23 cm were classified as undernourished, and those with less than 21 cm as severely undernourished [32, 33]. Studies have reported that MUAC is a reliably efficient alternative indicator for body mass index for evaluating adult nutritional status, particularly in developing countries where large logistical mobilization is needed to accurately measure the height and weight in population-based surveys [34, 35]. Its positive association with infant breast milk intake, breast milk volume and quality, its measurement simplicity and ability to predict mortality, particularly among the older adults, are additional advantages [35–38].

Detailed lists of agricultural asset ownership, livestock and food crops produced, were counted and converted to monetary terms and quintile classified. The lowest two quintiles were treated as “poor” and the remaining three upper quintiles as “not poor”. Maternal health practice index was constructed from two maternal health service utilization indicators: ever use of modern family planning methods and delivering at health facilities. If the score was 2 (mother used both health services), then it was operationalized as “good”. If the score was < 2 then it was classified as “poor”. A household’s access to media is considered if a given household has access to television, radio or mobile phone. Improved water and sanitation services were computed using the latest WHO/UNICEF Joint Monitoring Program (JMP) ladders for improved water and sanitation sources [39]. The quality of housing materials and cleanliness of cooking fuel were determined by reproducing the approaches used by Adebowale el.al [40]. Principal component analysis was performed on the proportion of nine housing and environmental variables [41]. The nine variables are access to media, electricity, improved water and sanitation services, cleanliness of cooking fuel, availability of kitchen, quality of the housing materials of the floor, wall, and roof. Then, four principal components with eigenvalues ≥1.0 were retained to derive the housing and environmental factors index (HAEFI). The variable agricultural crop diversity was operationalized based on whether the households, with access to farmland, were able to produce at least two food crops. Households with no crop or monocrop production were specified as having no crop diversity. Recent morbidity history was said to be existent if there was report of illness among household member/s 2 weeks before the date of survey. Physician review based on verbal autopsy was employed to ascertain the most likely causes of death (CoD) and all causes were classified using the tenth edition of International Classification of Diseases tool (ICD-10) [42]. Adult deaths from chronic infectious and non-infectious diseases (notably tuberculosis, HIV/AIDS, non-communicable diseases such as diabetes mellitus, hypertension, endocrine disorder and others) were operationally defined as “chronic CoD”. These diseases were classified under the same broad CoD group because these specific CoD may generally be associated with longer duration of illness and need for long-term care. Therefore, relative to all other CoD, chronic CoD might have caused long-term

family stress and health care expenditure, and adverse social and economic consequences to the deceased adults (before their death) and their family and household in general. Adult deaths from all acute infectious diseases, external causes like assault, and the undetermined cases were then classified as "all other CoD". In this study, we hypothesized that maternal undernutrition might be higher for mothers living in households that experienced adult death from chronic CoD, as compared to those living in the households that experienced no adult death or adult death from all other CoD. Investigating maternal nutritional status with such operational classification of the CoD could have empirical relevance to maternal health and nutrition policy since these CoD are contributors to adult health loss in the study community and in Ethiopia in general [43–46].

Statistical analysis

The factors determining maternal undernutrition were identified using generalized log-binomial model. This statistical procedure was chosen because it can generate estimates of adjusted prevalence ratios (adjPR), appropriate measure of association when the outcome of interest is not epidemiologically rare (> 10%), which is the case in this study [47–50]. In addition, its easiness of interpretation makes prevalence ratio preferable to the odds ratio [50]. Univariable log-binomial analyses were performed to observe the association of each independent variable with maternal undernutrition. In the next step, all the variables with a *P*-value of less than 0.25 in the univariable analysis were taken to the multivariable log-binomial model. Adjusted prevalence ratios and their 95% confidence intervals (95% CI) were reported at *P*-value of less than 0.05. In addition, we also assessed the factors associated with severe maternal undernutrition. In this case, since the prevalence of severe maternal undernutrition was less than 10%, we used multivariable binary logistic regression model to identify the potential associated factors. Similar to the above approach, variable selection was made at *P*-value of less than 0.25 in the univariable binary logistic regression and adjusted odds ratio (AOR) with 95% CI were produced from the multivariable model at *P*-value of less than 0.05. However, to encourage the interpretation of the associations from the perspective of practical (public health) significance, rather than focusing only on statistical significance, we decided to skip the *P*-values and instead report only the measures of association and their corresponding 95% CI. Categorical characteristics of the study participants are presented using frequencies and proportions, while the continuous characteristics are summarized using means with standard deviations (SD) and median with interquartile ranges (IQR), depending on their distribution. All analyses were performed in Stata 15.1 (StataCorp, LLC, College Station, TX).

Results

Characteristics of the study participants

Details of socio-demographic and agro-epidemiologic characteristics of the study participants and their households are presented in Table 1. Three-fourths (77.5%) of the households had access to farmland. The median farmland size, for those who had access to farmland, was 2 ha with an IQR of 1–3 ha (data not shown). The median (IQR) altitudinal location of the households, where the undernourished mothers lived in, was slightly higher than their counterparts, 2138 m (2,050–2321) vs. 2102.5 m (2,038 – 2270).

About one-third of the households (35.1%) had a higher housing and environmental factors index (HAEFI). One hundred and twenty-six (5.5%) of the households had a history of adult deaths and half of these deaths, 62 (49.2%), were from chronic diseases (Table 1). The mean (SD) household size was 6.21 (SD ± 2.04). The median age of the mothers was 27 years IQR of 23 to 30 years. More than three-fifths of the mothers had no formal education and the majority of the women (88%) were either housewives or farmers. The mean maternal MUAC was 23.0 cm with a SD of 1.6. Of the total 2260 mothers, 860 (38%; 95% CI: 36.1, 40.1%) were undernourished (MUAC < 23 to > = 21 cm) and 150 (6.6%%; 95% CI: 5.7, 7.7%) were severely thin (MUAC < 21 cm).

Household characteristics by agro-economic, infrastructural, housing and environmental factors

Table 2 provides quantile distribution of HAEFI by the component household related characteristics. More than half, 1266 (57.2%), of the households had access to improved water and 499 (22.5%) to sanitation services. Access to improved housing materials, electricity and clean cooking fuel is limited.

Generally, improved housing quality, access to electricity and use of non-biomass cooking fuel were observed for mothers in the higher quintile groups of HAEFI. Whereas higher access to improved water and sanitation services was observed for those mothers in the lower HAEFI quintiles (Table 2).

Factors associated with maternal undernutrition

Recent history of occurrence of household morbidity (adjPR = 1.49; 95%CI: 1.22, 1.81) was associated with an increased risk of maternal undernutrition. Similarly, household history of adult mortality from chronic diseases (adjPR = 1.28; 95%CI: 0.98, 1.67) was associated with a higher risk of maternal undernutrition with a

Table 1 Description of study participants by nutritional status, KA-HDSS, Tigray, northern Ethiopia ($n = 2, 260$)

Independent variables		Total counts (Column %)	Maternal nutritional status (Count, and row %)	
			Properly nourished	Undernourished
Residence	Rural	2121 (93.8)	1301 (61.3)	820 (38.7)
	Semi-urban	139 (6.2)	99 (71.2)	40 (28.8)
Age in years	Median (IQR*)	27 (23–30)	27 (22–31)	28 (23–30)
Age of child in months	Mean (±SD*)	10.5 (±6.4)	10.4 (±6.5)	10.8 (±6.3)
Education	No formal education	1372 (62.9)	865 (63.1)	507 (36.9)
	Primary	592 (27.2)	361 (61.0)	231 (39.0)
	Secondary and above	215 (9.9)	125 (58.1)	90 (41.9)
Occupation	Housewife/Farmer	1914 (88.0)	1192 (62.3)	722 (37.7)
	Government employee and others	199 (9.1)	121 (60.8)	78 (39.2)
	Daily laborer/ Unemployed	62 (2.9)	36 (58.1)	26 (41.9)
Asset-based wealth status	Poor	898 (39.7)	573 (63.8)	325 (36.2)
	Not poor	1362 (60.3)	827 (60.7)	535 (39.3)
Household history of adult death	No history adult death	2134 (94.4)	1328 (62.2)	806 (37.8)
	Death from chronic diseases	62 (2.7)	31 (50.0)	31 (50.0)
	Death from all other causes	64 (2.8)	41 (64.1)	23 (35.9)
Maternal health seeking	Poor	1009 (48.8)	601 (59.6)	408 (40.4)
	Good	1059 (51.2)	695 (65.6)	364 (34.4)
HAEFI*	Poor	1006 (45.4)	571 (56.8)	435 (43.2)
	Medium	431 (19.5)	288 (66.8)	143 (33.2)
	High	778 (35.1)	514 (66.1)	264 (33.9)
Morbidity in the past 2 weeks	No	2180 (96.5)	1363 (62.5)	817 (37.5)
	Yes	79 (3.5)	36 (45.6)	43 (54.4)
Household size	Mean and SD	6.21 (2.04)	6.25 (2.05)	6.15 (2.03)
Altitude (in meter)	Median and IQR	2110 (2041 – 2300)	2102.5 (2038–2270)	2138 (2050–2321)
Crop diversity	No	1039 (46.0)	590 (62.5)	449 (37.5)
	Yes	1221 (54.0)	810 (45.6)	411 (54.4)

**HAEFI* housing and environmental factors index, *IQR* interquartile range, *SD* standard deviation

marginal statistical significance. Compared to those mothers with low HAEFI scores, mothers with medium and higher HAEFI scores had 0.81 (adjPR = 0.81; 95%CI: 0.69, 0.95) and 0.82 (adjPR = 0.85; 95%CI: 0.72, 0.95) times lower risk of undernutrition, respectively (Fig. 1). In addition, good maternal health seeking practice (adjPR = 0.86; 95%CI: 0.7, .96) and diverse food crops production (adjPR = 0.72; 95%CI: 0.64, 0.81) were also associated with lower risk of maternal undernutrition (Fig. 1).

Although higher altitudinal location and rural residence were statistically associated with higher risk of maternal undernutrition in the univariable analysis (Additional file 1), these associations did not hold true when the effects of other fitted variables were adjusted in the multivariable model. Number of household size, mothers' educational status and occupation were not strongly associated with risk of maternal undernutrition (Fig. 1).

Figure 2 shows that mothers who lived in households with a history of adult mortality from chronic diseases had a 3.27 times (AOR = 3.27; 95%CI: 1.48, 7.22) higher odds of severe maternal undernutrition compared to those who lived in households with no history of adult deaths. The odds of severe maternal undernutrition was 45% (AOR = 0.55; 95%CI: 0.36, 0.85) for mothers who lived in households with a high HAEFI score. Similarly, mothers who lived in households that reported diverse food crops production showed 43% (AOR = 0.57; 95%CI: 0.39, 0.82) lower odds of severe maternal nutrition (Fig. 2). An additional table file shows details of the univariable and multivariable binary logistic regression results (Additional file 2).

Table 2 Distribution of housing and environmental factors index (HAEFI) by housing characteristics and access to different public services ($n = 2215$ households) in KA-HDSS, Tigray, Ethiopia

Characteristics		Distribution of HAEFI* (row %)					Total Frequency (Column %)
		Quintile 1	Quintile2	Quintile 3	Quintile 4	Quintile 5	
Floor	Unimproved	30.7	19.0	21.2	16.1	13.0	2026 (91.5)
	Improved	0.0	0.0	1.0	3.2	95.8	189 (8.5)
Wall	Unimproved	34.9	21.6	24.1	15.6	3.8	1781 (80.4)
	Improved	0.0	0.0	0.4	12.7	86.9	434 (19.6)
Roof	Unimproved	37.3	18.3	21.0	13.7	9.7	1221 (55.1)
	Improved	16.8	16.2	17.5	16.7	32.8	994 (44.9)
Access to electricity	No	33.1	20.0	19.0	15.3	12.6	1879 (84.8)
	Yes	0.0	2.4	22.0	13.4	62.2	336 (15.2)
Access to Media	No	5.8	39.9	10.8	26.4	17.1	659 (29.8)
	Yes	37.5	7.8	23.1	10.2	21.3	1556 (70.2)
Kitchen	No	32.9	16.5	18.7	13.2	18.7	614 (27.7)
	Yes	26.2	17.7	19.7	15.7	20.6	1601 (72.3)
Access to water	Unimproved	0.0	0.0	33.8	28.1	38.0	949 (42.8)
	Improved	49.1	30.3	8.7	5.2	6.6	1266 (57.2)
Access to latrine	Unimproved	23.8	20.6	16.5	17.4	21.7	1716 (77.5)
	Improved	42.9	6.2	29.5	7.0	14.4	499 (22.5)
Cooking fuel	unclean/biomass	29.1	18.0	20.1	15.5	17.3	2139 (96.6)
	clean/non-biomass	0.0	0.0	0.0	1.3	98.7	76 (3.4)

**HAEFI* Housing and environmental factors index

Discussion

This study presents evidence on the level and associated factors of maternal undernutrition in eastern part of Tigray, Ethiopia. The mean MUAC (± SD) of the participants was 23.0 ± 1.6 with an overall prevalence of maternal undernutrition (MUAC< 23 cm) of 38% and severe undernutrition (MUAC< 21 cm) with 6.6%. This study used high quality socio-economic, agro-ecologic and epidemiologic data from community-based surveys implemented in a health and demographic surveillance system platform. Our analysis reveals associations of household histories of adult morbidity and mortality, diverse food crop production, maternal health-seeking practice, housing and environmental factors index with maternal undernutrition.

A study from South Eastern Tigray reported a mean maternal MUAC value of 23.2 cm, which is similar to our finding (MUAC 23.0 cm) [17]. However, the level of severe maternal undernutrition in the cited study area in 2011 was about twice as high as in our study, with a magnitude of 13% vs. 6.6% respectively. Betemariam et al. found even a 24% prevalence of severe maternal undernutrition in Bale Zone of Ethiopia in 2013 [51]. This is nearly four-fold higher than the burden reported in our study, but the study population in that study was from a community that had a marginal agricultural production with cyclic food insecurity, and this may partially explain the observed difference. Similarly, a study based on a large representative survey sample from two Gojjam zones of the Amhara region found 52.9% maternal undernutrition (MUAC< 23 cm), a level much higher than the current finding [52]. The difference in the implementation period of the cited research works, agro-ecologic and cultural variations of the study areas might have contributed to the observed differences. The relatively lower burden of maternal undernutrition in the current study could partly be explained by the fact that the study area is known for being a hot-spot for various health and developmental interventions [53–55]. Nonetheless, the prevalence of maternal undernutrition is still high in our study community.

Morbidity and mortality of household members, particularly from chronic diseases and in developing country settings, could predispose households into a poverty trap [25, 29, 47]. Our data potentially hinted that mothers living in households that experienced adult mortality attributed to chronic diseases had increased risk of undernutrition, compared to those living in households without history of adult mortality. As shown in Fig. 2, the association of households' experience of chronic diseases attributed adult mortality with severe maternal undernutrition, however, is strong. In our previous work, however, we identified that nutritional insecurity of children aged 6 to 23 months did not vary by

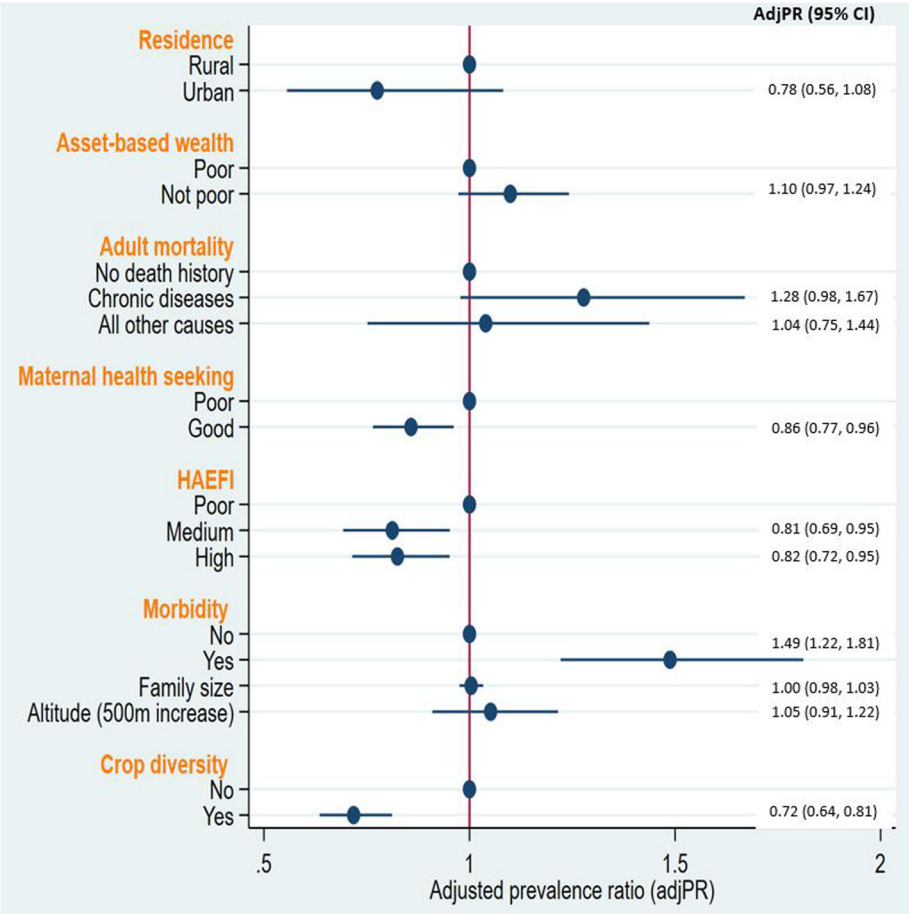

Fig. 1 Household factors associated with maternal undernutrition summarized by plots of adjusted PR and 95%CI from multivariable log-binomial model, KA-HDSS, Tigray, Ethiopia. *HAEFI = Housing and environmental factors index, PR = prevalence ratio, CI = confidence interval

households' history of adult mortality from chronic diseases [56]. This might be explained by the possibility of a buffering effect made by the mothers on the caloric intake of children, which in turn may have resulted in their increased maternal wasting [57]. Therefore, the current finding supports our proposed research hypothesis that the extent of maternal undernutrition, among mothers who lived in households that experienced adult mortality from chronic diseases, may be higher than among those mothers who did not live in such households. In general, chronic diseases are characterized by long duration of illness, with high out-of-pocket medical expenditure. This would more negatively impact nutrition security of poor and uninsured patients, and affected households could fall into a poverty trap [27, 58–60]. Loss of income, due to lower employment rate of the affected family members or chronic illness and mortality of the affected adults, is also another unavoidable negative consequence imperiling the economic welfare of households [58, 61–63]. Our data suggest that the synergistic negative economic impact of such household-level shocks might ultimately result in undernourishment of mothers, who were living in the households that experienced adult mortality attributed to chronic diseases. Most notably, a study from Ethiopia found a decline in dietary diversity and increase in mean dependency ratio following prime age adult mortality in poor households, regardless of the sex and position of the deceased adult [64]. In a rural setting of South Africa, household food security was affected by adult mortality, particularly by the death of a male wage-earner [65]. A survey conducted 3 years after identification of households affected by adult illness or mortality from HIV/AIDS, in comparison to the non-affected households, were found to have less production of food crops [63]. Furthermore, longitudinal studies linked the effect of adult mortality on the well-being of older household members; accordingly, a sharp drop in body mass index in the short term (possibly related grief and depression) and an increased probability of acute illnesses (explained by increased working hours in the field) in the long-term, were reported [62, 66]. We assume that this effect could plausibly be more intense for the lactating

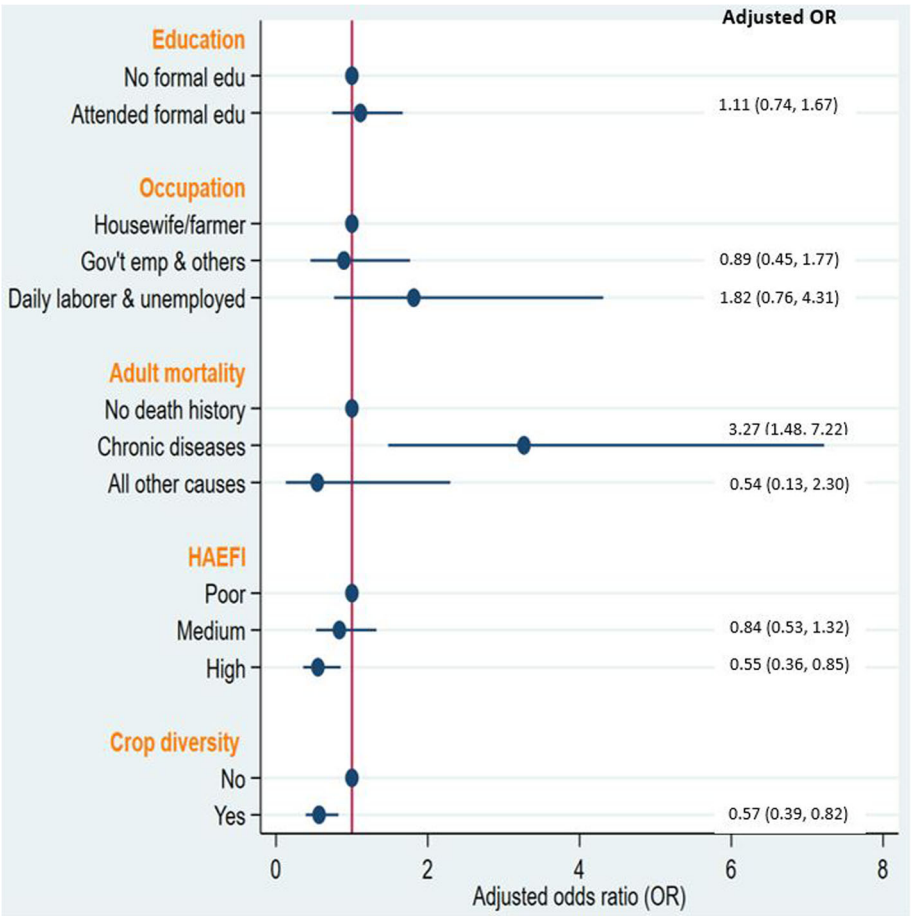

Fig. 2 Household factors associated with severe maternal undernutrition summarized by plots of adjusted odds ratio and 95%CI from multivariable binary logistic regression model, KA-HDSS, Tigray, Ethiopia. *HAEFI = Housing and environmental factors index, Gov't = Government, emp = employees, PR = prevalence ratio, CI = confidence interval

mothers, considering the cultural context in the study community that the mothers are the pillars and main caregivers to family members in addition to bearing the different laborious out-door responsibilities, especially if the husband is deceased. While this assumption needs to be tested in independent studies, we may conclude that lactating mothers living in households that experienced adult death due to chronic diseases are vulnerable to undernutrition. Thus, we strongly recommend that those lactating mothers, and their children, need targeted nutritional screening with a subsequent intervention for those who are already undernourished or found to be at a high risk of undernutrition.

Mortality of adult household member, especially if the deceased one is of prime-age, is associated with adverse income and assets shocks. Illness or mortality of male household head has been shown to lead to a lower crop production, severe impacts on farm production and livestock assets [63, 67]. A study conducted in a district proximal to our study community reported that lower farmland size and not cultivating maize were associated with severe undernutrition (MUAC< 21 cm) of lactating mothers [17]. Our observation, of a 28% lower risk of being undernourished for lactating mothers living in households which produced diversified food crops accords with these research findings. Another study reported a 27% reduction in total cultivated farmland following death of male head or spouse [67]. In our study, the mean household farmland size was significantly lower among the undernourished mothers than those who were not (mean difference was 0.28 ha; T_{calc} = 4.6189, $p < 0.001$). Additionally, HIV/AIDS-related adult mortality is associated with poor agricultural and resource management, such as watershed and soil conservation, diminished care to household family members, mostly felt by women, change in crop mix and lower capacity to ensure food security [67, 68]. This may impede the capacity to cultivate nutritious and diverse food crops and result in undernourishment of the lactating mothers.

We could show that there was a 14% lower risk of maternal undernutrition given the condition that the lactating mother had achieved a good maternal health seeking practice. The nutritional benefit of utilizing maternal health service has also been demonstrated by other studies [17, 51, 69]. Access to such infrastructural services, especially in rural areas, are clear determinants of maternal and child health [70, 71]. Our study revealed that better housing and environmental factor index scores are negatively associated with maternal undernutrition. This composite index was computed based on a number of relevant public health measures such as quality of housing materials, media access and cleanliness of cooking fuel, availability of environmental health services like access to improved water and latrine services. Media exposure increases maternal awareness, and so could positively influence health service utilization, such as antenatal care service [72], which in turn may increase the mothers' nutritional knowledge. Poor access to water and sanitation services were shown to exert the burden of water collection for the mother and reduces time for mother-child interaction, endangering nutritional well-being of both the mothers and the children [71, 73]. Given that the lactation period is already characterized by higher energy and nutrient requirements of the mother [74–76], the workload to fetch water may further increase energy requirements and enhance the risk of undernutrition. Our data indicate that the levels of moderate and severe maternal undernutrition were higher for mothers who did not have access to improved water relative to those who had access to improved water ($X^2_{calc} = 20.8$, $p < 0.001$), which is in line with earlier research showing the protective effect of improved water and handwashing on maternal undernutrition [77, 78].

Our study poses some limitations. Firstly, the surveillance site, source of the study data, was established not only with the aim of generating scientific health and demographic information, but also to serve as a platform for the implementation of various researches. Due to its proximity to the regional city and thus to Mekelle University, the study area has also been one of the sites for the community-based training program (CBTP) of the College of Health Sciences of the University. In this practical attachment program teams of health sciences and medical students are routinely involved in assessing the general health status of the community, designing, and implementing interventions for sets of identified and prioritized public health problems. This has been the tradition for many years to equip graduating students with various medical and public health skills. Because of these exposures, we may assume that the frequently exposed part of the study site's population could have a better health literacy level and healthy behavior compared to other communities. If this assumption holds true, the strength of the association of adult mortality from chronic CoD with maternal undernutrition might have been attenuated. However, we do not have the data to evaluate if this bias is induced to the estimates. Secondly, the association of maternal undernutrition with adult mortality attributed to chronic CoD is only at aggregate level and does not give detailed information of each of the chronic causes of adult death. Thirdly, the degree of maternal undernutrition may vary by the length of duration since the occurrence of adult death and the current analyses did not take into account this probable source of variation. Notwithstanding these limitations, our study is based on extensive and high-quality data, and its findings could be relevant to maternal nutrition and to the public health actors in general.

Conclusion

The level of undernutrition among the lactating mothers of the current study community was high. The factors identified in this study have empirical relevance to public health and nutrition policy. We observed that household morbidity history and adult mortality from chronic diseases were associated with increased risk of maternal undernutrition. On the other hand, good maternal health seeking practice, diverse food crops production, and higher scores of housing and environmental factors index were associated with better maternal undernutrition.

The current findings suggest the need for designing and integrating action-oriented nutrition-sensitive development programs (agriculture and economic sectors) to nutrition-specific interventions (health and nutrition interventions) and channeling such synergistic intervention to predominantly rural households of Ethiopia. This could sustainably improve nutritional well-being of mothers and children. A new and important aspect to consider is that lactating mothers living in households that experienced adult death from chronic diseases need targeted nutritional screening and intervention.

Supplementary information

Supplementary information accompanies this paper at https://doi.org/10.1186/s12889-020-09313-0.

Additional file 1: Supplementary Table 1. Factors associated with maternal undernutrition, identified by multivariable log-binomial analysis in KA-HDSS, Tigray, Ethiopia Ethiopia.

Additional file 2: Supplementary Table 2. Factors associated with severe maternal undernutrition, identified by multivariable binary logistic regression analysis in KA-HDSS, Tigray, Ethiopia.

Abbreviations

adjPR: Adjusted Prevalence Ratio; AOR: Adjusted Odds Ratio; CBTP: Community-Based Training Program; CDC: Centers for Disease Control and Prevention; CI: Confidence Interval; CoD: Causes of Death; EPHA: Ethiopian Public Health Association; ERC: Ethics Review Committee; FSC: Food Security Centre; HAEFI: Housing and Environmental Factors Index; HIV/AIDS: Human Immunodeficiency Virus/ Acquired Immunodeficiency

Syndrome; HRERC: Health Research Ethics Review Committee; ICD: International Classification of Diseases; IQR: Interquartile range; JMP: Joint Monitoring Program; KA-HDSS: Kilte Awaleo-Health and Demographic Surveillance Site; MUAC: Mid-Upper-Arm Circumference; SD: Standard Deviation; UNICEF: The United Nations Children's Fund; WHO: World Health Organization

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Authors' contributions
SFA, VS, EJK, and AW, and JF designed the research; SFA, VS, EJK, AW, JF, AMB, MT, JL, and GE conducted the research; SFA and AW performed the statistical analysis; SFA, VS, EJK, AW, and JF drafted the manuscript; SFA, VS, EJK, AW, JF, AMB, MT, JL, and GE reviewed and edited the final manuscript, and SFA takes the primary responsibility for the final content. All authors read and approved the paper.

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Availability of data and materials
The underlying data were extracted from both the Nutrition Survey and an ongoing surveillance site, KA-HDSS, and both are solely the property of KA-HDSS. The datasets analyzed during the current study are not publicly available because the data contain some sensitive information, such as causes of death for the deceased individuals along with GPS identified household locations. But, the data can be accessed from the corresponding author on reasonable request.

Ethics approval and consent to participate
The Ethiopian Science and Technology Agency ethically approved the ongoing surveillance project, KA-HDSS, with the ethical approval identification number of IERC-0030. Before the start of the data collection, the data collectors introduced themselves to the participants, gave information on the purpose of the study. Next, they explained to the study participants that they have the right to not participate or stop the interview at any time in the interview process if they want to decline from participating in the study. The process of data collection started following the study participants' verbal consent. The research tools, including the verbal consent procedures, were ethically approved. The interviewers are residents of the surveillance population, who actually were familiar with the culture of the community, helped for the proper implementation of the consent procedures. Additional ethical approval was also obtained from the Health Research Ethics Review Committee (HRERC) in Mekelle University (Reference number = ERC 1364/2019).

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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Chapter 5: Nutrition-specific and sensitive drivers of poor child nutrition in Kilte Awlaelo-Health and Demographic Surveillance Site, Tigray, Northern Ethiopia: implications for public health nutrition in resource-poor settings

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Nutrition-specific and sensitive drivers of poor child nutrition in Kilte Awlaelo-Health and Demographic Surveillance Site, Tigray, Northern Ethiopia: implications for public health nutrition in resource-poor settings

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ABSTRACT

Background: Child undernutrition is a prevalent health problem and poses various short and long-term consequences.

Objective: This study seeks to investigate the burden of child undernutrition and its drivers in Kilte Awlaelo-Health and Demographic Surveillance Site, Tigray, northern Ethiopia.

Methods: In 2015, cross-sectional data were collected from 1,525 children aged 6–23 months. Maternal and child nutritional status was assessed using the mid upper arm circumference. Child's dietary diversity score was calculated using 24-hours dietary recall method. Log-binomial regression and partial proportional odds model were fitted to examine the drivers of poor child nutrition and child dietary diversity (CDD), respectively.

Results: The burden of undernutrition and inadequate CDD was 13.7% (95% CI: 12.1–15.5%) and 81.3% (95%CI: 79.2–83.1%), respectively. Maternal undernutrition (adjusted prevalence ratio, adjPR = 1.47; 95%CI: 1.14–1.89), low CDD (adjPR = 1.90; 95%CI: 1.22–2.97), and morbidity (adjPR = 1.83; 95%CI: 1.15–2.92) were the nutrition-specific drivers of child undernutrition. The nutrition-sensitive drivers were poverty (compared to the poorest, adjPR poor = 0.65 [95%CI:0.45–0.93], adjPR medium = 0.64 [95%CI: 0.44–0.93], adjPR wealthy = 0.46 [95%CI: 0.30–0.70], and adjPR wealthiest = 0.53 [95%CI: 0.34–0.82]), larger family size (adjPR = 1.10; 95%CI: 1.02–1.18), household head's employment insecurity (adjPR = 2.10; 95%CI: 1.43–3.09), and residing in highlands (adjPR = 1.93; 95%CI: 1.36–2.75). The data show that higher CDD was positively associated with wealth (OR wealthy = 3.06 [95%CI: 1.88–4.99], OR wealthiest = 2.57 [95%CI: 1.53–4.31]), but it was inversely associated with lack of diverse food crops production in highlands (OR = 0.23; 95%CI: 0.10–0.57]).

Conclusions: Our findings suggest that the burden of poor child nutrition is very high in the study area. Multi-sectoral collaboration and cross-disciplinary interventions between agriculture, nutrition and health sectors are recommended to address child undernutrition in resource poor and food insecure rural communities of similar settings.

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Background

Child undernutrition is the leading cause of child morbidity and mortality globally [1,2]. It is still a persistently prevalent health problem in Ethiopia [3–8] even though its burden shows a declining trend [9]. According to the Ethiopian Demographic and Health Survey (EDHS) 2000 and 2016 child wasting, an indicator of acute food deficit, showed only a 2% decline at national level, and persisted at 11.1% in Tigray regional state [9,10].

Multiple factors and their complex interactions result in child undernutrition. In brief, the literature shows that high household wealth status, maternal access to health services, child dietary diversification, food security, access to improved water and sanitation, better housing quality, prevention and timely treatment of acute malnutrition are strongly associated with optimal child nutrition and survival [11–22]. On the other hand, maternal nutritional insult, larger family size with short birth interval, the absence of diverse agricultural food crop production, living in highlands and childhood morbidity, were reported to be associated with child undernutrition [11,14,15,22–30].

Nutritional wellbeing and survival of children could also be jeopardized through household shocks after illnesses or mortality of adult household

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members. Children living in households with a substantial loss of household earnings, due to a high burden of sickness-induced loss of employment, were found to be severely undernourished [30]. A significantly higher risk of falling into poverty and food insecurity was also observed for households which experienced adult mortality from both chronic diseases as well as acute infectious diseases [31–33] and this could also negatively impact child nutritional status and wellbeing.

Left unaddressed, child undernutrition has several short and long-term consequences to those who are affected and their future generations [11]. Adverse early life due to child undernutrition was related to lower human capital, with a likely intergenerational transmission of poverty (IGTP) [34,35], and higher risks of developing non-communicable diseases (NCDs) during adulthood [34,36,37]. Therefore, ensuring the nutritional wellbeing and survival of children, particularly during the first 1000 days of life, is one of the substantiated public health strategies recommended for reducing present and future disease burden caused by malnutrition [2,38,39]. The main objectives of this study were to assess the burden and nutrition-specific and sensitive drivers of undernutrition as well as dietary diversity among 6–23 months old children in Kilte Awlaelo-Health and Demographic Surveillance Site (KA-HDSS), Tigray, northern Ethiopia.

Methods

Setting, study design and data sources

Detailed descriptions of the surveillance site (KA-HDSS) have been published in prior research works [40,41]. This study used cross-sectional data collected during the second census of the site, which was held 5 years after its establishment in 2009. The census data collects several socio-demographic, economic, environmental, and public health-related data. Using the site's platform and its convenience for implementing other researches, baseline nutritional survey data of mothers and their children were collected as an add-on project. Concisely stated, nutrition-specific drivers refer to the immediate determinants of child nutrition and development, whereas nutrition-sensitive drivers refer to the underlying determinants mentioned in the UNICEF's framework for child nutrition, health and survival [11,38].

Study population

All the 1,525 children aged 6–23 months form the study population.

Measurement of variables

Nutritional status of children and their corresponding mothers was assessed using the mid upper arm circumference (MUAC) measured in centimetre (cm). Maternal MUAC below 23 cm [29,42] is categorized as undernutrition and a maternal MUAC below 21 cm [42] as severe undernutrition. Studies have shown that measuring nutritional status of non-pregnant mothers using MUAC can be a good substitute for body mass index [42–44]. Since MUAC is significantly age and sex dependent, particularly for children < 24 months, the decision of determining nutritional status of children by absolute MUAC estimates is problematic and needs to be adjusted for these factors [45–48]. A study in 2018, based on 255,623 measurements of 19 surveys found that the estimates of acute undernutrition by age-sex adjusted MUAC and weight for-height/length Z-score (WHZ) was similar, unlike the estimates from the absolute MUAC values which were discrepantly lower [49]. Acknowledging the relevance of the methodological recommendations of the cited studies, in this study, children's MUAC values were transformed to standardized z-score based MUAC (MUACZ) using WHO Anthro 2011 adjusting the age and sex of each child [50]. Then, child undernutrition was defined if the MUAC was <-2 z-score (MUAC <-3 z-score being defined as severe undernutrition and moderate undernutrition if the MUAC is <-2 to ≥-3 z-score). Biologically implausible MUACZ score values were dropped if the values fell out of the range of −5 and +5 [50]. Accordingly, two observations were dropped because their corresponding MUACZ scores were < −5.

Child's dietary diversity score (CDDS) was calculated out of seven food groups using the 24-hrs dietary recall method [51]. The responses to each of the seven food groups were dichotomized ('1' if a given food group was consumed or '0' if it was not consumed) and summed up to obtain the child dietary diversity score with values ranging from a minimum of 0 to a maximum of 7. This procedure was done using the World Health Organization (WHO) technique (51). Consumption of each food group was also disaggregated by age group of the children according to the WHO recommendation [52]. Then, in the model that examined the drivers of child undernutrition, child dietary diversity score was recoded as adequate (consumption of ≥4 food groups/day) and inadequate (consumption of <4 food groups/day) because consumption of four or more food groups was related to better diet quality [51,52]. However, in a separate model which analyzed the

drivers of dietary intake of the young children, CDDS was categorized as low (consumption of <4 food groups), medium (consumption of 4 to 5 food groups), and high (consumption of ≥6 food groups) [53–55].

Socio-economic position was measured using wealth index, applying principal component analysis [56,57], from a wide range of variables such as accessibility to improved water and sanitation services as defined by the WHO/UNICEF Joint Monitoring Program (JMP) ladders [58], levels of housing quality computed by replicating a prior research work [59], availability and quantity of agricultural ownership (farmland, bee hive, cart, livestock and food crops produced), access to electricity, media (created from single or joint ownership of TV or radio or phone), and other household ownerships like a bed with sofa, use of non-biomass energy source for food cooking etc. Detail of our methodology for generating wealth index is provided in Appendix D of the supplementary material.

The variable maternal health-seeking practice (mHSP) was constructed from two variables (current use of modern contraceptive and maternal tetanus toxoid immunization during pregnancy) and its values range from 0 to 2. This proxy variable was then dichotomized as 'good practice' if the score was 2 (mother used both maternal health services) and 'poor practice' if the score was less than 2 (mother used either none or only one of the two maternal health services). Altitudinal location of households was measured using geographic positioning system (GPS) and classified as highland (≥2, 300 meter) and low/midland (<2, 300 meter) [41]. Causes of adult death (CoD) were identified using physician review method and classified according to International Classification of Diseases version 10 (ICD-10) [60]. In this paper, the specific causes of death are then operationally reclassified as chronic causes (NCDs including cancer, cardio-vascular diseases, diabetes, and chronic lung diseases as well as chronic infectious diseases including TB and HIV/AIDS) and other causes (all acute infectious diseases, external causes, unspecified causes, undetermined and pregnancy-related CoD) primarily based on the chronicity of the CoD. The rationale underlying this classification is due to the difference in the length of the duration of illness of the CoD, which is primarily determined by the nature of the expected course of duration from clinical-stage development to the time of death. The assumption was that mortality from chronic CoD might have caused a differentially immense household level negative impacts, over the possibly longer period of illness of the deceased adults, and thereby distinctively expose the young children to undernutrition [30,61,62].

Statistical analyses

Modeling of child undernutrition was performed using generalized linear regression with a log link and binomial distribution. This statistical procedure was chosen, compared to the most commonly used binary logistic regression, because if the outcome is not rare (outcome > 10%), odds ratio (OR) can no longer approximate the risk ratio and is not an appropriate measure of association. Therefore, in studies with common outcomes, prevalence ratio (PR) should be used to measure an association [63,64]. In this study, the prevalence of child undernutrition (defined by MUAC <-2 z-score) was 13.7% which indicates that, in the study setting, the outcome of our interest is not a rare condition. Next, a proportional odds model (POM) was performed to identify the factors associated with child dietary diversity score. This statistical procedure was chosen as opposed to other modeling options, such as multinomial model or multivariable binary logistic regression model, because CDDS is a polychotomous variable with meaningfully inherent order. Thus, multinomial procedure was not used. POM is a more parsimonious, efficient and appropriate model than running multiple separate binary logistic regression models [65,66]. The POM convergence problem was avoided using the '*difficult*' command option in Stata 13.0 [64]. Then, *brant test* was used to assess the proportional odds/parallel-lines assumption of each variable. Using this test, the variable 'geographic location' had a significant p-value indicating that this variable violated the parallel-lines assumption of POM and hence a partial proportional odds model (PPOM), with gamma parametrization method, was fitted by un-constraining this variable and constraining all other variables. The interpretation of 'geographic location' variable based on the PPOM model has enabled us to identify its pattern of association with the outcome variable, which otherwise would have remained obscured in the POM. Evidence of multicollinearity was assessed using variance inflation factor (VIF) at cut-off value of greater than 10 [67] and no collinearity was found as reported in Appendix F1 of the supplementary material. In the univariable analysis of both models, all variables with a p value of < 0.25 were selected [68,69] and fitted into the multivariable models in which statistical significance was declared at p value of <0.05.

Results

Details of household level including socio-economic, agricultural, and epi-demographic characteristics are presented in Table A1. Generally, increasing pattern of quintile wealth index was observed for the

households with access to infrastructural service and improved public health indicators such as availability of electricity, improved housing quality, kitchen and non-biomass cooking fuel (Table A1).

Causes of adult death

Of the total 1,525 surveyed households, 91 (6 %) of the households had a history of death of an adult household member who deceased between 2009 and 2015. About half of the adult deaths, 45 (49.5%) were due to chronic diseases and the remaining 46 were due to other causes.

Young child undernutrition

This study focused on children from 6 months to 23 months of age. Almost half of the children were female (50.5 %). The mean (and standard deviation, SD) age of the study participants was 13.5 ± 4.9 months (13.5 ± 5.0 months for females and 13.4 ± 4.8 months for males). Out of the total 1, 525 study participants, 209 children, 13.7% (95% CI: 12.1–15.5%), were undernourished of which 43 (20.6%) were of a severe form. The burden of undernutrition was higher among male children compared to females (15.9% vs 11.6%, p = 0.014). The mean (SD) child MUACZ score was −0.87 (1.13). The distribution of MUACZ score of the study children was left shifted as compared with the Z-scores of WHO standard (Figure B1).

Based on MUAC cut off value of < 23 cm 39.9% (95% CI: 37.5–42.4) of the children's mothers were undernourished and 102 (16.9%) of these mothers were severely undernourished (MUAC < 21 cm). Access to adequate child dietary diversity was 18.7% (95%CI: 16.9–20.8%). Consumption of fruits and vegetables rich in vitamin A (3.3 % vs 10.1 %; p = 0.002) and dairy food (19.4% vs 31.5%, p < 0.001) was significantly lower for the undernourished children compared to those who were not (data not shown). As presented in Table 1, the burden of undernutrition was higher among young children who had lower mean dietary diversity intake and whose mothers were undernourished. Child undernutrition was also relatively high among those who were living in households which had lower wealth quintiles, higher mean family size, located in highlands, and living in households which experienced symptomatic morbidity (cough, diarrhea, fever, and/or any other symptom) and produced no diverse food crops (Table 1).

Patterns of nutritional outcomes and morbidity by age and sex

The percentage of occurrence of morbidity was higher in the households where the boys resided

Table 1. Nutritional status of children by selected independent variables, KA-HDSS, Tigray, northern Ethiopia (n = 1, 525).

		Row distribution of Nutritional status of children, n (%)		
Characteristics	Categories	MUAC ≥-2 *z*-score	MUAC <-2 *z*-score	Column total, n (%)
Residence	Semi-urban	80 (94.1)	5 (5.9)	85 (5.6)
	Rural	1,236 (85.8)	204 (14.2)	1, 440 (94.4)
Sex of household head	Male	1,137 (85.8)	188 (14.2)	1, 325 (86.9)
	Female	179 (89.5)	21 (10.5)	200 (13.1)
Sex of child	Male	635 (84.1)	120 (15.9)	755 (49.5)
	Female	681 (88.4)	89 (11.6)	770 (50.5)
Educational status of household head	No formal education	886 (85.8)	146 (14.2)	1, 032 (67.7)
	Formal education	428 (87.2)	63 (12.8)	491 (3.2)
	Missing			2 (0.1)
Occupation of household head	Farmer/housewife	1,123 (86.9)	169 (13.1)	1,292 (84.7)
	Daily laborer	110 (76.9)	33 (23.1)	143 (9.4)
	Government employee and others	83 (92.2)	7 (7.8)	90 (5.9)
Mean age of household head in years (SD)		42.3 (11.1)	44.8 (11.5)	1, 525
Mean child dietary diversity score		2.2 (1.5)	1.9 (1.3)	1, 525
Maternal MUAC	normal	814 (89.6)	94 (10.4)	908 (60.1)
	Undernourished	491 (81.3)	113 (18.7)	604 (39.9)
History of adult death	No history adult death	1,234 (86.0)	200 (14.0)	1, 434 (94.0)
	Yes-from chronic diseases	40 (88.9)	5 (11.1)	45 (2.9)
	Yes- from acute infectious diseases, injuries and other causes	42 (91.3)	4 (8.7)	46 (3.0)
Mean quintile wealth status (SD)		3.1 (1.4)	2.5 (1.4)	1, 483
Geographic location	Low/midland	906 (87.3)	132 (12.7)	1, 038 (68.1)
	Highland	306 (81.6)	69 (18.4)	375 (24.6)
	Missing			112 (7.3)
Morbidity history in the past 2 weeks	No	1,274 (86.7)	195 (13.3)	1, 469 (96.3)
	Yes	41 (74.5)	14 (25.5)	55 (3.6)
	Missing			1 (0.07)
Mean household size (SD)		6.2 (2.0)	6.8 (1.9)	1, 525
No crop/monocrop production	Yes	575 (83.8)	111 (16.2)	686 (45.0)
	No	741 (88.3)	98 (11.7)	839 (55.0)

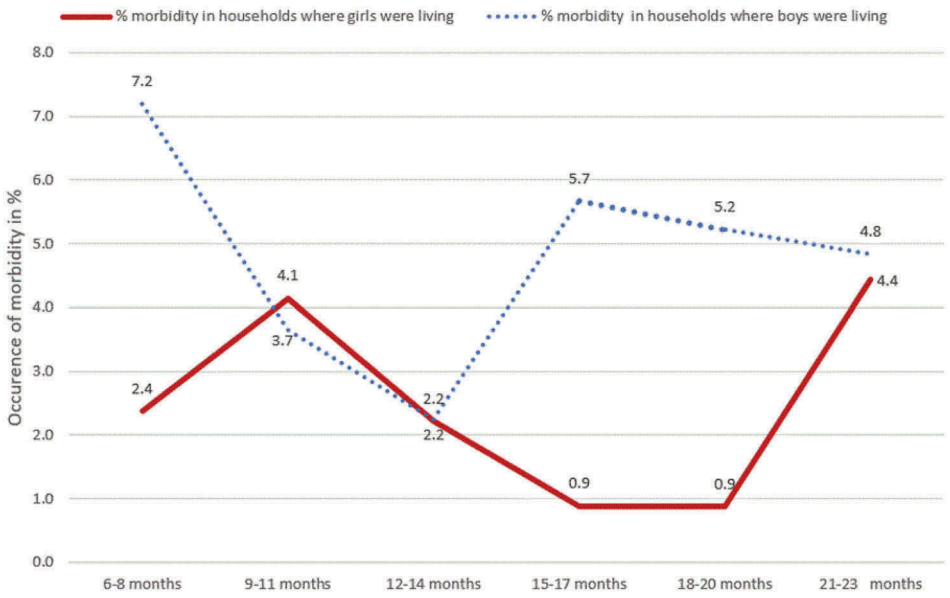


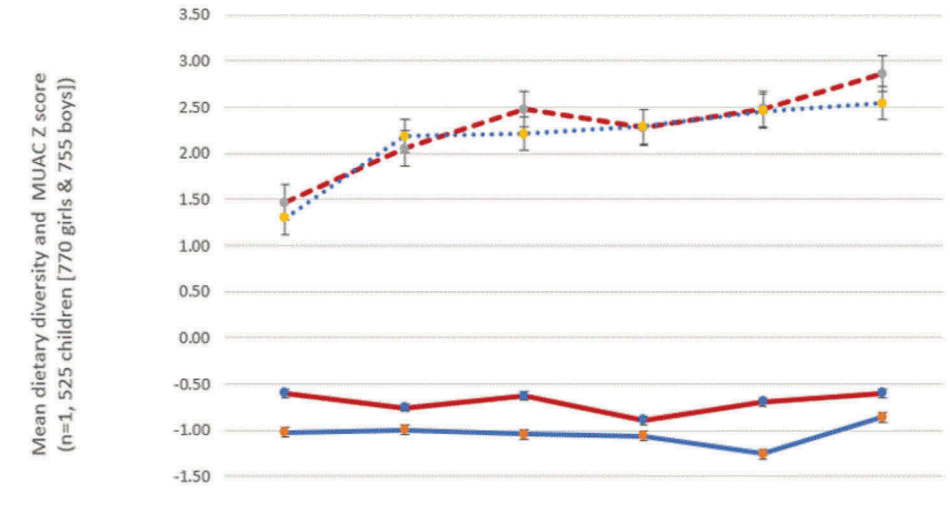
Figure 1. Distribution of households' experience of morbidity by sex and age of children, KA-HDSS, Tigray, northern Ethiopia (n = 1, 525).

as compared to the households where the girls resided, 4.8 % vs 2.5 % respectively. Boys were living in 65.5 % of the total households which reported occurrence of morbidity. Except for the boys in the age groups of 9–11 months and 12–-14 months, reports of occurrence of morbidity were lower for the girls compared to all other age groups (Figure 1).

As shown in Figure 2, the mean MUACZ score values of boys was consistently lower than that of girls across all age groups. In addition, the mean CDDS of girls was either higher or equal to that of the boys except for the 9–11 months age group (Figure 2).

Determinants associated with child undernutrition

We found that various determinants were significantly associated with child undernutrition including: maternal undernutrition (adjPR = 1.47; 95%CI: 1.14–1.89), inadequate child dietary diversity (adjPR = 1.90; 95%CI: 1.22–2.97), daily laborer occupation of household head (adjPR = 2.10; 95%CI: 1.43–3.09), and occurrence of



	6-8 months	9-11 months	12-14 months	15-17 months	18-20 months	21-23 months
mean female MUACZ	-0.60	-0.75	-0.63	-0.89	-0.69	-0.60
mean male MUACZ	-1.02	-0.99	-1.04	-1.06	-1.25	-0.85
mean female CDDS	1.5	2.1	2.5	2.3	2.5	2.9
mean male CDDS	1.3	2.2	2.2	2.3	2.5	2.5

Figure 2. Patterns of mean child dietary diversity score (CDDS) and MUACZ score by sex and age of children, KA-HDSS, Tigray, northern Ethiopia (n = 1, 525).

morbidity among a family member (adjPR = 1.83; 95% CI: 1.15–2.92) (Table 2). Furthermore, higher family size (adjPR = 1.10; 95%CI: 1.02–1.18) and residing in highlands (adjPR = 1.93; 95%CI: 1.36–2.75) were also significantly associated with a higher burden of undernutrition. However, the effect of highland geographic location was significantly modified by the diverse food cropping practice of households. Compared to lowlander children living in households with no crop or monocrop production, highlander children who lived in households that produced more than one type of food crop had a significantly lower prevalence of undernutrition (adjPR = 0.42; 95%CI: 0.23–0.77) (Table 2).

In comparison with the children who lived in the poorest households, those who lived in the poor, medium, wealthy, and wealthiest households had 0.65, 0.64, 0.46, and 0.53 times lower risk of child undernutrition. Moreover, history of adult death from both chronic and other CoD were not found to be associated with child undernutrition (Table 2).

Child dietary diversity by sex and age

Majority of the study participants, 81.3% (95% CI: 79.2, 83.1), had an inadequate dietary diversity. High child dietary diversity (≥6 food groups per day) was commonly observed among children whose household heads were married, wealthier households and children residing in low or midland geographic location (Table C1). The least consumed food groups among children in this study were fleshy (6.2 %) and vitamin A rich fruits and vegetables (9.2 %). Whereas, consumption of grains, roots, and tubers (89.8%) and eggs (43%) were considerably higher. Other food groups such as dairy foods, legumes and nuts, and other fruits and vegetables were consumed to 29.8 %, 23.3 % and 14.4 %, respectively. There was no significant difference found among consumption of each food group by sex, except for consumption of eggs, which was found to be more common among the female children (45.9% vs 40%, p = 0.018).

The consumption of each food group when disaggregated by age group of the children showed statistical significance (p < 0.01). We found that dairy foods, eggs, grains, roots and tubers were more likely to be offered to the younger age groups, while fleshy and vitamin A rich foods were more frequently consumed by the oldest age group (Figure 3).

Determinants associated with child dietary diversity (CDD)

Children from the wealthiest and wealthy households had 2.57 (OR = 2.57; 95% CI: 1.53–4.31) and 3.06 (OR = 3.06; 95% CI: 1.88–4.99) times greater odds of

Table 2. Prevalence ratios (PR) for the determinants of child undernutrition using crude and adjusted (for all the variables in the table) GLM log-binomial model, KA-HDSS, Tigray, northern Ethiopia (n = 1, 525).

		Undernutrition			
Variables	Categories	Crude PR (95% CI)	p-value	Adjusted PR (95% CI)	p-value
Residence	Urban	1.00		1.00	
	Rural	2.41 (1.02, 4.45)	0.045	1.77 (0.62, 5.04)	0.286
Sex of household head	Male	1.00		1.00	
	Female	0.74 (0.48, 1.13)	0.166	0.86 (0.56, 1.31)	0.472
Maternal health-seeking practice	Poor	1.00		1.00	
	Good	0.76 (0.55, 1.05)	0.098	0.92 (0.66, 1.27)	0.615
Age of household head (5-year increase)		1.08 (1.03, 1.14)	0.002	1.03 (0.97, 1.10)	0.358
Occupation of household head	Farmer	1.00		1.00	
	Daily laborer	1.76 (1.27, 2.46)	0.001	2.10 (1.43, 3.09)	<0.001
	Government employee and other occupations	0.60 (0.29, 1.23)	0.160	1.75 (0.75, 4.08)	0.196
Child dietary diversity score	Adequate	1.00		1.00	
	Inadequate	1.87 (1.23, 2.82)	0.003	1.90 (1.22, 2.97)	0.005
Maternal undernutrition	No	1.00		1.00	
	Yes	1.81 (1.40, 2.33)	<0.001	1.47 (1.14, 1.89)	0.003
Wealth index	Poorest	1.00		1.00	
	Poor	0.54 (0.38, 0.77)	0.001	0.65 (0.45, 0.93)	0.020
	Medium	0.52 (0.36, 0.74)	<0.001	0.64 (0.44, 0.93)	0.019
	Wealthy	0.35 (0.23, 0.54)	<0.001	0.46 (0.30, 0.70)	<0.001
	Wealthiest	0.42 (0.28, 0.62)	<0.001	0.53 (0.34, 0.82)	0.004
History of adult death in household	No history of death	1.00		1.00	
	Chronic diseases	0.80 (0.35, 1.84)	0.594	0.96 (0.42, 2.17)	0.918
	Acute, external and other causes	0.62 (0.24, 1.60)	0.327	0.61 (0.24, 1.53)	0.292
Geographic location	Lowland	1.00		1.00	
	Highland	1.45 (1.11, 1.89)	0.007	1.93 (1.36, 2.75)	<0.001
Two weeks history of morbidity	No	1.00		1.00	
	Yes	1.92 (1.20, 3.07)	0.007	1.83 (1.15, 2.92)	0.012
Household size		1.13 (1.06, 1.20)	<0.001	1.10 (1.02, 1.18)	0.016
No crop or monocrop production	Yes	1.00		1.00	
	No	0.72 (0.56, 0.93)	0.011	1.00 (0.70, 1.43)	0.999
Highland#variety crop production (yes)		0.56 (0.35, 0.90)	0.018	0.42 (0.23, 0.77)	0.005

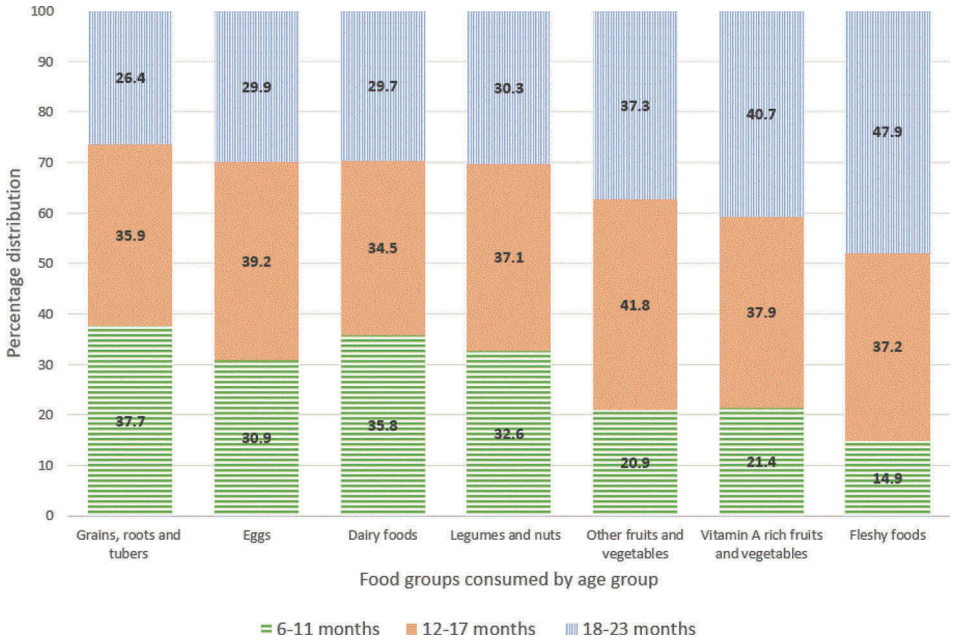


Figure 3. Proportion of children who consumed each food group per day by age group, KA-HDSS, Tigray, northern Ethiopia (n = 1,525).

having a higher dietary diversity compared to children from poorest households, respectively, given the other variables are held constant. Another factor that influenced the likelihood of a lower dietary diversity was when the household head was not in a marital relationship, but this association did not fully rule out the role of chance (Table 3).

As shown in Table 3, the variable 'geographic location' violates the parallel-lines assumption of the proportional odds model. Therefore, the interpretation of the pattern of association of this variable with the outcome variable should be based on its unconstrained effect. Accordingly, highlanders compared to lowlanders showed a 0.23 (OR = 0.23; 95%CI: 0.10–0.57) times lower likelihood of having a high vs the combined medium and low dietary diversity. However, the likelihood of the combined high and moderate dietary diversity vs low dietary diversity was 1.17 (OR = 1.17; 95%CI: 0.74–1.84) times higher for highlanders as compared to lowlanders. Additionally, for a unit increase in food crops variety in the highlanders, that is, going from monocrop/no

Table 3. Results from partial proportional odds model (POM) using child dietary diversity score with three ordered categories, KA-HDSS, Tigray, northern Ethiopia (n = 1, 525).

		High CDDS vs (low and medium CDDS)		High and medium CDDS vs (low CDDS)	
Variables	Categories	Adjusted OR (95% CI)	p-value	Adjusted OR (95% CI)	p-value
Household size		1.05 (0.96, 1.13)	0.297	1.05 (0.96, 1.13)	0.297
Maternal health-seeking practice	poor practice	1.00		1.00	
	Good practice	1.07 (0.78, 1.45)	0.678	1.07 (0.78, 1.45)	0.678
Household head occupation	Farmer				
	Daily laborer	0.77 (0.46, 1.30)	0.330	0.77 (0.46, 1.30)	0.330
	Govt. employee and all others	0.88 (0.47, 1.67)	0.704	0.88 (0.47, 1.67)	0.704
Wealth status	Poorest	1.00		1.00	
	Poor	1.09 (0.64, 1.86)	0.759	1.09 (0.64, 1.86)	0.759
	Medium	1.49 (0.90, 2.46)	0.124	1.49 (0.90, 2.46)	0.124
	Wealthy	3.06 (1.88, 4.99)	<0.001	3.06 (1.88, 4.99)	<0.001
	Wealthiest	2.57 (1.53, 4.31)	<0.001	2.57 (1.53, 4.31)	<0.001
History of adult death	No history of adult death	1.00		1.00	
	Death from chronic diseases	1.08 (0.51, 2.27)	0.841	1.08 (0.51, 2.27)	0.841
	Death from acute, external and other causes	1.20 (0.54, 2.65)	0.662	1.20 (0.54, 2.65)	0.662
Geographic location*	Low/midland	1.00		1.00	
	Highland	0.23 (0.10, 0.57)	0.002	1.17 (0.74, 1.84)	0.510
Farmland size	≤2 ha	1.00		1.00	
	>2 ha	1.28 (0.91, 1.80)	0.151	1.28 (0.91, 1.80)	0.151
Variety crop production (yes)#highland geographic location		2.92 (1.75, 4.85)	<0.001	2.92 (1.75, 4.85)	<0.001
Marital status of household head	Married	1.00		1.00	
	Not in marital relationship	0.59 (0.33, 1.06)	0.078	0.59 (0.33, 1.06)	0.078

*Gamma_2 value is significant (p < 0.001) for the variable 'Geographic location'; it violates the parallel-lines assumption of the POM

crops production to variety crops production and going from lowland to highland, the odds of having better dietary diversity was found to be 2.92 (OR = 2.92: 95%CI: 1.75–4.85) times higher given that the other variables fitted in the model are held constant.

Discussion and conclusion

This study examined the burden and drivers of poor child nutrition among children aged 6–23 months in KA-HDSS, northern Ethiopia. The prevalence of child undernutrition (13.7 %) and inadequate child dietary diversity (< 4 food groups/day) (81.3%) was found to be high in our study setting. Key nutrition specific drivers of undernutrition included maternal undernutrition, inadequate access to child dietary diversity, and occurrence of morbidity. Furthermore, the principal nutrition-sensitive drivers of undernutrition were household poverty, larger family size, daily laborer occupation of household head, residing in highlands (≥ 2,300 meter) particularly where no diverse food crop production farming was practiced. Moreover, higher child dietary diversity (≥ 6 food groups/day) was positively associated with better wealth status and diverse food crops production.

In the study area, the prevalence of acute child undernutrition (MUAC<-2 z-score) was higher than the regional and national prevalence [9]. It is also considerably higher than the WHO's 2025 target of 'reduce and maintain childhood wasting to less than 5%' [70]. Although the WHO's target for wasting, which is based on WHZ<-2 z-score, is not identical with MUAC<-2 z-score, these two nutritional indices were shown to have similar performance in diagnosing acute child undernutrition [71]. Wasting among young children is associated with later detrimental effect on skeletal growth subsequent to linear growth retardation [72,73], and especially its concurrence with stunting, predicts high risk of child mortality [74,75]. Moreover, evidence on developmental origins of health and disease (DOHaD) revealed that survivors of severe acute undernutrition were reported to show traits of thrifty growth in later life [37], specifically, the association of early childhood infections and growth failure with elevated cardiovascular risk factors during adulthood is novel [34,36]. Considering the short and long-term deleterious impacts of wasting, addressing its key drivers could enormously enhance young child survival and well-being in the study setting.

The sex-specific analysis of undernutrition showed that boys were evidently more disadvantaged than girls. Our result accords with the findings of other studies [75–77], but it is inconsistent with the study from elsewhere [78], which also reported child age as an important factor. On the other hand, other studies from north Ethiopia reported no sex-differential of wasting, but of stunting [26,72]. Researchers explained that sex-specific differential burden of child undernutrition could be a manifestation of the complex interplay of the biologically higher vulnerability of males to symptomatic infectious illnesses and various context-specific factors such as cultural practices [26,79]. The apparently higher morbidity exposure of boys and relatively higher intake of quality diets by girls, reported in this study, might partly explain the observed nutritional inequality. Yet, further understanding of the underlying factors of the observed sex-specific inequality of child undernutrition, using qualitative research approach and longitudinal quantitative measurements accounting for the transitory nature of wasting, could have vital implications to public health nutrition policy and decisions aimed at addressing health inequity and ensuring nutritional wellbeing of all young children.

Adequate dietary diversity is a useful indicator of dietary quality and nutrient intake for infants and young children [18,51,80]. More than four-fifths of the participants of this study had no access to adequate dietary diversity, and this finding is markedly lower than the national estimation by Aemro et.al, which was 89.2% [19]. Similar to previous studies, inadequate access to child dietary diversity is found to be a strong predictor of child undernutrition [18,22]. Our finding shows a significantly lower consumption of some nutrient dense foods such as dairy, fruits and vegetables rich in vitamin A by the undernourished children. This might have co-exposed them to various deleterious risk factors (mainly infections like diarrheal diseases) that could influence their nutritional wellbeing [11,81]. In general, the study area is one of the most food insecure parts of Ethiopia, and pro-poor-oriented policy level developmental programs have been shown to be promising in ensuring household food security [82–84]. On top of such policy efforts, the implementation of home-based nutrition-sensitive interventions (home gardening, effective safety net programs together with asset and income-generating activities to poor households) and advancing maternal knowledge on child feeding practices may sustainably improve child nutritional status in such food insecure settings [5,12,38,81,83–87].

Many studies revealed that maternal nutritional status determines birth outcomes and neonatal survival, and has a pivotal role in fetal and child nutrition and development [2,12,29,81,88]. Consistent with these findings, our study indicates that children of undernourished mothers (MUAC < 23cm) were also more likely to suffer from undernutrition in contrast to those whose mothers were not undernourished. This may highlight the constitutive importance of promoting maternal-child dyad nutrition to

substantially address young child undernutrition. The implementation of high impact maternal nutritional interventions could have indispensable inputs to reduce the burden of young child undernutrition and mortality [2,12,34]. Another notable finding of this study is the significant negative association of households' morbidity experience with the young children's nutritional wellbeing. Likewise, other studies identified that morbidity is considered to be one of the vital nutrition-specific determinant of child undernutrition, mainly due to its effect on dietary intake and nutrient utilization [11,25,27]. However, because of the limitation of our study design, we are not able to confirm if morbidity had resulted in child undernutrition or vice versa.

In line with other research findings [13,16,18,29,89], the current study has identified that higher household wealth status was associated with lower risk of child undernutrition. This association is independent of the effect of access to quality diet [18,90], a robust indicator of child undernutrition, and that wealth status may have influenced child nutritional status through multiple other pathways. As presented in our results, one such pathway could be the influence of wealth status on housing quality. This underscores the cross-functional role of household wealth on promoting young child nutrition by addressing the various nutrition-sensitive determinants of child undernutrition.

Higher family size was one of the strong nutrition-sensitive drivers of child undernutrition. This broadly substantiates the findings of previous studies [13,27,90,91]. In this study, the mean family size was differentially higher in the households where family planning (FP) was not utilized compared to the households where FP use was practiced (6.4 vs 5.9, $p < 0.001$). These findings imperatively call for making FP into effect to promote good nutritional status of mothers and their children [21,91]. The inverse association of household heads' employment insecurity with undernutrition and poor child dietary diversity is direct [17,22]. As similarly reported by other studies [24,28], the burden of undernutrition was significantly higher among highlanders. Our data suggest better access to housing quality, media, sanitation, and electricity services by the low and/or midland households as compared to the highland households could have contributed to the higher burden of undernutrition among the highlanders as compared to their counterparts. However, the association of residing in highlands with child undernutrition strongly decreases in households which practiced diversified food crop production. This clearly shows that interventions targeting the agricultural sector to become nutrition-sensitive could potentially accelerate long-lasting effect for ameliorating child undernutrition, particularly if it is linked with the nutrition-specific interventions [12,38,92]. Despite our expectation, we did not find a statistically meaningful difference in the burden of child undernutrition by history of adult death, and the small adult death events in the study households might have limited the ability to detect its effect on child undernutrition.

Our study identified that inadequate child dietary diversity, maternal undernutrition and occurrence of morbidity were the robust nutrition-specific drivers, whereas, household poverty, household heads' employment insecurity, larger family size, residing in highland households especially where no diverse food crops production was practiced were the strong nutrition-sensitive drivers of child undernutrition. The findings strongly suggest that intervention efforts aiming to reduce young child undernutrition should jointly address the examined nutrition-specific and sensitive drivers. For the success of such efforts in resource poor and food insecure rural settings, strong trans-sectoral collaborations and cross-disciplinary interventions, for instance the implementation of holistic developmental intervention programs and further interdisciplinary researches by the agriculture, nutrition and health sectors, could be highly important. The analysis of the effect of a wide range of possible drivers and the completion of the study before the 2016/17 el Nino shock, which may reflect the drivers of young child undernutrition under relatively stable conditions, are the major strengths of this study. However, due to the cross-sectional design of the study, the revealed relationships are only associational, and hence causality cannot be claimed.

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Author contributions

SFA, EJA, AMB, AAG, GE, JL, AW, and VS have substantial contributions to the conception or design of the work, the acquisition, analysis, interpretation of the data for the work; and drafting the work or revising it critically for important intellectual content; and final approval of the version to be published; and agreed to be accountable for all aspects of the work in ensuring that questions related to the integrity of any part of the work are appropriately investigated and resolved.

Disclosure statement

No potential conflict of interest was reported by the authors.

Ethics and consent

KA-HDSS was established with the ethical approval from Ethiopian Science and Technology Agency with an identification number of IERC-0030. Verbal consent was obtained from all the study participants. The Health Research Ethics Review Committee (HRERC) in Mekelle University also approved this study.

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Paper context

Acute child undernutrition remains a persistently prevalent health problem in Tigray region, where over the course of 16 years, its burden showed no change. The prominent added value of this paper is that it has identified the nutrition-specific and sensitive determinants of young child undernutrition by examining a wide range of socio-economic, epidemographic, agricultural, and other nutritional factors. Joint interventions by the agriculture, nutrition and health sectors are urgently needed to address young child undernutrition.

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Chapter 6: General discussion

Chapter 6: General discussion

This Ph.D. project was undertaken to investigate the epidemiology and social determinants of NCDs-ascribed adult mortality, and to examine the association of chronic diseases attributed adult mortality with maternal and young child undernutrition using longitudinal and cross-sectional data from Kilte Awlaelo-Health and Demographic Surveillance site (KA-HDSS). In furtherance of this aim, this project advances our understanding of the growing burden of NCD-ascribed adult mortality and its social determinants for a predominantly rural community located in the northern-most region of Ethiopia. This thesis presents several contributions to the literature. The first contribution is that it provides evidence on the level of adult mortality burden caused by NCDs and identifies its key social determinants. With this, it enriches the literature in relation to the severe impact of NCDs – as measured using adult mortality – from the context of a predominantly rural population in Eastern Zone of Tigray region, northern Ethiopia. To our knowledge, this work has shown for the first time that NCD-attributed mortality varies by the relationship that household members have with their household head: extended family and non-family members of the household head were observed to experience a differentially higher hazard of mortality compared to the household head. In addition, this work can be considered as the first study which has attempted to investigate whether mortality of adult household member due to chronic diseases (from both NCDs and chronic communicable causes) was associated with maternal and child undernutrition.

In the following sub-chapters, this doctoral thesis will summarize the key findings and conclude by detailing the strengths and limitations of the study.

6.1 Epidemiology and social determinants of adult mortality from NCDs

6.1.1 Epidemiology of adult mortality from NCDs

The first paper focused on determining the level of NCD-attributed adult mortality and its social determinants in the predominantly rural population of KA-HDSS population using longitudinally collected data from September 2009 to April 2015. Accordingly, this sub-section first discusses the evidence base regarding the epidemiology of NCD-attributed adult mortality with studies mostly implemented in similar surveillance research platforms, various independent field works, and national and global studies.

The first study (Chapter 3) found that 34.5% of the total 1,091 adult deaths were due to NCDs. With 33% of the total deceased adults, mortality from communicable diseases was comparable with that of NCDs. Our study suggests that a double mortality burden was evident, with injuries forming a triple mortality burden in the surveillance population, accounting for 11.5%. In agreement with our findings, studies from North-West and Eastern HDSS sites showed that a double mortality burden, both from NCDs and communicable diseases, has occurred in Ethiopia [1,2]. However, unlike the finding from North-West Ethiopia, the burden of mortality caused by NCDs in Eastern Ethiopia was lower than that of caused by communicable diseases,

although the trend for NCDs has shown increases since 2012 [2]. Similar to our finding, pooled data from 22 African and Asian HDSS sites showed that the share of NCD mortality was at 35.6% [3]; however, the proportions of NCD mortality were generally higher in Asian sites than in most African sites. This multisite study covered data which were available up to 2012. However, more recent data from Agincourt HDSS of rural South Africa and Korogwe HDSS of Tanzania showed comparable levels of NCD mortality, with 36% and 37.1% respectively [4,5]. With the exception of Navrongo of Ghana, African surveillance sites were observed to have lower NCD to non-NCD age standardized mortality ratios, demonstrating that NCDs did not exceed all other causes of death combined [6].

At a similar level with HDSS data from Eastern Ethiopia, NCDs accounted for 24% of adults deaths in Ifakara HDSS in 2007 [7], but this has probably underestimated NCD mortality because its analysis was confined only to those adults younger than 60 years old, and gaps in the study period could also explain the differences. On the other hand, more than half of the reported deaths were caused by NCDs in Eastern Uganda [8], and unfortunately, this study is likely to overestimate the burden of NCD mortality because young adults were not included in the analysis. Such over estimation was observed when the data from Ouagadougou HDSS revealed a higher (67.1%) share of NCD mortality [9]. As shown previously, variations in proportion of NCD-attributed mortality across HDSS sites could be due to differences in the distribution of HIV/AIDS, presence of slummy areas in the sites [3,6,10], or because of analysis of data covering different calendar periods, and difference in age groups included in the analyses. Whether the proportions of NCD mortality were derived only from cause ascertained adult deaths could also be an important source of variation in the proportion of NCD ascribed mortality. In our study, the burden of adult mortality from NCDs increases by 6.9% when only the 908 cause-ascertained deaths are considered. In addition to these factors, differences in access and quality of treatment provided to NCD patients and possible cultural barriers (such as care seeking from traditional healers and informal care givers) could also be an important source of variation [11,12]. Notwithstanding the variations in the levels of burden observed in these studies, all the above-cited studies suggest that adult mortality from NCD is increasing whilst the mortality caused by communicable diseases continues to pose major public health challenge.

Population-based longitudinal data showed that LMICs are in a fast state of epidemiologic transition [6]. A shift in causes of morbidity and mortality are documented in Ethiopia [13–15]. The high adult mortality shares from NCDs, as compared to communicable diseases, during later periods in Butajira district (1995 to 1999 vs. 2008 to 2019) could be a clear evidence that Ethiopia is experiencing an epidemiologic transition [16,17]. There was a significantly increased trend of NCDs-attributed mortality between 2008 to 2019 in the same district [17]. Also, the lower proportion of NCDs-attributed mortality revealed in former analysis of KA-HDSS data could also substantiate the interpretation that epidemiologic transition is going on in Ethiopia [18]. Analysis of Addis Ababa Mortality Surveillance data, covering 2007 to 2017, revealed a similar pattern of transition in cause of death from communicable diseases to NCDs [19]. However, this mortality surveillance-based data showed a higher

share of NCD mortality than our finding for two possible main reasons. On one hand, it came from the very urban population of Addis Ababa [19] where the risk of dying from communicable diseases could be lower than the predominantly rural KA-HDSS population, due to a relatively better access to health services [20]. As a result, people who can survive communicable diseases and attain a higher life expectancy are more likely to be affected by and die from NCDs [21]. It is clear that the distribution of NCDs and their risk factors is likely to be higher in the urban population as opposed to rural population [22,23]. But, this does not necessarily suggest a higher mortality proportion in the presence of better access to NCD treatment in the urban settings, i.e. urbanites may have a better chance of surviving the ravages of infectious diseases to live to develop NCDs, but may also be better able to survive NCDs, as compared with people in the countryside with less access to healthcare services. Driven by the prevalent NCD risk factors, and increased life expectancy, mainly due to a decline in communicable diseases, NCD- morbidity and mortality are becoming more prevalent in both rural and urban areas of Ethiopia [24–33].

Given the existing context of poor clinical service quality, the burden of adult mortality from NCDs and its impacts are likely to increase. A nationwide assessment of service availability and readiness in Ethiopia was undertaken in 2016, and the results have shown that NCD-related health service delivery was poor [34]. Low quality clinical service provision, manifested in diagnosis and treatment delay, could be a strong determinant of mortality [12,35]. Communities' perceptions of poor health service quality could also influence care seeking practice, and this alone was estimated to account for 18.1% of the NCD mortality in South Africa [4]. Compounded by patient- and health system-related factors, late stage diagnosis and treatment discontinuation could contribute to increased risk of mortality from NCDs [11,36–38]. For instance, nearly three-fourths of the breast cancer cases in South and South-west Ethiopia were otherwise diagnosed with late-stage disease [39], and this was shown to increase mortality risk [40,41].

According to this study, the majority of the total deceased adults (79.9%) and more than four-fifths (82.3%) of the NCD-attributed deaths occurred at home. If death at health facilities can be a good proxy for access to care or health seeking practice during terminal illness, then it was likely that health seeking practice of the deceased cases was poor during their terminal illness. Considering the delayed care seeking practice and financial problems borne by NCD patients, along with the barriers and slow transition of the health system to provide accessible NCD services [36,42,43] in the context of increasing NCDs and the Tigray region's poorly-prepared health system [44], our observation of higher burden of adult mortality from NCDs might be justifiably expected. With this in mind, efforts to optimize the Ethiopian health system to simultaneously address the prevailing challenges of double mortality burden is required [45,46], and this should also take into account the growing impact of external causes [47].

Regarding the most prominent specific causes of death, it was shown that cardiovascular diseases were the top cause of adult death in both sexes, accounting for 41.8% of the total NCD deaths (Chapter 3). Cerebrovascular accident (stroke) alone accounted for 22.1% of the NCD deaths with 53% of these deaths being clustered

among men. Similar to this study, almost 50% of the premature mortality in Iran were due to ischaemic heart disease and stroke [48]. In accordance with these findings, analysis of global burden of diseases data for Ethiopia showed that ischaemic heart disease and stroke were the leading causes of mortality in Ethiopia in 2015 [49,50]. Between 2007 and 2013, renal failure caused 12.2% of the total 377 NCD deaths in Northwest Ethiopia [1]; this was lower than our finding of 18.1%. The general trend of cardiovascular diseases and cancers as leading causes of death in the study population was in line with the KA-HDSS 2009-2011 data [51]. The evidence that cardiovascular diseases, especially ischaemic heart disease, are the leading cause of mortality in the older population is consistent with the literature [52]. Whilst this was the state of epidemiology in the burden of NCDs-attributed adult mortality in KA-HDSS during 2009 to 2015, Ethiopia's health system preparedness for facing this growing challenge, during the above period and since, seems in its infancy: only 1% and 7% of the 41% health facilities which were delivering cardiovascular disease service had trained staff and the 12 items of cardiovascular service indicators [34]. Cervical cancer diagnosis services were available only in 2% of the health facilities. The diagnostic and management services for diabetes mellitus were low, and DM service availability in rural health facilities was very limited compared to the urban health facilities, 5% vs. 34% respectively [34]. Evidence suggested that the physician to population ratio was low in Tigray, and with a high degree of doctors' turnover [53,54]. Mortality ascribed to ischaemic heart disease, congestive heart failure and chronic liver disease seem to follow similar trend with the surveillance sites located in Northwest, Eastern and Central Ethiopia [1,2,14]. Against this background, adult mortality from NCDs is unlikely to either decline or stabilize, and it would rather seem poised to continue imposing its irreversible public health burden both regionally and nationally. Moreover, adult mortality from NCDs will likely increase, especially in Tigray region, given the ongoing political instability in Ethiopia which has been accompanied by the bloodiest war since November 2020 and the disruption of regional health systems in the Tigray, Amhara and Afar regions [55–58].

6.1.2 Social determinants of adult mortality from NCDs: Age, literacy, & wealth status

Assessing the social-determinants of NCD attributed mortality was an important component of the investigation of burden of NCD mortality in KA-HDSS population (Chapter 3). The impact of socioeconomic contexts and positions in creating differential exposure to NCD risk factors, differential vulnerability, and differential health outcomes and consequences is well presented in the World Health Organization's Commission on Social Determinants of Health analytical framework for prioritizing public health conditions [59].

In this study, 65.4% of the NCDs deaths were clustered in the ≥65 age group (Paper I). Adjusting for several fitted variables including sex, marital status, education, wealth status, residence, the hazard of death was 35% excess per 5-year increase in age. Older age is often associated with higher likelihood of disability and mortality from NCDs [21,60]. In the analyses of KA-HDSS data, the strong effect of age on NCD-attributed mortality was clearly reflected when the protective effect of education was attenuated by 18% for every five-year age increase of the modeled cohort members (Chapter 3). This also implies that the protective effect of higher education

on NCD-ascribed mortality persists independent of the effect of age. Several lines of evidence suggest education as the strongest upstream determinant of health and disease [61–66]; and its influence on morbidity and mortality from NCDs is well-established, although its magnitude of impact differs by level of education [65,67–69]. NCD-ascribed mortality was inversely related to educational attainment [70,71]. Wekesah et al. estimated that a completion of a minimum of primary school level could have led to a 39% reduction in cardiovascular mortality [72]. Education- in relation to its positive association with increased health literacy leading to better care-seeking practice- might explain the lower hazard of NCD mortality for those with formal education than for those who were not able to read and write [12,73–76]. Educational attainment and health literacy could influence healthy behaviors, care-seeking practice and survival [75,77].

Analysis of 16-year cohort data showed strong inverse association of education, income, and occupation on all-cause mortality after adjusting the effect of age [78]. In contrast, our analysis showed no substantial variation in NCD-attributed adult mortality with respect to wealth status and occupation (Chapter 3). However, when we redefined our multivariable Cox proportional hazards model later, by combining the middle three quintiles as "medium wealth status", our data revealed that those which were in wealthiest (HR= 0.52 [95%CI: 0.33, 0.83]), and medium (HR= 0.67 [95%CI: 0.45, 0.99]) quintiles had 48% and 33% lower hazard of NCD-attributed mortality compared to those which were in the poorest quintile (quintile 1). It is notable that categorizing the lower two wealth quintiles (quintiles 1 and 2) as "poor", the upper two quintiles (quintiles 4 and 5) as "wealthy", and the middle quintile 3 as "medium" did conceal the effect of asset-based household wealth status on NCD-ascribed adult mortality in KA-HDSS. No change in effect size and direction of association was observed for the other fitted variables when the household wealth status variable was refitted with the new classification. In 2022, A meta-analysis from Ethiopia found that the poorest quintile was three times more likely to experience catastrophic medical expenses than the richest quintile, and selling household assets was the most important coping mechanism [79].

6.1.3 Social Determinants of adult mortality from NCDs: Relationship to household head

This study found evidence of an increased risk of death from NCDs among extended families and non-family household co-residents compared to heads of households (Chapter 3). This offered a valuably novel contribution to the literature by nuancing our understanding of excess hazard of NCDs-attributed adult mortality from within the households' structure in study population.

Similar to our finding, a study from India showed that household headship prevents long-term mortality among older adults, with 24% excess hazard of mortality for those who were not household heads compared to those who were household heads [69]. The explanation given in the Indian study [69] that reduced mortality hazard for household heads could be associated with their likelihood of control of household affairs (such as financial and social affairs) and greater sense of authority may as well explain our finding. Household resources may not be accessed equally by all the co-residing household members [80,81]. Evidence drawn from Ethiopian data also

showed that mortality was substantially associated with a weaker involvement in joint household decision making [82]. Moreover, Calvi et. al found less bargaining power by post-reproductive age women to access household resources, and their differentially lower access to intra-household resources was overlapping with their excess mortality [83]. It is unarguable that members that are living in rich households do not necessarily mean that these individuals are rich; as for example, one-third of the poor individuals in Bangladesh were living in non-poor families [84]. This may indicate differential access for resources by members of the same households. Due to such unequal intra-household conditions, the extended family and non-family co-residents of our study site, who might also be less contributing to their respective household economy because of their chronic morbidity, could be the most vulnerable segments in this regard, exposing them to a higher hazard of mortality from NCDs.

It can be expected that illness of a household member is a stressful experience to other caregiving families and co-residing members. This negative intra-household condition could often be of chronic experience when it is especially caused by NCDs and communicable diseases of chronic nature. In this case, health problems can spill over to care giving household members. Caregiving to NCD patients is an immense responsibility that may include one's own financial, employment, emotional and social life sacrifices [85]. Studies have shown that caregiving families of NCD patients could experience higher burden of physical, social, emotional and financial problems [86–88]. As the duration of care increases, so does caregivers' burden and risk of depression [86,89,90]. On top of other factors, including possible economic traps related to continual high medical expenditure, the need for long-term support could lead to compassion fatigue among the family caregivers, and all this may cumulatively increase hazard of mortality [11,38,41,79,85,91–93]. This mortality impact may be more pronounced in the vulnerable extended family and non-family members. On the other hand, the quality of intra-household relationship could be an important factor to consider, as this might have relevance to the social wellbeing of all household members [94,95], particularly to the extended family and non-family members as they could be worse exposed. Such problematic relationships were documented, especially between daughter-in-law and mother-in-law [96], and this may lead to reduced social support and increased depression- potentiating higher hazard of mortality among the vulnerable household members. Prior studies have underlined the significance of social support in reducing comorbidities and improving survival of breast cancer patients [97–99]. Regardless of the explanations presented above, to be able to uncover the possible reasons and improve our understanding of why extended family and non-family household members experienced differentially higher hazard of NCD-attributed adult mortality warrants further investigation. This may help to narrow intra-household inequalities in morbidity and mortality due to NCD.

6.2 Adult mortality from chronic diseases and undernutrition among lactating mothers

In chapter 4, we have described and presented nutritional status of lactating mothers with detailed interpretations of its factors including the agro-epidemiologic and housing factors. Adjusting for several factors,

the study has shown that good maternal health-seeking practice, production of diverse food crops, improved housing and environmental factors index (HEAFI) were associated with lower risk of maternal undernutrition. However, households' history of adult mortality from chronic diseases showed modest association with increased maternal undernutrition, but strongly associated with severe maternal undernutrition. Similarly, recent occurrence of household level morbidity was associated with increased maternal undernutrition.

In this section, I will briefly summarize and interpret the situation of maternal undernutrition in KA-HDSS, Eastern Zone of Tigray in the context of other settings and focus only on the association of households' experience of adult mortality from chronic disease and its association with maternal undernutrition. To date, this study is the first of its kind which attempted to explore the association of households' experience of adult mortality from chronic diseases with maternal and child undernutrition, with a particular focus on food insecure population of KA-HDSS, using longitudinal and survey data. There is a lack of the literature that investigates the association of chronic diseases ascribed adult mortality (both in their broad and specific category forms) with maternal and child undernutrition, but some works on the link between HIV/AIDS-related adult mortality and households' wellbeing and agricultural productivity have taken a similar perspective. This highlights that this topic is understudied, and may reflect the novelty of the current work. Researchers may, however, prioritize this understudied theme to bridge the evidence gap prevailing on this relevant public health domain. Both this sub-chapter and the upcoming sub-chapter will begin by summarizing the burden of maternal and child undernutrition respectively, and then proceed to interpret the findings with respect to chronic-disease-attributed adult mortality.

Due to their high nutritional demand, lactating mothers and their dyads are among the most nutritionally vulnerable household members [100,101]. This can be worsened due to inadequate dietary intake and poor dietary quality related to many other factors [102,103]. The prevalence of undernutrition (based on MUAC measurements) among lactating mothers of KA-HDSS was in the range of 36.1 - 40.1%, and this was slightly higher than the finding in Afar (33.3%) region [104], but much lower than the one reported from Amhara region [105]. However, the level of severe undernutrition (6.6% with MUAC <21 cm) in this study was lower than other studies [102,106,107]. As explained in Chapter 4, the relatively lower prevalence of severe undernutrition in this study, despite the high burden of overall undernutrition, might reflect the positive impacts made by development-focused interventions [108,109].

The distribution of undernutrition among reproductive age mothers varied spatially, with greater odds of undernutrition for mothers in Tigray and Afar region [110]. Regional differences in the burden of undernutrition among lactating mothers were also noted in Uganda [111]. Variations in agro-ecological conditions, socio-religious practices like religious fasting, vulnerability to disasters, availability of nutritional interventions, the settings and contexts from which the data came, that is, whether the data came primarily from agrarian, pastoral, or

humanitarian settings, or differences in study period and composition of the study participants might have contributed for the observed differences [104,105,107,111–113].

In line to our hypothesis, this study revealed suggestive evidence that maternal undernutrition was higher in households with a history of adult mortality from chronic diseases compared to the households which experienced no death or death from non-chronic diseases. Lactating mothers from affected households had 28% excess risk of severe undernutrition compared to those who were living in the non-affected households (chapter 5).

Prolonged duration of illness from chronic diseases may translate to increased household resource consumption, higher care burden, higher risk of depression among caregivers, and sustained stress to households. Each of these unfavorable conditions may influence the wellbeing of household co-residents, but greater impact could occur among the care givers, especially the mothers [114]. For instance, adults who emigrated for work to urban areas may come back to their family in need of care during their terminal illness from HIV/AIDS [115]. Home care provided by families is the primary form of informal care in Ethiopia. In connection with this, it was revealed that care burden could be associated with poor mental health and financial challenge among family caregivers [86,116–122], and this could negatively affect the dietary quality and feeding practice of the lactating mothers [123–126].

Long-term illness of the suffering patients could generally be associated with a continuous need for treatment and care throughout their lifetime, which often could be associated with high medical expenditure [127,128], due to the fact that direct and indirect costs were mainly incurred by the patients or their family members in the study area. This in turn may negatively impact the welfare and food consumption of households. In support of this explanation, a meta-analysis study from Ethiopia provided evidence of catastrophic medical expense for households afflicted by chronic diseases [79], and a link between expenditure induced by NCDs and consumption displacement among poor households was found in Bangladesh [129]. Evidence drawn from a panel household data showed a 7% consumption decline within the first five years after HIV/AIDS-caused adult death [130]. A study from Kenya showed that the odds of a household being impoverished due to out-of-pocket expenditures was nearly 32 higher with NCDs than with communicable diseases [131]. Numerous studies have shown that the cost of illness of chronic diseases incurred by Ethiopian households is at a very high level [79,91,127,132–138]. The effect of such expenses was shown to reduce food consumption in rural Ethiopia [139], and it could also expose households to food insecurity [140,141].

Impoverishment associated with the selling of household assets to compensate chronic medical expenditure could probably explain the observed higher maternal undernutrition in the affected KA-HDSS households. Selling household assets, especially sales of livestock in a predominantly agrarian community was found to be common in affected households [79,142,143], but members of households which lacked assets were obliged to leave their own field and work in someone's field to meet the needs of their families [143]. These conditions may reduce

crop production, an important factor associated with maternal undernutrition in this study (Chapter 4). It was shown that production of staple food was significantly lower in households affected by morbidity or mortality caused by HIV/AIDS as compared to the non-affected households [144]. Mortality of adult household members due to HIV/AIDS led to a change in household composition in rural Kenya with a further possibility of out-migration of the remaining working adults [145]. In Zambia, it was shown that initially poor households were less likely to attract additional adults, and this could imply an increase maternal workload in the study population [135,146]. The death of working adults (even death among >60 years) directly affects labor productivity, and this by itself can affect the quantity and types of food produced, which impacts dietary diversity and nutritional status of household members [146,147]. Given the heavy in-house and outdoor responsibilities (tasks like family care, water fetching, firewood collection, weeding, and herding livestock) that the rural mothers are expected to bear, such circumstances usually increase maternal workload exposing them to higher risk of undernutrition [147–153]. Misgina et al. showed that 59.2% of the mothers in KA-HDSS, interviewed before their pregnancy, rated their work burden as medium to difficult type [154]. As presented in chapter 4, the finding that households which experienced recent illness (within two weeks before survey initiation), compared to those which did not experience illness, had a 49% excess risk of maternal undernutrition, could perhaps substantiate the idea of maternal workload and care burden explaining our finding of a high undernutrition burden. Households affected by death or illness due to HIV/AIDS in 2002 had lower percentage of production of staple food in 2005 [144], showing that such conditions may not easily decay with time [130,145]. Off-farm incomes was reduced by about 35% to 40% for households affected by HIV/AIDS-ascribed adult mortality; net agricultural output was reduced by 68% when the deceased adult was a male household head [145]. Needless to mention, however, is that detailed primary data will need to be collected from the surveillance population to deeply nuance the mechanisms by which morbidity and mortality from chronic diseases influence nutritional status of lactating mothers and wellbeing of their infants and young children.

Recent evidence has highlighted that maternal and child undernutrition still remains a major global health problem and progress is slow in developing countries [155]. It is well documented that nutritional wellbeing of mothers is highly crucial not only to the health and survival of mothers, but also to that of their children, and can also expose them to a heightened risk of developing NCDs later in their lives [156–162]. For example, robust intergenerational linkage was found between maternal short stature with neonatal, infant, and under-5 mortality in Bangladesh [163]. Our research found that young children aged 6 to 23 months born to malnourished mothers had a 47% higher risk of malnutrition than their counterparts (Chapter 5).

6.3 Adult mortality from chronic diseases and young child undernutrition

Child undernutrition stubbornly persists as major health public health problem in Tigray region [164,165], and the zone where this study was implemented was one of the harder hit spots [166]. The burden of undernutrition (MUAC <-2 z-score) among 6 to 23 months old children was 13.7% with a 95% confidence range of 12.1 -

15.5% (Chapter 5). This was higher than the burden reported by Desalegn et al. using data collected in 2017 from Ganta Afeshum, Eastern Zone of Tigray [167]. The fact that the later study included apparently healthy children and that nutrition-sensitive intervention was ongoing by a German-based project could probably explain the higher burden of child undernutrition in our study area [168]. Data collected in two survey waves (from March to June in 2019) from food insecure areas of Tigray showed a substantial variation in child dietary diversity score by religious fasting period [169]. Despite the low proportions of infants and young children with adequate dietary diversity, the burden of undernutrition (8.6%) in these food insecure rural areas of Tigray region was lower than our finding [169]. It was also higher than the prevalence (9.4%) for 32 countries of sub-Saharan Africa, a study based on pooled demographic and health survey data covering 2010 to 2022 [170]. By contrast, our finding was almost comparable to the results of a study in Bangladesh (11), but lower than the finding in Burkina Faso, which reported a prevalence of 25% [171,172]. As explained by Paré et al., the Sahel region of Burkina Faso was described as a drought prone and highly food insecure region, aggravated by drought and socio-political unrest [172]. Compared to the present study, the level of undernutrition identified in the pastoralist community of Filtu town, Somali region, was higher by 3.8%; and, this discrepancy could be attributed to the fact that the study in Somali region was conducted during the drought season in which milk production, the main source of complementary food in this area, was highly reduced [173,174].

Our study showed that low child dietary diversity (consumption of <4 food types) was associated with 90% excess risk of undernutrition among the young children (Chapter 5). While fleshy (6.2%) and vitamin A rich fruits and vegetables (9.2%) were least consumed food groups, the most consumed foods were grains, roots and tubers (89.8%) followed by eggs (43%) and dairy foods (29.8%) (Chapter 5); the children in the KA-HDSS had a higher consumption of animal source foods compared to the food insecure districts of Samre Seharti and Tanqua Abergele districts in Tigray region [169]. Key barriers contributing to the very low consumption of animal source foods in these areas were identified: Low household income and sale of animal products to earn money, lack of nutritional knowledge, and poor linkage between the agriculture and health sectors [153]. Dietary diversity can prevent child undernutrition and enhance child survival by providing sufficient nutrients to infants and young children [170,175,176]. In this study, only 18.7% of children (6 to 23 months) in the KA-HDSS were fed with adequately diversified food (Chapter 5). This was higher than the finding in South Wello (7%), Southern Ethiopia of Gorche (10.6%) and Wondo Aleta (12%) areas, Dejen district in Northwest Ethiopia (13.6%), 13.4% in Burkina Faso, as well as the nationwide estimate of 10.8% in 2011 and 12.1% in 2016 [172,177–181]; but it was lower than the pooled meta-analytic estimate of Ethiopia (23.3%), 34.8% in Ghana, 30.4% in Nepal, and the overall finding for 32 sub-Saharan Africa countries (25.1%) [170,182–185]. On the other hand, our finding was comparable with the proportion of adequate dietary diversity reported in Ambo (17.9%), in North Showa (19.2%), and the 18% meta-analytic estimate for Ethiopia which pooled publications until 2018 [186–188]. Overall, child undernutrition, and poor child feeding practices remains a serious public health concern in Tigray region [189–196]. Like that of maternal undernutrition, child undernutrition and food consumption distribution also varied

spatially [110,164–166,197]. The extent of child undernutrition varies across studies depending on seasonality of data collection, household wealth status, maternal education and nutritional status, religious fasting, nutritional knowledge and feeding practices of mothers, epidemiology of childhood illness and treatment-seeking practice, setting and agro-ecology where the study population resides, availability of active nutrition-related interventions, urban-rural contexts - mainly because of its association with a relatively higher likelihood of access to treatment during illness, - improved water, and use of clean-burning energy, as well as media exposure [164,185,198–207].

A study in Kenya showed that income loss and treatment expense led to a reduction in dietary diversity, and that children living in HIV/AIDS affected households were undernourished [208]. Another study revealed that residing in HIV/AIDS affected households was associated with stunting of under 5-children, but not with wasting and underweight [209]. In this thesis, all nutrition-specific (inadequate dietary diversity, recent occurrence of morbidity and maternal undernutrition) and nutrition-sensitive (poorest household-level wealth status, larger family size, household head's employment insecurity and highland agro-ecologic zone) drivers of young child undernutrition are discussed in detail in Chapter 5.

The third research hypothesis of this study was that young child undernutrition is higher among young children who were living in households that experienced adult mortality from chronic diseases as compared to those who were living in households which did not experience adult mortality from chronic diseases. This hypothesis was not supported as we did not find evidence of higher risk of young child undernutrition in households which incurred adult mortality caused by chronic diseases (Chapter 5). There are three probable interpretations for this: (1) the number of deaths was small in the surveyed households, and this might have limited the ability of the data to detect differences; (2) as already discussed in Chapter 5, the absence of relevant differences could also have been due to the buffering role that lactating mothers had on their young children's risk to undernutrition. Explained in other way, the lactating mothers might have reduced their own food intake to continue feeding their children, exposing themselves to increased risk of undernutrition. This might have negated the potential adverse effect of adult mortality in exposing the young children to risk of undernutrition; (3) since the surveillance site did not collect morbidity surveillance data, our study was not able to identify how many of the examined households truly harbored chronic-disease-affected members or how many of the households experienced child mortality from chronic diseases. Because of this lack of data, the degree of association of chronic diseases attributed adult mortality with young child undernutrition could also be weaker if there were, for instance, higher morbidity or pediatric mortality from chronic diseases in the households which did not experience adult mortality from chronic diseases. Therefore, future research with more enriched and bigger data needs to be conducted, considering the current limitations. It could also be that other factors are more powerful determinants of young child undernutrition than the death of adult household members. The body of evidence suggests illness, quality of floor, intimate partner violence, maternal nutritional status and survival, household wealth status, and presence of additional non-maternal adult female household members

who can contribute to child care as potent factors of health and nutritional wellbeing in infants and young children [162,201,210–212].

6.4 Strengths and limitations

A number of strengths and limitations of this Ph.D. project are mentioned in the respective published works (Chapters 3, 4 and 5). I will now combine these stated strengths and limitations, and summarize them in a broader and detailed way in order to understand their implications on the findings.

The project has several strengths. First, this study is based on a big and pioneering population-based ongoing longitudinal KA-HDSS data in Tigray region of Northern Ethiopia, where data regarding the burden of adult mortality and its association with maternal and child undernutrition are lacking. Therefore, this study presents evidence on these critical public health challenges from the predominantly rural population that may be inferable to populations in similar settings. Previous analysis has shown that health and demographic surveillance data are generally regarded as robust and a network of such surveillance sites could increase extrapolation of findings [213]. The features of KA-HDSS databases allowed the linkage of various, dense longitudinal and survey datasets, and this enabled complex epi-demographic, agro-ecologic, socio-economic variables to be modeled. This has provided a unique opportunity in understanding how these variables were interacting with nutritional status of lactating mothers and their young dyads. Second, the data underlying this study were collected using standardized data collection tools and procedures. The employed data collectors, field supervisors and data clerks – high-school completed residents of the surveillance population – were intensively and regularly trained. These fulltime data collectors, supervisors, and full-time field coordinators of the surveillance project were also highly experienced with the data collection tools and procedures. The fact that these field staff know the culture of their community simplified the data collection procedure while adhering to local cultural contexts of the surveillance community and the ethical standards in research. All these strengths, along with the strict regular supervisions and support provided by the scientific staff members of KA-HDSS contributed to the quality of the big datasets. Together with this working background, it is also highly unlikely that deaths were missed in the surveillance site.

There are, however, a number of limitations that needs to be acknowledged when interpreting the results of this study. First, causes of death were identified using physician review of verbal autopsy questionnaires. This may not be an ideal method of determining causes of death [214]; it can be time and resource consuming as opposed to other methods [215]. The proportion of undetermined causes of death could be high – in this study, 18% of the causes were undetermined (Chapter 3). Since nearly three-fourths, 136 (74.3%), of the 18% indeterminate causes were among the eldest age-group (≥65 years old), the burden of adult mortality attributed to NCDs revealed in this study could probably be underestimated. Second, few adult deaths were observed in the households where the lactating mothers and their dyads were living. The degree and precision of the actual association might have been limited by this. Furthermore, this limited our assessment of maternal and young

child undernutrition in relation to chronic diseases-attributed mortality to the use of an aggregate model. Third, since the surveillance site has been exposed to different public health interventions (like health education services on nutrition education and latrine utilization) by graduating students of the College of Health Sciences from Mekelle University, the surveillance population's health literacy could be higher than the surrounding rural populations who were not exposed to any such training program. Any evaluative epidemiologic investigation implemented in KA-HDSS might also have similar effect of raising the population's nutrition- and child health-related literacy [216]. Because of these contextual circumstances, on the one hand, the estimated degree of association found in this study might have been lower than actuality, and on the other hand, extrapolation of this study's findings to other rural areas might be limited as this crucial factor (nutrition literacy of the lactating mothers) was not accounted for in this study. However, KA-HDSS is a young surveillance site, and to the best knowledge of the author, only one evaluative study has been conducted there [216]. Third, nutritional status of mothers and their offspring could vary by time since adult mortality, and the fact that this study did not account for this variable is worth mentioning, although the impact of adult mortality on households has not been seen elsewhere to quickly fade with time [130,217]. Fourth, the burden and distribution of morbidity and child mortality attributed to chronic diseases in the studied households are unknown. This study assumes randomness in distribution of these adverse health conditions. The association of maternal and young child undernutrition with chronic-disease-attributed adult mortality could be understated, for instance, if these factors were occurring at a higher rate among households which were not affected by adult mortality from chronic diseases. Fifth, the child dietary diversity score was determined using a single 24-hour dietary recall method may not sufficiently record the dietary intake pattern of the young children over a longer period [175]. Sixth, this study did not collect cost-of-illness data, nor data on the coping strategies implemented by the affected households following the sickness or death of an adult household member. Absence of such data has limited interpretation of the results, which otherwise were discussed using the available published evidence.

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Chapter 7: Conclusion and implication

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7.1 Conclusion

Notwithstanding the limitations mentioned in the previous chapter, this study contributes to existing knowledge of the NCDs burden by providing evidence on NCD-attributed adult mortality and its key social determinants in a predominantly agrarian community in Tigray region, northern Ethiopia. The present findings indicate that a double mortality burden from both NCDs and communicable diseases was evident in the study area, and this seems to be compounded by external causes of death. The results have shown how the hazard of adult mortality from NCDs increased for advancing age, illiteracy and for those who were extended family and non-family co-residents of the household heads (as opposed to the household heads themselves). Although further investigations are required, this study has gone some way towards enhancing our understanding of the association of households' experience of chronic diseases attributed adult mortality with undernutrition of lactating mothers and their young children controlling the effects of agro-ecologic, epi-demographic, housing, and socio-economic variables. In this regard, the current study has provided suggestive evidence of higher risk of maternal undernutrition for households which incurred adult mortality from chronic diseases. Young-child undernutrition in turn was strongly determined by maternal undernutrition, and other nutrition-specific and sensitive drivers (Chapter 5).

7.2 Implication

Findings of this study have several implications for practice and research that may help to reduce adult health loss caused by NCDs – and more generally by chronic diseases; this together with the additional recommended implications are expected to improve nutritional wellbeing of lactating mothers and their infants and young children. This sub-chapter will summarize the key implications divided into implications for practice and implications for research opportunities.

7.2.1 Implication for practice

A. Prevent NCD risk factors and promote early screening of NCDs

Prevention and control of the major NCDs risk factors- physical inactivity, unhealthy diet, tobacco consumption, and harmful use of alcohol- using the life course approach has been shown to be the most imperative public health intervention to reduce NCD burden [1,2]. In addition to impacting NCDs, addressing NCD risk factors, like tobacco use and alcohol consumption, may also have positive implication for promoting maternal and child nutritional status. A study from Ethiopia showed that husbands' alcohol consumption was a strong predictor of food insecurity among lactating mothers [3]. Moreover, it was shown to be associated with intimate partner violence and depression, which on their own are potent determinants of maternal and child undernutrition in developing countries [4,5]. The focus of NCD prevention should not, however, be limited only

to those risk factors; prevention and proper treatment of known infectious causes of cancer and chronic illness (like Helicobacter pylori, HIV/AIDS and human papilloma virus) can also contribute to reducing morbidity and mortality caused by NCDs [6].

In addition to addressing these well-substantiated classical NCD risk factors, targeted screening of vulnerable groups who are at risk of NCDs and chronic infectious diseases would help to detect these diseases early. With proper management, this could halt progress to advanced stages and reduce risk of complications. This can have relevance in terms of reducing care burden, cost of illness, and disability, and in enhancing patients' longer survival. In this regard, the role of preventive measures, such as vaccination against human papilloma virus and hypertension screening, are unquestionably effective interventions to control the prevalence and mortality of NCDs [7,8].

B. Improve NCD treatment and integrate NCD services into the primary health care

As summarized in Chapters 1and 6, the preparedness of the Ethiopian health system, both at the regional and national level, in terms of coverage and quality of NCD services, is highly limited and is faced by several challenges. It is characterized by a lack of trained health work force, fragmented NCD information system and data scarcity, poor coverage and quality of treatment service, chronic underfunding, weak integration into primary health care settings, lack of essential medicines, and poor governance. Continuous support and strengthening of the health system, using the World Health Organization's six building blocks, could be a vital approach to address these gaps [9]. As the majority of the essential health services packages in Ethiopia are delivered at the primary health care level, strong public-private partnership in the primary care setting could be crucial to increasing access for prevention, screening, diagnosis and treatment of NCDs [10–12].

The importance of integrating NCD-focused prevention, screening, treatment services, and routine information system with primary-level health care may crucially improve treatment access and effective resource utilization, improving NCD treatment outcomes and generating NCD-related data for informed decision making in the Ethiopian health care system. For instance, prevention and screening of some NCDs could be integrated into the health extension program package [13,14]. Moreover, the lack of standardized protocols for NCD data collection tools needs to be corrected [15], and routine NCD services data should be well integrated into the established health management information system. The health extension workers (HEWs), who deliver the most effective package of public health interventions, have been instrumental in addressing maternal and child health problems [14,16]. If the HEWs can be supported and trained, and their time management is well managed, these health professionals can provide multi-faceted opportunities in the fight against NCDs [17]. Evidence from previous studies has shown that adequately trained HEWs (community health workers) were able to reliably detect hypertension and identify individuals who are at high risk of cardiovascular diseases [18,19].

It is encouraging that Ethiopia has started generating nationwide population-based NCD data using the WHO STEPwise survey [20]. This could strengthen evidence-informed decision making regarding interventions designed

against NCDs. The collection of such data continuously in a controlled population at regular periods may give an opportunity to track the course and burden of NCDs, including the epi-demographic and nutrition transitions, in diverse Ethiopian regions [21]. Towards this end, the available Health and Demographic Surveillance Sites (HDSS) can provide a convenient platform to feasibly initiate such programs [22]. Combining NCD STEPwise survey data with HDSS data may have relevance in boosting epidemiologic investigations of NCDs as the HDSS system allows linkage with its dense data [23].

C. Promote NCDs- and nutrition-sensitive transdisciplinary interventions

Since NCDs, as well as maternal and child nutrition problems, are of complex and multifactorial origin, interventions derived from multi-sectoral collaborations is a key approach to address these major public health problems. Taking into account the findings revealed in this study, the following specific recommendations are suggested.

The present study indicated that the lack of diverse food crop production was a strong determinant of maternal undernutrition and child dietary diversity, both of which were also the main drivers of undernutrition among the infants and young children (Chapter 4 and 5). This underlines the need for collaborating with the agriculture sector to make it nutrition-sensitive – that is to make it better able to produce nutritionally rich and diversified foods. This can prevent undernutrition and enhance nutritional wellbeing among lactating mothers and their young children. Such intervention measures can also have a direct relevance in terms of reducing NCD burden. Studies have shown that dietary diversity is inversely related with depression and anxiety among pre-natal and post-partum women [24], factors which deterred good infant feeding practice [24,25]. The inverse association of dietary diversity with deleterious metabolic syndromes may substantiate the role of the agriculture sector as a strong stakeholder for NCD prevention [26]. Dietary diversity, an indicator of dietary quality, was also associated with blood antioxidant markers, which may play a promising role in reducing the prevalence and mortality from certain NCDs [27–29].

There is evidence that homestead food production can reduce child wasting and improve maternal nutritional status and empowerment [30,31]. There is also evidence of a positive impact of livestock production on dietary quality [32]. This stresses the role which the agriculture sector can have in reducing undernutrition among mothers and their children, with a possibility of impacting the future burden of NCDs as well. Despite their beneficial mutually-supportive roles, however, evidence obtained from the nearby areas found weak integration of nutrition and agriculture sectors [33]. As a gesture of collaboration, the extension workers from both the agriculture and health sectors could direct their integrated interventions to the rural households. However, these sectors must first develop guiding documents to equip the extension workers with the knowledge and skills which they can transfer to their community.

We have shown that lactating mothers, and their infants and young children, who were living in households that incurred recent morbidity were at higher risk of undernutrition. Besides, maternal health-seeking practice

and larger family size were associated with maternal undernutrition and young child undernutrition, respectively. These findings imply that the prevention of morbidity, increasing access to family planning, and health services can substantially improve nutritional wellbeing of lactating mothers and their young children. Family planning promotes good nutritional status among lactating mothers and their young children [34,35]. Family planning can improve family livelihood and literacy, and through this, it can have relevance for reducing the burden of NCDs in the consequent generations. We have also shown that increasing literacy, understanding details of the intra-household relationships and supporting the vulnerable extended family or non-family members of the household could reduce the hazard of mortality from NCDs. There is a need for the education, social affairs, health, and nutrition sectors to work in an integrative manner to systematically address adult health loss attributed to chronic diseases, and to reduce the associated burden of undernutrition among lactating mothers and their young children.

Findings of the current study showed that improving wealth status in the rural households can reduce NCD-ascribed adult mortality and undernutrition among infants and young children in KA-HDSS. Securing employment status of household heads can also decrease the burden of infant and young child undernutrition; those infants and young children whose household heads were daily laborers (employment insecure) were exposed to an increased risk of undernutrition. Furthermore, we have shown that improving housing and environmental conditions could reduce the prevalence of undernutrition among lactating mothers. Since housing quality and the energy use therein can also have major relevance in terms of reducing NCD burden and health loss among children, policy measures to improve these conditions should be implemented [36–40]. Based on evidence from the present study, designing and implementing interventions that aim to improve household level wealth could reduce young child undernutrition and NCD-attributed adult mortality. This could also improve nutritional wellbeing of lactating mothers by ameliorating housing conditions. Implementation of development-oriented interventions which aim to increase household assets – like livestock production – can increase consumption of quality diets [32]. This may also increase coping capacity of households in times of hardships (like occurrence of illnesses and deaths) by absorbing the shocks of medical expenditure, and related income loss. In conclusion, our study suggests integrated interventions drawn from these relevant sectors (health, nutrition, agriculture, education, economic affairs, water, and energy) can reduce adult health loss attributed to chronic diseases and ensure better nutritional status among lactating mothers and their young children. It is clear that all of these suggested transdisciplinary intervention efforts should also collaborate with the media sector, as well as the ministry of science and technology [41–43].

D. Implement interventions targeting the most vulnerable groups

A focus on vulnerable groups has ethical significance in the sustainable development goals [44]. Our study has highlighted the vulnerable adult population groups who faced higher mortality hazard from NCDs. Those who were unable to read and write, the elderly, and the poor, as well as those who were extended family or non-

family co-resident members of KA-HDSS households, had a differentially higher NCD-attributed mortality. Intervention measures targeting these vulnerable groups are needed to reduce NCD-attributed mortality burden in adult population. Unlike the interventions for other health problems, "cost sharing" between patients and the health sector is established as the major payment mechanism for NCD-treatment expenses, and this is believed to facilitate universal health coverage in Ethiopia [11]. NCD-patients are still at increased risk of becoming impoverished even under the revised Ethiopian health services package. Therefore, we recommend a fee exemption policy for the identified vulnerable population sub-groups, at least for the vulnerable adults affected by the most common NCDs (cardiovascular diseases, cancers and renal disorders).

Lactating mothers who were living in households which were affected by adult mortality from chronic diseases showed higher risk of undernutrition. Similarly, lactating mothers and their dyads who were living in households which experienced recent morbidity were at increased risk of undernutrition. Therefore, pro-poor development interventions (such as supporting the poor NCD-affected rural households to build assets) and cash and food transfers to affected households are needed to curb nutritional insecurity [45].

7.2.2 Implication for future research opportunities

Identification of households affected by adult deaths, assessing the epidemiology and social determinants of NCDs-attributed adult mortality, along with a comparison of the burden of undernutrition among lactating mothers and their young children was possible in KA-HDSS. The present thesis has highlighted key points in need of further investigation. Considering some of the summarized limitations, the following research opportunities are suggested.

- Further investigation, supplemented by qualitative data, is needed to understand how intra-household relationships and literacy impact NCD-attributed adult mortality in the context of the rural population of KA-HDSS. Moreover, detailed additional data on pathways to care – on role of informal care givers, care seeking from religious sites (like Holy Water) and traditional medicine – relating to patient survival would unquestionably be helpful to design culture-sensitive and context-specific NCD interventions.
- What is not yet clear and remains unaccounted for in this study is the occurrence of chronic diseases, morbidity and child mortality from chronic diseases on nutritional status of lactating mothers and young children. Accordingly, future studies that aim to investigate the association of adult mortality from chronic diseases with nutritional status of affected household members should also aim to collect data on occurrence of morbidity and child mortality-attributed to chronic diseases. This may have importance in identifying the role and severity of morbidity and mortality impacts separately. Furthermore, data on the cost of illness and coping mechanisms following illness or death of adult household members from chronic diseases should also be collected.
- Nutritional status of lactating mothers and their offspring may also need to be measured using more detailed nutritional outcome measurements like body mass index, height-for-age, weight-for-height, weight-

for-age, hemoglobin level, and other biochemical indicators; infant feeding practices and nutritional knowledge of lactating mothers need to be assessed using objective tools like NutriLit [46].

- Further data on how the time passed since an adult death influences maternal and young child undernutrition would be interesting, for it might provide evidence on critical time periods for appropriate intervention. The extent of undernutrition among vulnerable members of chronic diseases-affected households could especially be higher around the time of death (due to mourning and stress), and shortly afterwards because of lower income and skilled labor loss. For instance, if evidence shows higher burden of undernutrition during the time of severe illness (before adult death) for reasons of expenditure and care burden, the nature of the intervention would be different than if it was linked with mourning and stress. Examining whether the presence of other non-maternal adult female co-residing members mediates infant and young child nutrition would also be interesting for intervention purposes. Therefore, identifying this could help to design and implement context-specific interventions.
- This thesis inquired only retrospectively whether nutritional status of lactating mothers and their offspring vary by history of adult mortality attributed to chronic diseases. There was no baseline nutritional data for households before the occurrence of adult mortality, so this thesis was unable to study change in dietary pattern following death of adult household members. A consideration of this aspect could be an opportunity for investigation in future research.
- Last, but not least, the study site (KA-HDSS) is characterized by a high out-migration of its young adult residents. Studying how this demographic event is impacting epidemiology of NCDs, and the favorable and unfavorable influences it may have on nutritional status of lactating mothers, and on their infants and young children, would be of great public health relevance.

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Annex 3

Declaration in lieu of an oath on independent work

according to Sec. 18(3) sentence 5 of the University of Hohenheim's Doctoral Regulations for the Faculties of Agricultural Sciences, Natural Sciences, and Business, Economics and Social Sciences

1. The dissertation submitted on the topic

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……...

is work done independently by me.

2. I only used the sources and aids listed and did not make use of any impermissible assistance from third parties. In particular, I marked all content taken word-for-word or paraphrased from other works.

3. I did not use the assistance of a commercial doctoral placement or advising agency.

4. I am aware of the importance of the declaration in lieu of oath and the criminal consequences of false or incomplete declarations in lieu of oath.

I confirm that the declaration above is correct. I declare in lieu of oath that I have declared only the truth to the best of my knowledge and have not omitted anything.

Place, Date	Signature