Agroecosystem-based analysis of dietary intake and malnutrition among rural communities in Chemoga watershed of the Upper Blue Nile Basin, Ethiopia

(エチオピア青ナイル川上流部チェモガ流域の農村コミュニティにおける
食事摂取と栄養不良に関する農業生態系ベースの分析)

Biruk Yazie Wubetie

The United Graduate School of Agricultural Sciences
Tottori University, Japan

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A dissertation submitted to:

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In partial fulfilment of the requirements for the Degree of Doctor of Philosophy in Global Dryland Science

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2024

DEDICATION

I wholeheartedly dedicate this work to my beloved wife, Tigist Kefale Mekonen, and our wonderful children Kaleab Biruk, Soliyana Biruk and Eyuel Biruk, as well as my mother, Ziyin Getahun. Your unwavering support and love have been my greatest source of inspiration.

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ACRONYMS AND ABBREVIATIONS

AEZ	Agroecosystem Zone
AIC	Akaike Information Criteria
AMOS	Analysis of Moment Structures
ANOVA	Analysis of Variance
ARI	Acute Respiratory Infection
AVE	Average Variance Extracted
BIC	Bayesian Information Criteria
CFI	Comparative Fit Index
CIAF	Composite Index of Anthropometric Failure
CR	Composite reliability
CSA	Central Statistics Agency
DDS	Dietary Diversity Score
DIC	Deviance Information Criteria
EDHS	Ethiopian Demographic and Health Survey
EPHI	Ethiopian Public Health Institute
ENACTS	Enhancing National Climate Services
FAO	Food and Agriculture Organization
FDRE	Federal Democratic Republic of Ethiopia
GFI	Generalized Fit Index
HAZ	Height for Age Z-score
HDDS	Household Dietary Diversity Score
ICC	Intra-class Correlation Coefficient
IFAD	International Fund for Agricultural Development
IFPRI	International Food Policy Research Institute
KM	Kilo Meter
MK	Mann Kendall
MOR	Median Odds Ratio
NNP	National Nutrition Program

NSA	Nutrition Sensitive Agriculture
OR	Odds Ratio
PCV	Proportional Change in Variance
PVC	Partitioning of Variance Coefficient
RMSEA	Root Mean Square Error of Approximation
SD	Standard Deviation
SDG	Sustainable Development Goal
SEM	Structural Equation Modeling
SPSS	Statistical Package for Social Science
SRMR	Standardized Root Mean Squared Residual
TLU	Tropical Livestock Unit
UNICEF	United Nation International Children Emergency Fund
WASH	Water Sanitation and Hygiene
WAZ	Weight for Age Z-score
WDDS	Women Dietary Diversity Score
WFP	World Food Program
WHO	World Health Organization
WHZ	Weight for Height Z-score

Chapter One

1. General introduction

1.1 Background

1.1.1 Concepts and scopes of malnutrition

The World Health Organization (WHO) defines malnutrition as a state of nutrition in which a deficiency, excess or imbalance of nutrients including protein, energy and others causes measurable adverse effects on tissue or body form (body shape, size, composition), body function and clinical outcome (WHO, 2019). Malnutrition is a broad term and can include not only protein-energy malnutrition (both overnutrition and undernutrition) but also includes deficiencies of micronutrients (De Onis et al., 2006; Meier & Stratton, 2008; Meijers et al., 2010). In this study, the focus is mainly on undernutrition/protein-energy malnutrition, although it is widely acknowledged that micronutrient malnutrition is a serious public health problem in Ethiopia.

Nutrient requirements differ according to the age, gender, level of physical activity, height, weight, stage of life, and health status of each individual. Therefore, the prevalence of malnutrition can vary among individuals depending on the thresholds and cut-off values used to determine the risk of malnutrition (to identify normal versus abnormal status or low versus high risk) micronutrients (Meier & Stratton, 2008; Meijers et al., 2010). Protein-energy malnutrition that manifested in the forms of stunting, wasting and underweight has remained a significant global public health issue in the 21st century in both developing and developed countries. Stunting is a chronic form of malnutrition that refers to a child who is too short for his or her age. Children affected by stunting can suffer severe irreversible physical and cognitive damage that accompanies stunted growth. The devastating consequences of stunting can last a lifetime and even affect the next generation (Victora et al., 2008). While wasting is an acute form of malnutrition that manifests when a child is too thin for his or her height. Wasting is the result of recent rapid weight loss or the failure to gain weight. A child who is moderately or severely wasted has an increased risk of death, but treatment is possible. In other way, underweight can be either chronic or acute forms of malnutrition (Meijers et al., 2010).

Dietary diversity is a qualitative measure of food intake, indicating the variety of food groups consumed within a specific time frame. It serves as a proxy indicator of household food security (household dietary diversity score) and nutrient sufficiency (individual dietary diversity score) (FAO, 2007, 2021; G. L. Kennedy et al., 2015; Swindale & Bilinsky, 2006). A more diversified diet is an important outcome in and of itself. A more diversified diet is associated with a number of improved outcomes in areas such as birth weight, child anthropometric status, and improved hemoglobin concentrations. According to WHO, a healthy diet protects against malnutrition in all its forms, as well as non-communicable diseases such as diabetes, heart disease, stroke, and cancer. It contains a balanced, diverse, and appropriate selection of foods eaten over a period of time (UNICEF/WHO/WORLD BANK, 2021).

1.1.2 Global and regional prevalence of malnutrition

A report by different United Nation organizations including FAO, indicated that with just eight years left to end the Sustainable Development Goals of ending hunger, food insecurity, and all types of malnutrition (SDG Targets 2.1 and 2.2), the trajectory we are currently on indicates a troubling trend. The burden of malnutrition persists as a formidable challenge worldwide, signaling that the global community is not making sufficient progress in the right direction. According to current estimates in 2022, 22.3 percent (148.1 million) of children under 5 years of age were stunted and 6.8 percent (45.0 million) wasted (FAO et al., 2023). Although there has been some progress, rates of malnutrition reduction are far below what is needed to reach the World Health Assembly (WHA) target for 2025 and the Sustainable Development Goals (SDG) target for 2030. If recent trends continue, these targets will only be achieved in 2035 and 2043, respectively (FAO et al., 2023).

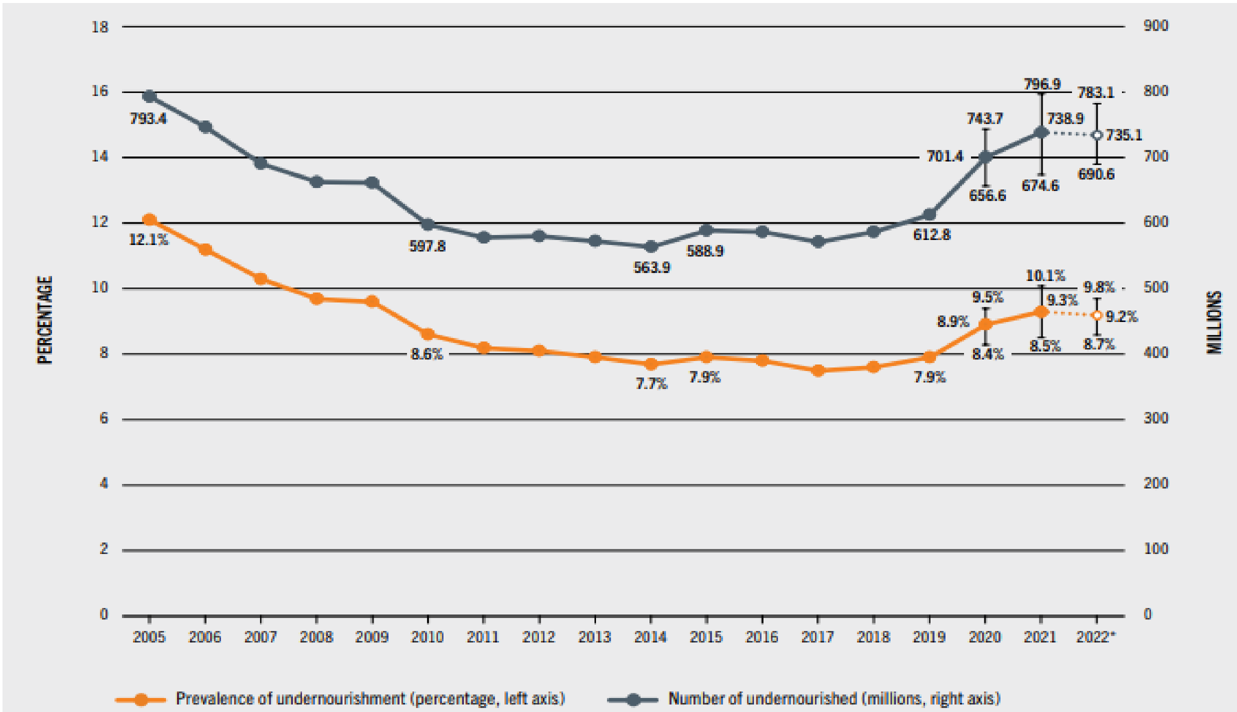

Figure 1-1: The number of undernourished people and its trend in the world (FAO, IFAD, UNICEF, WFP and WHO, 2023).

Moreover, more than two out of five, and more than one quarter of all children under 5 affected by stunting and wasting lived in Africa, respectively (UNICEF/WHO/WORLD BANK, 2021). To conclude, if recent trends are not reversed, the target of ending hunger, food insecurity and all forms of malnutrition (SDG 2.1 and 2.2) will not be met.

1.1.3 Overview of malnutrition in Ethiopia

Looking at the situation in Ethiopia, child malnutrition has notably decreased over the last 20 years, yet its prevalence remains alarmingly high. According to Ethiopian Demographic and Health Survey (EDHS) report, the prevalence of stunting, wasting, and underweight was estimated approximately 38%, 10%, and 24%, respectively (Figure 1-2) (CSA and ICF, 2016).

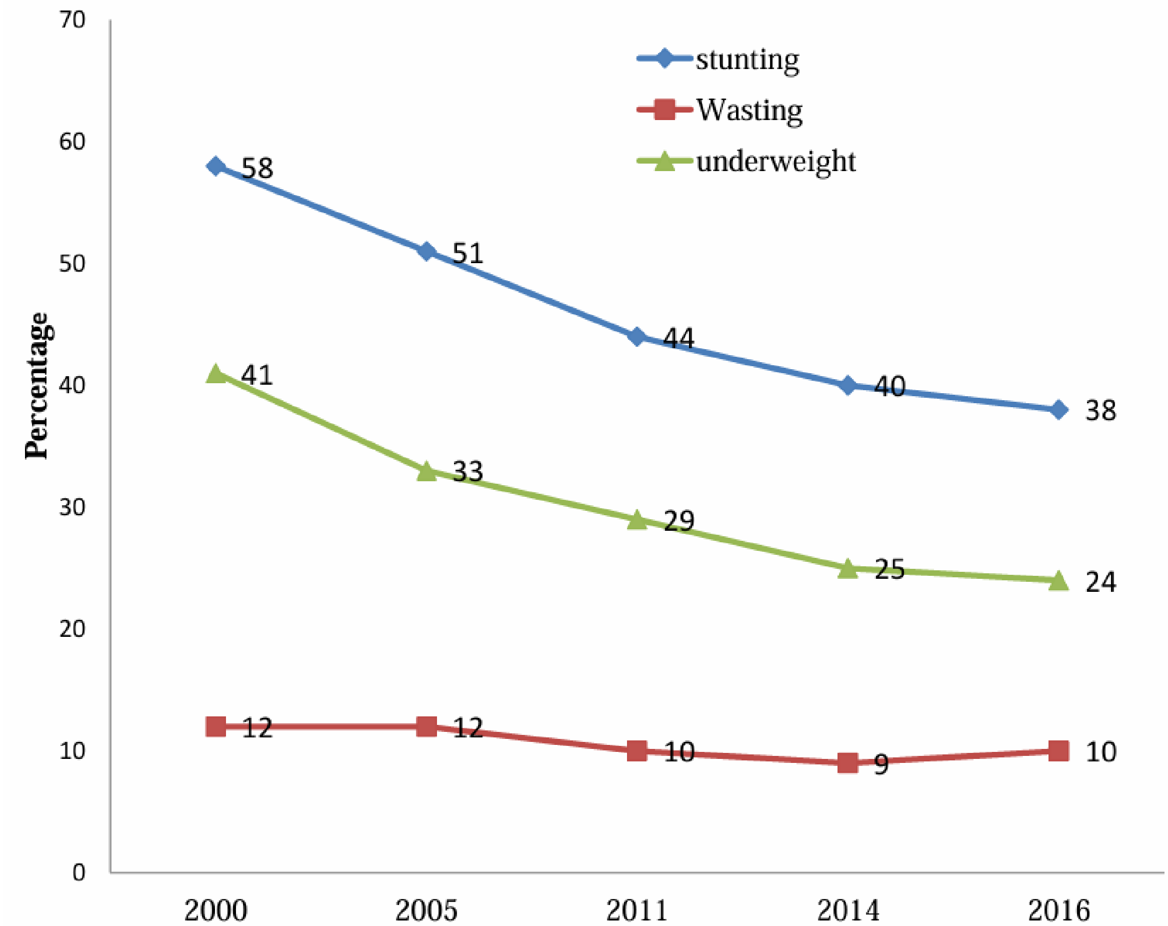

Figure 1-2: Trends of child malnutrition in Ethiopia from 2000-2016 (CSA and ICF, 2016)

This trend analysis confirmed that malnutrition remains a critical public health concern in Ethiopia, with stunting being one of the most persistent and troubling manifestations, particularly in the Amhara region, which is the focus of current study. Despite national efforts to address malnutrition, the prevalence of stunting in the Amhara region remains higher compared to other parts of the country, suggesting unique regional challenges that need to be explored (Fenta et al., 2020). As shown in Figure 1-3, the higher prevalence of stunting was recorded in the Amhara region in the past consecutive Ethiopian demographic and health surveys, even higher compared to the national average.

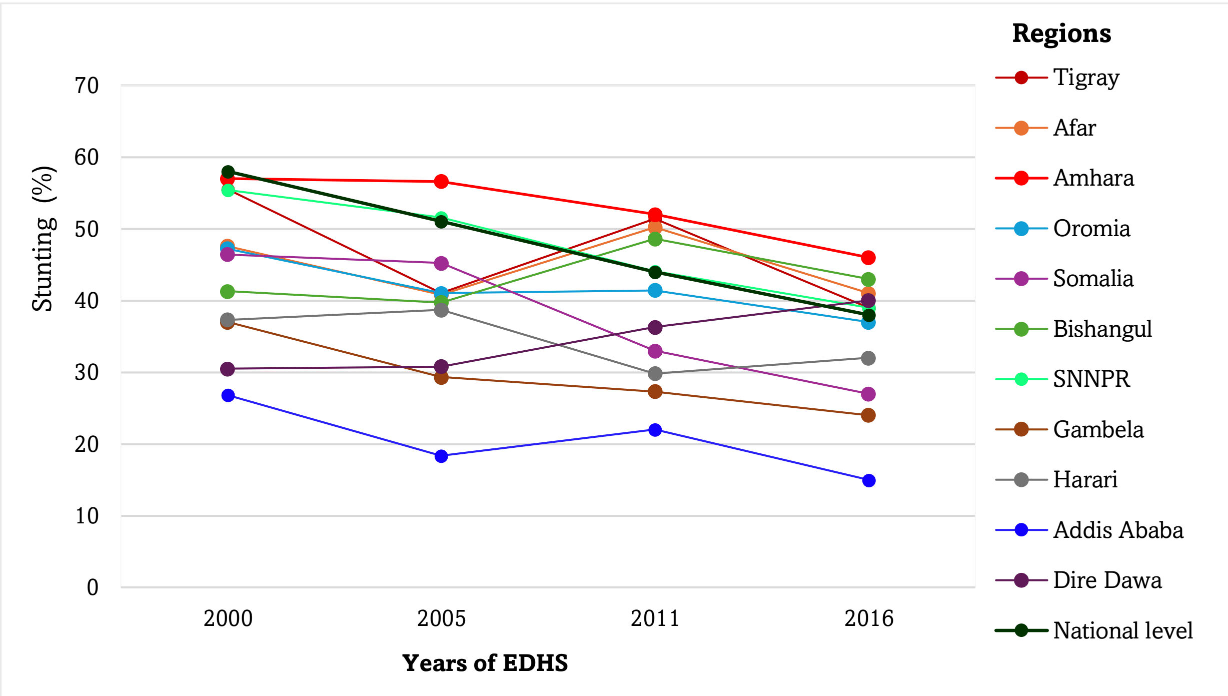

Figure 1-3: Trends of stunting from 2000-2016 across regions of Ethiopia

1.1.4 The linkage between agroecosystem, and dietary intake and nutritional outcome

The structure of an agroecosystem is a consequence of its environmental setting (e.g., climate, soil, topography), agricultural practices and technologies, and farmers' social setting (e.g., human values, institutions and skills) (Conway, 1985; Simane et al., 2013a). Therefore, agroecosystem-based analysis show a remarkable degree of differentiation in terms of production orientation and socio-economic characteristics of the farming communities suggesting different options and interventions towards tackling overall malnutrition challenges (Chegere & Stage, 2020; Fernandez & Méndez, 2019; Hanley et al., 2021; Kansanga et al., 2021, 2021; Khonje et al., 2022; Stratton et al., 2020).

Different studies have shown that dietary diversity and nutritional status of individuals were positively correlated (Alemu, Ahmed, Yalew, Birhanu, et al., 2017; Bayih et al., 2022;

Gebremedhin et al., 2017). Poor nutritional status in communities can have several causes, but a key factor is poor dietary quality with insufficient intake of nutritious foods, including fruits, vegetables, pulses, and animal-sourced foods. (Khonje et al., 2022). Child undernutrition is notably prevalent in rural regions of Africa, where many households livelihood is relied on subsistence farming (Chegere & Stage, 2020; Habtemariam et al., 2021; Khonje et al., 2022; Sibhatu & Qaim, 2018; Stratton et al., 2020). It is reasonable to anticipate that agroecosystem-based diversification of farm-level production could enhance family diets and nutrition, either through the subsistence pathway or by increasing income through selling products in the market. Hence, it is evident that agriculture and nutrition are intrinsically interconnected, and the emerging concept of nutrition-sensitive agriculture is becoming increasingly critical, emphasizing the importance of dietary diversity and the optimal utilization of both plant and animal-based foods (Khonje et al., 2022; MoANR and MoLF, 2017). Nutrition-sensitive agriculture stands as a pivotal approach within agricultural development, prioritizing year-round availability, access, and consumption of diverse, safe and nutritious foods of plant and animal source. By placing sustainable agricultural systems at its core, this approach aims to address malnutrition and its repercussions comprehensively (GJennifer Lane et al., 2017; Kiptoo et al., 2021; Rosenberg et al., 2018; Sharma et al., 2021).

The Ethiopian government has also emphasized the importance of diversifying production as a component of its investment policy; however, the agriculture sector has primarily concentrated on increasing productivity and promoting market-oriented cultivation of cash crops, often with limited attention given to expanding the availability of diverse food options and ensuring overall nutrition security (Goshu, 2013). Hence, agriculture's impact on nutrition in Ethiopia has been constrained, largely due to the low dietary diversity observed within households (CSA and ICF, 2016). A recent study conducted in Ethiopia found that households were more inclined to consume nutrient-rich foods when they were produced within the household. This suggests that focusing on boosting the production of certain crops, rather than striving for overall production diversity, could be more effective in enhancing the quality of household diets (Kennedy et al., 2018). Generally, human nutrient requirements and nutritional security can be ensured through diet diversification, and inadequate dietary diversity is highly correlated with poor nutritional status (Kennedy et al., 2018). Yet, poor agricultural practices in smallholder farmers can precipitate food insecurity and, consequently worsen diet quality and potentially increase the risk of various forms of malnutrition (FAO, IFAD, UNICEF, WFP, 2021). Hence, agroecosystem-based analysis reveals key agricultural and nutrition-related challenges unique to each area. Solutions can be suggested for these issues, with some requiring research interventions while others necessitate extension and development efforts (Simane et al., 2013a; Teklu et al., 2023).

1.1.5 Determinants of malnutrition

There is a large body of literature that has identified and examined the basic, underlying, and immediate causes of malnutrition. The immediate cause of malnutrition is typically an insufficient intake of food and nutrients necessary for health, or frequent illnesses that hinder nutrient absorption and utilization (UNICEF, 2021; Victora et al., 2008) . A study conducted in different parts of Africa like, Nigeria (Akombi et al., 2017; Ogbo et al., 2015), Tanzania (Chegere & Stage, 2020; Debela et al., 2021), Kenya (Catherine Muthoni Njeru et al., n.d.; Muthini et al., 2020), South Africa (Modjadji et al., 2020) and Ethiopia (Alemu, et al., 2017; Bayih et al., 2022; Fenta et al., 2020; Fenta et al., 2022; Fentahun et al., 2016; Wubetie & Mekonen, 2022), demonstrated the influence of dietary intake and disease experiences on nutrition status of individuals, particularly children.

Moreover, empirical evidence in different parts of the world have revealed that the underlying determinants of malnutrition were household food insecurity (Burki, 2022; Mulu & Mengistie, 2017; Randell et al., 2021; WHO; FAO; IFAD; UNICEF; WFP;, 2022; Wubetie & Mekonen, 2022), inadequate feeding and caring practices (Ahmed et al., 2020, 2021; Gebremedhin et al., 2017; Hassen et al., 2021; Workicho et al., 2021), unhealthy home environments (Alemu, et al., 2017; Atinkut Asmare et al., 2022; Mekuria et al., 2017), and limited access to healthcare services (Black et al., 2013; Danso & Appiah, 2023; Mohseni & Aryankhesal, 2020). Studies conducted in low-income countries have also found that socioeconomic and environmental factors including maternal empowerment, agricultural practices, access to market and climatic shocks were influenced the nutritional status of individuals as a basic cause (Alemu, et al., 2017; Ayenew et al., 2018; Debela et al., 2021; Delbiso et al., 2017; FAO, 2022; Gupta et al., 2020; Jones et al., 2019; Sibhatu & Qaim, 2018).

1.1.6 Actions taken to tackle malnutrition, and its linkage with SDGs.

Nutrition is mentioned specifically in SDG 2 but is central to the achievement of all 17 SDGs (FAO et al., 2023). According to the 2016 Global Nutrition Report, about 12 of 17 SDGs indicators have strong and direct linkages with nutrition. And the document points out that "to attain SDG 2 (End hunger, achieve food security and improved nutrition, and promote sustainable agriculture)—and other SDGs—we must implement policies that make food, health, education, WASH (water, sanitation, and hygiene), and poverty reduction systems more nutrition oriented (Figure 1-4). We need policies that make food, social, health, and living environments conducive to behaviors that will reduce malnutrition in whatever form it takes (IFPRI, 2016). The below Figure x illustrates the link between nutrition and sustainable development goals.

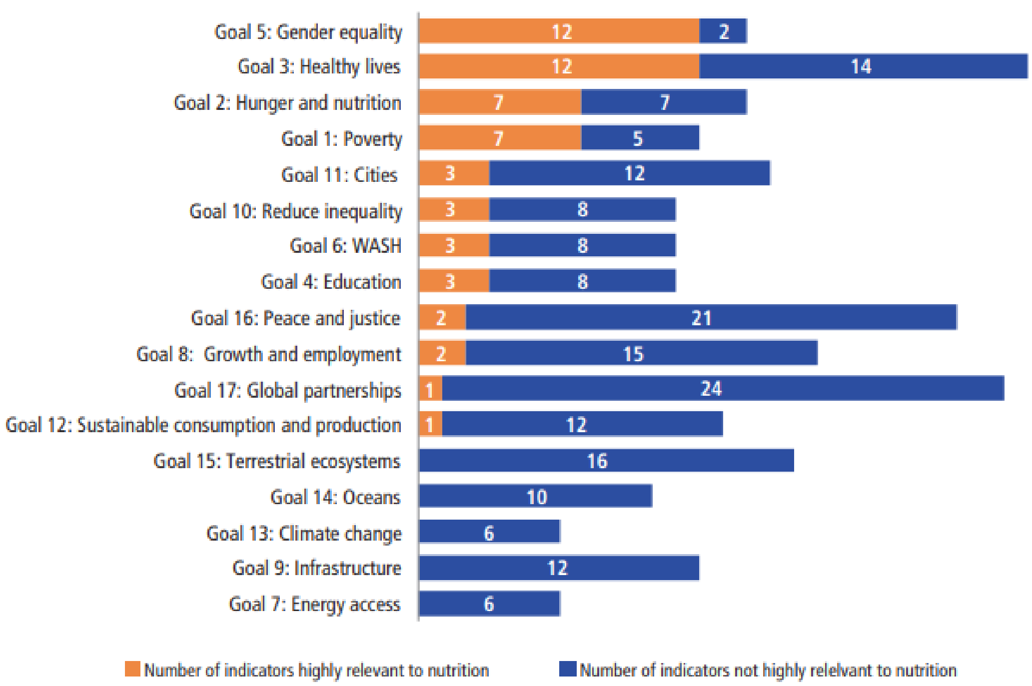

Figure 1-4: Number of indicators in each SDG that are highly relevant for nutrition (IFPRI, 2016).

Therefore, the global commitment to end all forms of malnutrition is addressed through the vivid application of nutrition intervention, which is comprised of nutrition-specific and -sensitive interventions (Mekonnen et al., 2022; Ruel & Alderman, 2013). Nutrition-specific interventions address the immediate determinants of malnutrition, while nutrition-sensitive interventions can influences nutritional outcome indirectly as underlying determinants of nutrition (Abera et al., 2019; Arriola et al., 2020; Rosenberg et al., 2018; Ruel & Alderman, 2013). Hence, promoting the agricultural sector with a view of nutrition-sensitive productivity will assist in accelerating nutritional gains in the community, and enhance the production of diverse crops that enrich the quality of diets including micronutrient-rich foods. For instances, home gardens promote the production of nutrient-rich fruits and vegetables that can grow well in local conditions (Bayih et al., 2022; Cabalda et al., 2011; Hirvonen & Headey, 2018). For appreciable health and nutrition impact, where nutrition-specific intervention alone cannot bring desirable change, nutrition-sensitive agricultural interventions should be coupled with behavior change communication campaigns (Mahumud et al., 2022; Workicho et al., 2021). These all collectively improve knowledge on the importance of a healthy diet, dietary diversity, and best practices for food preparation, child feeding, and health seeking behavior.

In Ethiopia, the available intervention strategies for the reduction of malnutrition are mainly focusing on direct nutrition-specific programs and poor integration with nutrition sensitive agriculture such as supporting the livelihood of rural households, promoting gender equality and nutrition education (MoANR and MoLF, 2017; Wordofa & Sassi, 2020). Currently, there are some initiatives underway to promote nutrition-sensitive agriculture like, home gardening practices through the provision of egg-laying hens, ingredients for preparing complementary foods, and fruit and vegetable seeds (GJennifer Lane et al., 2017).

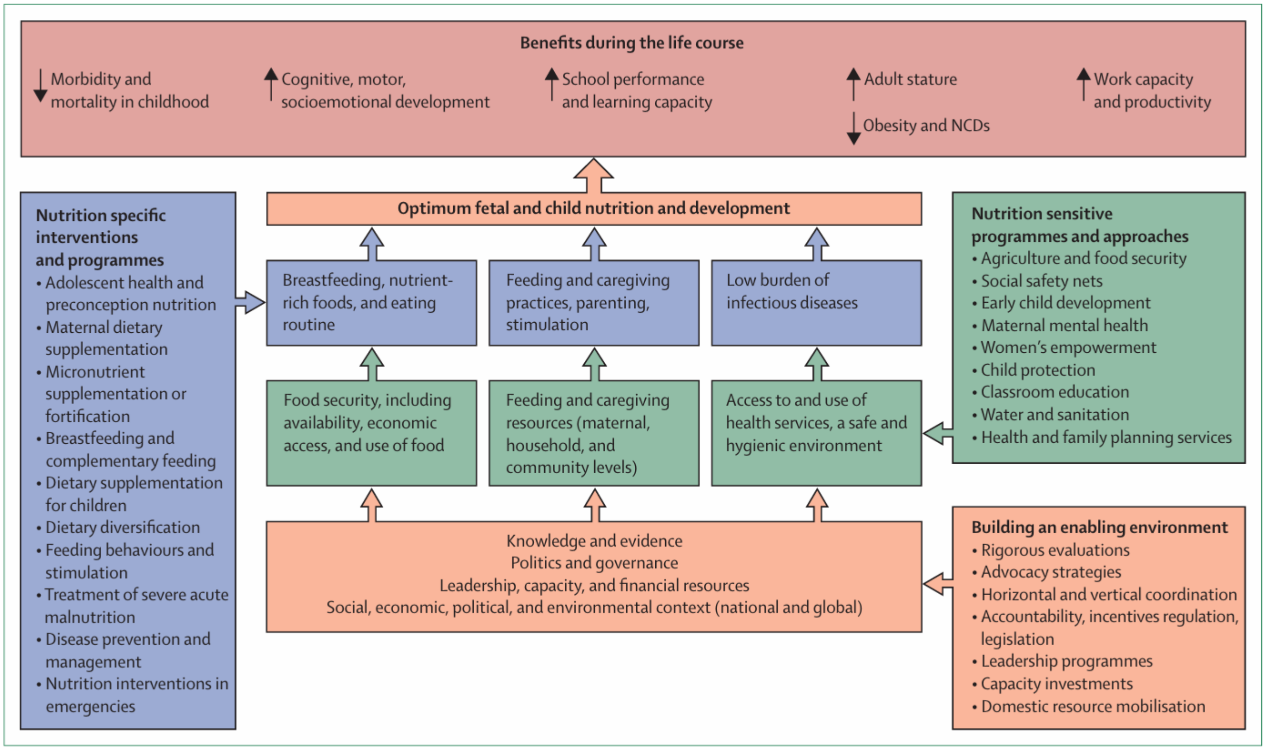

Figure 1-5: Lancet series framework for actions to achieve optimum nutrition and development (Black et al., 2013)

In line with the global commitment, the Ethiopian government is working to speed up the reduction of malnutrition through developing legal frameworks and implementing various programs on the ground. The government has stressed both direct nutrition interventions combined with nutrition sensitive policies and programs by recognizing malnutrition as a public health problem. Therefore, the first National Nutrition Program (NNP I) was launched from 2008 to 2013 (Kennedy et al., 2015). Prior to the first NNP I was established, most nutritional initiatives in Ethiopia focused primarily on emergency feeding and micronutrient supplementation, with minimal emphasis on preventive measures. Based on the achievements and lessons from NNP I, the second phase of the National Nutrition Program (NNP II) was launched from 2016 to 2020, with greater emphasis on multisectoral coordination and the integration of nutrition with other development sectors such as health, agriculture, and water and sanitation (Baxter et al., 2008; FDRE, 2016; Kennedy et al., 2015). In addition, the Seqota Declaration (2015-2030) was launched with the aims of eliminating all forms of malnutrition among children under age of two by 2030 (MoANR and MoLF, 2017). Likewise, the Nutrition Sensitive Agriculture (NSA) strategy has designed with agriculture as a primary sector that can and should play a crucial role in enhancing the community's nutritional health, and aiding in the fight against malnutrition in the country. However, regardless of those collective efforts, its effect in reducing the prevalence of malnutrition is not as expected to the target to be attained, and unacceptably high number of children (~ 40%) are still suffered with stunting (CSA and ICF, 2016).

1.2 Rationales of the study

Currently, large proportion of Ethiopian children have been suffering with different forms of malnutrition, mainly undernutrition. So far, there have been no studies that have thoroughly examined child malnutrition, encompassing a comprehensive analysis of malnutrition by considering demographic, socio-economic and environmental aspects of the rural community. However, this research fills the gaps by taking into account agriculture and environment-related data, customized to align with the UNICEF conceptual framework on causes of malnutrition in the context of Ethiopia. Moreover, the existing research in Ethiopia has focused on a single conventional anthropometric failure that undermine the challenges that children have been facing in realty at the ground, and therefore, this study tried to use the composite index of anthropometric failure to determine the level of malnutrition and its determinants through the application of advanced analysis techniques, particularly structural equation modeling. Hence, the findings of the current study provide valuable insights for shaping nutrition program planning and policy formulation, serving as an entry point for integrated multisectoral intervention approaches by mainstreaming the issues of nutrition.

1.3 Research objectives

General Objective:

The main aim of this study was to examine the status and determinants of dietary intake and malnutrition challenges among rural communities across contrasting agroecosystems in Chemoga watershed of the Upper Blue Nile Basin, Ethiopia.

Specific objectives:

1) To explore the pattern of household dietary diversity and its linkage with agricultural production across contrasting agroecosystems of Chemoga watershed.

2) To analyze malnutrition and its determinants among children under-five years of age across contrasting agroecosystems of Chemoga watershed.

1.4 Research questions

1) How is the status of dietary diversity and its linkage with agricultural production in rural households across contrasting agroecosystems of Chemoga watershed?

2) What is the prevalence of malnutrition and its determinants among children under the age of five within contrasting agroecosystems of Chemoga watershed?

1.5 Organization of the thesis

In this section, the organization of the PhD thesis is outlined briefly. Figure 1-6 describes the schematic presentation of the thesis.

Chapter 1 presents the general introduction that includes scopes of malnutrition in this study, a general overview of malnutrition from global to Ethiopian context, determinants of malnutrition, agroecosystem-based analysis of dietary diversity and malnutrition, and measures taken to reduce malnutrition globally and in local contexts. It also includes the objectives, research questions and description of the study area.

Chapter 2 describes the status and determinants of household dietary diversity as well as their nexus with agricultural food production. It explains how food production diversification can contribute to diversifying the family diet in the rural subsistence farming set-up. Therefore, in this chapter agroecosystem based-multilevel analysis was carried out to explore the influence of household level and cluster level on household dietary diversity score across contrasting agroecosystems of Chemoga watershed. The main food groups produced and consumed in each agroecosystem are also displayed in this chapter.

Chapter 3 investigates malnutrition and its determinants among children under-five years of age across contrasting agroecosystems of Chemoga watershed, Upper Blue Nile Basin. This chapter describes the status om malnutrition among children by using composite index of anthropometric failure, and conventional indices. The direct and indirect effect of basic, underlying, and immediate factors on child malnutrition are presented using structural equation modeling. This chapter also presents the minimum dietary diversity score among children and their mothers.

Chapter 4 presents general conclusions and recommendations. It concludes the findings of this study as per the intended objectives. This chapter presents suggestions for future research perspectives and policy direction to address malnutrition.

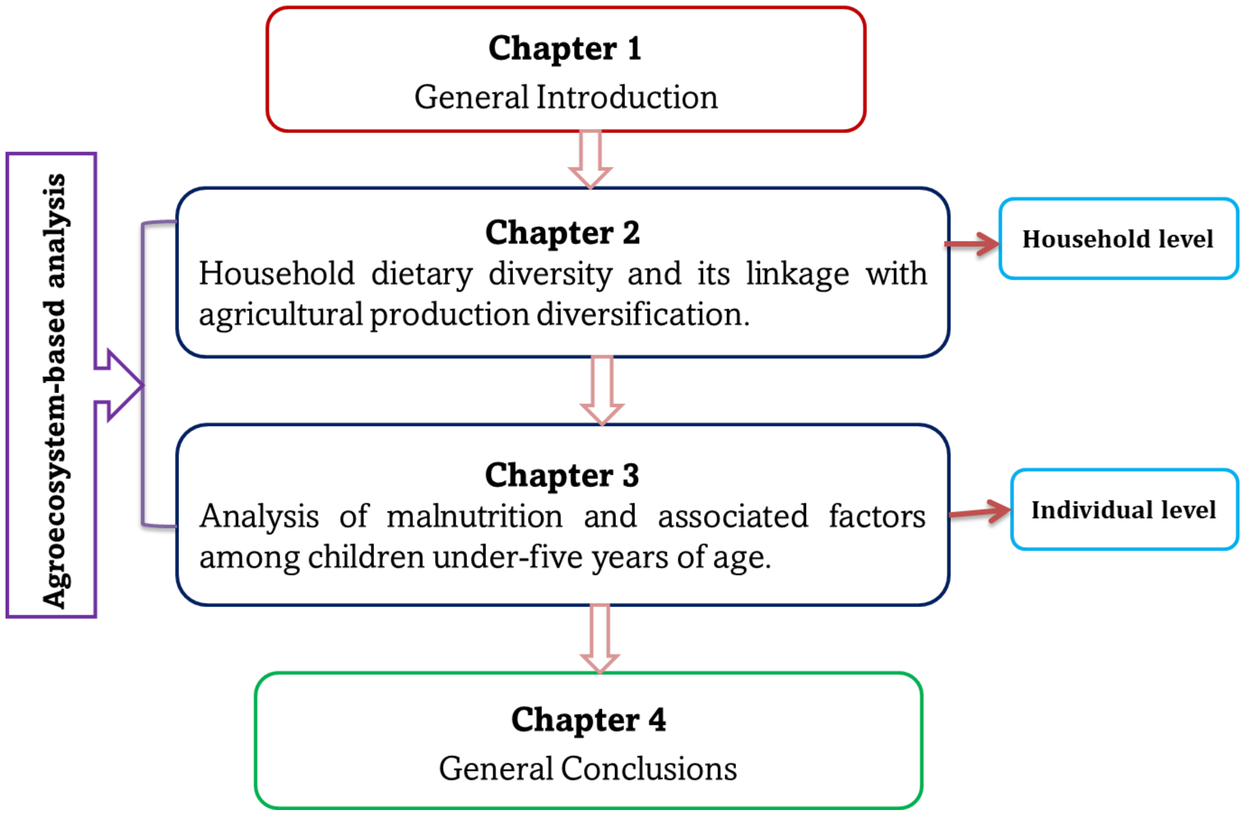

Figure 1-6: Schematic presentations of thesis structure.

Chapter Two

2. Agroecosystem-based analysis of household dietary diversity and its linkage with agricultural production diversification in the Upper Blue Nile Basin, Ethiopia: Multilevel analysis approach

Parts of this chapter is published as:

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2.1 Introduction

Inadequate dietary intake and malnutrition is a global issue, but it is particularly severe in low-income African nations, particularly in sub-Saharan countries where the majority of individuals rely on agriculture for their sustenance and livelihoods (Hirvonen et al, 2017; Sibhatu & Qaim, 2018). The United Nation's Sustainable Development Goal (SDG) 2 prioritizes the eradication of hunger and the attainment of food security and nutrition by promoting sustainable agriculture by 2030 (WHO, FAO, IFAD, UNICEF, WFP, 2022). Improving agricultural production increases access to both dietary diversity and the quantity of food available for household consumption. It also serves as an income source for purchasing other items, such as education and health care, which can in turn also improve nutrition levels (Bakhtsiyarava & Grace, 2021; Deaconu et al., 2021b; Workicho et al., 2016).

Evidence points to the issue of dietary diversity being a public health concern in many low-income countries such as Ethiopia (Kennedy et al., 2015). Understanding the connection between agricultural production diversification and dietary diversity should help to address the issue of malnutrition in developing countries where rural households typically rely heavily on grains as staple foods. This is especially true in Ethiopia's smallholder subsistence farms where poor diets are commonplace (Bakhtsiyarava & Grace, 2021; Esaryk et al., 2021; Muthini et al., 2020; Sekabira & Nalunga, 2020; Sinyolo et al., 2021; Teklewold et al., 2019). Promoting more nutrition-sensitive agriculture and expanding access to diverse food sources can help to reduce the prevalence of malnutrition in this region.

Ethiopian national nutritional policy (FDRE, 2016) and dietary diversity guidelines (Ethiopian Public Health Institute (EPHI), 2022) have encouraged people to eat a variety of foods to meet their nutritional requirements. However, there has been limited progress in reducing malnutrition through the implementation of these guidelines (Ethiopian Public Health Institute (EPHI) & ICF, 2021). Previous studies conducted in Ethiopia have also not considered how different agroecosystems could influence agricultural production, household dietary diversity, and overall nutrition. A comprehensive agroecosystem analysis study conducted by (Simane et al., 2013a) identified six distinct agroecosystems within the Choke Mountain watershed, which is part of my study area. These distinct agroecosystems comprise the Abay valley and fragmented lowlands, midland plains with black soil, midland plains with brown soil, midland with sloping lands, hilly and mountainous highlands, and the Afro-alpine zone. Specifically, my study area extends to only four of these agroecosystems.

Previous nutrition-focused studies placed more emphasis on nutrition and public health, while disregarding the issue of agriculture (Gebremedhin et al., 2017; Jateno et al., 2023; Kera et al., 2024; Mekuria et al., 2017; Moga Lencha et al., 2022). Similarly, agricultural-related studies have concentrated on boosting agricultural productivity but mainly ignored nutrition and related issues. In this study, we investigated dietary diversity and its association with food production by introducing agroecosystems as the key determinant for targeting nutrition-sensitive agriculture. The concept was built around the environment-agriculture-nutrition nexus. Methodologically, this study used a multilevel approach to look at determinants of dietary intake at both the household and agroecosystem levels in contrast to most previous studies in Ethiopia, which have utilized a single-level analysis that cannot account for the hierarchical nature of data and sampling procedures (Alemu, et al., 2017). The study area consisted of distinct agroecosystems in the Chemoga watershed in the Upper Blue Nile region of Ethiopia, which are diverse with regards to temperature, rainfall, soil type, and farming system (Simane et al., 2013).

The influence of agroecosystems could be manifested in the pathways of their effects on household dietary intake through food production and via geographic accessibility to markets, roads, and other rural services. As such, the primary goal was to gather relevant information to gain an improved understanding of household dietary diversity and explore the role that production diversification could play within household diets and nutrition so that appropriate interventions could be implemented with the goal of enhancing nutrition-sensitive agriculture while also considering the varied features across the watershed. To achieve this goal, we had three specific objectives: (1) to examine the variety of food consumption and the range of food group production across various agroecosystems; (2) to determine whether family diets show any linkages with farm production diversification among smallholder farmers; and (3) to analyze the determinants that contribute towards households' dietary diversity amongst smallholder farmers.

2.2 Materials and Methods

2.2.1 Study area

This study was conducted in the Chemoga watershed, which is part of Ethiopia's Upper Blue Nile Basin's headwater zone in the Choke mountain section of East Africa (Simane et al., 2013). It has an area of 823 km^2, with elevations ranging from 800 to 4200 m above sea level, and is situated 300 km northwest of Ethiopia's capital, Addis Ababa, within the country's Amhara Region and East Gojjam Zone (Figure 2-1). Due to differences in climate parameters (e.g., temperature and rainfall), soil type, topography, farming system or agricultural technologies and practices, and farmers' social setting (e.g., human values, institutions), this watershed is classified into five agroecosystems (Simane et al., 2013): Abay valley lowlands (AEZ-1), which is part of the Abay gorge and characterized by adverse agroecological conditions and substantial soil degradation; midland plains with brown soil (AEZ-2), which has higher agricultural production and productivity; midland sloping lands with red soils (AEZ-3), which is distinguished by high soil acidity and steep slopes with a high rate of soil erosion; hilly and mountainous highlands (AEZ-4), which has a steep and mountainous landscape and unfavorable agricultural agroecological conditions; and an Afro-alpine zone at the summit of Choke mountain protected from human settlement (AEZ-5). The fifth zone was not considered in the household survey, but still it was considered for physical characteristics analysis of the study area.

The primary purpose of mapping agroecosystems is to delineate areas with similar sets of potentials and constraints for development. It helps to identify promising directions for further in-depth research work and development plans (Simane et al., 2013). Mixed farming systems are applied throughout all zones except for AEZ-5, consisting of crop production (sorghum/maize/teff, wheat/maize, wheat/barley, or potato/barley) and livestock rearing comprises cows, oxen, sheep, goats, horses, mules, donkeys, and hens.

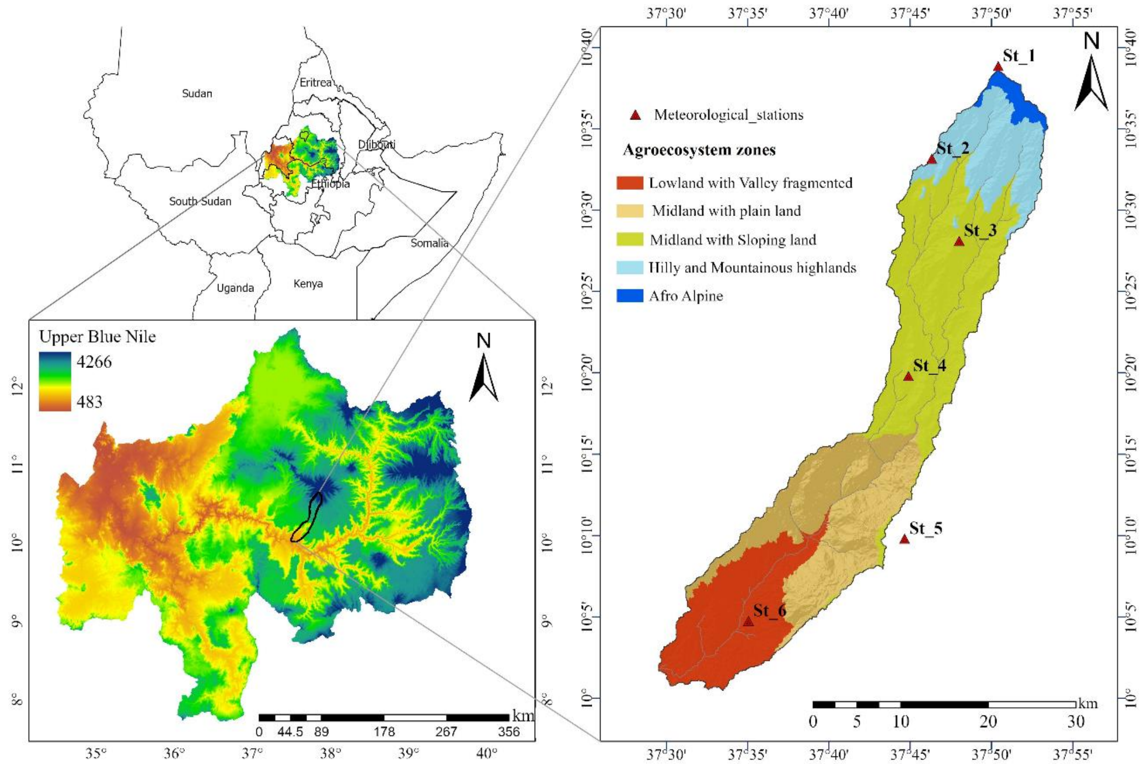

Figure 2-1: Location map of the study area, meteorological stations, and agroecosystem zones.

2.2.2 Study design, sample size, and sampling procedure

A cross-sectional study design was employed. A multi-stage sampling procedure was applied to select the study participants, with agroecosystem type used as a parameter to stratify the sample. All kebeles (the smallest administrative unit in Ethiopia) in the Chemoga watershed were identified, and then one representative kebele from each agroecosystem was chosen through simple random sampling. Aratu Amba, Dendegeb, Debre Zeyit, and Dangule were selected to represent AEZ1–4, respectively. Systematic random sampling techniques were used to select households, and the selection was proportionate to the size of each kebele.

The following single population proportion's sample size determination formula was used to determine the appropriate sample size.

$$n = \frac{\left(Z_{\alpha/2}\right)^2 * \mathrm{p(q)}}{\mathrm{d}^2} \tag{1}$$

where n is the required sample size; $Z_{\alpha/2}$ is the upper point of $\alpha/2$, which has a value of 1.96 in the standard normal distribution with a 95% confidence level; p is prevalence of the outcome of interest and assumed to be 50% - since no more previous study on the area; q is $(1 - \mathrm{p})$; and d is the desired precision, which is 5%. To achieve the desired precision level, a 5% non-response rate was considered. As a result, 404 household heads were eventually chosen as the survey participants.

2.2.3 Data collection

Most of the data were collected in a detailed household survey of farm households in the Chemoga watershed from 20 August to 30 September 2021. The household survey used semi-structured questionnaires to collect detailed household-level data on demographics, socioeconomic conditions, dietary diversity, and agricultural production. The English version of the questionnaire was translated into Amharic (the local language). Data collectors received training to ensure that they understood the questions and could easily administer the questionnaires. Additionally, a pre-test was conducted on 20 people (about 5% of the sample) with similar backgrounds outside of the study area to validate the questionnaire. The formal household survey was supplemented with information from key informant interviews (development agents, kebele administrators), focus group discussions (women, youth, and elders; 5–7 individuals per group discussion), and field observations. Respondents were asked about the foods that household members had eaten and beverages they had consumed in the last 24 - hrs. This study used the FAO guideline to classify food into 12 groups (FAO, 2007; Swindale & Bilinsky, 2006). A household dietary diversity score (HDDS) was calculated by considering how many food groups were consumed over this 24-hrs. period (see Section 2.6). Similarly, farm production diversity scores were calculated by listing all crops grown and animals reared in the last 12 months and categorizing them into the same 12 food groups used for the dietary diversity analysis. This was done to better account for diet and nutrition from a broader perspective than a simple crop or livestock species count alone. Rainfall and temperature data were obtained from Ethiopia's National Meteorology Agency from 1983–2018.

2.2.4 Data management and analysis

The data were cleaned, coded, and input into SPSS version 28 before being exported to STATA version 17 (Stata Corp LP, College Station TX) for analysis with descriptive (percentage, mean, standard deviation) and inferential (chi-square test, *t*-test, one-way ANOVA) statistics. A wealth index was calculated using principal component analysis based on the available main assets owned by households. To investigate temporal and regional differences in rainfall and temperature, the Mann–Kendall test was utilized with a 0.05 significance level, and $|z|$ values greater than 1.96 were recognized as significant. Multilevel mixed-effect generalized linear modeling was used to measure the relation between household and agroecosystem determinants and HDD.

2.2.5 Empirical model

A multilevel mixed-effect generalized linear model with a binomial family and logistic distribution link function was deployed to evaluate the relationships between dietary intake in households and agroecosystem zone characteristics. This approach allowed for an examination of both household- and cluster/agroecosystem-level variables in one analysis, instead of needing to conduct several conventional single-level analyses. Additionally, due to the multistage cluster sampling process, households were found to be nested within agroecosystem zone clusters; as such, dietary intake in households likely correlated to related agroecosystem factors. The maximum likelihood estimation method was utilized while adjusting for both levels of variables during the analysis.

The model can be expressed in the following equations:

$$Y_{ij} = \beta_{0j} + \beta_{1j}x_{1ij} + \beta_{2j}x_{2ij} + \beta_{3j}x_{3ij} + \beta_{4j}x_{4ij} + \epsilon_{ij} \quad (\boldsymbol{level\ 1}) \qquad (2).$$

$$\beta_{0j} = \gamma_{00} + \gamma_{01}Z_{1j} + \gamma_{02}Z_{2j} + \mu_{0j} \quad (\boldsymbol{level\ 2}) \qquad (3).$$

Where, $\beta_{1j} = \gamma_{10}$ $\quad \beta_{2j} = \gamma_{20}$ $\quad \beta_{3j} = \gamma_{30}$ $\quad \beta_{4j} = \gamma_{40}$

Mixed model:

$$Y_{ij} = \gamma_{00} + \gamma_{10}X_{1ij} + \gamma_{20}X_{2ij} + \gamma_{30}X_{3ij} + \gamma_{40}X_{4ij} + \gamma_{01}Z_{1j} + \gamma_{02}Z_{2j} + \mu_{0j} + \epsilon_{ij} \qquad (4).$$

Where Y_{ij} is HDD status (the dependent variable) for household i, in agroecosystem j; β_{0j} is the intercept for the j^{th} agroecosystem zone; β_{1j}, β_{2j}, β_{3j}, and β_{4j} are the regression coefficients associated with X_{ij} for j^{th} agroecosystem; γ_{00} is the overall mean intercept; γ_{01} and γ_{02} are the regression coefficients associated with the agroecosystem -level variables; γ_{10}, γ_{20}, γ_{30}, and γ_{40} are the overall slope adjusted for the agroecosystem level variables; Z_{ij} represents variables at the agroecosystem level; ϵ_{ij} is the random error, and μ_{0j} are the random effects at agroecosystem j adjusted for agroecosystem level variables on the intercept. For simplicity, this can be rewritten as the log of the probability of having adequate dietary diversity among households as follows:

$$log\left[\frac{Y_{ij}}{1-Y_{ij}}\right] = \beta_0 + \beta_1 x_{ij} + \beta_2 z_{ij} + \mu_j + e_{ij} \qquad (5).$$

where Y_{ij} is the probability of having adequate HDD for household i in the agroecosystem zone j. In this multilevel analysis, four models were assessed to determine which model best fit the data. The first model is a null model that did not include variables from either the household or agroecosystem zone level; it was created to evaluate the hypothesis that there was no difference in dietary diversity results between households within different agroecosystem zones and only included a random intercept for total variance in dietary intake. Model-2 included all household-level variables, model-3 included all agroecosystem-level variables, and model-4 incorporated all household- and agroecosystem-level variables.

In this modeling, measures of association were used to estimate the likelihood of adequate diversified dietary intake as an odds ratio (OR) with 95% confidence intervals. Crude associations between independent variables and a dependent variable were first determined, using any variables with $p \leq 0.25$ from the bi-variable analysis as candidates for further analysis in the multilevel analysis. All variables with $p \leq 0.05$ were considered to be statistically significantly associated with HDD status. Multicollinearity was tested via the variance inflating factor (VIF), and the contingency coefficient depended on the type of variables. Measures of variation in the random-effect parts of the model were reported as partitioning of variance coefficient (PVC)/intraclass correlation coefficient (ICC), proportional change in variance (PCV), and median odds ratio (MOR). The ICC measured the variations in HDDS that resulted from different agroecosystem zones along the study watershed; higher ICC values (above 5%) reveal more agroecosystem characteristics influencing household variation in the dietary variety score. The ICC can be calculated as follows:

$$ICC = \frac{\delta^2 u}{\delta^2 u + \delta_e^2} \tag{6}$$

where δ_u^2 is between-group variation and δ_e^2 is within-group variation. It can also be computed as

$$ICC = \frac{\delta^2}{\delta^2 + \frac{\pi^2}{3}} \tag{7}$$

where δ^2 is the estimated variance of cluster/agroecosystem zones. Because it is difficult to obtain the variance within groups in the model estimate, the term is replaced with $\frac{\pi^2}{3}$ (have the value of 3.29) (Austin et al., 2018; Leckie et al., 2019; Merlo et al., 2005, 2016). Similarly, the total variation attributed to household- and agroecosystem-level factors in each model can be measured with the proportional change in variance and calculated as:

$$PCV = \frac{\delta^2 A - \delta^2 B}{\delta^2 A} \tag{8}$$

where δ^2A is the variance of the initial model, and $\delta^2 B$ is the variance of model with more factors that measure variation attributed by both level factors, with the null model used as a reference (Merlo et al., 2019). The MOR is the median value between the clusters of the highest probability of having adequate dietary diversity and the cluster of having the lowest probability when two households are randomly selected from two agroecosystem zones. According to (Merlo et al., 2005), the MOR can be calculated using the following formula:

$$MOR = exp\left(\sqrt{2 * \delta_u + 0.6745}\right) \approx exp\left(0.954\sqrt{\delta_u}\right) \quad (9)$$

The Deviance Information Criteria (DIC) (−2log likelihoods), Bayesian Information Criteria (BIC), and Akaike Information Criteria (AIC) were used to estimate the goodness of fit of the model adjusted for different level factors. The models with the lowest values of DIC, BIC, and AIC were selected as having the best fit.

2.2.6 Key variables considered in the study

The HDDS was used as an indicator of food security and nutrition, referring to the variety and quality of foods available in a household. This score was calculated based on the number of food groups consumed by household members over a 24-h period. A higher score implies better dietary diversity and a more balanced and nutritious diet. The values range from 0 to 12 based on the intake of 12 food groups (FAO, 2007; Swindale & Bilinsky, 2006). There is no single food that can contain all essential nutrients for adequate health; a greater variety of food groups included in the daily diet results in a greater probability of fulfilling nutrient needs (Kennedy et al., 2015). Therefore, a diet with adequate diversity may indicate adequate nutrient intake, thereby suggesting that dietary diversity could serve as a proxy indicator to reflect food security and nutritional status at the individual and household levels (Swindale & Bilinsky, 2006; Workicho et al., 2016). Therefore, the outcome variable for this study was HDD status, defined as 1 if it was adequate and 0 otherwise. When using mean HDDS as an indicator of dietary diversity, it is necessary to compare changes in HDDS with a benchmark/target level of diversity. Unfortunately, cut-off point, or target level of diversity is not available in the case of household-level dietary diversity measurements. However, household dietary measurement guidelines (FAO, 2007; Swindale & Bilinsky, 2006) have recommended developing a HDDS target by taking the average HDDS of the 33% of households with the highest diversity (i.e., the upper third or upper tercile of diversity). In this study, the average HDDS in the upper third is 7 food groups. Therefore, a HDDS ≥ 7 was considered to be adequate, and HDDS ≤ 6 was considered to be inadequate. Table 1-1 presents a description of key predictor variables hypothesized to influence the study's outcome variables.

Table 1-1: Description and measurement of predictor variables.

Variable	Description	Measurement/unit
Educational level	Educational status of respondents	Categorical, 1 if cannot read and write; 2 if informal education; 3 if elementary school; 4 if high school and above
Dependency ratio	Ratio of household members < 15 & > 64 years old aged to15-64 years old age	Metric, ratio
Land holding	Total land owned by the household	Metric, Hectar
Livestock size	Total livestock owned by household	Metric, Tropical Livestock Unit
Farm production diversity	Farm production diversification ranging from 0 to 12 based on 12 possible food groups produced by household in the last 12 months	Metric, number of food groups produced
Home gardening	Household practicing home gardening	Binomial, 1 if yes; 0 otherwise
Meal frequency	Number of meals household consumes per day	Metric, number
Wealth status	Wealth based on a wealth index constructed from the household's assets	Categorical, 1 if poor; 2 if middle; 3 if rich
Health extension contact	Frequency of health extension contacts in the last 12 months	Metric, number
Market distance	Distance to the nearest market center	Metric, minutes of walking
Market accessibility	Availability of local market	Binomial, 1 if yes, 0 otherwise
Agroecosystem zone	Agroecosystem zones in which the household lived	Categorical, 1 if AEZ-1; 2 if AEZ_2; 3 If AEZ-3; 4 if AEZ-4
Long-term annual mean temperature	Average temperature within a specific agroecosystem during the last 35 years	Metric, °C
Long-term annual mean rainfall	Average annual rainfall within a specific agroecosystem during the last 35 years	Metric, mm

2.3 Results

2.3.1 General demographic and socioeconomic characteristics of the respondents

Table A1 in the appendix presents summary statistics from the 396 valid responses for the important demographic and socioeconomic characteristics of the study population. The average age of the household head was about 47 years old, and female-headed households accounted for less than 5% of the total. On average, households had about 5 members, of which about 27% were economically dependent. The majority of the household heads (64%) reported they could not read and write, and less than 2% attended high school or above. About one-third of households were classified as poor, with the largest proportion observed in the lowland and fragmented valley, and hilly and mountainous highland agroecosystem zones (AEZ1 and 4); most of the relatively wealthier households were in the two midland zones.

In a 24-h period, the average consumption was about 5 food groups, with a minimum of 2 and a maximum of 10 out of the predefined 12 food groups; the amounts varied significantly across agroecosystems. About 31% of the households took only 2 meals per day, mainly lunch and dinner (see appendix Table A1), with the majority located in AEZ-2. However, households residing in this agroecosystem tend to possess a relatively higher socio-economic status than those in other areas. This distinction could potentially stem from variances in feeding habits influenced by cultural factors across different agroecosystems. Accessibility to markets was also poor; households walked more than 2 h on average to get to the nearest market. Households in AEZ-2 travelled a relatively shorter distance (<1 h). However, the coverage of safe drinking water (pipe water) in AEZ-2 was unexpectedly very limited (only 33%) compared to other areas.

2.3.2 Agroecosystem-related physical characteristics

ENACTS grided rainfall and temperature data from 1983 to 2018 were obtained from the National Metrological Agency of Ethiopia. Rainfall and temperature (maximum and minimum) data were extracted from ENACTS grided data for each agroecosystem zone from different stations located along the watershed (Fig. 2-1). As shown in Table 1-2, AEZ-4 and AEZ-5 experienced high mean rainfalls over the last 35 years as compared to the other agroecosystems, particularly AEZ-1. These observations are supported by information obtained from key informant interviews and focus group discussions during the data collection period. Incorporating the issues of agroecosystem rather than using the conventional agroecology in this research gives further advantage to take in to account the social component of the community besides to the physical environment (Simane et al., 2013a). The farming community in each of the agroecosystems cultivates different kinds of staple food crops (Table 1-2), and their household food supply is highly dependent on their own production. They also reared different livestock across agroecosystem zones, especially in the hilly and mountainous highland agroecosystem zone, horse and sheep production are particularly important. Horses rather than oxen are used as draught power in this area, unlike in the other agroecosystem zones (field visit observation).

Table 1-2: General characteristics of the agroecosystems in Chemoga watershed.

Agroecosystem	**Mean annual temp (°C)**	**Mean annual rainfall (mm)**	**Altitude (m asl)**	**Farming system**
AEZ-1	15.7–27.4	996.29	800–1400	Sorghum-maize-teff
AEZ-2	10.4–22.7	1251.10	1400–2400	Wheat-maize
AEZ-3	10–22	1282.40	2400–2800	Wheat-barley
AEZ-4	8.8–21.2	1399.30	2800–3800	Potato-barley
AEZ-5	5.4–18.1	1434.5	3800–4200	Choke protected area

Sources: Own survey (temperature, rainfall) and (Simane et al., 2013). Rainfall and temperature data are averages from 1983–2018.

The Mann–Kendall test results show significant changes in the increments of the trends of mean rainfall in the wet season (Table 1-3). In particular, there is a significant increasing trend of mean rainfall in the Afro-Alpine and hilly and mountainous highland agroecosystem zones. No other defined trends in rainfall were observed in the other agroecosystem zones in both annual and seasonal series. The minimum and maximum temperatures showed significant incremental trends in the seasonal and annual time series across the whole watershed. The highest temperature increase was observed in the minimum temperature (1°C/decade) in the dry season at AEZ-1, but the maximum temperature did not significantly change in annual and seasonal time series on this area (Table 1-3).

Table 1-3: Annual, wet, and dry season temperature and rainfall trend analysis (1983–2018).

Attribute	AEZ	**Parameter**	**Annual**		**Wet season**		**Dry season**	
			Z-value	Change (°C/decade)	Z-value	Change (°C/decade)	Z-value	Change (°C/decade)
Temperature	AEZ-5	T_{min}	4.15**	0.4	2.00*	0.2	4.40**	0.6
		T_{max}	4.21**	0.4	3.72**	0.4	3.35**	0.3
	AEZ-4	T_{min}	4.48**	0.3	2.60*	0.2	4.23**	0.4
		T_{max}	4.81**	0.4	4.21**	0.4	3.47**	0.4
	AEZ-3	T_{min}	5.54**	0.3	4.78**	0.3	4.49**	0.4
		T_{max}	4.48**	0.3	4.40**	0.3	3.15*	0.4
	AEZ-2	T_{min}	5.46**	0.3	4.67**	0.3	4.09**	0.3
		T_{max}	4.09**	0.3	3.96**	0.3	2.95*	0.4
	AEZ-1	T_{min}	5.05**	0.6	1.19	0.1	5.08**	1.0
		T_{max}	0.64	0.1	−0.10	0.01	1.25	0.2
			Z-value	Change (mm/decade)	Z-value	Change (mm/decade)	Z-value	Change (mm/decade)
Rainfall	AEZ-5		1.62	75.6	2.79*	66.0	1.14	23
	AEZ-4		1.57	55.8	2.25*	46.2	0.31	6
	AEZ-3		1.41	43.7	1.87	37.9	0.2	2
	AEZ-2		0.34	8.3	0.1	3.0	−0.0001	-
	AEZ-1		0.23	4.5	0.5	9.9	−0.82	−16

* $p < 0.05$; ** $p < 0.01$.

The results of the Mann–Kendall test revealed that there were no significant changes in annual rainfall over the last 35 years across the different agroecosystem zones of the Chemoga watershed (Figure 2-2). The annual mean temperature, however, increased throughout, except for T_{max} in AEZ-1 (St_6).

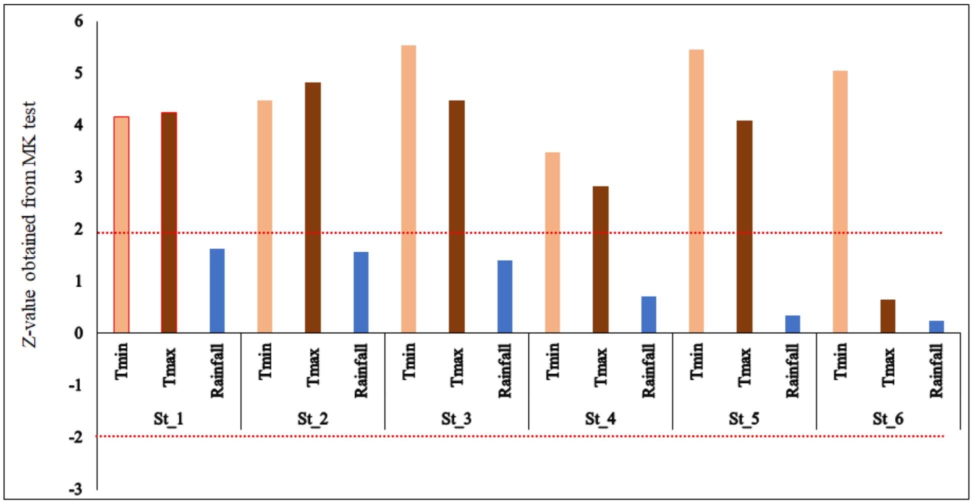

Figure 2-2: Z-scores of the Mann–Kendall test for annual temperature and rainfall series for the period 1983–2018. The two dotted red lines represent the theoretical critical values (±1.96) of the test at ≤5% probability level. St_1 represents AEZ-5, St_2 is AEZ-4, St_3 is AEZ-3, St_4 and St_5 represent AEZ-2, and St_6 is AEZ-1 (see also Figure 2.1).

2.3.3 Household dietary diversity and agricultural production diversification

The overall average HDDS in the study area was 5.11 (±1.48), with the lowest scores observed in AEZ-1 and AEZ-4 (see appendix Table A1). The average food production diversification score was 4.91. The ANOVA results (F-test = 5.34, $P < 0.01$) indicated the presence of significant differences in mean HDDS across the agroecosystem zones, but not in the average production diversification score (Figure 2-3). In general, households residing in AEZ-2 and -3 (the midland agroecosystem zones) were found to have better dietary diversity and agricultural food production diversity scores, which is in agreement with the results of previous studies (Alemu et al., 2017; Simane et al., 2013).

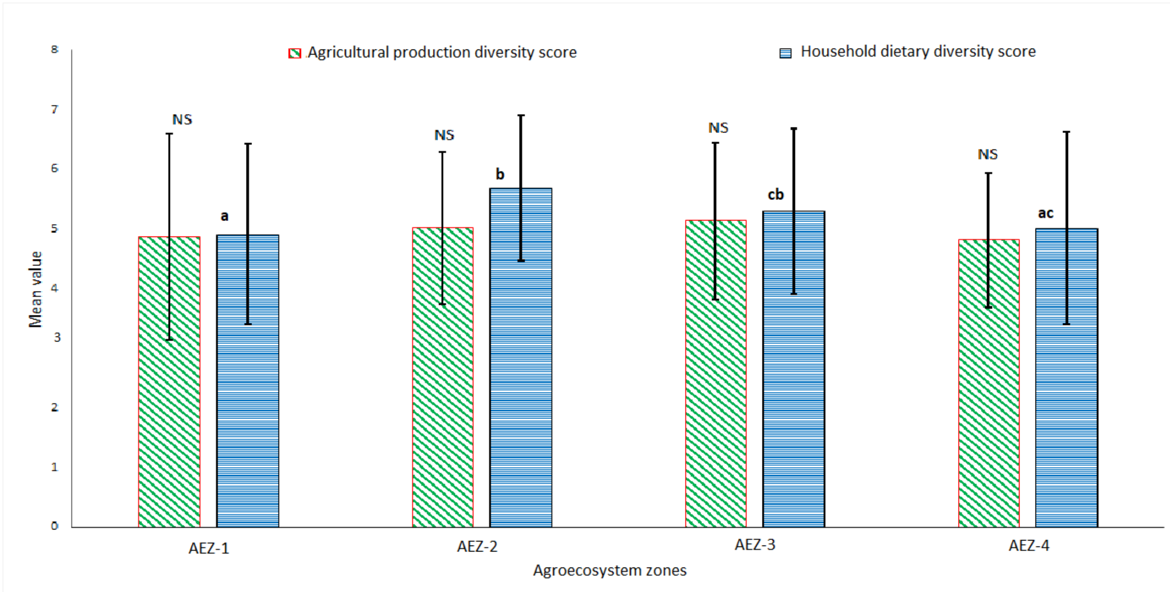

Figure 2-3: Household dietary diversity scores (HDDS) and farm production diversification scores (APDS) across agroecosystems. NS: not significant; bars with different letters for HDDS are significantly different ($p < 0.05$).

Overall, households in the study watershed produced cereals (100%), livestock (97.5%), tubers and roots (72%), beverages (69.1%; particularly '*tella*', a local beverage), and legumes (65.7%) (Figure 2-4). Production of fruits, fats and oils, sweets, and fish was extremely low. Households consumed cereal-based foods ('*Injera*') and potatoes with legumes ('*Shiro wet*' stew with onion and oils added) on a daily basis, whereas nutritionally important foods such as meat, eggs, milk, fish, fruits, and vegetables were the least consumed food groups (Figure 2-4).

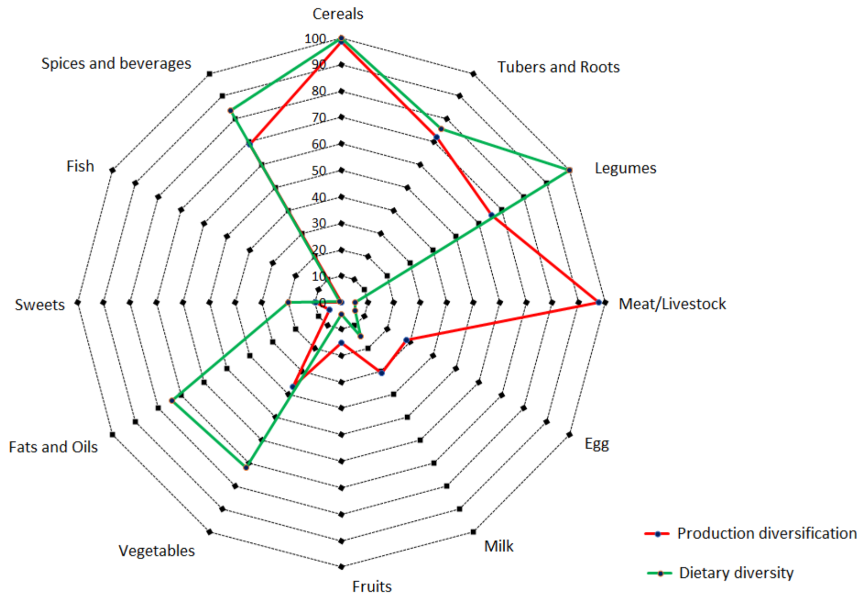

Figure 2-4: Food production for the past 12 months and its consumption in the household within 24 h preceding the survey by percentage.

Figure 2-5 summarizes the diversity of household diets in the 24-h period preceding the survey and production diversification for the last 12 months in the four agroecosystem zones. The consumption of animal-source foods was very limited despite their high production potential, but it was more prevalent in AEZ-2. Cereals and legumes were commonly consumed in all zones. The tuber and root food group were a common staple food in AEZ-2, AEZ-3 and AEZ-4, whereas it was rarely produced and consumed in AEZ-1. Particularly in AEZ-4, potatoes are commonly consumed daily at breakfast, lunch, and dinner throughout the year (based on information obtained from the focus group discussion and key informant interviews). Despite their nutritional importance, dairy, eggs, poultry, livestock/meat, and vegetables were infrequently produced and consumed.

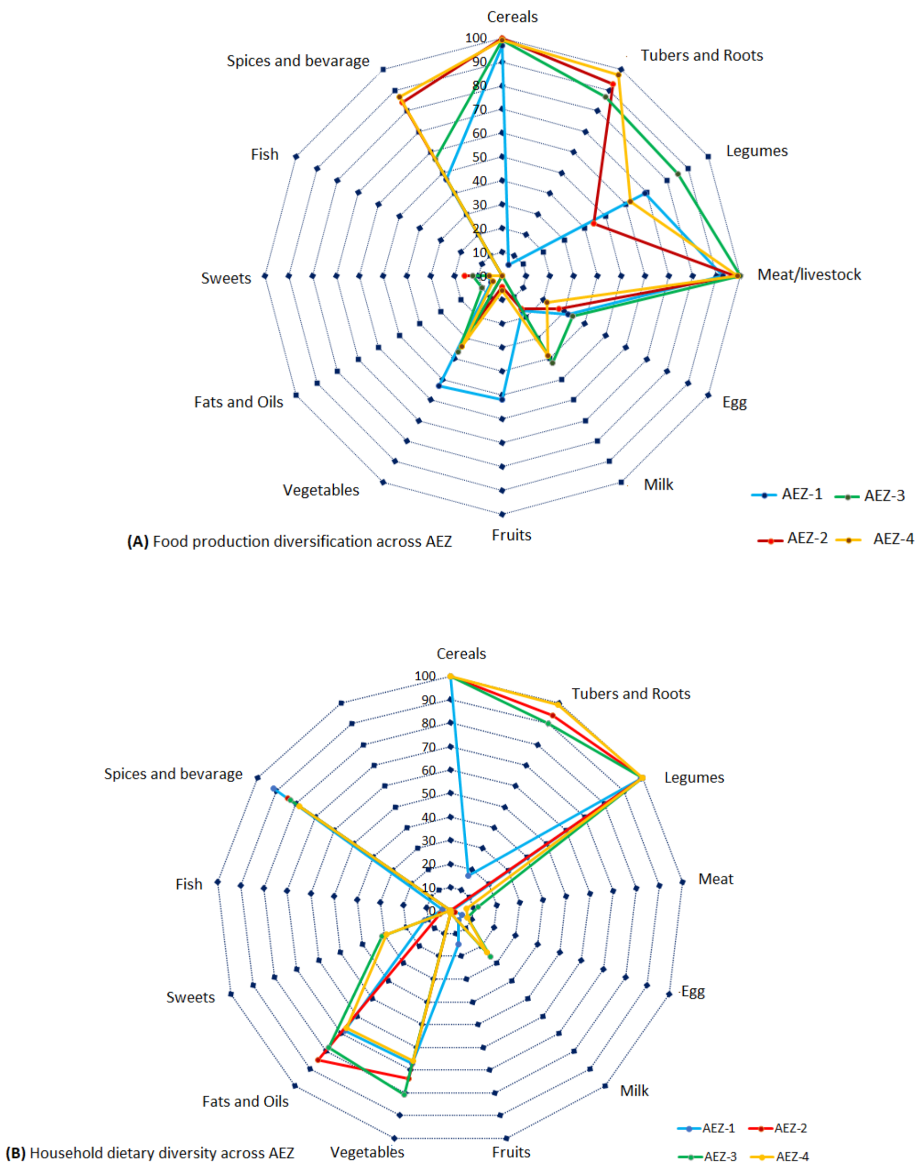

Figure 2-5: Food group production (A) and consumption (B) across the four agroecosystem zones. Results reflect the percentage of households that reported consuming the food group within a 24-h period preceding the survey, and production in the past 12 months.

2.3.4 Consumption of animal-sourced foods and fruits and vegetables

Only 22% of households consumed animal-sourced food in the 24-h period prior to the survey in all agroecosystem zones (Figure 2-6). Consumption of meat and eggs was particularly rare at 5.3% and 6.1%, respectively. Fish is not widely available, except in certain circumstances (e.g., from the Blue Nile River in AEZ-1). This is likely due to socioeconomic and cultural limitations on access to these animal-sourced food items, which provide valuable protein and micronutrients (Workicho et al., 2016). On the other hand, fruits and vegetables were consumed at a rate of 72%, but most of this (66.5%) came from nutritionally poor food items like onions and from local vegetables (e.g., Ethiopian collard greens) that are nutritionally valuable but only seasonally available. Only 10.3% of households consumed vitamin A-rich fruits and vegetables, which are essential sources of dietary micronutrients.

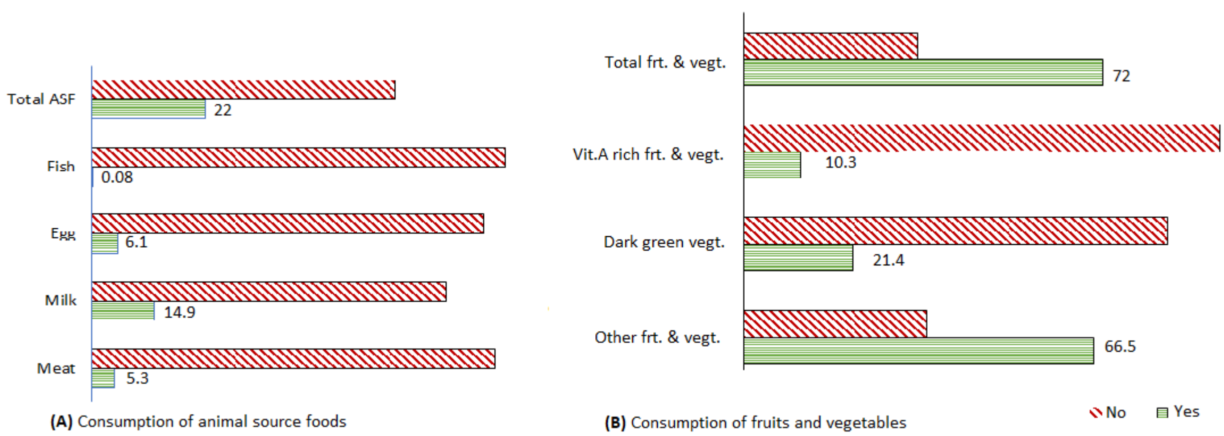

Figure 2-6: Consumption of animal - sourced (ASF) foods and fruits and vegetables (%).

Because they are so important, we looked at the consumption of sources of vitamin A and iron in more detail. The results are summarized in Table 1-4; 41.4% of households consumed vitamin-A source foods, with plant-based and animal-based vitamin-A foods consumed by 30.8% and 20% of households, respectively. The findings also revealed differences in the proportion of household consumption patterns across households among the agroecosystem zones. Household consumption of animal-based sources of iron was only 6%, with organ meat contributing an almost negligible amount (Table 1-4).

Table 1-4: Consumption of food sources of vitamin-A and iron.

Micronutrient	Food source	Food group	Response (yes, %) AEZ-1	AEZ-2	AEZ-3	AEZ-4	Total
Vitamin-A	Plant-based	Vitamin-A rich vegetables	9.6	2.3	19	1.8	8.1
		Dark-green leafy vegetables	30.9	20.5	37	11.4	24.5
		Vitamin-A rich fruits	13.8	1.1	3	0.9	4.5
		Total plant based	41.5	23.9	46	14	30.8
	Animal- based	Organ meat	1.1	0	0	1.8	0.8
		Eggs	5.3	2.3	8	7.9	6.1
		Fish	3.2	0	0	0	0.8
		Milk products	5.3	1.1	26	23.7	14.9
		Total animal based	12.8	3.4	33	27.2	19.9
		Overall Vitamin-A	46.8	27.3	58	33.3	41.4
Iron	Animal-based	Organ meat	1.1	0	0	1.8	0.8
		Flesh meat	1.1	0	12	5.3	4.8
		Fish	3.2	0	0	0	0.8
		Overall iron	4.3	0	12	7	6.1

2.3.5 HDD status and its association with production and consumption of different food groups

The majority of the respondents (80%) had inadequate dietary diversity (Table 1-5), where a HDDS ≥ 7 was considered to be adequate. More specifically, more than 85% and 81% of households in AEZ-1 and AEZ-4, respectively, had inadequate dietary diversity (data not shown in Table 6). Food production such as tubers and roots, milk products, egg, sweets and spices, and beverages were significantly associated with HDDS. In contrast, production of cereals, legumes, vegetables, fruits, livestock, fish, and fats and oils were not significantly linked to HDD, because a comparable proportion of households produced these food groups.

The number of livestock (in TLU) was highly associated with HDD, unlike the result with the dichotomous yes or no response on livestock production. Overall agricultural production diversification was strongly related to the dietary diversity status of the household—those with a high HDDS had a significantly higher mean farm production diversity score than their counterparts (Table 1-5). Moreover, the linkage between household dietary diversity and food production diversification is well investigated in the multilevel model analysis by controlling other important predictor variables in (Table 1-6).

The proportions of households that consumed vegetables, eggs, milk products, fats and oils, sweets, and beverages were significantly associated with dietary diversity which was higher among households with adequate dietary diversity (Table 1-5). The consumption of cereals, legumes, and fruits food groups was not significantly different among households in the adequate and inadequate categories, mainly because of homogeneity in consumption of cereals and legumes.

Table 1-5: HDD status and its association with individual food group production and consumption (%).

	HDD status					
	Adequate (n = 316)		**Inadequate (n = 80)**		**X^2 test**	
Food group	Production	Consumption	Production	Consumption	Prod.	Cons.
Cereals	98.4	100	100	100	1.28	-
Legumes	67.1	99.7	60	100	1.42	.25
Tubers & roots	69.6	72.5	81.3	88.8	4.28*	9.21**
Vegetables	34.7	65.8	46.3	95	3.98	26.79**
Fruits	14.3	3.8	18.8	6.2	0.99	0.94
Livestock/meat	97.2	3.5	98.8	12.5	0.66	10.34**
Egg	25	2.5	42	20	9.59**	34.22**
Milk	27.8	7.9	41.3	42.5	5.40*	60.26**
Fish	0.9	0.3	0	2.5	0.77	4.04*
Fats and oils	5.1	67.7	5	98.8	0.001	31.94**
Sweets	7.3	13	19.2	47.5	10.12*	47.65**
Spices and beverages	66.3	80.1	80	98.8	5.57*	16.45**
Variable	**Mean (SD)**	**-**	**Mean (SD)**	**-**	***t*-test**	**-**
PDS	4.79 (1.35)	-	5.61 (1.26)	-	−4.94**	-
Livestock size	4.42 (2.38)	-	5.90 (2.40)	-	−4.96**	-

* p< 0.05, ** p< 0.01; PDS: Production diversification score

2.3.6 Determinants of household dietary diversity status

Ten predictor variables were included in the final model computation. In this multilevel analysis, 4 models were run, and the final model was explained HDD well, and was used for further interpretation because its DIC, BIC, and AIC values were all smaller than those of the other models. For the ICC value, we always considered the null model.

The results from Table 1-6 demonstrate a statistically significant variation in dietary diversity scores between households located in different agroecosystem zones within the Chemoga watershed. The null model showed that 25.90% of the variance in scores resulted from these differences. In addition, after accounting for household and agroecosystem factors in Model 3, the proportional change in explained variance (PCV) was 83.48%, which indicates that most of the variability is linked to the contrasting agroecosystem zones (Table 1-6). Moreover, households located in agroecosystems with higher scores were 1.13 times more likely to have adequate diversity as compared to households situated in much lower scoring areas. This multilevel analysis demonstrated the presence of significant heterogeneity in HDDS among households across different agroecosystems (Table 1-6).

Variables were added to the subsequent models (as shown in Table 1-6) to assess their relationship with HDD and to explain its variation across agroecosystems. As a result, household wealth status, agricultural food production diversification, number of meals per day, market access, and annual mean rainfall were all significantly related to HDDS.

Table 1-6: Multilevel analysis output on determinants of household dietary diversity status.

Fixed-Effect	**Household dietary diversity status**			
Variable	**Null Model**	**Model-1**	**Model-2**	**Model-3**
	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
Dependency ratio		0.93 (0.46, 8.03)		0.86 (0.41,8.42)
Wealth status				
Poor (ref.)		1		1
Middle		1.32(0.57,3.03)		1.36(0.60,3.05)
Rich		2.51(1.24,5.08)*		2.49(1.19,5.21)*
Landholding size		0.58 (0.24, 1.43)		0.45 (0.17, 1.17)
Livestock size		1.06 (0.90, 1.24)		1.08 (0.91, 1.29)
Production diversity		1.26(1.01, 1.59)*		1.45(1.13, 1.86)**
Home gardening				
No (ref.)		1		1
Yes		1.46 (0.90, 2.37)		1.56(0.96, 2.55)
Meals per day		2.74(1.52,4.94)**		3.26(1.80,5.90)**
Health extension contact per year		1.00 (0.89, 1.06)		1.00 (0.87, 1.07)
Market access				
No (ref.)			1	1
Yes			1.00 (0.99, 1.01)	1.01(1.00, 1.02)*
Mean rainfall			0.99(0.98, 1.0)**	0.99(0.98, 1.0)**
Constant (intercept)	0.02 (0.01, 0.06) **	0.001 (0.0001, 0.01) **	9.87 (3.6, 25) *	2.52 (0.001, 35.8)
Random-Effect				
Measure of variation				
	Null Model	Model-1	Model-2	Model-3
Variance(cluster)	1.15**	0.11**	0.13**	0.19**
ICC/PVC (%)	25.90	3.24	3.8	5.46
PCV (%)	Reference	90.43	88.70	83.48
MOR	2.78	0.86	0.94	1.13
Model fit statistics				
DIC	204.850	163.70	183.17	149.54
AIC	413.70	347.40	374.37	323.08
BIC	421.66	386.90	389.95	369.68

* $p < 0.05$, ** $p < 0.01$.

2.4 Discussion

This study examined household dietary diversity and its linkage with agricultural production diversification by considering contrasting agroecosystem zones. Based on standards in the HDD measurement guideline (FAO, 2007; Swindale & Bilinsky, 2006), only about 20% of households in the study area had adequate dietary diversity (Table 1-5). There was significant variation across the agroecosystems, with households in the lowland and valley fragmented, and hilly and mountainous highland zones having relatively lower HDDS. Understanding this type of specific variation in household dietary intake can aid in targeting and designing agroecosystem-based nutrition-sensitive agricultural interventions through efficient allocation of scarce resources to those most in need (Ahmed et al., 2021; Alemu, et al., 2017).

This study also analyzed the influence of household- and agroecosystem-related determinants on dietary diversity using a multilevel mixed-effect analysis and found that HDD status depended on both household- and agroecosystem-level determinants. Diversification in food production was assessed as a key predictor variable using the same 12 food groups used in the HDDS, rather than considering the simple count of individual food crops and livestock product items produced. As shown in Table 1-6, food production diversification positively influenced the dietary diversity of rural farm households. Holding other variables constant, households were 1.45 times more likely to have adequate dietary diversity for every one unit increase in their farm production diversity score. Therefore, this finding supports the idea that there is a positive association between production diversity and dietary diversity. This makes sense in the context of rural Ethiopia, where much of what is grown on the farm is consumed by the household. It also suggests that increasing the variety of crops produced could lead to improved dietary diversity and nutrition. This finding is also consistent with several studies that have also found a positive association between farm production diversification and dietary diversity (Hagos et al., 2014; Michler & Josephson, 2017; Mulenga et al., 2021; Sibhatu & Qaim, 2018; Sinyolo et al., 2021).

In another way, by cultivating multiple crops, households can not only fulfill their own food requirements but also have extra produce that can be sold or exchanged for additional income. This diversification of income sources improves household food security and makes them more resilient to economic shocks, which in turn promotes dietary diversity and nutritional well-being in subsistence farming communities. The study conducted by Sibhatu et al. (2015) highlights the positive relationship between agricultural diversification, income generation and food security among subsistence farming households. Moreover, a study by Muthini et al. (2020) found that production diversity is significantly associated with dietary diversity of women and entire household but is not associated with the dietary diversity of children in Kenya. This discrepancy may be caused by issues with how food is allocated within households. When adults prioritize consuming diverse foods or sell them for income, it can limit children's access to a varied diet, even if the household produces a diverse range of foods.

Household wealth is an important variable that indicates the general economic well-being of a household, and we anticipated that there would be a positive relationship between wealth and HDD. Results revealed that household wealth status was positively associated with HDDS (Table 1-6). Households in AEZ-1 and AEZ-4 generally had lower HDDS and relatively poorer livelihood conditions as compared with those of the other two zones. This finding is in agreement with a study that demonstrated that poorer farm households are worse off in terms of dietary diversity (Ayenew et al., 2018). Even if food is available, poorer households have limited purchasing power in the market, especially for higher priced items like animal-sourced foods, and some market-oriented food groups like, sweets, and fats/oils in Ethiopian case. In addition, poorer households have a more limited capacity to invest in agricultural inputs to produce more diversified products. (Minja et al., 2021) reported, however, that wealth status had no significant influence on HDD, but nearly all of the respondents of their survey were in the same wealth status group.

Household consumption of meals in terms of both quantity and quality has a direct effect on dietary diversity, nutritional status, and overall health outcomes. Our results showed that households who consumed a higher number of meals per day were more likely to have adequate dietary diversity compared to households that consumed a lower number of meals per day (OR = 3.26, CI = 1.80, 5.90) (Table 1-6). Of-course, despite the importance of meal frequency to improve the diet quality, monotype starch dominated energy/calorie source meals with legume-based stew (locally called Shiro Wet) are common in the study area (Figure 2-4., Table 1-6). Even, almost one-third of households could not eat three meals (breakfast-lunch-dinner meal pattern) per day (Table A1). It could be linked to either limited access to food, or cultural practices regarding meal patterns. Due to cultural norms and dietary preferences, some households or farming communities may not follow the traditional breakfast-lunch-dinner structure and, instead, consume fewer meals per day. Previous studies have shown that households and individuals who consume fewer meals per day are more likely to have inadequate dietary diversity and experience undernourishment (Clausen et al., 2005; Mekuria et al., 2017; Sitotaw et al., 2017; Wubetie & Mekonen, 2022). Therefore, consumption of a limited number of meals per day leading to the overall trend of limited food variety resulted in inadequate nutritional status among members of the household.

Another crucial factor affecting the dietary intake of rural households is their access to markets, which can be assessed by the proximity of local markets to the household. By adjusting other variables, households who have better access to local markets were slightly more likely to have an adequately diversified diet than households with worse access; however, the marginal effect was relatively small (Table 1-6). Physical proximity to markets can facilitate both the sale and purchase of farm products. It is worth noting that the relationship between production and consumption is not always confined to subsistence farming because there are situations where cash income generated from agricultural sales can also make an important contribution to improve dietary quality. Our finding is in agreement with the results of previous studies (Koppmair et al., 2017; Sibhatu & Qaim, 2018) that demonstrated that improved market access can lead to greater diversity in food systems without requiring farmers to individually maximize diversity on their own farm. The implication is that rural farming families who live closer to local markets have better chances to participate in these markets and potentially buy a wider range of food items to supplement their own production. Households in AEZ-2, which has better access to the local market, were able to diversify their diets, especially with fats/oils and vegetables (mainly onions), which were mainly accessed at the market than their own production. It is evident that households in urban areas have more diverse diet consumption habits as compared to those in rural areas, mainly due to the fact that urban households have relatively easier access to markets (Sinyolo et al., 2021).

Climate change is widely anticipated to have a negative affect both on food security, dietary diversity, and the overall nutritional status of the farm households (Bakhtsiyarava & Grace, 2021). The current study revealed a significant negative correlation between HDDS and the long-term average annual rainfall in the study watershed. The multilevel mixed-effect model output showed that when the annual mean rainfall is increased by one unit, the likelihood of a household having adequate dietary diversity score is reduced almost by 1% (OR = 0.99; CI= 0.98, 1.00) (Table 1-6). Teklewold et al. (2019) also identified an inverse relationship between rainfall intensity and dietary diversity in Ethiopia. The research demonstrated that farmers are less likely to consume a diverse range of foods when faced with either a high or low amount of rainfall. This type of non-linear relationship between amount of rainfall and diet diversity was observed in AEZ-1, which had limited rainfall and lower HDD, and AEZ-4, which had excess rainfall and also had lower HDD. However, this finding is not consistent with most previous studies conducted in different areas, which showed that regions with relatively high levels of rainfall are associated with greater dietary diversity (Hagos et al., 2014; Murendo et al., 2018). According to research by Bakhtsiyarava & Grace (2021) in Ethiopia, greater dietary diversity is linked to higher levels of rainfall in the previous year or long-term amounts of rainfall. Our focus group discussions and key informant interviews indicated that the communities experienced frequent snowfall and erratic rainfall that reduced their crop productivity and diversity as well as food availability, particularly in AEZ-1 and AEZ-4.

In addition, declining crop production and diversity were reported as a reason for reduced household income and a shift from subsistence agricultural to migratory unskilled wage work in the nearest city. Particularly, households in AEZ-4 experienced high mean rainfall amounts and frequent snowfall, which created unfavorable conditions for agriculture as compared to the other agroecosystems, which leads their livelihood to rely on government food aid for the last couples of years. Temperature is also hypothesized to have an influence on HDD, but in this study, it was not included in the model as a predictor variable because of its high multicollinearity with rainfall.

2.5 Conclusion

Enhancing the dietary diversity of households is a crucial step toward improving human nutrition and health. Even though the study area has diverse agroecosystems that could potentially produce a variety of foods, consumption of diverse nutrient-dense foods (animal origin and fruits and vegetables) was very limited—only one in five households had an adequate dietary diversity score across the whole study area. However, there was significant variation in the intake of diversified food groups in the different agroecosystem zones. Households in the lowlands of Abay valley and the hilly and mountainous highlands had relatively lower dietary diversity compared with those in the midland agroecosystems. Moreover, the diet of rural households in this study were predominantly starchy-based foods, mainly cereals, roots and tubers that are rich in energy, and legume-based foods, primarily in the form of a local stew (locally called Shiro wet). Consumption of animal-sourced foods and fruits and vegetables (good sources of micronutrients) was found to be very limited across the entire study region.

In small-scale subsistence farming households, agricultural food production is viewed as a direct pathway to dietary diversity and nutritional status through access to food for consumption. Therefore, understanding the linkage between dietary intake and the food production system at the household and agroecosystem level could be used as an entry point to strategically design nutrition-sensitive agricultural programs that go beyond the promotion of increasing production and productivity of conventional staple foods.

In the multilevel analysis, a significant variation of HDDS was observed across agroecosystems. Unexplained variation due to agroecosystem was decreased between the null model and the adjusted full model—just after controlling for both level of factors. Therefore, farm production diversification, wealth status, number of meals per day, market access, and long-term annual mean rainfall all significantly influenced HDDS. Therefore, the use of this type of agroecosystem-based multilevel analysis on the determinants of HDD demonstrated systematic and operational advantages when considering the design of appropriate nutrition-sensitive agricultural strategies in the study area.

The study’s findings provide some key insights for interventions that aim to improve household dietary diversity and nutrition through advocating that policymakers make agricultural programs more sensitive to nutrition. One approach is to take into account the local context, particularly variations across agroecosystems, to better allocate limited resources to benefit needy segments of the community. Moreover, the subsistence pathway should not be the sole mechanism considered in the production–household diet linkage. In some cases, earning cash income from the sale of agricultural products could also be an important pathway to improve dietary quality through better access to products in the market. It is evident that households who accessed the local market in AEZ-2 were more diversified in their diet than others. Hence, investing in infrastructure (e.g., roads, local market) to improve rural farm households’ accessibility to markets is another pathway to improve dietary diversity.

Chapter Three

3. Analysis of malnutrition among children under five years across contrasting agroecosystems of Northwest Ethiopia: Application of structural equation modeling

Parts of this chapter is published as:

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3.1 Introduction

Malnutrition remains a significant global public health challenge despite concerted global efforts to enhance child nutrition. As of 2022, statistics reveal a distressing reality: globally, over one-fifth of children aged <5 years were stunted (amounting to 148.1 million children) and 45 million children were affected by wasting (FAO et al., 2023). Even more alarming is the fact that approximately 5.2 million children aged <5 years died to malnutrition-related complications, with nearly half of these fatalities attributed to malnutrition (FAO et al., 2023). The prevalence of malnourished children is disproportionately concentrated in Asia and Africa, with these regions bearing the brunt of the crisis. For instance, by 2020, more than half of all stunted and more than two-thirds of all wasted children aged <5 years lived in Asia, and two of every five stunted and more than one-quarter of all wasted children aged <5 years lived in Africa (UNICEF/WHO/WORLD BANK, 2021).

Echoing the global trend, child malnutrition remains a pressing public health issue in Ethiopia. The latest Ethiopian Demographic and Health Survey (EDHS) underscores this reality, revealing that 38% of children aged <5 years across Ethiopia are stunted, with an alarming 46% of children aged <5 years in the Amhara region being stunted. In addition, approximately 24% and 10% of these children are underweight and wasted, respectively (CSA and ICF, 2016). The ramifications of child malnutrition are profound, accounting for approximately 28% of child mortality, 16% of primary school repetition, an 8% reduction in the workforce, and an annual economic cost of 55.5 billion Ethiopian birr, equivalent to approximately 16.5% of the country's gross domestic product (African Union Commission, 2013).

Addressing the burden of child malnutrition requires a comprehensive understanding of its determinants within specific contexts, including at the individual, household, community, region, and environmental levels (Black et al., 2020). The framework conceptualized by United Nations International Children's Emergency Fund (UNICEF) identifies three types of determinants of malnutrition: basic, underlying and immediate (UNICEF, 1990). Empirical studies conducted globally confirm that a child's dietary intake and disease experiences constitute immediate causes of malnutrition (Abebe et al., 2017; Ahmed et al., 2021; Alemu, et al., 2017; Danso & Appiah, 2023; Manongga & Yutomo, 2023). Similarly, studies conducted in various developing countries, including Ethiopia, highlight the significant association between child malnutrition and underlying determinants such as food security, feeding and care practices, health services, and household environments (water, sanitation, and hygiene) (Abate & Belachew, 2019; Abebe et al., 2017; Ahmed et al., 2012; Ahmed et al., 2021; G. Alemu et al., 2023; Arriola et al., 2020; Baye et al., 2020; Bayih et al., 2022; Christian et al., 2023; Corsi et al., 2016; Debela et al., 2021; Derso et al., 2023; Dewey, 2016; Hirvonen et al, 2017; Hirvonen & Headey, 2018; Randell et al., 2020a; Sharma et al., 2021; Tarekegn et al., 2022). In addition, these studies also highlight the significant role of basic factors, such as maternal education, media exposure, training, nutrition sensitive agricultural practices, agroecosystem characteristics, and household wealth in child malnutrition.

The Ethiopian government has demonstrated a strong commitment to addressing child malnutrition, as evidenced by the formulation of numerous multisectoral programs, policies, and initiatives since 2008. These include the National Nutrition Program (NNP-I and NNP-II), Nutrition Sensitive Agriculture (NSA) policy, Seqota Declaration, National Nutrition Policy and Strategy, and the recently developed Food-Based Dietary Guideline (Baxter et al., 2008; FDRE, Ministry of Health, 2022; MoANR and MoLF, 2017). However, despite these efforts, child malnutrition persists in Ethiopia, particularly in the Amhara region, where nearly half of all children aged<5 years are reported to be stunted (CSA and ICF, 2016). This underscores the need for further research to provide us with a comprehensive understanding of the prevalence of child malnutrition and its determinants.

Although previous studies have provided valuable insights into child malnutrition, significant research gaps remain, particularly with regard to the effects of agriculture and agroecosystem characteristics on child malnutrition, which are often overlooked in the existing literature. In addition, methodological advances are warranted to better capture the complex and multifaceted nature of malnutrition determinants (Mattes et al., 2022).

To this end, we used structural equation modeling (SEM) techniques in the present study, leveraging the UNICEF conceptual framework, to analyze the hierarchical relationships between malnutrition and its determinants. Unlike conventional regression analysis, SEM offers a more nuanced understanding of these relationships by allowing for the measurement of latent variables and their direct and indirect effects on malnutrition. Furthermore, this study used the Composite Index of Anthropometric Failure (CIAF) to comprehensively assess the prevalence of child malnutrition, thereby mitigating the risk of underestimation associated with conventional single anthropometric indicators (Nandy & Svedberg, 2012).

The aims of the present study were to comprehensively examine the prevalence of malnutrition and to explore its determinants among children aged <5 years in Northwest Ethiopia. The findings hold significant implications for stakeholders involved in nutrition-sensitive and nutrition-specific intervention programs, facilitating a nuanced understanding of spatial variations across agroecosystems.

3.2 Conceptual framework

Drawing upon UNICEF's conceptual framework and prior studies conducted in developing countries (Aboagye et al., 2021; Fenta et al., 2021; UNICEF, 1990), this study adapts a conceptual framework tailored to the Ethiopian context. The framework delineates the determinants and consequences of child malnutrition, operating across multiple levels of causation, from broad socioeconomic and environmental factors to immediate child-level factors. At its core, the framework distinguishes between basic, underlying, and immediate factors hypothesized to impact child malnutrition directly and indirectly, as shown in Figure 3-1. Immediate causes, such as exposure to disease and inadequate dietary intake, are identified as primary instigators of malnutrition in children. However, factors within each child’s household (e.g., insufficient access to food, poor maternal and child feeding practices, inadequate health services, and poor household environment encompassing issues like lack of safe water and sanitation), are recognized as proximal determinants significantly affecting the immediate causes of malnutrition. These household level determinants represent proximal factors directly affecting a child’s nutritional status. Beyond the household level, broader social factors encompassing socioeconomic status and environmental conditions are identified as distal causes, exerting their influence by shaping the quality and quantity of the resources available within households. Consequently, factors operating at the societal level are deemed as basic or root causes underlying child malnutrition.

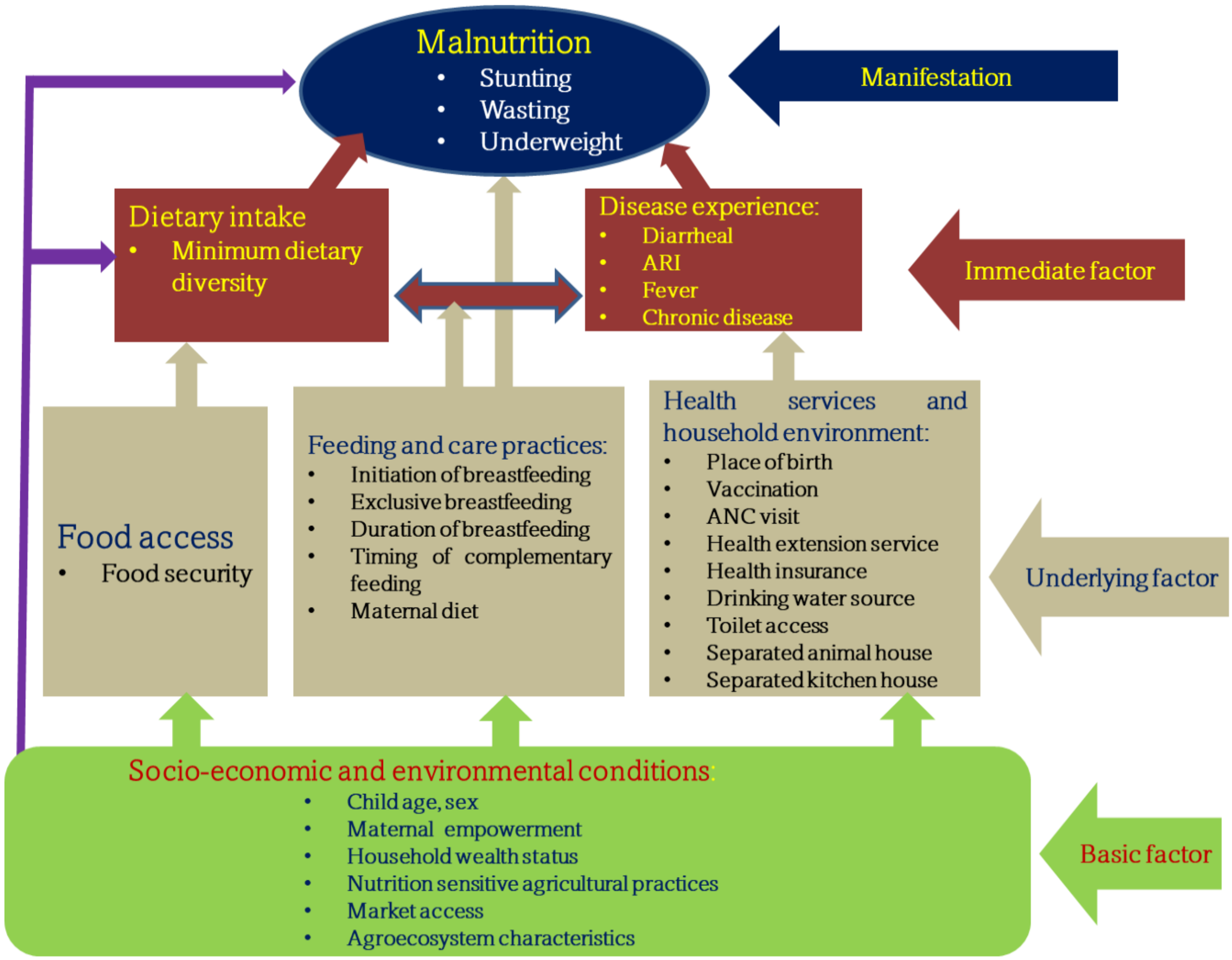


Figure 3-1: Conceptual framework for determinants associated child malnutrition; Adapted from UNICEF conceptual framework (UNICEF, 1990)

3.3 Materials and methods

3.3.1 Study area

The Chemoga watershed in the northwest part of Ethiopia is located within the Upper Blue Nile Basin (Figure 3-2), a region characterized by its diverse topography, ranging from highlands to lowlands. The Chemoga watershed is approximately 300 km northwest of Addis Ababa, the capital of Ethiopia, and covers a considerable land area with varying climatic and ecological conditions. The area is predominantly characterized by contrasting agroecosystems with diverse agricultural practices (Table 2-1), with altitudes ranging from 800 m above sea level (asl) in the lowlands and valley fragmented to higher peaks in the hilly and mountainous highlands (4200 m asl) (Simane et al., 2013a). The Chemoga watershed plays a vital role in the hydrology of the region, ultimately contributing to the flow of the Blue Nile River. Human activities, such as crop cultivation, livestock grazing, and settlement, are prevalent throughout the watershed, including along the steep slopes, exerting pressure on the natural environment and contributing to land degradation (Meshesha et al., 2024; Wubetie et al., 2024). Livelihoods in the area primarily rely on a mixed farming system integrating both crop cultivation and the rearing of livestock. Overall, the Chemoga watershed serves as an important ecological and hydrological component of the Upper Blue Nile Basin, playing a crucial role in sustaining local livelihoods and biodiversity.

Table 2-1: General characteristics of the agroecosystems in Chemoga watershed.

Agroecosystem[A]	Mean annual temperature (°C)	Mean annual rainfall (mm)	Altitude (m asl)	Farming system
AEZ-1	15.7–27.4	996.29	800–1400	Sorghum-maize-teff
AEZ-2	10.4–22.7	1251.10	1400–2400	Wheat-maize-teff
AEZ-3	10–22	1282.40	2400-2800	Wheat-barley
AEZ-4	8.8–21.2	1399.30	2800–3800	Potato-barley
AEZ-5	5.4–18.1	1434.5	3800–4200	Choke protected area

Rainfall and temperature data are averages over 1983–2018 from the Ethiopian Metrological Agency. [A]Locations of the different agroecosystem zones (AEZ) are shown in Figure 3-2. AEZ-1, lowland with valley fragmented; AEZ-2, midland plain with red soils; AEZ-3, midland with sloping

land; AEZ-4, hilly and mountainous highland; AEZ-5, afro alpine.
Sources: Own survey and (Simane et al., 2013a).

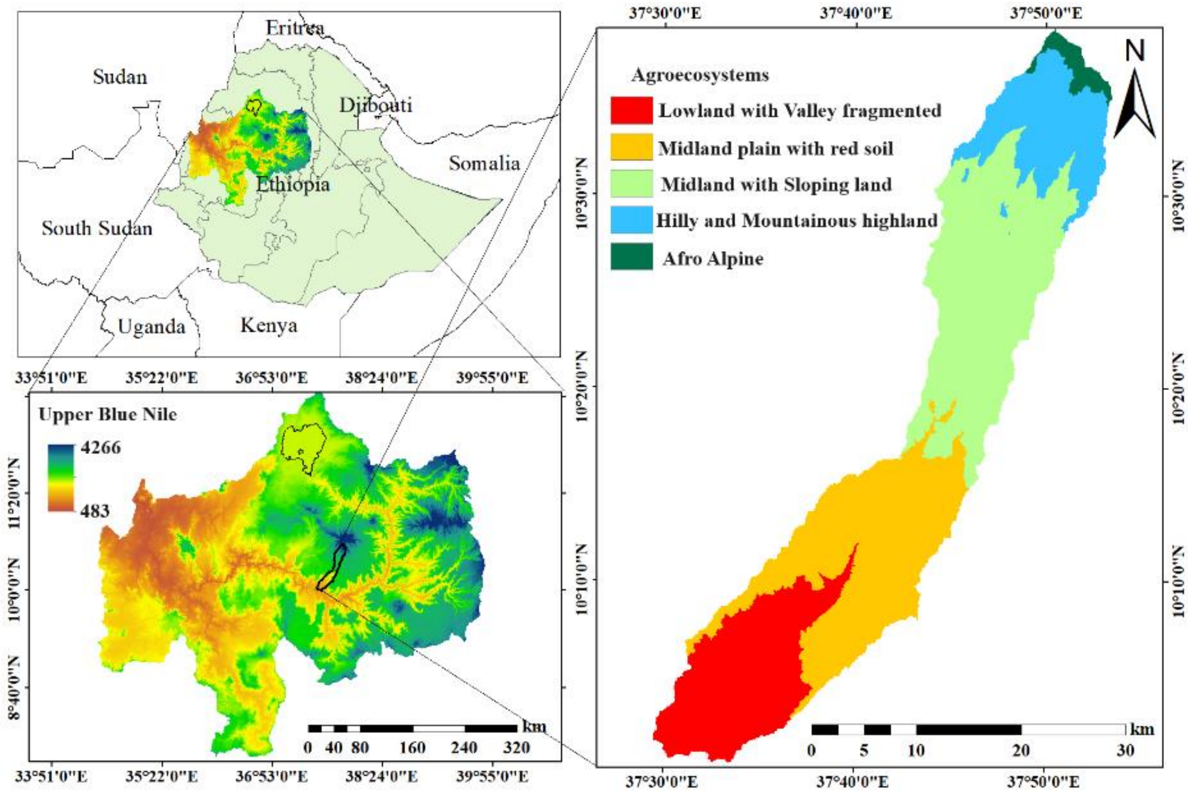


Figure 3-2: Maps showing the location of the study area.

3.3.2 Study design and sampling procedures

The present study employed a cross-sectional study design and strategically used a multi-stage sampling method, with agroecosystem typology serving as a key stratification parameter. Initially, the Chemoga watershed was delineated with five distinct agroecosystems. that covered three districts namely Sinan, Gozamin, and Baso Liben. Subsequently, a four representative kebele (the smallest administrative units in Ethiopia, each classified according to its unique agroecosystem characteristics) were randomly chosen from four agroecosystems within three districts in the Chemoga watershed, namely Sinan (AEZ-3, AEZ-4), Gozamin (AEZ-1, AEZ-2), and Baso Liben (AEZ-1, AEZ-2). Since there are no human settlements within the afro-alpine agroecosystem (AEZ-5), it has been excluded from the sample selection process. In collaboration with local health extension workers, households with children aged <5 years were identified in the selected kebeles using the health post's records as the sampling frame. Then, using a systematic random sampling approach, child–mother pairs were selected, with sample sizes allocated proportionately based on the number of children aged <5 years in each of the kebele. In cases where an individual mother had more than one child aged <5 years, one child was randomly selected for inclusion in the study. The determination of sample size adhered to the established formula for single population proportion, ensuring appropriateness and rigor in the sampling process:

$$n = \frac{\left(Z_{\alpha/2}\right)^2 \times \mathrm{p(q)}}{\mathrm{d}^2}$$

where n is the required sample size, $Z_{\alpha/2}$ is the upper point of $\alpha/2$ (which has a value of 1.96 in the standard normal distribution with a 95% confidence level), p is the prevalence of the outcome of interest and was assumed to be 50% because there have been no previous studies in the area; q is calculated as (1–p), and d is the desired precision (5%). To achieve the desired precision level, a 5% non-response rate was considered. Finally, the study included 404 pairs of children aged <5 years along with their mothers.

3.3.3 Data collection methods

The study used a detailed household survey and anthropometric assessments involving 404 children aged <5 years with their mothers. The survey was conducted in June and July 2023. Data were collected through semi-structured questionnaires and anthropometric measurements. This was complimented with focus group discussion and key informant interviews. The survey covered comprehensive information at various levels (child, maternal, household and community), encompassing data on socioeconomic conditions, food security, dietary diversity, and relevant agricultural practices. The survey was administered by trained health and agricultural extension workers well-acquainted with the sampled kebeles. The survey was closely supervised by the first author (BYW). To facilitate smooth administration, data collectors underwent a day-long training session. The survey was enriched with insights from key informant interviews, involving health and agricultural extension workers, alongside field observations.

3.3.4 Data measurement

3.3.4.1 Food security data

Food security status was assessed using the Household Food Insecurity Access Scale (HFIAS), a validated tool used in various developing countries (Coates et al., 2007). This tool consists of nine standard generic questions addressing a household's experiences over the past month across three domains of food insecurity: (i) anxiety and uncertainty regarding food availability, including worries about whether the household would have enough to eat; (ii) limitations in the variety and preferences of food accessed; and (iii) insufficient food intake in terms of meal sizes and their frequences.

3.3.4.2 Dietary diversity data

Each child's mother was asked about the foods that she and her child had eaten, and the beverages they had consumed in the past 24 h. This study used the Food and Agriculture Organization of the United Nations (FAO) guideline, which measures dietary diversity across seven food groups for children and 10 food groups for women (WDDS). Dietary diversity scores (DDS) for children and women were calculated by summing the number of food groups consumed in the 24 h prior to the survey (FAO, 2007).

3.3.4.3 Anthropometric measurements

Anthropometric data were obtained by measuring children's weight and height. Weight measurements in children were obtained without footwear and with minimal clothing, using the recommended UNICEF weighing scale to the nearest 0.1 kg. In cases where children refused to be weighed, their mothers would carry them and stand on the scale; the child's weight was then determined by subtracting the mother's weight from the combined weight of the mother and child. Scales were calibrated before weighing each child using a fixed 2-kg mass. For children who could stand independently, height was measured, without footwear, to the nearest 0.1 cm using a standard calibrated standing height board. Children were positioned against the standing board, ensuring five body parts (heels, bat, buttocks, shoulders, and back of the head) touched the board. A measuring tape was fixed to the board, and the child stood with their head comfortably erect, aligning the lower border of the eye's orbit with the external canal of the ear. Measurements were taken using a horizontally held thin wooden board by touching the top of the head. For children who could not stand independently, length measurements were taken to the nearest 0.1 cm by using a length board fixed with measuring tape and equipped with a headpiece and elongated foot piece. During measurement, the child's head touched the headpiece, and their heels contacted the foot piece. The hands remained relaxed throughout the measuring process. For each child, three consecutive measurements of weight and height/length were obtained, with the average of the three measurements used in the final analysis. The age of the child, in months, was determined from the date of birth (as reported by the mother) to the day of data collection.

3.3.5 Data quality assurance

Data quality was ensured through a meticulous design of the questionnaire and data collection process. Data collectors and supervisors underwent training on both data collection procedures and ethical considerations. A pre-test survey was conducted on 5% of households with similar backgrounds outside the targeted watershed to validate and tailor the questionnaire to local conditions. This iterative process validated the questionnaire and allowed for the customization of instruments. Supervisors checked daily basis to ensure completeness and consistency. In addition, the principal investigator (BYW) monitored the overall quality of data collection as well as thorough entry, and proper management of all data before final analysis.

3.3.6 Data management and analysis

Data were managed using SPSS version 28 (IBM Inc., Armonk, NY, USA). The data were then exported to Stata version 17 (Stata Corp, College Station, TX, USA) for further analysis by a combination of descriptive (percentage, mean, standard deviation [SD]) and inferential (chi-squared test, *t*-test, one-way analysis of variance [ANOVA]) statistics. The study primarily used SEM to measure the direct and indirect effects of risk factors on child malnutrition. In addition, a logistic regression model was used to analyze the direct influence of immediate factors only on child malnutrition using SPSS software. A household's wealth index was computed through principal component analysis based on the main assets owned by the households (as shown in the supplementary material). Standard deviation for the Z-score was computed for height-for-age, weight-for-age, and weight-for-height indices by comparison against the median of Worl Health Organization (WHO) standards, using Emergency Nutrition Assessment (ENA) and WHO Anthro plus software.

3.3.7 Structural equation modeling (SEM)

The hierarchical, complex, and interconnected nature of determinants associated with child malnutrition requires a model that is capable of incorporating and estimating a set of equations simultaneously. This study used the SEM model, considering multiple levels (basic, underlying, immediate), with each level representing variables influencing one another that are treated as a dependent or response variable, as shown in the conceptual framework (Figure 3-1). SEM combines statistical elements of multiple regression, confirmatory factor analysis and path analysis (Harris & Gleason, 2022). This analysis was performed using AMOS version 29 software. It examines complex models with both measured and unmeasured variables (latent variables), allowing the inclusion of endogenous, exogenous and mediator variables. Unlike path analysis, SEM entertains latent variables alongside observed variables (Harris & Gleason, 2022). Mediation analysis was performed to predict the indirect effect of determinants on child malnutrition. In the context of the SEM framework, mediation is categorized as either full or partial (MacKinnon et al., 2000). Mediators can further be classified as single or multiple, single when only one variable lies in the causal pathway between exogenous and endogenous variables, and multiple when more than one mediator operates concurrently at the same stage in the structural model (termed “serial” or “sequential” mediation) (MacKinnon et al., 2000). Multigroup SEM analysis was conducted to estimate the effects in the structural model across different groups, offering insights into possible variations in relationships among variables across these groups.

SEM has two parts: a measurement model and a structure model. In the present study, model fitness for both models was determined using the goodness-of-fit index (GFI), comparative fit index (CFI), root mean square error of approximation (RMSEA) and standardized root mean squared residual (SRMR) (Hair et al., 2010). Before running SEM, confirmatory factor analysis was performed to verify the model’s fit by excluding items with low factor loading. The measurement model was validated through reliability and validity assessments prior to evaluation of causal relationships among variables in the structural model. The reliability test reflects the internal consistency of observed variables through composite reliability, whereas validity examines the extent to which the indicator or a measure accurately reflects its constructs. Therefore, construct reliability and validity were determined using composite reliability (CR) and average variance extracted (AVE). The maximum likelihood estimation procedure was used in model analysis. The estimation of indirect effects used the product-of-coefficients test, whereas total effects were obtained by summing the direct and indirect effects, using bootstrap techniques to determine the level of significance. The Bayesian analysis method addressed missing data with the assumption of missing completely at random. Standardized and unstandardized coefficients, and their exponential (odds ratio), were used to estimate the direct, indirect, and total effects of predictors on child malnutrition. Ultimately, statistical significance was declared when $p < 0.05$. Generally, SEM provided a comprehensive analysis of the complex relationships influencing child malnutrition.

3.3.8 Operational definitions and key variables of the study

Malnutrition, as conceptualized in this study, encompasses various manifestations of undernutrition, namely stunting, wasting, and underweight. These conditions collectively contribute to a state of malnutrition, which is assessed through the CIAF, categorizing individuals into malnourished and normal groups.

The CIAF represents a comprehensive metric that evaluates malnutrition by combining multiple anthropometric failure indicators, including stunting, wasting, and underweight into a single index. It provides a more holistic measure of nutritional status than individual indicators alone.

The main variables in this study are derived from the UNICEF conceptual framework, with some modification by customization to the Ethiopian context. Therefore, by reviewing various related literature, the key basic, underlying, and immediate factors are identified and included in the final model. For the sake of SEM analysis and interpretation in AMOS software, some multiple categorical measured variables, such as education, vaccination, wealth index and agroecosystems were changed to dummy categories (Table 2-2).

Table 2-2: Description and measurement of predictor variables.

Variable	Indicators	Measurement	Level
Latent variable			
Women empowerment	Education level	1, can read &write; 0, otherwise	Basic factors
	Nutrition related training taken	1, yes; 0, otherwise	
	Media exposure	1, yes; 0, otherwise	
NSA practices	Home-gardening	1, good practice; 0, poor practice	
	Livestock in TLU	Number of livestock in TLU	
Feeding and care practices	Initiation of BF	1, started within 1hr; 0, otherwise	Underlying factors
	Exclusive BF	1, yes; 0, otherwise	
	Initiation of CF	1, started on time; 0, otherwise	
Household environment	Toilet availability	1, yes; 0, otherwise	

	Kitchen house	1, separated from living quarters; 0, otherwise	
	Animal house	1, separated from living quarters; 0, otherwise	
Health services	Vaccination	1, fully vaccinated; 0, otherwise	
	ANC visit	1, ≥ 4 visit; 0, otherwise	
	Health insurance	1, they have; 0, otherwise	
	Extension service	Number of contacts per year	
Disease experience	Diarrheal disease	1, experienced it; 0, otherwise	Immediate factor
	Fever	1, experienced it; 0, otherwise	
	ARI	1, experienced it; 0, otherwise	
	Chronic illness	1, experienced it; 0, otherwise	
Observed variables			
Wealth status	Wealth index	1, rich; 0, poor	Basic
Food access	Food security	1, food secure; 0, food insecure	Underlying
Maternal diet	Minimum WDDS	1, ≥ 5 food groups; 0, otherwise	Underlying
Child dietary intake	Minimum CDDS	1, ≥ 4 food groups; 0, otherwise	Immediate
Agroecosystem	AEZ	1, AEZ-2,3,4; 0, AEZ-1	Basic
Malnutrition	CIAF	1, malnourished; 0, otherwise	Outcome

AEZ, agroecosystem zone; ANC, antenatal care; ARI, acute respiratory infection; BF, breastfeeding; CDDS, dietary diversity score for children; CF, complementary feeding; CIAF, Composite Index of Anthropometric Failure; NSA, Nutrition Sensitive Agriculture practices; TLU, Tropical Livestock Unit; WDDS, dietary diversity score for women.

3.3.9 Ethical considerations

Before data collection, ethical approval was obtained from the Department of Rural Development and Agricultural Extension, College of Agriculture and Environmental Sciences, Bahir Dar University. During the survey, an official letter was sent to all districts to obtain permission for data collection. Verbal consent was obtained from all study participants before the commencement of data collection. The data obtained from each study participant was kept confidential.

3.4 Results

3.4.1 Basic sociodemographic characteristics

Of the final 400 children aged <5 years included in the study (99% response rate), approximately 54% were boys and about 46% were girls (Table 2-3). The mean age of the children stood at 23 months, while the mean age of the mothers was 34 years. A significant majority (~95%) of mothers were married. Only 18% of the mothers had basic literacy skills; furthermore, only 10.3% had had the opportunity to participate in formal education (Table 2-3).

Approximately one-quarter of the mothers received training pertaining to child nutrition, covering essential aspects such as infant and child feeding practices, and overall health awareness. Of note, 40% of the mothers were equal decision makers in their households, particularly on significant matters. Approximately two-thirds of the households fell within the bracket of poor to middle wealth, indicative of the prevalent economic challenges faced by the studied communities (Table 2-3).

Table 2-3: Socio-demographic and economic characteristics of the respondents.

Characteristics		Agroecosystem zones (%)				
		AEZ-1	AEZ-2	AEZ-3	AEZ-4	Total
Child sex	Girls	45.0	46.3	52.0	41.1	46.3
	Boys	55.0	53.7	48.0	58.9	53.8
Child age	0 – 6 months	18.0	10.2	16.7	3.3	12.3
	6 - 23 months	40.0	48.1	33.3	46.7	42.0
	24 - 59 months	42.0	41.7	50.0	50.0	45.8
Maternal education	No education	82.0	90.7	79.4	73.3	81.8
	Informal education	13.0	0.0	1.0	20.0	8.0
	Primary education	4.0	9.3	14.7	1.1	7.5
	Secondary & above	1.0	0.0	4.9	5.6	2.8
Marital status	Single	0.0	7.4	3.9	1.1	3.3
	Married	97.0	91.7	91.2	98.9	94.5
	Widowed	3.0	0.9	4.9	0.0	2.3
Household wealth	Poor	53.0	11.1	44.6	63.3	33.3
	Meddle	28.0	25.9	51.5	32.2	34.3
	Rich	19.0	63	4.0	4.0	32.3
Maternal Training	No	83.0	81.5	60.8	77.8	75.8
	Yes	17.0	18.5	39.2	22.2	24.3
Media exposure	No	97.0	88.9	92.2	82.2	90.3
	Yes	3.0	11.1	7.8	9.8	17.8
Decision making	No equal power	35.0	69.4	65	73.3	60.5
	Equal power	65.0	30.6	35	26.7	39.5
Maternal age (mean ±Sd)		31.53	34.37	32.17	34.52	33.13
		(5.74)	(4.84)	(5.68)	(4.55)	(5.38)
Family size (mean ±Sd)		4.540	5.194	4.912	5.300	4.98
		(1.40)	(1.38)	(1.78)	(1.89)	(1.64)
Landholding size (mean ±Sd)		1.47	1.47	.45	1.0	1.11
		(1.04)	(.92)	(.54)	(1.17)	(1.03)
Livestock size (mean ±Sd)		3.18	7.25	2.70	2.36	3.97
		(1.84)	(3.21)	(2.0)	(2.16)	(3.12)
Market distance (mean ±Sd)		93.08	85.0	34.80	42.0	64.54
		(21.80)	(17.61)	(13.52)	(29.60)	(33.2)

3.4.2 Food security, dietary diversity and feeding practices

As presented in Table 2-4, most children (61%) in this study were from food insecure households. Most children (~90%) were exclusively breastfed up to 6 months of age and approximately 92% were breastfed within 1h of birth. However, nearly half the children (46%) were not introduced to complementary feeding within the recommended time of 6 months. For children, the mean(±SD) child DDS was 3.62 ±1.03 (out of seven standard food groups), and only 43.5% achieved the minimum DDS (four or more food groups) in the 24 hours prior to the survey.

The number of children achieving minimum DDS differs significantly between the malnourished and normal nutritional status groups (Table 2-4). For the mothers, the mean minimum DDS was 4.45±0.84 (out of 10 standard food groups), and approximately 40% met the minimum DDS (five or more food groups; Table 2-4).

Table 2-4: Household food security, maternal and child diet and their feeding practices

Variables	Malnutrition status (%) Malnourished	Normal	Total	X^2
Household food security status				
Food insecure	38.3	22.5	60.8	48.30**
Food secure	10.8	28.5	39.3	
Exclusive breastfeeding				
No	6.0	4.5	10.5	1.25
Yes	43.0	46.5	89.5	
Initiation of breastfeeding				
Not within 1h of birth	6.0	2.0	8.0	9.41**
Within 1h of birth	43.0	49.0	92.0	
Initiation of complementary feeding				
Not timely	24.0	21.5	45.5	1.88
Timely started	25.0	29.5	54.5	
Minimum child DDS				
Not achieved	37.4	19.1	56.5	55.25**
Achieved	11.5	32.0	43.5	
Minimum maternal DDS				
Not achieved	28.2	31.8	60.0	3.68*
Achieved	22.8	17.3	40.0	

*P<0.05, **P<0.01; DDS, dietary diversity score.

As shown in Figure 3-3, starch staples (e.g. grains, roots, and tubers) formed a significant component of the daily diet, with approximately 85% of children and all mothers reporting consumption of starch staples within the 24-h period preceding the survey. Legumes and nuts, as well as other fruits and vegetables (particularly onions) were the most frequently consumed food groups, whereas both children and mothers consumed notably less animal-based foods and vitamin A rich fruits and vegetables (see Figure 3-3).

There was a linear relationship between children and their respective mothers in the distribution of food group consumption (Figure 3-3C), although the primary focus of the comparisons was to determine intrahousehold variations in dietary intake due to possible misconceptions about child feeding habits in rural families.

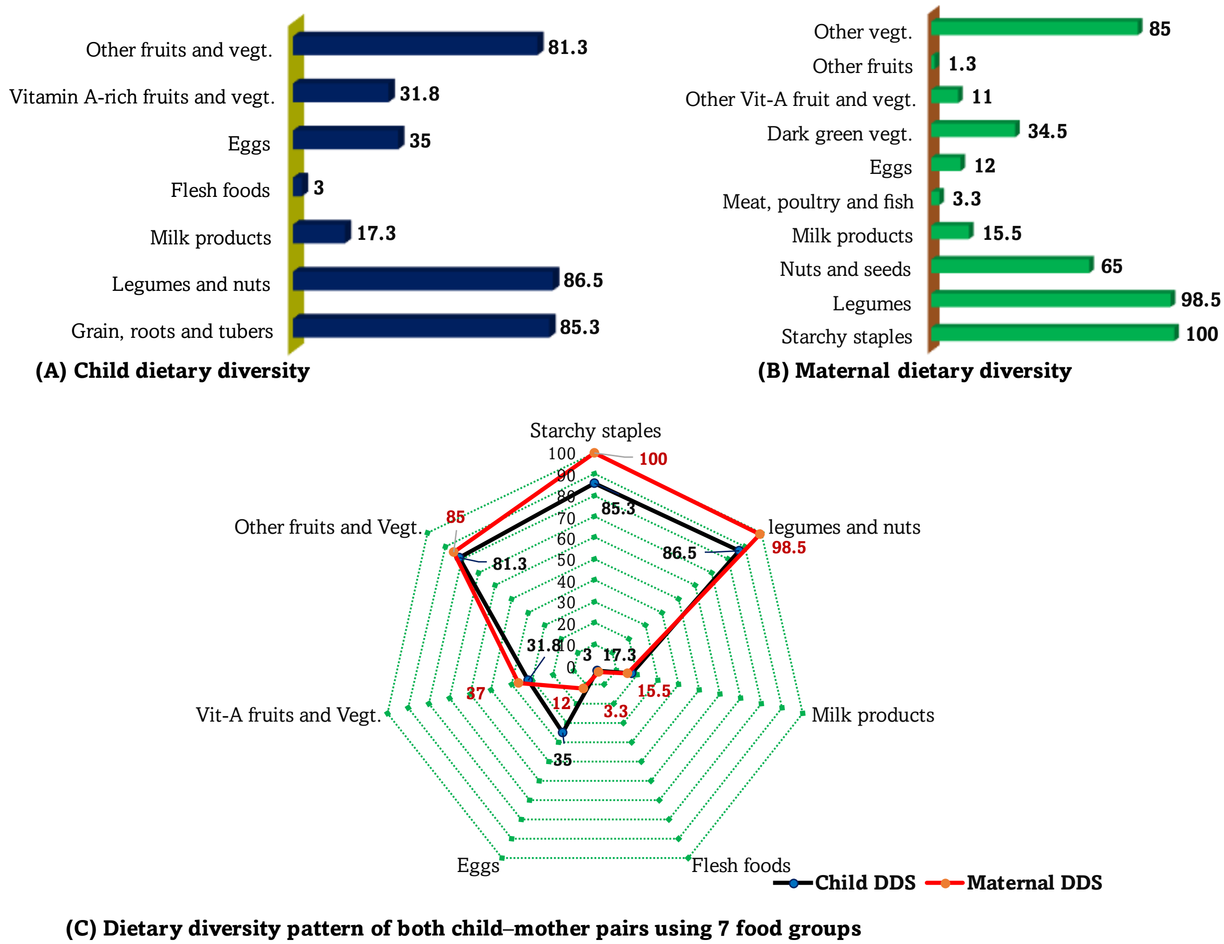
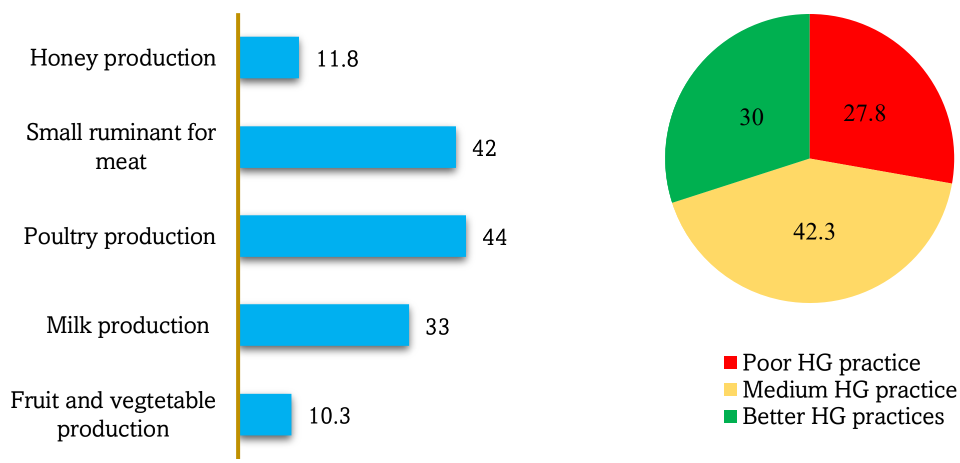


Figure 3-3: (A,B) Minimum dietary diversity among children (A) and mothers (B). (C) Consumption patterns among children and mothers based on 7 food groups

3.4.3 Home gardening as a nutrition-sensitive agricultural practice

The home-gardening practices among surveyed households were limited in scope. Approximately 10% of households cultivated micronutrient-rich fruits and vegetables, specifically dark-green leafy and Vitamin A-rich varieties (Figure 3-4). Conversely, there was relatively robust production of animal-based foods, although actual consumption remained constrained. Assessment of home gardening practices, based on the home gardening index derived through principal component analysis, revealed that approximately 30% of households had a higher level of engagement in home gardening activities (comparison is done only themselves, not standardized cut-off points or criteria) aimed at enhancing both food security and household income (Figure 3-4).



(A) Home-gardening practices (B) Home-gardening practices status

Figure 3-4: Home-gardening practices as nutrition sensitive agricultural practices in the households (%).

3.4.4 Household environment, health services and children's disease experiences

Regarding water, sanitation, and hygiene within households, slightly more than half (53.4%) of households had access to piped drinking water (Table 2-5). Furthermore, over three-quarters of households had their own toilets, separate kitchens, and animal housing that was detached from their primary living quarters. Approximately 69.5% of mothers adhered to the recommended minimum number of antenatal care (ANC) visits during pregnancy; however, approximately 27.5% of children included in the study were delivered at home without professional assistance.

Nearly four of five children had received complete vaccinations. On average, the mothers of the surveyed children had had interactions with health extension workers twice in the previous year (Table 2-5). In addition, slightly over four-fifths of households had availed themselves of health insurance services. However, instances of fever and diarrheal diseases were reported for approximately one-fifth of children (Table 2-5).

Table 2-5: Household environment and health service utilization, and disease experiences.

Variables	Indicators	Responses	Malnutrition status (%) Malnourished	Normal	Total	X^2
Household environment	Water source	Not pipe	21.1	25.6	46.6	2.19
		Pipe water	28.1	25.3	53.4	
	Toilet access	Open field	10.3	6.0	16.3	6.15*
		Own toilet	38.8	45.0	83.8	
	kitchen house	Not separate	5.0	2.5	7.5	4.05*
		Separate	44.0	48.5	92.5	
	Animal housing	Not separate	8.0	7.8	15.8	0.10
		Separate from living quarters	41.0	43.3	84.3	
Health services	ANC follow-up	< 4 times	16.8	13.8	30.5	2.46
		≥ 4 times	32.3	37.3	69.5	
	Place of birth	Home	15.8	11.8	27.5	4.16*
		Health institution	33.3	39.3	72.5	
	Child Vaccination	Not at all	1.3	1.3	2.5	4.09*
		Partially vaccinated	10.8	7.2	18.0	
		Fully vaccinated	37.0	42.5	79.5	
	Health insurance	No	10.8	8.3	19.0	2.16
		Yes	38.3	42.8	81.0	
	No. of health extension contact in past 12 months[A]		2.02 ±2.4	2.9±2.5		t=-3.69**
Disease experiences	Diarrhea	No	36.5	46.3	82.8	18.4**
		Yes	12.5	4.8	17.3	
	ARI	No	46.0	49.5	95.5	2.35
		Yes	3.0	1.5	4.5	
	Fever	No	37.8	44.8	82.5	7.93**
		Yes	11.3	6.3	17.5	
	Chronic disease	No	41.8	49.0	90.8	14.08**
		Yes	7.2	2.0	9.3	

[A]Data are given as the mean ±SD. *p<0.05, **p<0.01.
ANC, antenatal care; ARI, acute respiratory infection

3.4.5 Prevalence of stunting, wasting, and underweight, and overall CIAF

The height-for-age, weight-for-age, and weight-for-height indices (stunting, underweight, and wasting, respectively) were compared with a WHO standardized normal distribution curve, which has a mean of zero and an SD of 1. As indicated in Table 2-6, approximately 39% of children aged <5 years in this study have experienced stunting, with approximately 6% classified as severely stunted. The overall mean (±SD) of the height-for-age Z-score was –1.34±0.35, with statistical analysis (ANOVA F=2.43, P=0.065) suggesting that there is no significant difference in mean scores for children across the four distinct agroecosystems (Figure 3-5A). The prevalence of wasting (weight for height) and underweight (height for age) was 9.5% and 11.5%, respectively, with approximately 1% of children experiencing severe forms of these conditions.

Table 2-6: Prevalence (%) of malnutrition based on z-scores.

	Severity of malnutrition			
Forms of malnutrition	Moderate (Z-score –2 to –3)	Severe (Z-score <–3)	All children (Z-score <–2)	Mean ±SD Z-score
Stunting (HAZ)	32.8 (22.0–43.6)	6.3 (3.4–9.2)	39.1 (30.3–47.9)	–1.34±0.35
Wasting (WHZ)	8.4 (4.6–14.4)	1.1(0.4–2.1)	9.5 (4.6–14.4)	0.21±0.49
Underweight (WAZ)	10.2 (5.2–15.2)	1.3 (0.3–2.2)	11.5 (5.7–17.2)	–0.51±0.23
CIAF			49	

Unless indicated otherwise, data show the percentage of children in each group, with 95% confidence intervals given in parentheses. CIAF, Composite Index of Anthropometric Failure; HAZ, height-for-age Z-score; WAZ, weight-for-age Z-score; WHZ, weight-for-height Z-score.

The ANOVA test revealed significant differences in mean Z-scores for both weight-for-height (F=21.36, P<0.001) and height-for-age (F=17.54, P<0.001) indices across agroecosystems.

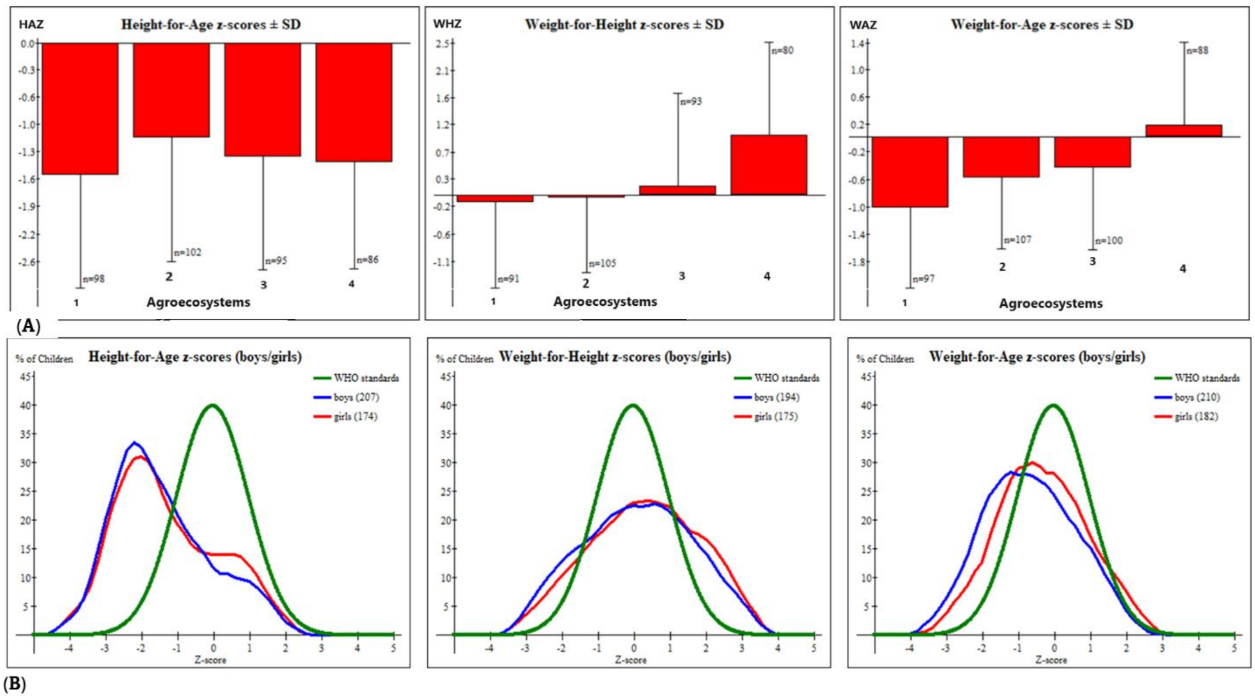


Figure 3-5: (A) Mean (±SD) height-for-age (HAZ), weight-for-height (WHZ), and weight-for-age (WAZ) Z-scores across agroecosystems. (B) Prevalence of stunting (HAZ), wasting (WHZ), and underweight (WAZ) in the study area compared with World Health Organization (WHO) standards.

Based on the CIAF, nearly half the children in the study were malnourished. Of these, slightly less than one-third (31.5%) were stunted or had a short stature (Figure 3-6). Approximately 10% of children had double anthropometric failures (both stunting and either wasting or underweight simultaneously), whereas 2% had triple anthropometric failures (stunting, wasting, and underweight concurrently). Chi-squared analysis revealed statistically significant differences in the distribution of malnourished children across various AEZs (χ^2=24.84; P<0.001). Notably, the prevalence of malnutrition was higher in the lowland and valley fragmented agroecosystem (AEZ-1).

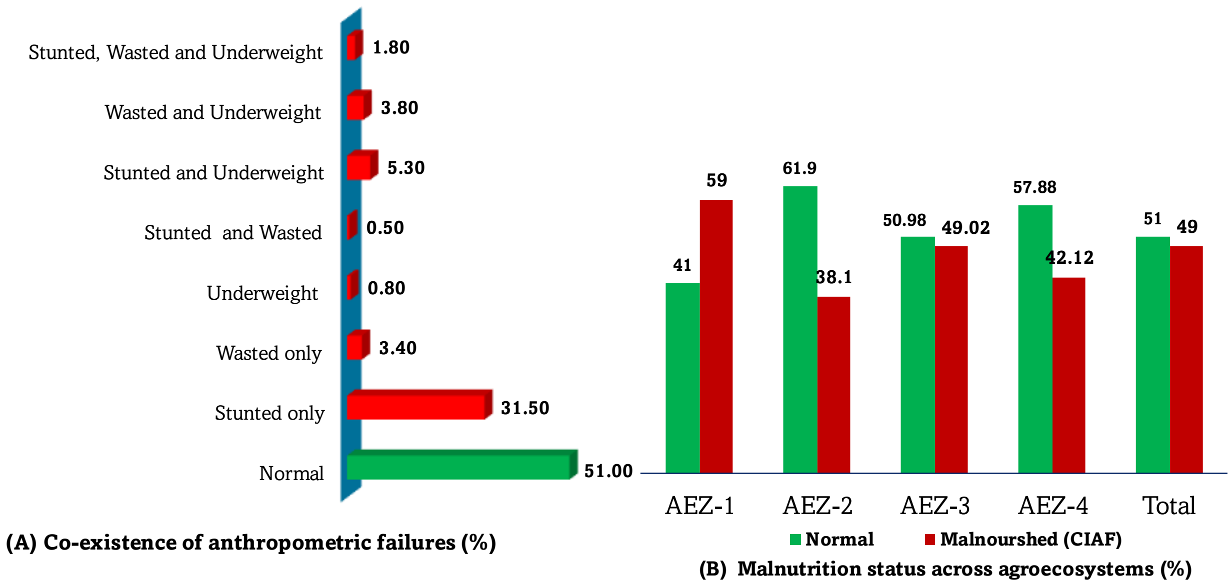


Figure 3-6: (A) Burden of the coexistence of indices of anthropometric failure among children. (B) Prevalence and distribution of overall malnutrition across agroecosystem zones (AEZ).

3.4.6 Determinants associated with child malnutrition

SEM analysis was conducted at both the measurement and structural levels. The path diagram in (Figure 3-7), illustrates detailed hypothetical relationships between exogenous and endogenous variables.

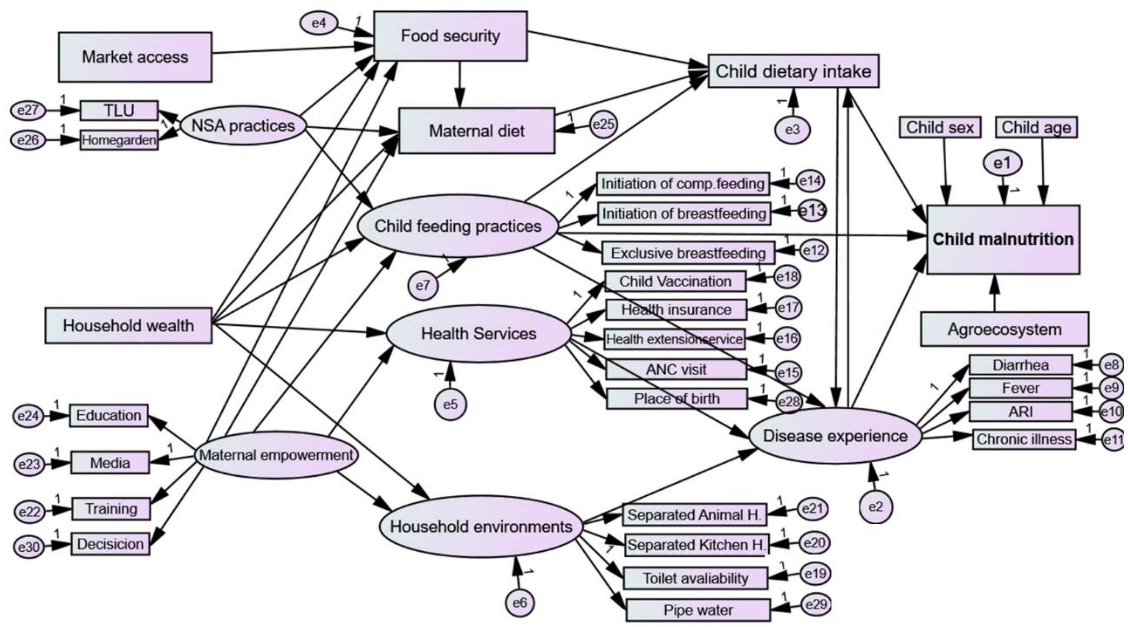


Figure 3-7: Conceptual structural equation modeling and its hypothesized path diagram. Circles in the SEM diagram indicate latent exogenous and endogenous variables, whereas rectangles represent observed or measured exogenous and endogenous variables. Arrows between circles and rectangles indicate the paths and relationship between variables, as denoted by their coefficients. ANC, antenatal care; ARI, acute respiratory infection; CF, complementary feeding; NSA, Nutrition Sensitive Agriculture ; TLU, Livestock size by Tropical Livestock Unit; Decision, decision making; Media, Media exposure.

3.4.6.1 Measurement model

Confirmatory factor analysis was used to test the measurement model. During this process, factor loadings for each item within every construct were examined, and items with low factor loadings were excluded. The fitness of the measurement model was assessed based on the CFI, with a threshold of ≥0.9, and the SRMR, with a threshold of <0.08. Construct reliability was evaluated using the CR, with a threshold of ≥0.7. The validity of constructs was assessed through the AVE, with a threshold of ≥0.5. As indicated in Table 2-7, all values met their respective acceptance thresholds, indicating that the constructs were reliable and valid, and the measurement model adequately fit the data The anticipated outcome for the chi-square test of model fitness was non-significant. However, it was indeed significant as expected, due to its sensitivity to sample size during model testing.

Table 2-7: Reliability and validity tests of constructs, and model fit statistics for the measurement model.

Constructs/Latent variables	No items	CR	AVE	CFI	SRMR	x^2 (p value)
NSA practices	2	0.71	0.58	0.99	0.01	58.55 (0.01)
Maternal empowerment	3	0.78	0.56	0.99	0.023	76.77 (0.001)
Feeding and care practice	3	0.70	0.45	0.99	0.01	60.14 (0.001)
Household environment	3	0.77	0.53	0.98	0.001	190.33 (0.001)
Health services	4	0.76	0.50	0.99	0.01	49.4 (0.001)
Diseases experience	4	0.80	0.51	0.94	0.05	21.25 (0.001)

AVE, average variance extracted; CFI, comparative fit index; CR, composite reliability; NSA, Nutrition Sensitive Agriculture; SRMR, standardized root mean squared residual.

3.4.6.2 Structural model

The fitness of the structural model was evaluated using several indices (Table 2-8). The GFI yielded a value of 0.91, slightly surpassing the acceptable range of >0.9. The CFI returned a value of 0.78, falling below the desired threshold of >0.9. The RMSEA was calculated at 0.082, slightly exceeding the acceptable range of <0.08. However, Chi-squared divided by degrees of freedom yielded a value of 3.71, which falls within the acceptable range of 3–5. Given these results, the model required modification to ensure that all model fit statistics fell within their acceptable ranges. Therefore, model modifications were made iteratively until all indices met the criteria for a satisfactory fit. This process aimed to enhance the overall fitness of the structural model and improve its validity for the dataset under investigation. The model is very complex and involves more measured variables, which makes it difficult to be more fitted; however, the model is still good enough to predict the data. The main intention of SEM analysis is to verify a theoretical hypothesis rather than solely enhance a model's goodness-of-fit. Pursuing improvements in fitness alone may result in inappropriate model configuration. Consequently, the model may fail to accurately represent reality, thus diminishing the persuasive power of the researcher's argument.

Table 2-8: Model fitness indices for the modified structural model

Indices	x^2	**df**	x^2**/df**	**RMSEA**	**CFI**	**GFI**
Structural model	867.90	234	3.71	0.082	0.75	0.91
Acceptable range	-	-	3-5	< 0.08	> 0.9	> 0.9

CFI, comparative fit index; GFI, goodness-of-fit index; RMSEA, root mean square error of approximation.

3.4.6.3 Direct effects of structural model

Figure 8 shows the finalized structural model following re-specification of the conceptual model, incorporating adjustments based on modification indices to enhance model fit. Table 2-9 provides insights into the direct effects within the model. Child dietary intake was found to have a significant negative direct effect on children's malnutrition (β=–0.295, Exp(B)=0.75, P=0.001), indicating that an increase in dietary intake is associated with a decrease in the likelihood of malnutrition. Conversely, disease experiences as a risk factor had a significant positive effect on children's malnutrition (β=0.306, Exp(B)=1.36, P=0.009), suggesting that experiencing disease increases the likelihood of malnutrition.

Furthermore, the model confirmed that agroecosystem has a significant negative effect on children's malnutrition status (β=–0.051, Exp(B)=0.60, P=0.015), indicating that children in the lowland and valley fragmented agroecosystem (AEZ-1) were at higher risk of malnutrition than children in other agroecosystems. The direct effect of exogenous variables on malnutrition in the SEM analysis with their regression path coefficients are provided (Table 2-9; Figure 3-8).

Table 2-9: Standardized and unstandardized estimates for direct effects on structural model

Direct effect paths			S (β)	β	S.E.	Exp(B)	P
Child malnutrition	←	Child dietary intake	–0.295	–0.295	0.048	0.75	0.001
	←	Feeding & care practice	–0.001	–0.059	0.130	0.55	0.647
	←	Agroecosystem zone	–0.113	–0.051	0.021	0.60	0.015
	←	Disease experience	0.151	0.306	0.118	1.36	0.009
Child dietary intake	←	Food security	0.475	0.478	0.041	1.61	0.001
	←	Maternal diet	0.278	0.282	0.041	1.33	0.001
	←	Feeding & care practice	0.082	0.158	0.100	1.17	0.115
Disease experience	←	Household environment	–0.182	–0.155	0.056	0.86	0.006
	←	Child dietary intake	–0.104	–0.051	0.028	0.95	0.068
	←	Feeding & care practice	1.958	1.865	1.137	6.46	0.101
	←	Health services	–2.172	–2.14	1.51	0.12	0.063
Food security	←	NSA practices	0.084	0.172	0.086	1.19	0.046
	←	Wealth status	0.422	0.254	0.029	1.29	0.001
	←	Maternal empowerment	0.262	0.903	0.216	2.47	0.001
Maternal diet	←	Wealth status	0.089	0.053	0.035	1.05	0.125
	←	Food security	0.145	0.144	0.055	1.15	0.009
	←	NSA practices	0.064	0.13	0.09	1.14	0.148
Feeding & care practice	←	NSA	0.174	0.186	0.066	1.20	0.005
Household environment	←	Maternal empowerment	0.144	0.177	0.124	1.19	0.155
Health services	←	Wealth status	0.138	0.042	0.021	1.04	0.049
	←	Feeding & care practice	0.99	0.970	0.168	2.64	0.001

NSA, Nutrition Sensitive Agriculture policy; S (β), standardized coefficient; Exp(B), Exponential of coefficient

Moreover, to see only the effect of agroecosystem variation on child malnutrition, binary logistic regression was conducted by controlling or adjusting for other immediate factors that are shown in the conceptual framework. Using AEZ-1 as the reference group, adjusted odds ratios for the likelihood of being malnourished were 0.424 (P=0.027) in AEZ-2, 0.609 (P=0.207) in AEZ-3, and 0.274 (P=0.001) in AEZ-4 (Table 2-10).

Table 2-10: Direct effect of immediate factors on malnutrition (Binary logistic regression analysis)

Variables (Immediate factors)	B	S.E.	Exp(B)	Sig.
Agroecosystem				.004
Agroecosystem(1)	-.858	.389	.424	.027
Agroecosystem(2)	-.495	.393	.609	.207
Agroecosystem(3)	-1.295	.377	.274	<.001
Exclusive breastfeeding(1)	.158	.292	1.171	.588
Child dietary diversity (1)	-1.661	.260	.190	<.001
Diarrheal disease(1)	.583	.366	1.791	.111
Child fever(1)	-.291	.367	.748	.428
ARI(1)	.302	.598	1.352	.614
Constant	.877	.682	2.403	.198

3.4.6.4 Indirect and total effects in the mediation analysis of the structural model

Serial mediation analysis was applied because the mediators have a kind of hierarchal or sequential nature (Figure 3-8). Therefore, the serial mediation analysis, detailed in Table 2-11, elucidated several significant pathways contributing to the relationship between various factors and child malnutrition. Maternal empowerment had a negative and significant direct effect on malnutrition (β=–0.06, Exp(B)=0.94, P=0.012). This effect was fully mediated via food security, maternal diet, household environment, minimum child dietary diversity, and child disease experiences. Similarly, the effects of NSA practices (β=–0.03, Exp(B)=0.97, P=0.038) and household wealth status (β=–0.12, Exp(B)=0.89, P=0.001) on malnutrition were fully mediated and significantly negative, indicating no direct effect. Food security, maternal diet, household environment, and health service utilization were identified as underlying causes of malnutrition, with only indirect and significantly negative effects on child malnutrition (Table 2-11).

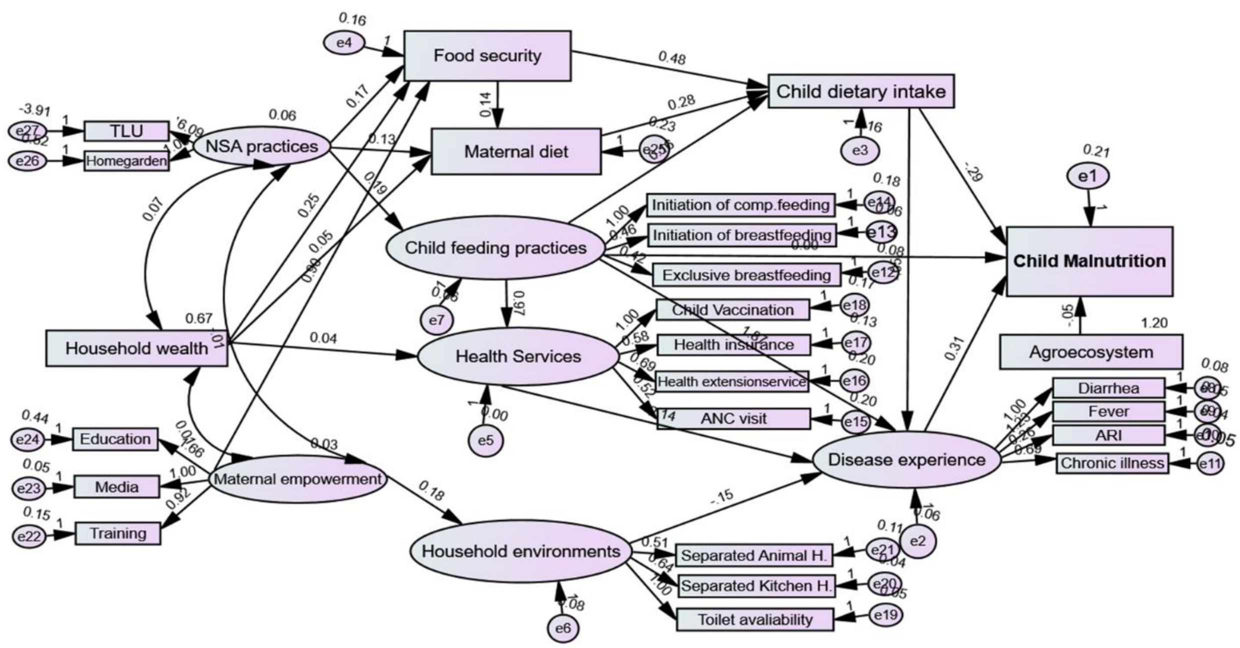


Figure 3-8: Direct effect estimates of modified SEM and its output paths diagram. Circles in the SEM diagram indicate latent exogenous and endogenous variables, whereas rectangles represent observed or measured exogenous and endogenous variables. Arrows between circles and rectangles indicate the paths and relationship between variables, as denoted by their coefficients. ANC, antenatal care; ARI, acute respiratory infection; CF, complementary feeding; NSA, Nutrition Sensitive Agriculture ; TLU, Livestock size by Tropical Livestock Unit; Decision, decision making; Media, Media exposure.

Child feeding and care practices were considered as both underlying and immediate causes of malnutrition, with no significant direct effect (β=–0.001, Exp(B)=0.99, P=0.995), but a negative and significant indirect effect (β=–0.059, Exp(B)=0.941, P=0.045) mediated by dietary intake and child disease experiences. Child dietary intake (minimum dietary diversity) had a partially mediated effect on malnutrition via disease experiences, with a significant total effect. In addition, the SEM output confirmed that agroecosystem and disease had a fully unmediated significant relationship with malnutrition.

Table 2-11: Mediation Effects (Standardized) on Child Malnutrition in the Structural Model

	Direct effect		Indirect effect		Total effect		
Exogenous variables	β	Exp(B)	B	Exp(B)	β	Exp(B)	Mediation analysis
NSA practices	–	–	–0.03	0.97*	–0.03	0.97*	Full mediation
Empowerment	–	–	–0.06	0.94*	–0.06	0.94*	Full mediation
Wealth status	–	–	–0.12	0.88**	–0.12	0.88*	Full mediation
Agroecosystem	–0.11	0.89*	–	–	–0.11	0.89*	Not applicable
Food security	–	–	–0.16	0.85**	–0.16	0.85**	Full mediation
Maternal diet	–	–	–0.09	0.91**	–0.09	0.91**	Full mediation
Health services	–	–	–0.33	0.72**	–0.33	0.72**	Full mediation
HH environment	–	–	–0.03	0.97*	–0.03	0.97*	Full mediation
Feeding and care	–0.001	0.99	–0.059	0.94*	–0.06	0.94	Full mediation
Child dietary diversity	–0.30	0.74**	–0.02	0.98*	–0.32	0.73**	Partial mediation
Disease	0.15	1.16**	–	–	0.15	1.16**	Not applicable

*P<0.05, **P<0.01; NSA, Nutrition Sensitive Agriculture; Empowerment, Maternal Empowerment; Disease, Disease experience

Moreover, the standardized coefficients for indirect and total effects resulting from mediation analysis within the entire structural model are provided in appendix Table A2 and Table A3, respectively.

3.4.6.5 Agroecosystem-based multigroup SEM analysis

In this study, a multigroup SEM analysis was conducted to compare two distinct groups, resulting in the formation of four binary groups: AEZ-1 vs. other AEZs (AEZ-2, -3, -4); AEZ-2 vs. other AEZs; AEZ-3 vs. other AEZs; and AEZ-4 vs. other AEZs. Figure 3-9 presents the structural model, wherein each parameter is uniquely named across the groups, with 'a' and 'b' followed by group numbers representing the relationships between variables. The comparison analysis, facilitated by the chi-squared difference test (x^2=108.53, p<.001), revealed a significant difference between AEZ-1 and other AEZs when contrasting the structural weights constrained model with the unconstrained model-free model. However, although this test indicated a significant difference in group overall, it did not pinpoint where specific paths in the model differed.

Further examination revealed that specific paths, such as b1_1, b9_1, b10_1, b14_1, and a11_1, exhibited significant differences between AEZ-1 and other AEZs (Figure 3-9; Table 2-12). Overall, the comparison between the overall structural weight model and the unconstrained model demonstrated significant differences, implying variations in the effects of paths between AEZ-1 and other AEZs. However, the chi-squared difference test did not reveal significant differences in the structural model weights between AEZ-2 and other AEZs (χ^2=–420.38), AEZ-3 and other AEZs (χ^2=–403.492), and AEZ-4 and other AEZs (χ^2=–671.56).

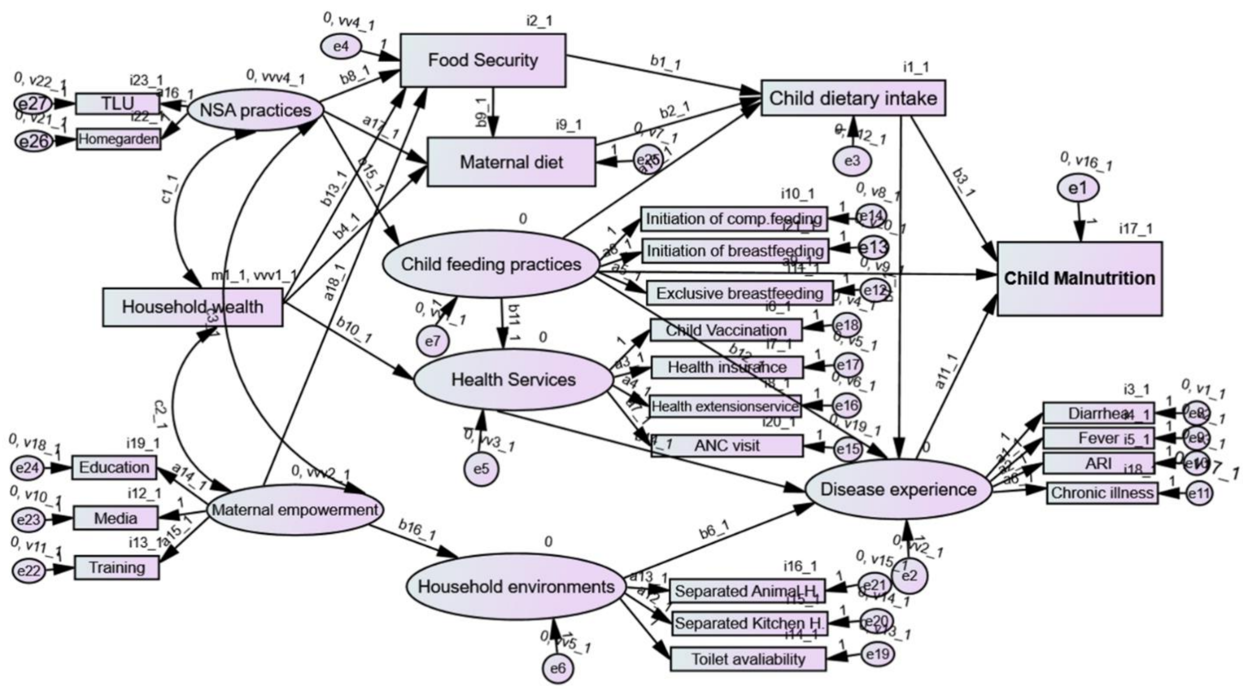


Figure 3-9: Path diagram for multigroup SEM analysis between agroecosystem zone (AEZ)-1 and other AEZs. Circles in the SEM diagram indicate latent exogenous and endogenous variables, whereas rectangles represent observed or measured exogenous and endogenous variables. Arrows between circles and rectangles indicate the paths and relationship between variables, as denoted by their coefficients. ANC, antenatal care; ARI, acute respiratory infection; CF, complementary feeding; NSA, Nutrition Sensitive Agriculture ; TLU, Livestock size by Tropical Livestock Unit; Decision, decision making; Media, Media exposure.

In the multigroup SEM analysis, each structural relationship was individually constrained to determine if specific relationships differed across the groups. The results of constraining the relationship 'a11_1' revealed a significant chi-squared difference (χ^2=6.412, P<0.01), indicating that the effects of disease on malnutrition vary significantly between children living in AEZ-1 and those living in other AEZs.

Furthermore, the model results showed significant chi-square difference tests in the specific relationship paths of the constrained “b1_1 (χ^2=12.589, P<0.01), b9_1 (χ^2=16.69, P<0.01), b10_1 (χ^2=3.32*), and b14_1 (χ^2=48.04, P<0.01)” between children living in AEZ-1 and those living in other AEZs. However, there were no significant differences between these two groups in the remaining paths in the structural model, despite the overall structural model showing significant differences between the two groups (Figure 3-9; Table 2-12).

Table 2-12: Agroecosystem as Moderator in the Multigroup SEM Analysis

Specific relationship paths		Group				Model comparison (x^2-difference test)
		AEZ-1		Other AEZs		
		β	Exp(B)	β	Exp(B)	
Malnutrition	←Child dietary intake	−0.14	0.87	−0.31	0.73**	−19.47
	←Feeding & care practice	−0.03	0.97	−0.70	0.50	−19.83
	←Disease experience	3.04	20.91**	0.295	1.34**	6.412**
Child dietary intake	←Food security	0.22	1.25**	0.57	1.77**	12.59**
	←Maternal diet	0.41	1.51**	0.21	1.23**	2.93
	←Feeding & care practice	0.01	1.01	0.66	1.93	−19.96
Disease experience	←Household environment	0.04	1.04	0.001	1.01	0.34
	←Child dietary intake	−0.79	0.45	−0.03	0.76	−19.75
	←Feeding & care practice	0.01	1.01	−1.81	0.16	−16.41
	←Health services	−1.46	0.23*	−0.83	0.44	48.04**
Food security	←wealth status	0.27	1.30**	0.30	1.35**	.384
	←Maternal empowerment	0.03	1.03	0.91	2.48**	1.814
Maternal diet	← Wealth status	0.140	1.15**	0.07	1.08	1.17
	←Food Security	0.23	1.26**	0.21	1.23**	16.69**
	←NSA	−0.15	0.86	0.001	1.001	1.50
Feeding & care practice	←NSA	−0.14	0.87	−0.002	0.99	0.80
Household environment	←Maternal empowerment	−0.01	0.99	0.29	1.34**	1.53
Health services	← Wealth status	0.15	1.16*	−0.03	0.97	3.32*
	←Feeding & care practice	0.007	1.01	−0.05	0.95	−12.81
Overall model comparison (structural weight model Vs. unconstrained model)						108.14**

*P<0.05, **P<0.01; AEZ, agroecosystem zone; NSA, Nutrition Sensitive Agriculture.

3.5 Discussion

In this study, we investigated the prevalence of child malnutrition. Among children aged <5 years in this study, approximately 39% were stunted (i.e., short stature for their age). This figure aligns closely with the national prevalence of stunting reported in the latest EDHS of 38%. However, it is of note that the prevalence of stunting in this study was slightly lower than that reported specifically for the Amhara region of 46% (CSA and ICF, 2016). The difference between our findings and those for the Amhara region could be attributed to the wider geographical coverage of the latter, encompassing significant spatial variations in the environment and agricultural productivity. Such discrepancies in environmental conditions and agricultural productivity may give rise to diverse socioeconomic conditions, which, in turn, could influence the prevalence of child malnutrition. The prevalence of wasting and underweight in this study were lower than the national averages reported in the EDHS of 10% and 24% respectively (CSA and ICF, 2016), as well as lower than those reported for the Tigray region of northern Ethiopia (Gebretsadik et al., 2023). These findings suggest that stunting, representing a chronic form of malnutrition, is the predominant anthropometric failure affecting children in the Chemoga watershed.

In addition, we found a high prevalence of CIAF in this study, with approximately half the children experiencing some form of anthropometric failure. The prevalence of CIAF surpassed that of single conventional indices of anthropometric failure, such as stunting, wasting, and underweight. Significant variations in the prevalence of CIAF were observed across the four AEZs in the study. The highest prevalence of CIAF was reported in the lowland and valley fragmented agroecosystem (AEZ-1), whereas the lowest was recorded among children from AEZ-2 (midland with red soil). The higher prevalence of child malnutrition in AEZ-1 is consistent with findings reported previously (Alemu, et al, 2017; Alemu, et al., 2017; Deaconu et al., 2021a; Simane et al., 2013a), may be due to unfavorable agroecosystem conditions resulting in lower agricultural productivity and weak socio-economic status. Of note, a lower proportion of children from the hilly and mountainous highland agroecosystem (AEZ-4) were malnourished. This could be attributed to their dietary practices, characterized by the high consumption of potatoes, which are high in calories, as a staple food. Moreover, the environmental advantages of cold temperatures in AEZ-4 may contribute to the maintenance of better health conditions among children, as suggested by previous studies (Randell et al., 2020, 2021). However, this stands in stark contrast to the lower prevalence reported in AEZ-4 in previous studies (Abate & Belachew, 2019; Simane et al., 2013a), underscoring the complex interplay among environmental factors, dietary practices, and nutritional outcomes across different AEZs. A possible reason for the apparent discrepancy could be differences in how children's nutritional status was assessed: unlike the previous studies, which used a conventional single index of anthropometric failure, we used CIAF in the present study. This finding provides significant insights into specific geographic variations in child malnutrition, offering advantages in identifying the neediest subpopulations and allocating scare resources for further nutrition-sensitive and nutrition-specific interventions not only in the study area, but also in other similar environments (Ahmed et al., 2021).

In this study we used SEM to investigate causal relationship between various determinants (including basic, underlying, and immediate factors), and child malnutrition. Our analysis revealed negative and statistically significant direct and indirect effects of child dietary intake on malnutrition. Specifically, the odds ratio for the total effect (combining direct and indirect effects) of minimum dietary diversity on malnutrition was 0.75. This implies that with each unit increase in a child's DDS, the odds of experiencing malnutrition decrease by 0.75 units. In simpler terms, achieving minimum dietary diversity is associated with a notable 25% reduction in the relative risk of malnutrition. This underscores the significance of dietary diversity in mitigating the likelihood of malnutrition among children. Furthermore, our analysis revealed that the effect of dietary diversity on malnutrition was partially mediated through the exposure of children to diseases. This suggests that adequate diversification in a child's diet, encompassing foods from at least four of seven food groups as recommended by FAO (FAO, 2007), could enhance nutrient adequacy, subsequently lowering children's susceptibility to diseases and thereby reducing the risk of malnutrition. However, it is concerning that more than half of the children in this study failed to meet the minimum DDS, particularly lacking in the consumption of animal-based foods and fruits and vegetables. This finding echoes findings of prior studies conducted not only in Ethiopia (Ahmed et al., 2021; Alemu, et al., 2017; Molla et al., 2021) but also across Sub-Saharan Africa (Aboagye et al., 2021; Baye et al., 2020) and in countries like South Africa (Modjadji et al., 2020) and Ghana (Frempong & Annim, 2017), highlighting the challenge of improving nutritional status without ensuring adequate dietary diversity among children in the region.

Our analysis also revealed a direct and significant positive effect of disease experiences on malnutrition. Specifically, the unmediated effect of disease exposure on malnutrition was quantified with an odds ratio, indicating that for each unit increase in a child's exposure to disease, the odds of being malnourished increase by 1.36 units. Consequently, children experiencing disease are more likely to suffer from malnutrition compared with their healthier counterparts. This finding aligns with prior research, including reports from the EDHS (CSA and ICF, 2016) and UNICEF (UNICEF, 2021), and studies conducted in Northwest Ethiopia (Bayih et al., 2022). It underscores the detrimental impact of various diseases on children's nutritional status, which can be attributed to factors such as loss of appetite, the malabsorption of nutrients, and overall malfunctioning of metabolic processes.

In parallel with this descriptive result child malnourishment, SEM and binary logistic regression analysis were conducted to measure the influence of agroecosystem characteristics on child malnutrition. The result of these analysis confirmed that agroecosystem is significantly associated with malnutrition Based on logistic regression output, compared with a child from the lowland and valley fragmented agroecosystem (AEZ-1), the risk of being malnourished was reduced by 42% and 27% for children from midland with red soil (AEZ-2) and hilly and mountainous highland (AEZ-4) agroecosystems, respectively (Supplementary Table 1). Studies from the Amhara region in Ethiopia (Alemu, et al., 2017) and from Indonesia (Manongga & Yutomo, 2023) and Equador (Deaconu et al., 2021b) provide evidence of the effects of agroecosystem and agroecology on an individual's nutritional status. The higher risk of malnutrition in AEZ-1 could be related to higher climate change vulnerability and the resulting lower agricultural productivity and socioeconomic status compared with the midland with red soil agroecosystem (AEZ-2) (Simane et al., 2013a).

Similarly, comparing children in AEZ-1 to those in AEZ-4, the observed variations in nutritional status could be due to differences in dietary habits. In AEZ-4, potatoes are a staple calorie-rich food consumed daily, potentially leading to additional weight gain and an increase in anthropometric indices. Another factor contributing to differences between AEZ-1 and AEZ-4 could be the environmental conditions. AEZ-4 is characterized by cold temperatures, which could provide an advantage for maintaining health compared with AEZ-1; in AEZ-1, children are exposed to higher temperatures and may be more susceptible to heat stress, which aggravates the burden of child malnutrition. This is supported by findings of studies conducted in Ethiopia (Randell et al., 2021) and Uganda (Amondo et al., 2023). Moreover, in multigroup SEM analysis used to investigate differences in path coefficients across AEZs in which agroecosystem was used as moderator variable after being recategorized into four dichotomous groups, the Chi-squared test for the whole structural model across all groups was only significant for the first group (AEZ-1 vs. others [AEZ-2, -3, and -4]). Further analyses were performed for AEZ-1 vs. others to identify differences in specific path coefficients, in addition to the whole structural model. This analysis highlighted specific entry points for further nutrition-sensitive and specific-interventions to reduce the burden of childhood malnutrition.

In this study, childcare and feeding practices, treated as a latent variable, were hypothesized to have direct and indirect effects on child malnutrition. However, SEM analysis indicated insignificant direct effects of child feeding practices on malnutrition, thus not supporting our prior hypothesis. In contrast, previous studies conducted in Ethiopia (Abebe et al., 2017; Ahmed et al., 2021; Bayih et al., 2022; Gebremedhin et al., 2017), Nigeria (Ogbo et al., 2015) and India (Dhami et al., 2019) demonstrated an effect of child feeding practices, particularly breastfeeding and complementary feeding, on child nutritional status using various regression analyses other than SEM. Despite the lack of a direct effect, the indirect effects of care and feeding practices on malnutrition in the present study were statistically significant and negative. These indirect effects were mediated through a child's dietary intake and disease. Children who initiated breast feeding within 1 h of birth, were exclusively breastfed up to 6 months of age, and who were introduced to semisolid and solid complementary food in timely manner were less likely to have a history of illness and inadequate dietary diversity. Consequently, this led to a reduced risk of childhood malnutrition.

Household food security is a key underlying determinant of malnutrition (WHO; FAO; IFAD; UNICEF; WFP;, 2022; Wubetie & Mekonen, 2022). Mediation analysis in the present study revealed that household food security had a significant negative indirect effect on child malnutrition. Children from food-secured households were less likely to be malnourished than children from food-secured households. When a child is from a food-secure household, the relative risk of being malnourished is decreased by 15% compared with a child from a food-insecure household. This finding is supported by the findings of a study in Indonesia that used SEM analysis (Manongga & Yutomo, 2023).

The household environment, particularly factors related to water, sanitation, and hygiene, plays a pivotal role in influencing child malnutrition. As per our prior hypothesis, the result of SEM analysis confirmed a negative and statistically significant indirect effect of household environment on malnutrition through the mediator of disease experience. In this study, a child from a healthy household environment (i.e., with their own toilet, separated kitchen facilities, and housing animals separately) was less likely to be malnourished compared with children from less ideal household environments. This finding aligns with those of studies conducted in Ethiopia (Takele et al., 2023) and Indonesia (Manongga & Yutomo, 2023) using SEM analysis, as well as other studies conducted in Ethiopia (Abebe et al., 2017; Mekonnen, 2013) Nigeria (Ogbo et al., 2015), and India (Dhami et al., 2019). A potential explanation for the role of household environment in child malnutrition is that an unhealthy household environment could facilitate the rapid spread of infectious disease. This result emphasizes the need to address not only direct determinants of nutrition but also broader household environmental determinants, through which their impact is indirectly manifested (Black et al., 2013).

In the SEM analysis, treating health services as a 'latent variable' provides a comprehensive understanding of its influence on child malnutrition. Considering child vaccination status, ANC visits, household health insurance and health extension services as components to measure the latent construct 'health services' emerge as a vital strategy in the broader effort to combat child malnutrition. In the present study, the effect of health services on child malnutrition was negative and statistically significant, and was fully mediated through disease experience. This aligns with previous studies conducted in Ethiopia (Ma'Alin et al., 2016; Mekonnen, 2013) and Indonesia (Manongga & Yutomo, 2023), and suggests that ensuring adequate health services utilization can play a crucial role in improving child health and consequently reducing the prevalence of malnutrition.

The findings of this study underscore the crucial influence of maternal empowerment and maternal diet in the complex framework of child malnutrition. In addition to working on a child directly, it is important to ensure the empowerment of mothers alongside addressing their dietary needs. The path coefficient in the SEM analysis revealed that the indirect effect of maternal diet on child malnutrition was negative and statistically significant. A child's mother who achieved the minimum of five of ten food groups in a population can be used as a proxy indicator for better micronutrient adequacy (FAO, 2021). Other studies also have consistently shown an association between inadequate maternal dietary diversity and an increased likelihood of child malnutrition (Black et al., 2013; FAO, 2021; Farah et al., 2019; Takele et al., 2023). This may be due to the influence of a mother's cultural preferences, adherence to food taboos, limitations regarding food access and economic constraints, ultimately affecting a child's dietary diversity and their nutritional outcome. This dual approach of targeting both children and their mothers are pivotal in devising a comprehensive strategy to improve child nutrition.

Similarly, SEM analysis revealed that maternal empowerment significantly influenced malnutrition at the far distance as basic factors. When a mother's empowerment was increased by 1 unit, the likelihood of her child to being malnourished was reduced by 0.94

units or its risk of malnutrition is decreased by 6%. This may be attributed to empowered mothers being more likely to have high decision-making power in the household regarding child food and health care services. This finding aligns with the results of community based cross-sectional studies conducted in Ethiopia (Alemu, et al., 2017; Fenta et al., 2021) and Tanzania (Debela et al., 2021), as well as the findings of a systematic review study (Santoso et al., 2019); collectively, the results of these studies showed that maternal empowerment serves as a distant basic determinant of child nutrition, encompassing aspects such as education level, media exposure and decision making power regarding a child's health and nutrition.

Household wealth was found to have significant negative indirect effects on malnutrition. According to serial mediation analysis, when the wealth index increased by 1 unit, the odds of malnutrition among children decreased by 0.88 units. In this study, children from poor households were more likely to experience any forms of malnutrition than children from rich households. The effect household wealth was fully mediated, and the hypothesis in the conceptual structural model is supported. This finding is also supported by other studies (Abate & Belachew, 2019; Aboagye et al., 2021; Bahru et al., 2020; Baye et al., 2020; Fenta et al., 2020; Kassie & Workie, 2020; Manongga & Yutomo, 2023; Ogbo et al., 2015; Tesfaw & Woya, 2022).

Most importantly, this study indicated that the probability of a child being malnourished was significantly lower among children from households who practiced better NSA, which was measured in this study as home gardening practices and livestock production. The effects of NSA practices on child malnutrition were indirect and fully mediated via underlying and immediate factors. These findings are consistent with some previous studies (Cabalda et al., 2011; Hirvonen & Headey, 2018; Selepe & Hendriks, 2014). The likely explanation for the finding is that is that NSA practices play a crucial role in addressing the problem of food insecurity (the physical and economic accessibility of food) at a household level, which is one of the key underlying determinants of child malnutrition. In subsistence rural families, NSA practices, particularly home-gardening, allow families to cultivate a variety of fruits and vegetables, as well as animal-based foods that promote a diverse and nutritious diet for children. This diversity ensures that children receive essential micronutrients necessary for their growth and development (Baxter et al., 2008).

3.6 Conclusions

In the present study, the prevalence of child malnutrition across four agroecosystems in northwest Ethiopia was unacceptably high. The prevalence of child malnutrition varied spatially, and was particularly high among children residing in the lowland and valley fragmented agroecosystem compared with other areas. Furthermore, a high proportion of both children and their mothers did not meet the required minimum dietary diversity, in particular, the consumption of animal-based foods and fruits and vegetables was limited. SEM analysis was used as a robust analytical tool to address the hierarchical nature of risk factors of child malnutrition. The SEM analysis confirmed the direct effect of immediate factors and uncovered indirect effects of basic and underlying determinants for child malnutrition, by adapting the modified version of UNICEF's conceptual framework for malnutrition.

Based on SEM analysis, disease experience and minimum dietary diversity have significant direct effects on child malnutrition, whereas the direct effects of childcare and feeding practices were not statistically significant. Underlying factors such as health service utilization, household environment, feeding practices, household food security, and minimum maternal dietary diversity, as well as basic factors such as household wealth, maternal empowerment and NSA practices had significant indirect effects on child malnutrition. The holistic analytical approach used in this study allowed for a more comprehensive understanding of the dynamics and multifaceted nature of malnutrition, providing valuable insights into the implementation of sustainable and targeted nutrition-sensitive and specific-interventions. Based on our findings, we also recommend considering geographical differences in the burden of childhood malnutrition when planning interventions.

Chapter Four

4. General conclusions and future directions

4. 1 Conclusions

Malnutrition remains a pressing public health issue in Ethiopia. In this study, we investigated the challenges of inadequate household dietary intake and child malnutrition across a contrasting agroecosystem of Chemoga watershed. Improving the dietary diversity of households is a crucial step toward improving human nutrition and health. Based on the findings of this study, the consumption of nutrient-dense foods (such as those of animal origin and fruits and vegetables) was very limited, and very few households (only one in five households) achieved an adequate dietary diversity score throughout the entire study area. The family diet in the study area were predominantly starchy-based foods, mainly cereals, roots and tubers that are rich in energy, and legume-based foods, primarily in the form of a local stew (locally called Shiro wet). However, dietary diversity varied significantly across different agroecosystem zones. Households in the lowlands of Abay Valley and hilly and mountainous highlands regions had lower dietary diversity compared to those in midland agroecosystems. Smallholder subsistence farmers in developing countries are the most affected segments of population by undernourishment, and farm-level production diversification is viewed as a good direct pathway to improve diets and nutritional outcomes.

This study revealed the positive association between household dietary diversity and farm-level production diversification. Hence, agricultural production diversification might help to improve family diets and nutrition either through immediate food access or through increasing cash income when selling the product in the market. Therefore, understanding the linkage between dietary intake and the food production system at the household and agroecosystem level could be used as an entry point to strategically design nutrition-sensitive agricultural programs that go beyond the promotion of increasing production and productivity of conventional staple foods. In the multilevel analysis, a significant variation of HDDS was observed across agroecosystems. Unexplained variation due to agroecosystem was decreased between the null model and the adjusted full model—just after controlling for both household and cluster level of factors. Therefore, farm production diversification along with other factors including wealth status, number of meals per day, market access, and long-term annual mean rainfall all significantly influenced HDDS.

Moreover, the study found that the prevalence of child malnutrition was unacceptably high. The prevalence varied spatially and was especially high among children in the lowland and valley fragmented agroecosystems compared to other areas. Like the household dietary diversity challenges that reported in chapter two, high proportions of children and their mothers did not meet the minimum dietary diversity requirements, particularly in consuming animal-based foods and fruits and vegetables. The SEM analysis confirmed the direct effect of immediate factors, and indirect effects of basic and underlying determinants for child malnutrition, by customizing the UNICEF's conceptual framework of malnutrition to the Ethiopian rural communities contexts. Therefore, disease experience and minimum dietary diversity have significant direct effects on child malnutrition. In addition, their nutritional outcomes have influenced by underlying and basic factors—including health service utilization, household environment, feeding practices, household food security, and minimum maternal dietary diversity, household wealth, maternal empowerment, and NSA practices indirectly and significantly.

To summarize, nutritional improvements among smallholders require dietary diversification, which, in turn, calls for increased diversity in agricultural food production. Moreover, the subsistence pathway should not be the sole mechanism considered in the production–household diet linkage. In some cases, earning cash income from the sale of agricultural products could also be an important pathway to improve dietary quality through better access to products in the market. Hence, investing in infrastructure (e.g., roads, local market) to improve rural farm households' accessibility to markets is another pathway to improve dietary diversity. Hence, the holistic analytical approach used in this study allowed for a more comprehensive understanding of the dynamics and multifaceted nature of inadequate dietary intake and malnutrition, providing valuable insights into the implementation of sustainable and targeted nutrition-sensitive and specific-interventions. Therefore, we recommend considering geographical and socio-economic differences when planning those interventions. One of the strengths of this study lies in the application of advanced data analysis techniques including multilevel analysis and structural equation modeling. The other strong side of this study is that the data for analyzing dietary diversity were collected during the most vulnerable months of the year, when food access is limited, highlighting the importance of not undermining the problem.

4.2 Prospects for future research

Seasonality plays a crucial role in studying dietary diversity within subsistence farming communities, since agricultural activities are closely tied to seasonal patterns. Seasonal variations can affect agricultural productivity, income generation, and ultimately, food security. Analyzing dietary diversity within the context of seasonality provides insights into how these variations impact the food and nutritional status of the household. However, this study was conducted within the framework of fulfilling a PhD requirement, which has constrained to access seasonal data for depth analysis. Therefore, further research is needed to investigate the impact of seasonality on dietary diversity scores, including both pre- and post-harvest seasons by allocating enough time and budget.

Additionally, this study solely utilized qualitative measures of dietary intake as a proxy measure for nutrient adequacy based on a 24-hour recall period. Thus, it would be important to incorporate quantitative measures of food portions consumed over a specified timeframe. This could involve implementing detailed dietary assessment methods such as food weighing or using food composition table of the country to accurately capture the quantity and variety of foods consumed by individuals within the study households. Hence, it could be possible to obtain a more precise understanding of dietary diversity and nutritional adequacy by collecting quantitative data on food intake, thus enriching the findings and enhancing the overall validity of the study.

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SUMMARY

Despite the United Nation's Sustainable Development Goals (SDGs) emphasize improving dietary diversity and overall nutritional status globally through the promotion of sustainable agriculture, significantly high segments of population in low-income countries still have been facing with the challenges of malnutrition. As per the global concern, malnutrition, particularly in the form of stunting, wasting and underweight remains an urgent public health problem in Ethiopia. In Ethiopia, child malnutrition can have a multiple of causes, but a key factor is directly related to poor dietary quality with insufficient intake of nutritious foods, including animal sourced foods, and fruits and vegetables. In turn, family diet is directly linked to food system and agricultural practices, especially in rural households of Ethiopia where their daily diet is highly relied on their own production. Taking this issue into account, this study employs an agroecosystem-based analysis to examine the critical link between agriculture, dietary intake, and nutritional outcomes within a specific rural context. However, little attention has been given to the contribution of nutrition-sensitive agriculture in improving diet and nutrition, and most of previous studies, including Ethiopian Demographic and Health Survey (EDHS) lacks data related to agricultural and environmental details.

Hence, this study is aimed to examine the status and determinants of dietary intake and malnutrition challenges across contrasting agroecosystems in Chemoga watershed, the Upper Blue Nile Basin, Ethiopia. Specifically, the objectives of this study include: (i) to explore the pattern of household dietary diversity and its linkage with agricultural production across contrasting agroecosystems, and (ii) to analyze the prevalence of malnutrition and its determinants among children under-five years of age across contrasting agroecosystems. The study was conducted in the Chemoga watershed, considering four distinct agroecosystem zones: lowlands and Abay fragmented valley (AEZ-1), midland plains with brown soil (AEZ-2), midland sloping lands with red soils (AEZ-3), and hilly and mountainous highlands (AEZ-4). The data was collected from 2021 to 2023, by two terms both at household and individual level. This study comprises four chapters.

Chapter 1 presents the introductory sections of the study, includes scopes of malnutrition, overview of malnutrition globally and in Ethiopian context, determinants of malnutrition, agroecosystem-based analysis of dietary diversity and malnutrition, and measures taken to reduce malnutrition globally and in local contexts. It also includes the objectives, research questions and outline of the doctoral thesis.

Chapter 2 explores the pattern of household dietary diversity and its linkage with agricultural production across contrasting agroecosystems of Chemoga watershed. The main objective of this study was to gather relevant information to gain an improved understanding of household dietary diversity and explore the role that production diversification could play within household diets and nutrition so that appropriate interventions could be implemented with the goal of enhancing nutrition-sensitive agriculture. Data were collected predominantly through semi-structured questionnaires from 396 households from four distinct agroecosystems. The household survey was complimented with focus group discussion, key informant interview and field observations. Data were analyzed using descriptive and inferential statistics, and a multilevel mixed-effect model. Results showed that the usual dietary intake of households has a monotonous pattern dominated by starchy staple foods, and consumption of fruits, vegetables, and animal-sourced foods was very limited. One out of five households had inadequate dietary diversity but varied significantly across agroecosystems. About 26% of the heterogeneity in dietary diversity was attributed due to agroecosystem level factors. Family diet intake was positively associated with their own farm-level food production diversity. Moreover, in the fixed-effect part of the multilevel model, farm-level production diversification, along with wealth status, number of meals per day, market access, and annual mean rainfall were significantly associated with household dietary diversity status. The findings of this research contribute to give insights on the linkage between dietary diversity and production diversification among subsistence rural farmers across contrasting agroecosystem zones. Therefore, understanding agroecosystem variations and local context in the rural subsistence farming setup is a key point in designing nutrition-sensitive agriculture. In addition, it requires collaboration across multiple sectors to leverage potential synergies and trade-offs among farm diversification, market access, and other contextual determinants.

Chapter 3 analyzes malnutrition among children under five years across contrasting agroecosystems of Chemoga watershed. This study examined the prevalence of malnutrition, and its determinants among children aged <5 years. A community based cross-sectional study design was employed. About 400 children with their mothers from four agroecosystems were included in this study. Data were collected through semi-structured questionnaires and anthropometric measurements, complimented with focus group discussions, and key informant interviews. Direct and indirect effects of determinants on child malnutrition were examined using structural equation modeling (SEM). The overall prevalence of child malnutrition, measured using the Composite Index of Anthropometric Failure (CIAF), was 49%, with notable variation across agroecosystems (from 36.1% [midland with red soil] to 59% [lowland and valley fragmented]). Disease experience had significant positive direct effects on malnutrition. Dietary intake had negative and significant total (direct and indirect) effects on malnutrition, partially mediated through disease experience. Serial mediation in SEM analysis revealed significant indirect relationships between malnutrition and food security, feeding and care practices, household environment, health services, maternal diet, maternal empowerment, household wealth and nutrition sensitive agricultural practices. In conclusion, child malnutrition was highly prevalent, and higher among children in the lowland and valley fragmented agroecosystem, characterized by unfavorable agro-climatic conditions, lower wealth status, poor health services access, and higher disease (particularly malaria) exposure. This study demonstrates the dynamics and multifaceted nature of malnutrition, highlighting the importance of considering geographical and socio-economic differences when planning interventions for childhood malnutrition and its determinants. Finally, intensive social and behavioral change communication campaigns regarding to child diet and health should be delivered for mothers or care givers.

Chapter 4 presents a comprehensive summary of the entire thesis, encompassing conclusions, policy implications, study limitations, and future research directions. The findings of this study indicated that a cereal-based starchy diet is a common daily food dish, while consumption of fruits, vegetables, and animal-source food is very limited, at both household and child level. In subsistence farming, household dietary intake was associated with agricultural production diversification. This research also demonstrated that the prevalence of child malnutrition was unacceptably high, exhibiting significant spatial variability across agroecosystems. The direct and indirect effects of basic, underlying, and immediate factors on child malnutrition were examined through SEM analysis. This study calls for designing agroecosystem-based nutrition-sensitive agriculture strategies to improve dietary intake and the overall nutritional status in subsistence rural communities. Apart from implementing nutrition-sensitive agricultural practices, it is essential to conduct comprehensive social and behavioral change communication campaigns aimed at rural families to enhance dietary habits and overall nutritional status.

As a strength, to analyze the dietary diversity, the data was collected during the most vulnerable months of the year when food access is limited, highlighting the importance of not undermining the problem. However, further research is needed to investigate the impact of seasonality on dietary diversity scores, including both pre- and post-harvest seasons. Additionally, this study solely utilized qualitative measures of dietary intake as a proxy measure for nutrient adequacy based on a 24-hour recall period. Thus, it would be important to incorporate quantitative measures of food portions consumed over a specified timeframe.

博士論文の要旨

国連の持続可能な開発目標（SDGs）は、持続可能な農業を促進することによって食生活の多様性と全体的な栄養状態を世界的に改善することを強調しているにもかかわらず、低所得国の人口のかなり高いセグメントは、依然として栄養不良の課題に直面している。世界的な懸念として、特に発育阻害、消耗症、低体重の形での栄養失調は、エチオピアにおいて依然として緊急の公衆衛生問題である。エチオピアでは、子供の栄養不良にはさまざまな原因が考えられるが、重要な要因は、動物由来の食品、果物、野菜などの栄養価の高い食品の摂取不足による食事の質の悪さに直接関係している。次に、家族の食生活は、特にエチオピアの農村部の家庭では、毎日の食生活を自家生産に大きく依存しており、食料システムや農業慣行に直接関係している。この問題を考慮して、本研究では、農業生態系ベースの分析を採用し、特定の農村状況における農業、食事摂取、栄養状況の間の重要なつながりを調査する。しかし、栄養に配慮した農業が食生活と栄養の改善にどのように貢献しているかについてはほとんど注目されておらず、エチオピア人口保健調査（EDHS）を含むこれまでの研究のほとんどには、農業と環境の詳細に関するデータが欠けている。そこで本研究では、エチオピアの青ナイル川上流域のチェモガ流域における対照的な農業生態系全体にわたって、食事摂取と栄養不良の課題の現状と決定要因を調べることを目的とする。具体的には、本研究の目的には、（i）対照的な農業生態系全体にわたって、家庭の食事の多様性のパターンと農業生産との関連性を探ること、および（ii）対照的な農業生態系全体にわたって、5歳未満の子供の栄養不良の頻度とその決定要因を分析することが含まれる。この研究は、チェモガ流域で実施され、4つの異なる農業生態系ゾーン（低地とアバイの断片化された谷（AEZ-1）、褐色土壌の中部平野（AEZ-2）、赤色土壌の中部傾斜地（AEZ-3）、丘陵と山岳の高地（AEZ-4））を対象とした。データは2021年から2023年まで、世帯レベルと個人レベルの両方で2期にわたって調査を実施した。本研究は以下の4つの章で構成されている。

第1章では、研究の導入部分を示し、栄養不良の範囲、世界およびエチオピアの状況における栄養不良の頻度の概要、栄養不良の決定要因、農業生態系に基づく食事の多様性と栄養不良の分析、および世界および地域の状況で栄養不良を減らすために講じられた対策が含まれている。また研究の目的、研究課題、博士論文の概要も含まれている。

第2章では、チェモガ流域の対照的な農業生態系における世帯の食事の多様性のパターンと農業生産との関連性について検討する。この研究の主な目的は、世帯の食事の多様性をよりよく理解し、生産の多様化が世帯の食事と栄養にどのように影響するかを調べるために関連情報を収集することである。この理解は、栄養に配慮した農業を促進するための適切な介入の実施に役立つ。データは主に、4 つの異なる農業生態系の 396 世帯から半構造化質問票を通じて収集された。世帯調査は、フォーカス グループ ディスカッション、主要情報提供者へのインタビュー、および現場観察によって補完された。データは、記述統計と推論統計、およびマルチレベル混合効果モデルを使用して分析された。結果は、世帯の通常の食事摂取は、でんぷん質の主食が主流の単調なパターンであり、果物、野菜、動物由来の食品の消費は非常に限られていることが示された。5 世帯のうち 1 世帯は 24 時間以内に食事の多様性が不十分だったが、農業生態系間で大幅に異なった。食生活の多様性における異質性の約 26% は、農業生態系レベルの要因によるものだった。世帯の食生活の多様性スコアは、その農場レベルの食料生産の多様性と正の相関関係があった。さらにマルチレベルモデルの固定効果部分では、農場レベルの生産の多様化は、富の状態、1 日の食事回数、市場へのアクセス、および年間平均降雨量とともに、世帯の食生活の多様性の状態と有意に関連していた。この研究の調査結果は、対照的な農業生態系ゾーンにまたがる自給自足の農

村農家における食生活の多様性と生産の多様化の関連性についての洞察を提供することに貢献する。したがって、農村の自給自足農業体制における農業生態系の変動と地域の状況を理解することは、栄養に配慮した農業を設計する上で重要なポイントである。さらに、農場の多様化、市場へのアクセス、およびその他の状況決定要因間の潜在的な相乗効果とトレードオフを活用するには、複数のセクター間の連携が必要である。

第3章では、チェモガ流域の対照的な農業生態系における5歳未満の子供の栄養失調を分析する。この研究では、5歳未満の子供の栄養失調の頻度とその決定要因を調査した。コミュニティベースの横断的研究設計が採用された。4つの農業生態系から約400人の子供とその母親がこの研究に含まれた。データは、フォーカスグループディスカッションと主要情報提供者へのインタビューを補完する半構造化質問票を通じて収集された。子供の身長と体重を含む人体測定値が取得された。構造方程式モデリング（SEM）を使用して、決定要因の子供の栄養失調への直接的および間接的な影響を調べた。複合人体測定障害指数（CIAF）を使用して測定された子供の栄養失調の全体的な頻度は49%で、農業生態系間で顕著なばらつきがあった（36.1%[赤土の中部]から59%[低地と断片化された谷]まで）。疾病経験は栄養不良に有意な正の直接的影響を及ぼした。食事摂取は、部分的に疾病経験を介して、栄養不良に負の有意な全体的（直接的および間接的）影響を及ぼした。SEM 分析における連続的媒介により、栄養不良と食糧安全保障、栄養摂取および養育慣行、家庭環境、保健サービス、母親の食事、母親のエンパワーメント、家庭の富、栄養に配慮した農業慣行との間に有意な間接的関係が明らかになった。結論として、子どもの栄養不良は広く発生しており、不利な農業気候条件、低い富の状態、保健サービスへのアクセスの悪さ、および病気（特にマラリア）への曝露の高さを特徴とする低地および谷間の断片化された農業生態系の子どもの間ではより高かった。本研究は、栄養不良の動態と多面的な性質を示し、小児の栄養不良とその決定要因に対する介入を計画する際には、地理的および社会経済的差異を考慮することの重要性を強調している。最後に、子どもの食事と健康に関する集中的な社会的および行動変革コミュニケーションキャンペーンを、母親または介護者向けに実施する必要がある。

第4章では、結論、推奨事項、および今後の研究の方向性を網羅した論文全体の包括的な要約を示す。この研究の結果は、穀物ベースのでんぷん質の食事が一般的な日常の食事である一方、果物、野菜、動物性食品の消費は、世帯レベルでも個人レベル（子供と母親）でも非常に限られていることを示している。自給農業では、世帯の食事の多様性は農業生産の多様化と関連していた。本研究では、子供の栄養不良の蔓延率が許容できないほど高く、農業生態系全体で大きな空間的変動を示していることも示された。子供の栄養不良に対する基本的、根底的、および即時の要因の直接的および間接的な影響は、SEM 分析によって調べられた。したがって、本研究では、自給自足の農村コミュニティの食事摂取量と全体的な栄養状態を改善するために、農業生態系に基づく栄養に配慮した農業戦略を設計することを求めている。栄養に配慮した農業慣行を実施することとは別に、農村部の家族を対象とした包括的な社会的および行動的変化のコミュニケーション　キャンペーンを実施して、食習慣と全体的な栄養状態を改善することが不可欠である。本研究の強みは、食料へのアクセスが制限される最も脆弱な月における食生活の多様性を分析するためにデータを収集したことであり、問題を軽視しないことの重要性を強調している。しかし、季節性が食生活の多様性スコアに与える影響を調査するには、事前および事後の調査を含め、さらなる研究が必要である。本の研究では、24 時間の想起期間に基づく栄養価の適切な指標として、食事摂取量の定性的な指標のみを使用した。したがって、特定の期間内に消費された食品の量的な指標を組み込むことが重要になる。

LIST OF PUBLICATIONS

1. Wubetie, B. Y., Tsunekawa, A., Haregeweyn, N., Tsubo, M., Nigussie, Z. and Meshesha, T. M. (2024). Agroecosystem-based analysis of household dietary diversity and its linkage with agricultural production diversification in the Upper Blue Nile Basin, Ethiopia: Multilevel analysis approach. *Environmental Development*, *50*, 100999. DOI: 10.1016/j.envdev.2024.100999 (published, this article covers Chapter two in the thesis)
2. Wubetie, B. Y., Tsunekawa, A., Haregeweyn, N., Tsubo, M., Nigussie, Z., Meshesha, T. M. and Abe, T. (2024). Analysis of Malnutrition among Children under Five Years across Contrasting Agroecosystems of Northwest Ethiopia: Application of Structural Equation Modeling. *Nutrients*, *16*(8), 1208. DOI: 10.3390/nu16081208 (published, this article covers Chapter three in the thesis)

APPENDIX

Table A1: Summary statistics on respondents' demographic and socioeconomic characteristics.

Variable	Response category	Response (% unless otherwise noted) by AEZ				
		AEZ-1	AEZ-2	AEZ-3	AEZ-4	Total
Sex of household head	Female	5.3	1.1	1	10.5	4.8
	Male	94.7	98.9	99	89.5	95.2
Education level	Cannot read and write	69.1	72.7	60	56.1	63.9
	Informal education	20.2	23.9	27	23.7	23.7
	Primary school	10.6	3.4	13	14	10.6
	High school and above	0	0	0	6.1	1.8
Wealth status	Poor	33.3	14.8	25.0	49.1	31.6
	Medium	44.7	37.5	26	37.7	36.4
	Rich	22.3	47.7	49	13.2	32.1
Irrigation access	No	35.1	98.9	77	93.9	76.8
	yes	64.9	1.1	23	6.1	23.2
Home gardening practices	No	39.4	86.4	57	73.7	64.2
	yes	60.6	13.6	43	26.3	35.9
Pipe water access	No	33	67	15	19.3	32.11
	Yes	67	33	85	80.7	67.9
Meal frequency	Twice per day	39.4	70.5	6.0	15.8	31.1
	Three times per day	60.6	26.1	85	64	60.1
	Four times and above	0	3.4	9.0	20.2	8.8
Age	Mean (SD)	46.04 (12.2)	46.65 (11.7)	47.97 (11.6)	46.81 (11.9)	46.9 (11.9)
Household size	Mean (SD)	4.92 (1.76)	4.01 (1.39)	4.92 (0.90)	5.07 (1.60)	4.78 (1.49)
Dependency ratio	Mean (SD)	0.35	0.21	0.23	0.27	0.27

		(0.23)	(0.21)	(0.19)	(0.19)	(0.21)
Landholding size	Mean (SD)	1.08	0.91	1.2	0.76	0.98
		(0.80)	(0.47)	(0.54)	(0.30)	(0.57)
Livestock holding	Mean (SD)	4.16	5.0	5.54	3.5	4.73
		(2.31)	(2.53)	(2.39)	(1.78)	(2.46)
Production diversity score	Mean (SD)	4.87	5.02	5.14	4.82	4.96
		(1.72)	(1.27)	(1.31)	(1.13)	(1.37)
Household dietary diversity score (HDDS)	Mean (SD)	4.91	5.69	5.29	5.01	5.11
		(1.52)	(1.22)	(1.39)	(1.62)	(1.48)
Health extension contact	Mean (SD)	6.80	4.33	5.32	4.30	5.16
		(4.12)	(3.90)	(2.83)	(2.33)	(3.45)
Distance from the nearest market	Mean (SD)	158.16	56.30	175.23	155.09	139.48
		(26.75)	(25.40)	(28.05)	(17.96)	(50.53)

There were 396 valid responses, which equals a non-response rate of 1.98%.

Table A2: Standardized indirect effect of structural model

Exogenous variables	Endogenous variables (Estimates with P-value)							
	FA	MD	FC	HS	HE	CD	Disease	Malnutrition
NSA practices	-	.012 (.087)	-	.18 (.003)	-	.08 (.012)	-.05 (.007)	-.03 (.038)
Empowerment	-	.049 (.026)	-		-	.17 (.013)	-.33 (.066)	-.06 (.012)
Household wealth	-	.06 (.012)	-		-	.24 (.001)	-.32 (.002)	-.12 (.001)
Agroecosystem	-	-	-	-	-	-	-	-
Food access	-	-	-	-	-	.04 (.016)	-.05 (.111)	-.16 (.001)
Maternal diet	-	-	-	-	-	-	-.03 (.108)	-.09 (.001)
Feeding & care	-	-	-	-	-	-	-2.20 (.001)	-.059 (.045)
Health services	-	-	-	-	-	-	-	-.33 (.009)
Household environment	-	-	-	-	-	-	-	-.03 (.024)
Child dietary intake	-	-	-	-	-	-	-	-.02 (.031)
Disease experience	-	-	-	-	-	-	-	-

Abbreviations of endogenous variables: FA-food access, MD-maternal diet, FC-feeding and care practice, HS-health service, HE-household environment, CD-child dietary intake, Disease-disease experience

Table A3: Standardized total effect of structural model

Exogenous variables	Endogenous variables (Estimates with P-value)							
	FA	MD	FC	HS	HE	CD	Disease	Malnutrition
NSA practices	.08 (.120)	.08 (.181)	.17 (.003)	.18 (.003)	-	.08 (.012)	-.05 (.007)	-.03 (.038)
Maternal Empowerment	.34 (.014)	.05 (.026)	-	-	.12 (.219)	.17 (.013)	-.04 (.066)	-.06 (.012)
Household wealth	.42 (.001)	.15 (.013)	-	.14 (.008)	-	.24 (.001)	-.33 (.001)	-.12 (0.001)
Agroecosystem	-	-	-	-	-	-	-	-.11 (0.015)
Food access	-	.15 (.022)	-	-	-	.51 (.001)	-.05 (.111)	-.16 (.001)
Maternal diet	-	-	-	-	-	.28 (.001)	-.03 (.108)	-.09 (.001)
Feeding & care	-	-	-	.99 (.001)	-	.08 (.233)	-.23 (.030)	-.06 (.491)
Health services	-	-	-	-	-	-	-.99 (.001)	-.33 (.009)
Household environment	-	-	-	-	-	-	-.18 (.043)	-.03 (.024)
Child dietary intake	-	-	-	-	-	-	-.10 (.113)	-.31 (.001)
Disease experience	-	-	-	-	-	-	-	.145 (.009)

Abbreviations of endogenous variables: FA-food access, MD-maternal diet, FC-feeding and care practice, HS-health service, HE-household environment, CD-child dietary intake, Disease-disease experience