SPATIAL VARIATIONS AND ASSOCIATED FACTORS OF HOUSEHOLD FOOD INSECURITY AND CHILD UNDERNUTRITION IN EAST GOJJAM ZONE, ETHIOPIA: A MULTILEVEL MIXED EFFECTS MODEL.

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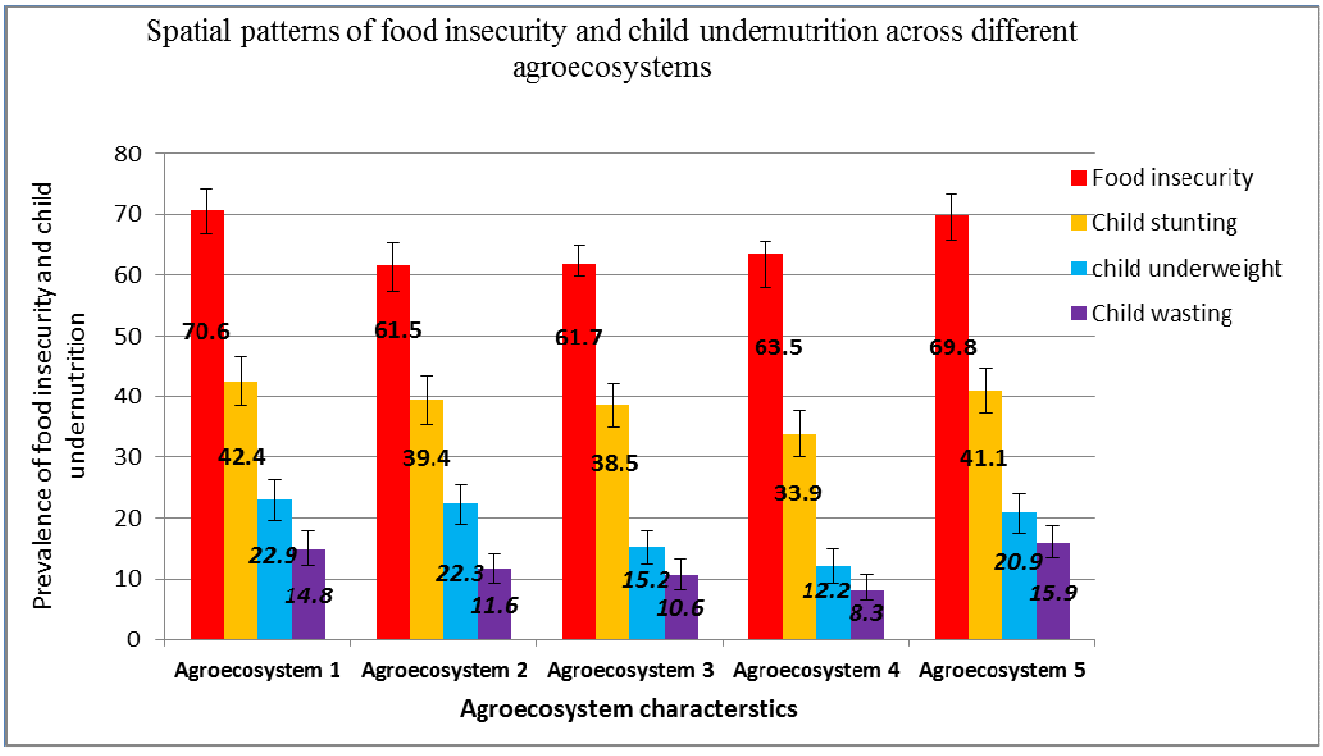

Dissertation for the Degree of Doctor of Philosophy (PhD) in Public Health

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Declaration

I, the undersigned, declare that this is my original work, has never been presented in this or any other University, and that all the resources and materials used for the dissertation, have been fully acknowledged.

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This dissertation has been submitted for examination with my approval as University supervisor.

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Supervisor (secondary) name: - _____

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Date: - _____

List of original papers

This dissertation is based on the following four original papers, which are listed from I –IV.

Paper I. Spatial Variations of Household Food Insecurity in East Gojjam Zone, Amhara Region, Ethiopia: Implications for agroecosystem based intervention (Agric & Food Secur 2017; 6:36).

Paper II. Spatial Variations of child undernutrition in East Gojjam Zone, Ethiopia: Implications for agroecosystem based geographical targeted intervention (under review in international journal in health equity with ID IJEH-D-17-00256).

Paper III. Both individual and community level factors are essential for household food insecurity in East Gojjam Zone, Ethiopia: A Multilevel Analysis (under review in food security journal with an ID FOSE-D-17-00323).

Paper IV. Individual and community level factors with a significant role in determining child height-for-age Z score in East Gojjam Zone, Amhara Regional State, Ethiopia: A Multilevel analysis (Archives of Public Health 2017; 75: 27).

Acronyms and abbreviations

AAU	Addis Ababa University
ANC	Ante Natal Care

AOR	Adjusted Odds Ratio
CI	Confidence Intervals
CNH	Coupled Natural and Human System
CSA	Central Statistical Agency
CSI	Coping Strategy Index
DD	Dietary Diversity
DDS	Dietary Diversity Score
DES	Dietary Energy Supply
DIC	Deviance Information Criteria
EDHS	Ethiopian Demographic and Health Survey
FANTA	Food And Nutrition Technical Assistance
FAO	Food And Agricultural Organization
FVS	Food Variety Score
GDP	Gross Domestic Product
GIS	Geographic Information System
GPS	Global Positioning System
HABP	Household Asset Building Program
HAZ	Height For Age Z Score
HCES	Household Consumption And Expenditure Survey
HFIAP	Household Food Insecurity Access Prevalence
HFIAS	Household Food Insecurity Access Scale
ICC	Itra-class Correlation Coefficient
IDDS	Individual Dietary Diversity Scores
IFAD	International Fund For Agricultural Development
IFPRI	International Food Policy Research Institute
IRB	Institutional Review Board
IYCF	Infant And Young Child Feeding
LLR	Log Likelihood Ratio
MOR	Median Odds Ratio
MPH	Master of Public Health
MUAC	Mid-Upper Arm Circumference

NCHS	National Center for Health Statistics
NNP	National Nutrition Program
ORs	Odds Ratios
PCA	Principal Component Analysis
PCV	Proportional Change In Variance
PNC	Postnatal Care
PSNP	Productive Safety Net Program
SD	Standard Deviations
SPSS	Statistical Package For The Social Sciences
SSA	Sub Saharan African
UN	United Nations
UNICEF	United Nations International Children Emergency Fund
US	United States
VRP	Voluntary Resettlement Program
WASH	Water, Sanitation And Hygiene
WAZ	Weight For Age Z Score
WB	World Bank
WFP	World Food Program
WHO	World Health Organization
WHZ	Weight For Height Z Score

Glossary of operational definitions and concepts

- **Additional income source: -** It refers to the portion of farm household income obtained off the farm activity, including nonfarm wages and salaries, pensions, and interest income earned by farm families.

- **Agroecosystem: -** Agroecosystem refers to an agricultural ecosystem which is determined using climate change adaptive capacity and vulnerability, soil type, topography, various organisms in the area, agricultural technologies and practices, and farmers' social setting parameters.
- **Child hood diarrheal disease: -** The presence of childhood diarrhea three or more loose stools or watery diarrhea in a day during the 2 weeks preceding the survey.
- **Child stunting:** - An anthropometric index which reflects long term cumulative effects of inadequate nutrition and health. It is defined as low height-for-age at < -2 SD of the median value of the NCHS/WHO international growth reference.
- **Child underweight: -** An anthropometric index of weight-for-age represents body mass relative to age. Defined as low weight-for-age at < -2 SD of median value of the NCHS/WHO international growth reference.
- **Child wasting: -** a nutritionally deficient state of recent onset related to sudden food deprivation or mal-absorption or poor utilization of nutrients which result in rapid weight lost. Wasting refers to low weight-for-height at < -2 SD of median value of the NCHS/WHO international growth reference.
- **Climate change adaptive capacity:-** The ability of a system (e.g. community or household) to anticipate, deal with and respond to the climate change.
- **Climate change vulnerability:-** The exposure and sensitivity of a system (or population) to external shocks and stresses, such as climate impacts, mitigated by the ability of that system to adapt.
- **Climate change: -** A statistically significant changes in either the mean state of the climate or in its variability, persisting for an extended period (decades or longer).
- **Community level factors:-**The term in the current study is used to refer to variables that characterize the community or having neighborhood effect.
- **Deviance information criteria: -** The Deviance information criterion is used as a measure of overall fit of a model. The model with the smallest DIC is estimated to be the model that would best predict the association between the predictor variables and outcome variables.
- **Food access:-** Concerns a household's ability to acquire adequate amounts of food, through one or a combination of own home production and stocks, purchases, barter, gifts, borrowing and food aid.

- **Food availability:-** is the physical presence of food in the area of concern through all forms of domestic production, commercial imports and food aid.
- **Food security: -** Food insecurity is defined as a state in which "all people at all times have both physical and economic access to sufficient food to meet their dietary needs for a productive and healthy life.
- **Food secure household:-** A household experiences none of the food insecurity (access) conditions, or just experiences worry only, but rarely.
- **Food stability:-** The continuous supply of adequate food all year round without shortage with the notion of both availability and access dimensions of food security.
- **Food utilization:-** refers to households use of the food to which they have access, and individual's ability to absorb and metabolize the nutrients which measures efficiency of the body utilize for the intended use.
- **Child immunization ststus:-** It is defined as a child has received a BCG vaccination against tuberculosis, rota virus, pneumonia, three doses of DPT vaccine to prevent diphtheria, pertussis, and tetanus (DPT); at least three doses of polio vaccine; and one dose of measles vaccine.
- **Household dietary diversity score**: - It refers to food groups consumed from the total 12 food groups by the respective household members during the 24 hours (during day and night) prior to the survey.
- **Household food insecurity access domains: -** It refers to summary information on the prevalence of households experiencing one or more behaviors in each of the three domains (anxiety and uncertainty, insufficient quality, and insufficient food intake and its physical consequences).
- **Household: -** It refers to the group of individuals living together, typically sharing meals, shelter, resources or a food budget, have common cooking and eating arrangement and who are under the control of one domestic head.
- **Individual level factors: -** It refers to variables that characterize individuals and household level factors.
- **Intra class correlation coefficient (ICC):** - The intra-class correlation coefficient is an important measure of the relatedness of clustered data which explains the proportion of total variance in the outcome that is attributable to the cluster level.

- **Median odds ratio (MOR)**:- It refers the median value of the odds ratio between the area at highest risk and the area at lowest risk when randomly picking out two areas the MOR can be conceptualized as the increased risk that (in median) would have if moving to another area with a higher risk.
- **Micro credit access: -** Household level access of loan from the micro credit associations during the survey year to improve the household livelihood.
- **Mildly food insecure household: -** A household worries about not having enough food sometimes or often, and/or is unable to eat preferred foods, and/or eats a more monotonous diet than desired and/or some foods considered undesirable, but only rarely. But it does not cut back on quantity nor experience any of three most severe conditions (running out of food, going to bed hungry, or going a whole day and night without eating).
- **Moderately food insecure household: -** A Household sacrifices quality more frequently, by eating a monotonous diet or undesirable foods sometimes or often, and/or has started to cut back on quantity by reducing the size of meals or number of meals, rarely or sometimes. But it does not experience any of the three most severe conditions.
- **Multilevel mixed effects model:** - It is a statistical model used in multilevel analysis with an analytical approach that is appropriate for data with nested sources of variability. The model contains a mixture of fixed effects (or fixed coefficients) and random effects (or random coefficients).
- **Proper household refuse disposal: -** Households dispose the household generated refuses within in a pit/storage place.
- **Proper latrine utilization: -** It refers to households having functional latrines, safe disposal of child feces, no observable feces in the compound and show at least one sign of use (foot path to the latrine not covered by grass, absence of spider weave in squatting hole, presence of anal cleansing material, fresh feces in the squatting hole, and the slab is wet).
- **Severely food insecure household :-** Households which have reduced meal size or number of meals often, and/or experiences any of the three most severe conditions (running out of food, going to bed hungry, or going a whole day and night without eating), even as infrequently as rarely.

- **Single level model:** - It is a statistical model which is concerned with the analysis of the relationship between variables that are measured without taking into consideration hierarchical levels in the data.
- **Women participation in decision making: -** The decision making power of woman on household resources or the ability of the woman to make decisions on how to use and when to use the resources of household.

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Executive Summary

Background: - Child undernutrition remains a major public health challenge. The magnitude of the problem varies based on geographical location. In Ethiopia, spatial analysis studies were done based on coarse spatial resolutions. To be more efficient in targeting interventions geographically, spatial analysis using micro level spatial resolution is recommended. Accordingly, different studies were done to identify factors associated with food insecurity and child undernutrition, but most of them ignore either the individual or community level factors. Hence, identification of spatial variations and individual and contextual level determinant factors of food insecurity and child undernutrition in

relation to the agroecosystem is essential to deliver targeted, efficient and sustainable solutions to the problems.

Objectives: - This study determined spatial variations of food insecurity and child undernutrition. The study also identified the role of individual and community level factors of food insecurity and child undernutrition using multilevel mixed effects regression analysis in East Gojjam Zone, Ethiopia.

Methods: - An agroecosystem linked to community based comparative cross sectional survey was conducted among 3108 households with children aged 6-59 months. Multistage cluster random sampling technique was used to select study participants. Data were collected on household geographical location, socio-demographic characteristics, child and maternal anthropometry and on potential individual and community level determinant factors. Collected data were entered using Epi info version 3.5 and exported to World Health Organization (WHO) Anthro to determine child nutritional status.

SaTScan software was used to determine spatial variations of food insecurity and child undernutrition using SaTScan Bernoulli model. To identify the most likely clusters using SaTScan software, the Log Likelihood Ratio (LLR) at 95% Confidence Interval (CI) and P value less than 0.05 as the level of significance were considered. To identify determinant factors of food insecurity and child undernutrition, multilevel mixed effects ordinal regression and multilevel mixed effects linear regression analyses were used, respectively. The results of fixed effects were shown as an adjusted odd ratio (AORs) for the multilevel mixed effects ordinal regression and regression coefficients for the multilevel mixed effects linear regression. The results of random effects were presented as variance and the intra-class correlation coefficient (ICC) was calculated to estimate unexplained variance attributable to cluster level.

Results: - The overall prevalence of household food insecurity was 65.3% (95% CI: 63.5, 67.00). The highest prevalence of food insecurity was observed from the lowlands of the Abay Valley (70.6%, 95% CI: 66.9, 74.2). Followed by the hilly and mountainous highland areas of Choke Mountain (69.8%, 95% CI: 65.9, 73.3). Similarly, sample clusters taken from hilly and mountainous highland areas (LLR: 11.64; $P<0.01$) and low lands of the Abay Valley (LLR: 8.23; $P<0.05$) were identified as the most likely primary and secondary clusters, respectively.

The prevalence of stunting 39.0% (95% CI: 37.32, 40.75), 18.7% (95% CI: 17.32, 20.0) underweight, and 12.22% (95% CI: 11.12, 13.42) wasting were observed in the study area. The highest prevalence of wasting (15.9%; 95% CI: 13.5, 18.8) was observed from hilly and mountainous highlands. The highest prevalence of child stunting (42.4%; 95% CI: 38.5, 46. 6) and underweight (22.9%; 95% CI: 19.7, 26.3)) were observed from the lowlands of Abay Valley. SaTScan spatial analysis indicated that sample clusters taken from the hilly and mountainous highlands were the most likely primary cluster for child wasting (LLR: 13.0, $p < 0.01$) and underweight (LLR: 23.16, $p < 0.001$). Also, primary cluster for child stunting was identified from lowlands of Abay Valley (LLR: 10.78, $p<0.05$).

After adjusting for both individual and community level determinant factors, 1.5% ($p<0.001$) of the variance of food insecurity was attributable to the cluster level. Similarly, after adjusting for all potential determinant factors, 2.4% ($p<0.001$) of the child weight for height Z score and 1.4% ($p<0.001$) of the child height for age Z score variance were due to cluster level. From level one factors, in the final model, household head being male, marital status being in union, higher parental education, women's participation in household decision making, having additional income sources, better crop production in the survey year and application of chemical fertilizer have a positive influence in mitigating household food insecurity. From community level determinant factors, households being from hilly and mountainous highlands and lowlands of the Abay Valley were more severely household food insecure compared to midland plain areas. Households with better farmland size showed less severe household food insecurity in the study area.

In the study, from level one factors, the number of under five children, antenatal (ANC) follow up, breast feeding initiation time, household dietary diversity, mother nutritional status, household food insecurity and diarrheal morbidity were associated with weight for height Z score. From level two factors, agroecosystem characteristics, proper household refuse disposal practice, agroecosystem characteristics and proper latrine utilization were significantly associated with child weight for height Z score. From level one factors, child age in months, child gender, the number of under-five children in the household, child immunization status, breastfeeding initiation time, mother nutritional status, child diarrheal morbidity, household level water treatment practice and household dietary diversity showed a statistical significant association with child height for age Z score. From level two factors, agroecosystem characteristics, proper household refuse disposal practice and proper latrine utilization were significantly associated with child height-for-age Z score.

Conclusions: - The prevalence of food insecurity and child undernutrition were public health concerns in the study area. Spatial variations of household food insecurity and child undernutrition were observed across the agroecosystems. Households from the lowlands of Abay Valley and hilly and mountainous highland areas were more vulnerable to food insecurity and child undernutrition compared to midland areas. The SaTScan cluster level spatial analysis identified statistical significant hotspot clusters for food insecurity, childhood stunting, underweight and wasting. The multilevel mixed effects analysis indicated that the heterogeneity of food insecurity, childhood stunting and wasting were observed after adjusting to potential individual and community level determinant factors. Both individual and community level factors played a significant role in determining food insecurity and child undernutrition (stunting and wasting). An agroecosystem characteristic was one of the community level factors affecting household food insecurity and child undernutrition.

Recommendations: - The spatial variation of food insecurity and child undernutrition based on agroecosystem characteristics should be fully understood by program implementers and policy makers during planning, resource allocation and community mobilization in the study area. Water, sanitation and hygiene interventions are important in the study area. Further study on spatiotemporal variations of food insecurity and child undernutrition at different time is recommended. Also, food insecurity and child undernutrition intervention strategies and plans designed using aggregated or macro level evidence may not indicate the true picture of spatial distribution of the problem at lower government administrative units. So, program level planning may take into account agroecosystem based micro level variations to allocate resources. Policy and intervention strategies aiming at mitigating food insecurity and child undernutrition should address the effects of lower and community level determinant factors using the integration of individual/household level and geographical targeting.

Key words: - Food insecurity, child undernutrition, spatial variations, multilevel, agroecosystem, Ethiopia.

1. Introduction

1.1. Background

According to the Food and Agriculture Organization (FAO) definition, food insecurity refers to limited or uncertain physical and economic access to secure sufficient quantities of nutritionally adequate and safe foods in socially acceptable ways to allow household members to sustain active and healthy living (1). Food insecurity has four dimensions: food availability, food access, food utilization, and food stability (2).

Household food availability refers to physical presence of food either though growing, manufacturing, importing and/or transporting (2). Food access refers to the ability of a household and its members to acquire enough food through production, exchange or transfer (3, 4). Food access dimension of food insecurity is generally applied at the household level, referring to the extent to which households have the means to access food using their income, own production, food assistance, bartering, and other sources (5, 6). Food utilization is the way people use the food and is dependent on the quality of food, its preparation and storage method, nutritional knowledge, as well as on the health status of the individuals consuming the food (6, 7). Food stability refers to the temporal determinant of factors of food insecurity and affects food availability, access and utilization (2).

Child undernutrition refers to the proportion of children whose dietary energy consumption is continuously below the minimum dietary energy requirement for maintaining a healthy life and carrying out light physical activity (8). Child undernutrition which is measured using anthropometric method can be stunting (chronic undernutrition), wasting (acute undernutrition) and underweight (stunting, wasting, or both) (9, 10) .

Stunting is expressed as low height relative to age that results from a slowing in skeletal growth (9, 10). Children with height for age z-scores below minus two standard deviations from the median of the reference population are considered short for their age or stunted (9, 10). Wasting or thinness is expressed as a low body weight relative to height that result from a current significant loss of weight observable by a deficit in tissue and fat mass (9, 10). Children whose weight for height's Z scores below minus two standard deviations (z- scores <-2SD) from the median of the reference population are considered wasted (i.e. too thin for their height) (9, 10). Underweight is expressed as low weight for age Z score that

resulted from either a failure to gain weight relative to age or a loss of weight relative to height (9, 10). It is a composite index of stunting and wasting which means children may be underweight if they are either stunted or wasted, or both (9, 10). Children whose weight for age's Z-score below minus two standard deviations (z- scores <-2SD) from the median of the reference population are considered underweight (9, 10).

Agroecosystem refers to agricultural ecosystem, including biophysical and human components, their interactions and its services that are useful to support human well-being (11). The relationship between food insecurity, child undernutrition and environmental services is too complex and multi directional. Agroecosystem services have a potential to affect crop productivity and then increase food insecurity, especially to the rural community that depend on agriculture (12). Similarly, food utilization is also affected by the environmental services from the agroecosystem, including water and sanitation (WASH) services and disease distribution (12) which are among the causes of child undernutrition (6).

1.2. Statement of the problem

Food and Agricultural Organization (FAO), World Food Program (WFP) and the International Fund for Agricultural Development (IFAD) joint report indicated that food insecurity is a major public health problem. The severity of the problem is very high in low income coutries, including Sub Saharan Africa (13). In Ethiopia, the magnitude of food insecurity is a major public health challenge (14). In the country, different pocket studies indicated high prevalence of food insecurity which ranges from 54.1% in 2011 to 70.7% in 2014 (15-19).

Literature indicated that food insecurity has a wide range of negative health impacts beyond undernutrition. Food insecurity and health are intertwined in a vicious cycle through nutritional, mental health, and behavioral pathways (2). Insufficient quality and quantity of food can lead to macronutrient and micronutrient deficiencies, which can affect both acquisition of different diseases, including HIV and chronic diseases and health outcomes among people with those conditions. Evidences indicated that feelings of deprivation or anxiety about food supply can have mental health consequences, such as depression and anxiety, which can contribute to acquisition and progression of HIV and NCDs (2, 20).

Food insecurity affects total caloric intake as well as diet quality (i.e., macro- and micronutrient intake) and deteriorates nutritional status particularly children and pregnant women. Limited amount of food in terms of quantity leads to hunger and undernutrition can arise, which can eventually lead to wasting, stunting, and immune deficiencies (2, 20, 21). Similarly, poor quality of food due to food insecurity leads to different chronic illness due to obesity, including high blood pressure, increased rates of diabetes and poor diabetes outcomes and developing gestational diabetes mellitus (2, 20).

Food insecurity is associated with feelings of helplessness, shame, and humiliation as central to the experience of food insecurity. Having insufficient food can undermine social relationships and lead to feelings of low self-efficacy among women (2, 20). It is documented that chronic psychosocial stress due to food insecurity may increase the risk for obesity by increasing the relative consumption of energy-dense foods (20). Food insecurity is associated with poor health behaviors affecting the prevention, management, and treatment of disease. An inability to fulfill subsistence needs, including household food needs, can lead people to make unhealthy decisions that may increase their risk of illness, such as engaging in risky sexual behaviors in exchange for food, or overreliance on cheap, calorically dense nutrient poor food (20). Evidences indicated that food insecurity has been associated with HIV

acquisition risk and poor TB and HIV related health outcomes, including poor TB and ART drugs adherence (20).

As mentioned above, food insecurity is one of the intermediate factors affecting child nutritional status (21) and childhood undernutrition is one of the development challenges (14, 22, 23). The joint United Nations International Children Emergency Fund (UNICEF), World Health Organization (WHO) and World Bank (WB) report in 2016 indicated that there were 159 million (23.8%) stunted and 50 million (7.5%) wasted children at global level (24).The problem was more severe in Africa, where 32% of children were stunted (24). As indicated in EDHS 2016 report, childhood stunting is more serious in Ethiopia (38%) with regional variations, where the highest prevalence (46.3%) was observed from Amhara Regional State (25).

Childhood undernutrition is one of the risk factors contributing to child mortality and morbidity (26). In Ethiopia, 57% of all child deaths are related to undernutrition (27). Child undernutrition leads to late enrollment to schools, repetitions in primary school, workforce reduction and economic loss in the country (28). Also, childhood undernutrition elongates school enrollment age (29), limits growth and development of young children and infants (30-32), lowers cognitive and academic performance, affects psychosocial interaction, elevated experience of anxiety, depression and other symptom of common mental disorders (33, 34).

Cognizant of the impacts of child undernutrition on the nation development, in the last 15 years, Ethiopia has made significant progress in developing its policy, strategic and program environments and service delivery platforms to eliminate food insecurity and child undernutrition (35-38). The commitments of the government and its partners to address nutritional problems are encouraging (35-38). The efforts, include designing strategies to address food insecurity and nutritional problems (39) through agricultural extension packages, National Nutrition Program (NNP), Health Extension Program, Health Sector Development Program, National Nutrition Strategy and National Food Security Strategy (35-38, 40). Also, the government publicly pledged in 2015 the so called "SEQOTA" Declaration to end child undernutrition by the year 2030 (37).

To bring sustainable solutions and meet the needs of the most vulnerable community (41), recognition of the spatial distribution and determinant factors of food insecurity and child undernutrition in specific contexts is very crucial. In Ethiopia, spatial analysis of child undernutrition showed clear spatial

variations of the problem at country level (42-45). This spatial variation might be attributed to agronomic related factors, community climate change vulnerability and adaptive capacity, population pressure, presence of irrigation (46) and ecosystem services to the farming community (47).

Ecological factors have a significant role in deriving the geographical distribution of human disease because it affects the interaction of host, vector and the environment (47, 48). Understanding geographical distribution of child undernutrition in relation to agroecosystem services might help to target nutrition intervention strategies (48). Literature from Malawi's study indicated that the ecosystem characteristics associated with the dietary diversity, consumption of vitamin A rich foods and diarrhea disease among children which are recognized as determinant factors of child undernutrition (47). Therefore, food insecurity and child undernutrition spatial variation analysis using the application of geographical information system (GPS) taking agroecosystem characteristics into account is very important to target interventions focusing on resource allocation and mobilizing the community and different stakeholders.

In the Ethiopian context, much was done to identify the prevalence of household food insecurity and child undernutrition and their determinant factors in different parts of the country (15-19, 49-58). However, those studies did the analysis using single level regression ignoring the presence of neighborhood effects, the multistage cluster sampling procedure and the presence of community level factors, including agroecosystem characteristics which might undermine estimation of effect measures (59-61).

So, to improve the limitations of those studies, identification of the determinant factors using appropriate methodology is essential. Therefore, the current study assessed the individual and community level determinant factors of household food insecurity and child undernutrition across different agroecosystem using multilevel analysis.

1.3. Rationale of the study

Different studies identified certain geographical regions are highly vulnerable to household food insecurity (62-64) and child undernutrition (42, 43, 65, 66). For example, studies from West Africa (67), Sub Saharan African (SSA) countries (68), Nigeria (65) and Ethiopia (42, 44, 45) showed a clear spatial variation of child undernutrition.

In Ethiopia, except one study (45), other spatial variations of child undernutrition studies focused on coarse spatial resolutions (42-44) which may consist of different agro ecological zones within a cluster which could not help to identify the spatial distributin of child undernutrition based on ecological zones to prioritize and design interventions. Also, to be more efficient in geographical targeted nutritional interventions, spatial analysis based on micro level spatial resolution is recommended (43, 44, 67).

Understanding household food insecurity and child undernutrition spatial variations at micro level using Geographic Information System (GIS) (69) is very important to identify the most affected community, to design local interventions, to allocate scarce resources to the most affected areas, to convince policy and decision makers and program managers using local evidence and to ensure equity in the community (70).

Moreover, having a clear picture of spatial variations of household food insecurity and child undernutrition based on agroecosystem characteristics which varies in climate change vulnerability and adaptive capacity may assist to target climate change adaptation and mitigation strategies to reduce household food insecurity and child undernutrition to an acceptable level. Therefore, this study assessed the spatial variations of household food insecurity and child undernutrition across different agroecosystems in East Gojjam Zone, Amhara Regional State, Ethiopia.

In addition, most of the studies in Ethiopia, identified determinant factors of household food insecurity and child undernutrition using single level classical regression without checking the presence of spatial dependency due to neighborhood effect of predictors, hierarchical nature of the sampling procedures and presence of community level determinant factors (15, 49-52, 54, 57, 58, 71). Also, some determinant factors associated with child nutritional status may have externalities either positively or negatively on the nearby child nutritional status which is commonly called neighborhood effect (72). As a result, doing the regression analysis using single level modeling without checking the presence of spatial autocorrelation produces biased estimates because of the multilevel dependency or correlation among the observations in the above situations (59-61, 73).

Thus, the individual and community level aspect of household food insecurity and child undernutrition using multilevel mixed effects regression model needs to be explored in order to overcome the analytical difficulties that arise when data are organized hierarchically and there is an intragroup correlation among the observations (59, 61). The multilevel analysis studies done in Ethiopia and elsewhere abroad, focused on large scale geographical locations which showed heterogeneity in child undernutrition after controlling potential determinant factors (42, 74). However, the reported heterogeneity was expected since there is clear variation in determinant factors of child undernutrition. So, assessing the heterogeneity of child undernutrition after controlling potential associated factors at micro level is very useful in designing interventions.

In addition, none of the above studies gave emphasis on the association between agroecosystem characteristics with food insecurity and child undernutrition considering it as a communal factor. Linking agroecosystem characteristics with food insecurity and child undernutrition gives strong evidence in the absence of interventional studies to see the effect of the agroecosystem on the food system (75). Therefore, this study identified individual and community level associated factors of household food insecurity and child undernutrition) using multilevel mixed effects regression analysis.

The application of spatial and multilevel mixed effects regression analysis together allow us to draw a more complete picture of food insecurity and child undernutrition spatial varitions and their determinant factors at different levels for policy recommendations in relation to designing intervention strategies (76). This kind of analysis will provide relevant information for formulating intervention strategies and programs, particularly on the neighborhood effects, health inequalities, on planning and organizing health care facilities and environmental health services (59).

Policy makers and development agencies working to mitigate food insecurity and child undernutrition can use the evidence to target agroecosystem based geographical interventions. The results can help for allocating scarce resources based on vulnerability, to mobilize resources at community level and to improve program coverage through identifying communities that need special assistance. Also, the findings can give directions to focus on factors that determine food insecurity and child undernutrition both at individual and community level.

2. Literature Review

2.1. Household Food Insecurity

2.1.1. Magnitude of Food Insecurity

Food insecurity is one of the biggest challenges to global societies with geographical variations in its magnitude between developed and developing countries (77-79). The FAO, 2015 report indicates that almost all hungry people, 780 million live in developing countries (13). Sub-Saharan Africa is the most food insecure Region in the world. The Region accounts for about a quarter of the total population, it is estimated to account for over half of the number of food insecure population in 2016 (80). The Region's food insecurity situation is projected to be improved, but more slowly than other regions (80).

Ethiopia is known for its significant agricultural potential because of its water resources, fertile land areas and its large labor potential (81). However, the country is among the poorest and most food insecure countries of the world (82). The problem of food insecurity has continued to persist in the country as many rural households have already lost their livelihood due to recurrent drought and crop failure (83). In the country, food insecurity was recognized as a key problem and development challenge in the early 1970s and become pervasive in the subsequent decades (83). Combination of natural and man made factors have resulted in this serious and growing food insecurity problem in many parts of the country (83). The food insecurity problem is not distributed randomly which showed significant spatial characteristics in different geographical locations (84). Different studies in Ethiopia from different parts of the country showed spatial variations in food insecurity prevalence. For example, studies from Addis Ababa (85), Sidamo Zone (86), Farta District (55) and North West Ethiopia (15) reported food insecurity prevalence of 58.16%, 54.1%, 70.7% and 55.3%, respectively.

2.1.2. Measurements of food insecurity

The dimensions of food insecurity provide a framework for measuring food insecurity and most food insecurity indicators measure one of the three dimensions, or a component of these dimensions (2). Furthermore, since availability, access, and utilization generally correspond to the national, household, and individual levels, respectively, each dimension is usually measured at its corresponding level. The food instability dimension of food insecurity affects all the three other dimensions (87).

Regardless of the dimensions, the ultimate final goal of any food insecurity measurement is to ensure that individuals can utilize sufficient quantity and quality of food in a secure and stable way (2). Food insecurity has a number of measurments based on the objective of the study (2, 3, 88-91). For example, Food balance sheet (2), undernourishment (90, 91), household consumption and expenditure survey (HCES) (2), Dietary diversity, food variety score (FVS), coping strategy index, household food insecurity survey measure, and household food insecurity access scale can be used as measures of food insecurity (2, 88, 89). In Ethiopia, different food insecurity measurement tools have been used by different researchers in different areas and each tool has its own strengths and limitations (15, 49-52, 54, 57, 58, 71).

HFIAS is a tool to assess whether households have experienced problems in food access in the preceding 30 days of the survey or not. The tool is composed of nine questions that ask about modifications households made in their diet or food consumption patterns due to limited resources to acquire food (3). This tool is a continuous, linear scale ranging from 0 to 27 (3, 88). The Household food insecurity access prevalence (HFIAP) status indicator can be used to report household food insecurity (access) prevalence and it categorizes households into four levels of household food insecurity (access): food secure, mild, moderate and severely food insecure (3).

2.1.3. Factors associated with food insecurity

The root cause of food insecurity in low income countries is related with poverty (84, 92). Also, food insecurity is related to social and political instability, poor governance, frequent drought and famine (92). Climate variability and weather condition in relation to community vulnerability and adaptive capacity are among the main determinant factors that affect rural household food access (49, 93). A Food insecurity situation review in Ethiopia indicates that several factors are identified for the deteriorating situation of food security in the country (81). Those are population pressure, drought, shortage of farm land, soil erosion, lack of oxen, poor food production system, outbreak of plant and animal diseases, poor soil fertility, poor farming technology, weak extension services, poor labor work force, poor infrastructure and pre and post harvest crop loss (81).

Agroecosystem characteristics determined using climate variables, soil type, topography, various organisms in the area, agricultural technologies and practices, and farmers' social setting (94), have its contribution through different pathways on the food system in the country (95). Agroecosystem analysis

in relation to its potential and constraints to developmental activities is very important to design effective food and nutrition interventional strategies (95). Food insecurity in the community has the potential to increase the pressure on natural resources and poor natural resources management lead to food insecurity in the community. Better management of agroecosystem has a strong association with sustainable food system in the farming community (96) which helps to alleviate food insecurity. Due to this fact, at global level, there is a paradigm shift towards an ecosystem based approach for food insecurity interventions (96).

To mitigate food insecurity and undernutrition in the community, it requires a holistic approach with healthy ecosystem as a foundation (97). Recognizing the multiple functions of agroecosystem is essential for food insecurity and undernutrition interventions. To ensure food security, it is important for decision makers to support the management of agroecosystem services by taking appropriate policy measures that encourage the use of technologies and approaches, including sustainable land management, water resources management and sustainable agricultural practices (97).

It is documented that vulnerability to food insecurity is a common problem in semi arid lowlands and mountainous highland areas, including in Ethiopia, where rural households depend on rain fed agriculture for crop production (98). A study from North West Ethiopia indicated that households in the highland agro-ecological zones were more food insecure than lowland areas (15). However, there was no statistical significant differences between lowland and middle land agro ecological zones in household food insecurity (15). This might be explained as most highland areas are mountainous and hilly which are prone to soil erosion and degradation, and those could reduce agricultural productivity which is the primary source of food (15, 93). Such kind of problem is more severe in countries like Ethiopia, where soil erosion and land degradation are common events since there are no sustainable soil and water management practices (99).

Literature show that being married may increase household family size, which lowers the amount of food distributed to family members (78, 100). Evidences both from Ethiopia and elsewhere showed that family size has negative impacts on household food security. The majority of farm households in low income countries are small scale semi subsistence producers with limited participation in non agricultural activities. Because land and finance to purchase agricultural inputs are very limited, increasing family

size, according to the literature, tends to exert more pressure on consumption than the labour it contributes to production (15, 16, 77, 101-103).

Better educational status of the family members, particularly maternal and paternal education makes them familiar with new skills, ideas, modern agricultural technology application and other developmental activities which could mitigate household food insecurity (15, 85). Studies from Pakistan (101) and Malawi (77) indicate that households with educated household heads are more likely to be food secure compared to households with uneducated heads. The influences of education on food insecurity depend on the context and education alone may not reduce food insecurity if other economic opportunities, such as employment, are not available (104).

Empowering women using different strategies, including strengthening their asset base like natural and physical capital, human capital, social and financial capital and by providing the legal and institutional framework to guarantee their command over resources is considered as one means to reduce food insecurity. Women play important roles as producers of food, managers of natural resources, income earners, and care takers of household food and nutrition security. Women empowerment to decide on household resources have a positive influence to reduce household food insecurity (105). Understanding the dimensions of 'women's empowerment' that influence food security among rural households is crucial to inform policy (106).

The wealth status of the household as proximate indicator of household economic status affects food insecurity. Directly, wealth allows greater flexibility of food choices and stability through lean times. Indirectly, wealth status may be correlated with other variables that also reflect food choices, educational status and marital status. Studies from South Africa and Pakistan indicated that households with better monthly income have a negative effect on household food insecurity status (78, 101).

Micro credit accesses to farmers and additional income generating activities have positive contributions in mitigating food insecurity (77, 107, 108). Micro credit access to the farmers, serves as a means to increase crop productivity and help to expand income generating activities which help to achieve food security (107). The micro credit access allows farmers to do off farm activities and households with off farm activities have a better survival mechanism when crop production fails due to different causes (77). Farmers off farm activity can be considered as one of the major coping strategies during food shortage/insecurity (103). In addition, household income from nonfarm activity increases the probability

of the household to use modern agricultural inputs to produce more crop and enable households to fulfill the family consumption through purchasing from the market (16).

Also, micro credit access and off farm income generating activitities helps the mothers to purchase agricultural inputs, including fertilizer and improved seed to increase crop productivity. Farmers' use of agricultural inputs to increase crop productivity has an important role in determining household food insecurity (77, 103, 107). Application of improved seed and fertilizer to increase crop productivity has a significant effect in reducing food insecurity (77, 103). Farmers who used fertilizer improved household food insecurity compared to farmers who did not use fertilizer (109).

Literature show that households nearer to market centers had better chances to be food secure due to the fact that households nearer to market center have the probability of selling what they produced and purchase food from the market (16). Evidence from Ethiopia suggests that distance from market center and household food insecurity have a significant statistical association (16).

2.2. Child undernutrition

2.2.1. Magnitude of child undernutrition

The 2016 UNICEF, WHO and World Bank joint estimate of child undernutrition indicates 23.2% and 6.2% stunted and wasted children in 2016, respectively at global level (24). In Africa, higher prevalence of childhood stunting (32%) was reported compared to the global level prevalence (24). Unequal progress in childhood stunting reduction was observed among WHO regions. For example, Asia reduced childhood stunting almost by half (47.6% to 25.1%) and Africa showed only limited progress (42.3% to 32.0%) in reducing childhood stunting between 2000 and 2015 (24). However, the prevalence of childhood wasting, increased from 5.1% to 6.2% between 2000 and 2015 (24).

Ethiopia has the highest rates of undernutrition in Sub-Saharan Africa (24). In the EDHS 2016 report, a prevalence of 38.4 % stunted, 9.9% wasted and 23.6% underweight children were observed (25). Amhara Regional State childhood stunting (46.2%) and underweight (28.4%) were higher than the national level prevalence (25). Also, different pocket studies from various geographical locations suggest higher child undernutrition prevalence in Ethiopia (51, 110). For example, a study in West Gojjam Zone indicate that 14.8 %, 43.2% and 49.2% of under five children were suffering from wasting, underweight and stunting,

respectively (110). Similarly, a study from North West Ethiopia indicated that the prevalence of childhood wasting, underweight and stunting were 37.6%, 21.9% and 17.3%, respectively (51).

As indicated in table 1 below in Ethiopia, childhood undernutrition is decreasing through time in the last 15 years. For example, childhood stunting, underweight and wasting prevalence decreased from 58% to 38.4%, 41% to 23.6% and 12.0% to 9.9%, respectively between 2000 and 2016(25). In Ethiopia, the reduction of childhood wasting within the last 15 years period showed very slow progress compared to child stunting and underweight (25, 111-113).

In Amhara Regional State, which is one of the states in Federal Democratic Republic of Ethiopia, childhood stunting and underweight are decreasing through time from 57% to 46.3% and 51.8% to 28.4%, respectively, between 2000 and 2016 (25). In the region, like the global and national trends, childhood wasting did not show improvements over time. The recent mini EDHS 2014 and EDHS 2016 reports indicated that childhood stunting (42.4% to 46.3%) and underweight (27.9% to 28.4%) increased between 2014 and 2016. Table 1 below shows the trends of childhood under nutrition from 2000 to 2016 in Ethiopia and Amhara Regional State (25, 111-113).

Table 1:- Trends of child undernutrition in Ethiopia and Amhara Regional State, 2000- 2016.

Nutritional indices	National					Amhara Region				
	2000	2005	2011	2014	2016	2000	2005	2011	2014	2016
Stunting	58	48	44	40	38.4	57	56.6	52	42.4	46.3
Underweight	41	33	29	25	23.6	51.8	48.9	33.4	27.9	28.4
Wasting	12	12	10	9	9.9	9.5	14.2	9.9	9.7	9.8

Different efforts are undergoing both globally and at national level to reduce the magnitude of child undernutrition. The global trend of childhood stunting prevalence and the number of affected children is decreasing between 1990 and 2014 (24). However, this reduction at all levels is not enough to achieve the UN 2030 sustainable development goal to end all forms of child undernutrition by 2030 (24) and the 2025 global target to reduce child stunting by 40% and child wasting to less than 5% between 2013 and 2025 (114). As indicated in table 1 above, both the national and regional level child undernutrition reduction progresses are very slow to achieve the national targets of "SEQOTA" 2015 declaration to end child undernutrition by 2030 (37). Also based on the progress in reduction of child undernutrition in the

last 15 years, it might be very difficult to address the National Nutrition Program II (NNP II) targets to reduce childhood stunting to 26% from 40%, underweight to 13% from 25 % and wasting to 4.9% from 9 % between 2014 and 2020 (36).

2.2.2. Spatial variations of child undernutrition

Spatial variations were observed in child undernutrition at global level (10). The variation is more pronounced based on socioeconomic status of the regions. For example, less than half of all children under five years live in lower middle income countries where two thirds (66%) of all stunted children live. Asia and Africa bear the greatest share of child undernutrition and more than half (56%) of all stunted under five children lived in Asia and more than one third (37%) lived in Africa. Also, two third (68%) of all wasted children lived in Asia and more than one quarter (28%) of wasted children were from Africa (10). Studies from West Africa (67), Sub Saharan Africa (68) and Nigeria (65) showed a clear spatial variation of child undernutrition across different geographical locations within the states. Studies indicated that the presence of spatial heterogeneity in child undernutrition and recommended geographical targeting to reduce the inequalities (115).

In Ethiopia, a clear spatial variation was observed in the prevalence of child undernutrition among regional states based on the recent 2016 EDHS report (25). For instance, in reference to the WHO recommended criteria for assessing the severity of child undernutrition, EDHS 2016 report using the prevalence at the population level from nine regional states and two town administrations, four were in very high severity (>40% prevalence) level of childhood stunting. The other four were in high severity (30 -39 % prevalence) of stunting, two were classified under medium severity (20 -29% prevalence) of stunting and only one town administration was classified under low severity (less than 20% prevalence) levels for child stunting (9).

In areas, where there are spatial inequalities in childhood undernutrition, interventions should be targeted based on vulnerability (69) through allocating scarce resources to the most affected areas (70). To identify the most affected geographical locations, epidemiologists are gradually incorporating spatial analysis into public health research using the application of geographical information system (116). This approach has the potential to improve the efficiency of public health interventions (117) by identifying people at the highest risk of disease (117, 118).

For the spatial analysis, different spatial statistics approaches have been proposed to test for spatial clustering and can be used in various applications. The power of the methods varies greatly for different test statistics and alternative clustering models. As a result, consideration of the power of the method is important before we decide which test statistic to use (119). Spatial SaTScan analysis is one of the strongest approaches to detect local clustering of the public health problems (116, 120). This spatial analysis approach has been used to investigate the spatial epidemiology of different public health problems like spatial distribution of malaria (121, 122), HIV infection (123), childhood diarrhea disease distribution (124, 125) and child nutritional status (44, 45) in the country. Similarly, elsewhere abroad the SaTScan spatial analysis approach has been used to identify the hotspot areas of HIV risky behaviours and infection (126-130), maria infection and prediction (94, 131-133), different infectious disease mapping (134-136) and diarrheal disease (137).

2.2.3. Measurements of child undernutrition

Different assessment methods, including anthropometric, dietary survey, biochemical or laboratory method and clinical or physical examination method can be used to assess nutritional status of a community (79). Each nutritional assessment method has its own strength and limitations (138).

Anthropometry method is a technique that uses human body measurements to draw conclusions about the nutritional status of mainly under five children. To carry out anthropometric analysis, child's age, sex, height and weight should be measured. These measurements are used to generate indices such as, height for age z score, weight for age z score and weight for height z score (139, 140). In this method, Z-score unit of measure to determine the nutritional status of a child can be used and each child's anthropometric index is compared to a reference distribution for the index of interest (139). The distance from the median individual to the reference population indicates whether a child is suffering from wasting, stunting or underweight (139). Anthropometric methods are simple to use in community based surveys, inexpensive, accurate and can give gradable results compared to other methods (138). However, this method cannot detect impaired nutritional status of short duration and specific nutritional deficiencies in the community, including under five children (138).

Biochemical assessment deals with measuring the level of essential dietary constituents in the body fluids (blood and urine) which is helpful in evaluating the possibility of child undernutrition. Biochemical assessment basically works on the principle that any variation in the quantity and composition of the diet

is reflected by changes in the concentration of nutrients or their compounds in tissue and body fluids, and /or by the appearance or disappearance of specific substances (138). The biochemical tests can detect sub clinical undernutrition and give gradable nutritional information (138). However, this method needs highly trained staff, involves invasive procedures, needs many quality control procedures during the sample taking, difficult to carry out the test and analysis, there is no ideal biomarker for each nutrient and it needs sophisticated instruments (138).

Clinical method, nutritional assessment is the simplest method to assess the nutritional status of an individual. It involves looking for changes (clinical signs/symptoms) in the body which are indicative of a particular nutrient deficiency. This method needs to have knowledge about specific nutrition deficiency signs and symptoms (141, 142). The clinical method of nutritional assessment is too cheap, non-invasive and quick method. However, it is very subjective, it needs professionals with clinical background to collect data and less specific in which other diseases may have similar signs and symptoms (138).

Dietary survey methods are used to find out what and how much a client is eating. These methods are record method, 24 hour dietary recall, dietary history and a food frequency questionnaire. These can be used to assess eating habits, food allergies and intolerances, and reasons for inadequate food intake during illness (98). The record method of dietary survey is more accurate and there is no respondent's memory loss. However, it has a high burden on the respondent, costly, change of the dietary habit during the survey and it needs literate respondents (138). The 24 hour dietary recall method is cheap, and quick, less respondent burden, respondents have no change to bias their dietary habit. However, it does not indicate the usual individual intake, there may be respondents memory laps, sensitive to social desirability bias, less precise and accurate, difficult to estimate the portion consumed by the individual (138). The dietary history method of dietary survey is very difficult to validate, it needs highly trained interviewer and it gives a relative estimate if not an absolute information. The food frequency questionnaire method is less costly if it is self administered and less respondent burden. However, this method is not applicable in multicultural society where different staple foods are consumed and it needs educated respondents to make it self administered (143).

2.2.4. Factors associated with child undernutrition

To reduce the burden of child undernutrition, identifying the determinant factors in specific context is very important (140). The UNICEF conceptual framework developed back in 1990 (21) remains to be

one of the most commonly used important frameworks for understanding child undernutrition determinant factors at different levels (21). This framework recognizes three levels of determinant factors of child undernutrition: the basic, underlying and immediate causes of child undernutrition (21) and understanding factors associated with child undernutrition in a given context is critical in delivering appropriate, effective and sustainable interventions and adequately meeting the needs of the most vulnerable population groups (32).

2.2.4.1. Immediate causes

The most important immediate determinant factors contributing to child undernutrition, include the disease burden and dietary intake at the individual level (21). These factors themselves are interdependent since children with inadequate dietary intake are more susceptible to disease; and disease in turn depresses appetite, inhibits the absorption of nutrients in food, and competes for the child's energy (32). Undernutrition weakens the immune system, putting children at higher risk of more severe, frequent and prolonged bouts of illness. Child undernutrition is also a consequence of repeated infections, which may further worsen the child's nutritional status at a time of greater nutritional needs (144). For example, studies from Ethiopia (52, 56, 110) and Cambodia (145) indicated a statistical significant association between child undernutrition and child's episode of diarrhea in two weeks immediately before the survey.

Child and maternal dietary intakes are categorized under the immediate causes of child undernutrition (42, 112, 145-149). Proper breast milk feeding of the infant improves child nutritional status since it is the main source of active and passive immunity, gives adequate nutrient and protects the infant from infection (146). Its early initiation is also important for the child, which is recommended to be started within an hour of delivery (112). UNICEF and WHO recommend the introduction of solid food to infants around age 6 months because breast milk alone is no longer adequate to maintain a child's optimal growth after 6 months (112). After 6 months, the minimum dietary diversity should be maintained to the infant. Dietary diversity (DD) relates to nutrient adequacy (147) particularly micronutrient adequacy of children's diet (140). So, maintaining the minimum diversity of diet is an important determinant factor for the child physical and mental development and performance of the human body in general (148). Literatures show that proper maternal nutrition and nutritional status are strongly associated with child nutritional status (42, 145, 149).

Evidences indicate that child age is one of the determinant factors of child nutritional status (145, 149, 150). Studies from three Asian republics (150), Bangladesh (151), Kenya (149) and Cambodia (145) indicate that there were statistical significant association between child undernutrition and child's age (152). This might be related to the fact that when the child age increases, it starts to move independently outside of home and gets exposed to infection. Also, an increase of a child's attention to the external stimuli might cause the child not to be available easily for the mother to give care and timely breastfeeding (152). Literatures indicate that the effect of child gender on nutritional status is mixed and no strong conclusions can be drawn, even for individual countries (145, 149), including Ethiopia(42, 53, 74).

2.2.4.2. Underlying causes

The underlying determinant factors of child undernutrition, include household food insecurity, environmental sanitation and maternal and child care practices (21). The underlying causes, which impact child nutritional status through the immediate determinant factors, manifest themselves at the household level. The first, household food security, is assured access to enough food of adequate quality for living an active and healthy life (32). The second refers to the quality of care practices for the child and its mother and the third underlying determinant factor category is environmental sanitation which, include access to safe water, personal hygiene, proper latrine utilization and sanitary facilities for disposing of household refuses (32).

Literature show that household food insecurity is among the key determinant factors of nutritional status of children (153). Food insecurity influences child nutritional status, which dictates both the quantity and quality of dietary intake (146, 147). Food security may be a necessary prerequisite for good nutrition outcomes, but it is not sufficient to ensure good nutrition (154). Studies from Colombia (110), Pakistan (111) and Ethiopia (51, 155) indicate a negative significant statistical association between household food insecurity and child nutritional status. The influence of food insecurity on child nutritional status might be indirectly through shaping other predictors like maternal nutritional status and intra household food distribution (156). For instance, within the household, mothers and children eat the least and last from the share of their family's food relative to their nutritional need in case of food insecurity situations (156).

Maternal health service utilization and health condition during pregnancy have an association with child nutritional status (157). Quality of Ante Natal Care (ANC) with full visit helps the mother to get information about child and maternal care and feeding practices (112). A study in Ethiopia indicated a positive significant association between child nutritional status and antenatal visit of the mother during pregnancy (56). Also, another study from Hawasa Zuria District of Ethiopia indicated that the mothers prenatal care visit with index child is the protective factor of child undernutrition (53). Proper medical attention and hygienic conditions during delivery can reduce the risk of infections in newborn babies and institutional delivery is recommended to reduce health risks of children, including undernutrition (112). Postnatal care of pregnant mothers are expected to improve child care practices in general and nutritional status in particular (158). Also, the postnatal follow up improves child nutritional status through providing important information on how to care and feed infants (112).

Health services access in terms of geographical distance is very important determinant factor to improve child nutritional status (158). A study in Ethiopia indicated that child nutritional status is determined by the distance between the location of the household and the nearest health center (56). The probability of being undernourished child declines with a decrease in distance to the nearest health center, since people from the distant area cannot access health services during illness and get advice on child care and feeding practices. In those areas, children without access to health services are more likely to be undernourished due to frequent and untreated or delayed treatment of infection (56).

When the number of under five children increase, the burden of care in terms of nutrition, finance and parenting time, gets compromised and thus affects nutrition outcomes of children (159). The number of under five children from a single mother might be related to the birth interval that affect the quantity and quality of care that mothers can provide for their children (160). Also, controlled family size reflecting the place of appropriate health enhancing population policies and measures in ensuring maternal and child health and nutrition (159). Studies from Nigeria (159), Somalia (138) and Ethiopia (74) indicate that the number of under five children is significantly associated with child nutritional status.

Immunization against vaccine preventable diseases has been recognized as one of the most cost effective intervention strategies to reduce child mortality, morbidity and undernutrition (161). Immunization is one of the most essential preventive health care priorities that has a very strong link to the nutritional status of children (162). Studies reported higher frequencies of morbidity from non immunized children which

may lead to a higher prevalence of child undernutrition (161). Studies from Nigeria (139), Kenya (163), Somalia (138), and Ethiopia (56) indicate that absence of immunization programs affects child nutritional status negatively.

Child care giver good personal hygiene, environmental sanitation, including good household waste (refuse) management practices (151), proper latrine utilization (140) and water source safety and safe handling at household level (160) have important roles in determining child nutritional status. Prevention of infectious disease burden through better sanitation and accessing safe drinking water sources are recognized as essential components in preventing child undernutrition (160). Studies from Bangladesh (151), India (84), Nigeria (140) and Kenya (164) indicate that unfavorable environmental health caused by inadequate water supply, poor personal hygiene and environmental sanitation increase the probability of infectious diseases and indirectly cause certain types of undernutrition.

2.2.4.3. Basic causes

The basic causes of child undernutrition are the most distal factors, including health service accessibility, educational status, marital status, fertility related factors, child age and gender related care practices, economical factors and agroecosystem characteristics (21). The basic determinant factors, which in turn impact nutritional status through the underlying determinant factors, manifest themselves at broader geographical levels, such as national, regional, or global. They form the economic, political, environmental, social and cultural context in which children's nutritional status are determined. Among the basic determinant factors, income and government responses to people's needs are also categorized under basic causes (32).

Education is one of the most important resources that enable women to provide appropriate care for their children (165) through bringing better income, good use of available information about child nutrition (160), enhancing the mothers' general knowledge, improving the allocation of resources to children's wellbeing and the care for the child (166). Studies from India (167), Bangladesh (166), Kenya (149, 163) and Mozambique (103) support the above evidence that mother educational level improve child nutritional status positively. Similarly, studies from Ethiopia demonstrate that mother education has a positive contribution to improve child nutritional status (52, 53). Similarly, child father educational status was independently associated with children's nutritional status (52) which may be related with higher educational status having the ability to make decisions that improve the nutritional status of children

(102, 103). Studies from Ethiopia (42) and Bangladesh (103) indicate that children from uneducated father were more likely to be undernourished compared to children of educated fathers.

Literature indicate that being female headed household has both negative and positive effects on child nutritional status through direct and indirect channels (160). Directly, households in which women have a greater say in decision making tend to have better indicators of child wellbeing, including better nutritional status. On the other hand, female headed households tend to have lower income and therefore worse nutritional status for themselves and children (160). A study from West African indicated that female headed households do not have better child nutrition outcomes than male headed households (160). Also, a study from Kenya indicate that children from female headed households were more likely to be undernourished than male headed households (163). This could be explained as female headed households tend to have limited resources which might worsen child nutritional status (159, 163). On the other side, a study from Nigeria indicate that women headed households, have a greater say in decision making and thus tend to have better child nutritional status (159). For example, in Ethiopia, being male headed household have a statistical negative association with child stunting (42, 74).

Resources available at household level show a positive, statistically significant association with improved child nutritional status (160). Those resources available to a household should translate into higher expenditures on food and health and this results in improved child nutritional status (168). Studies from India (167), Nigeria (159), Kenya (149), Cambodia (145) and Ethiopia (42, 74) illustrate that improving socioeconomic conditions measured using different indicators helped to improve the nutritional status of children. Women decision making power, control over resources, and autonomy in the household have the potential to enhance child nutritional status by improving child care practices (169, 170).

Agroecosystem characteristics not only affect child nutritional status through food insecurity and dietary diversity, but also it determines the infectious disease distribution in the community (95). The magnitude and distribution of infectious diseases depend on ecosystem services since it maintains the diversity of species in equilibrium and can often provide a disease regulating effect (97). The disease burden of the child is one of the most important immediate determinant factors contributing to children's nutritional status (21). A study from Ethiopia showed that children from highland and midland areas relatively prone to higher stunting and underweight compared to those in the lowlands (43). Similarly, a study from northwest Ethiopia showed that children from lowland areas are better in nutritional status (51). Those findings contradict with an agroecosystem analysis indicating highland and lowland areas show higher

climate change vulnerability and lower climate change adaptive capacity compared to midland areas which have the potential to lower crop productivity (93) and higher food insecurity and (49) then child undernutrition (171).

2.3. Impacts of food insecurity and undernutrition on health and welbeing

Food insecurity and malnutrition in all its forms are global burdens that affects almost every country in the world, leading to serious public health risks, incurring mortality, morbidity and high economic costs (12, 33, 75, 76, 85, 89, 172, 173). Evidences indicate that food insecurity and human health are intertwined in a vicious cycle through nutritional, mental health, and behavioral pathways (171).

Food insecurity has been found to be associated with poor mental health status independent of other indicators of low socioeconomic status, in both resource rich (174) and resource poor (175) settings. The mental health negative impact of food insecurity is more severe among women (176) because they are responsible to feed the family (177). Insufficient food access has the potential to undermine women's' social relationships and lead to feelings of low self efficacy among women (178) which creates deep sense of helplessness among women, leading to mental and emotional distress (176).

Disease prevention, management, and treatment are linked with food insecurity. An inability to fulfill subsistence needs, including household food needs, can lead people to make unhealthy decisions that may increase their risk of illness, such as engaging in risky sexual behaviors in exchange for food, or overreliance on cheap, calorically dense nutrient poor foods (179). Also, food insecurity was associated with poor health service seeking behaviour, limiting the disease prevention and control efforts, postponing needed medications and care practices, and with increased emergency department use and hospitalization (180). For example, food insecurity negatively impacts public health efforts to prevent and control TB and HIV infections and treatment outcomes (2).

Improvements in nutrition will contribute significantly in reducing poverty and in achieving health, education, and employment goals (12). In addition, it affects child growth and development (75, 76, 85), the education system (181) and school enrolment age (89, 182) and academic performance (33, 173). Food insecurity may lead to political instability, and a poor resilient environment (183). Also, food and nutrition insecurity deteriorate the mental health status of the community, particulary the women who is responsible to feed the family (2, 33, 173, 184).

Both inadequate quality and quantity of nutrition affects the nutritional status of under five children (172). When food quantity is limited, it leads to wasting, stunting, and immune deficiency (185). On the other hand, food insecurity also exerts negative impacts on health through effects on obesity, disordered eating behaviors (186) and poor diet quality (187). Undernutrition due to poor food quality can cause various diseases such as blindness due to vitamin A deficiency, neural tube defects due to folic acid deficiency, lower brain and nervous system development and lower school performance due to deficiency of iron, folic acid and iodine (26).

Also, at the global level, undernutrition has an economic implication. For example, hunger and undernutrition reduce gross domestic product by US$1.4–2.1 trillion a year at global level (12). The World Bank estimates that undernourished children are at risk of losing more than 10% of their lifetime earning potential (188).

In the Ethiopian context, it is estimated that undernutrition contributes to an estimated of 270,000 deaths of under-five children each year and fifty seven percent of all deaths of under five years are related to undernutrition (27). Of those, three quarters of the deaths result from mild to moderate undernutrition exacerbating the effects of common childhood illnesses (27). Also, in the country, undernutrition contributed to 28% of all child mortality, 16% of all repetitions in primary school and 8% of work force reductions, and costs 55.5 billion Ethiopian Birr (ETB) per year which is 16.5% of the Gross Domestic Product (GDP) (22). Another study by International Food Policy Research Institute (IFPRI) indicated that eliminating undernutrition in Ethiopia would prevent losses of 8–11% per year from the gross national product (12). According to the cost of hunger study, Ethiopia could reduce losses by 148 billion ETB in the year 2025 if childhood underweight and stunting rates were reduced to 5% and 10%, respectively (22).

2.4. Interventions of food insecurity and child undernutrition

It is well recognized that nutrition is central to the Sustainable Development Goals. From the total 17 SDGs, 12 of them contain indicators that are highly relevant for nutrition, reflecting nutrition's central role for sustainable development (12). Taking the importance of nutrition for development, various policies, strategies and measures have been put in place over the years in Ethiopia. The state government, various international organizations and non-governmental organizations played an important role to mitigate food insecurity (189). The major programs that have been and still are under implementation to

combat food insecurity in Ethiopia, include the Productive Safety Net Program (PSNP), Household Asset Building Program (HABP), Complementary Community Investment (CCI) project and Voluntary Resettlement Program (VRP) (189). PSNP was started in 2005 and it is implemented in selected Woredas of four Regional States, including Amhara Regional State. The program focuses mainly on public work activities, such as natural resources conservation, community water source development, small scale irrigation scheme's development and construction of social services, including rural roads, schools and clinics (190).

Similarly, HABP, as a complementary to the PSNP started in 2005 aimed to support those that have reached a status considered adequate for self sustenance during shocks. The support focuses on assisting business plan development and provision of credits to start their own businesses. The CCI is basically aimed at developing community infrastructure such irrigation schemes, rural roads and other social services through partnership in investment between the government and the community. The other intervention to reduce food insecurity is VRP which is aimed at resettling vulnerable people from degraded areas to more agriculturally favorable areas (190).

Despite the progress and achievements made so far, addressing the deep root causes of undernutrition and ending hunger call for high impact integrated and coordinated interventions (36). The causes and solutions of child undernutrition are linked to social and economic policies across numerous sectors (28). As a result, interventions to improve nutritional problems, include strong political commitment of the government, advocating the involvement and responses of different sectors, building national capacity, strong monitoring system and commitment of the community (28). In addition, to the above, strategies to reduce child undernutrition should focus on improving health environments through increasing access to safe water and sanitation services. Improving the quality of care practices for children through increasing women's education and promoting gender equality, including women's empowerment; and mitigating food insecurity by ensuring adequate availability of quality food at different levels (32). Nutrition has a multidimensional and multi sectorial nature, both in terms of effectiveness and outcome (12).

Recognizing the importance of different sector involvement to reduce the burden of malnutrition in Ethiopia, 13 ministries signed to work together on the implementation of National Nutrition Program II (2016 - 2020). The ministries have recognized that the high undernutrition rate in Ethiopia is

unacceptable and have stressed the need for strengthening collaboration to reduce the impact of undernutrition in the country (36).

In Ethiopia, different programs were developed either as nutrition sensitive or specific interventions (36). Nutrition specific interventions are actions that have a direct impact on the prevention and treatment of undernutrition, in particular during the 1,000 days covering pregnancy time (26). Nutrition specific interventions in the life cycle approach, the activities, include maternal nutrition and prevention of low birth weight, infant and young child feeding (IYCF), breastfeeding with early initiation (within one hour of birth), continued exclusive breastfeeding for the first six months. Those interventions followed by continued breastfeeding up to 2 years, safe, timely, adequate and appropriate complementary feeding from 6 months onwards, prevention and treatment of micronutrient deficiencies and prevention and treatment of severe acute malnutrition (26, 35).

Nutrition sensitive intervention approaches involve other sectors indirectly addressing the underlying causes of undernutrition (26). In Ethiopia, different nutrition sensitive intervention strategies were developed to support the efforts in reducing undernutrition. Those include Growth and Transformation Plan II, Agriculture Growth Program II, Productive Safety Net Program (PSNP) IV, Nutrition Sensitive Agriculture Strategic Plan, Health Policy, Health Sector Transformation Plan, Reproductive Health Strategy, National Strategy for Child Survival, School Health and Nutrition Strategy, National School Feeding Program, National Social Protection Policy and different supplementation and fortification directives (36).

As indicated in different strategies, achieving nutrition related goals requires multi-sectorial coordination and cooperation with many stakeholders, which has historically been challenging in nutrition (26). Recently, attention has increasingly been paid to improve synergies and linkages between agriculture and nutrition and health, in both the programmatic and the research communities (26). Social protection policy was designed to protect people against vulnerability, mitigate the impacts of shocks, improve resilience and support people whose livelihoods are at risk for food and nutrition insecurity (26).

2.5. Conceptual framework

The Food and Nutrition Security framework developed by UNICEF recognizes three levels of determinant factors of child undernutrition: the basic, underlying and immediate causes of undernutrition (21). The immediate causes of child nutritional status are dietary intake and health status of the child. The intermediate cause of the child nutrition status, include household food insecurity (in terms of availability and access), inadequate maternal and child care practice and an unhealthy environmental condition. These three factors result from the set of underlying causes of undernutrition. The basic causes, include socioeconomic, political conditions and natural resource in the community (21). The natural resources quality and quantity depend on the agroecosystem characteristics that have an influence on child nutritional status. The current study followed this conceptual framework to identify individual and community level determinants of food insecurity and child undernutrition based on the literature review.

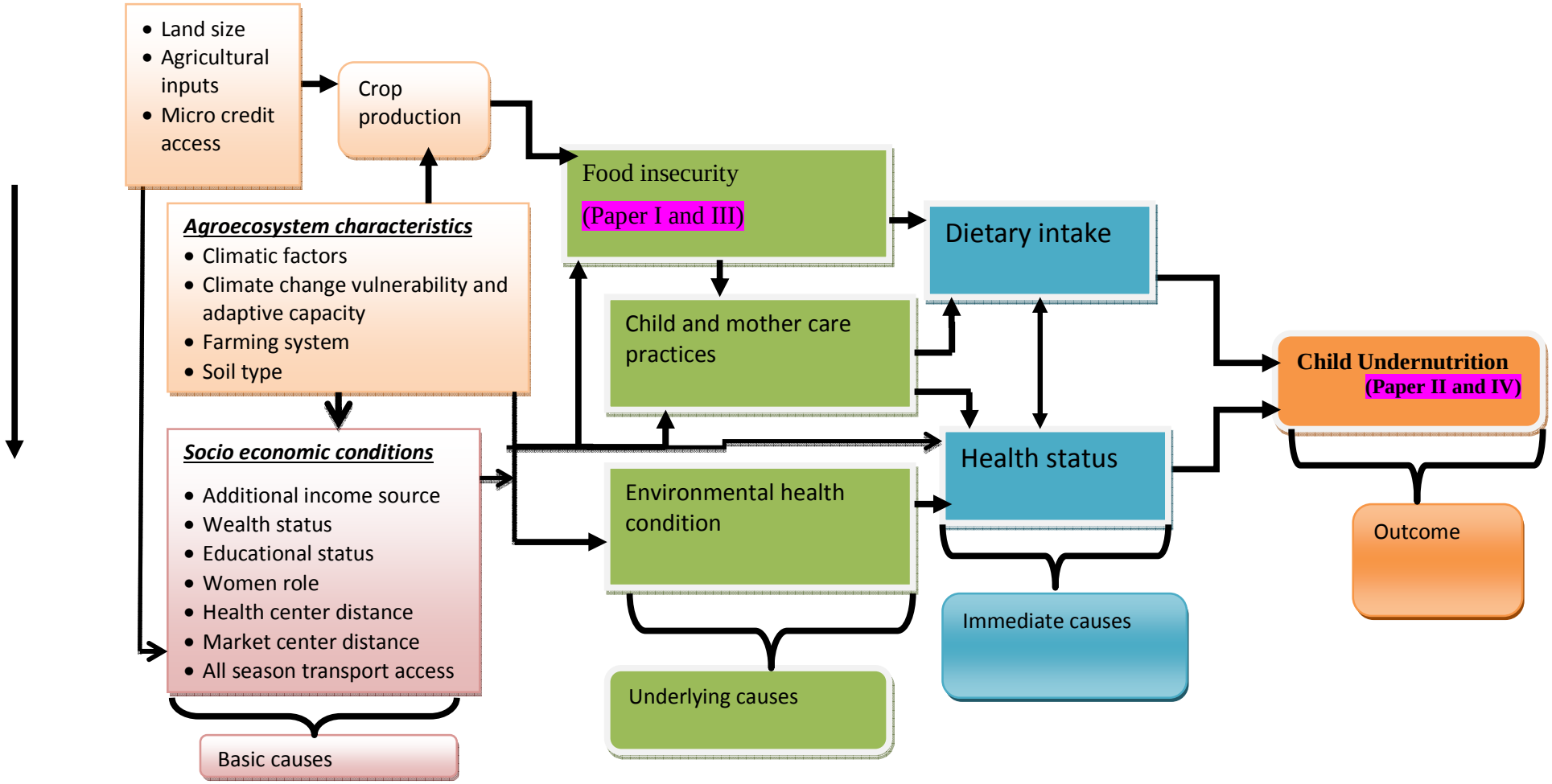


Figure 1:- Conceptual framework based on literature review on the pathways of determinant factors of food insecurity and child undernutrition.

3. Research objectives

3.1. General objective

The overall aim of this study was to assess the spatial variations and individual and community level associated factors of household food insecurity and child undernutrition in East Gojjam Zone, Amhara Regional State, Ethiopia.

3.2. Specific objectives

- To identify the spatial variations of household food insecurity across different agroecosystems in East Gojjam Zone (Paper I).
- To determine the spatial variations of child undernutrition across different agroecosystems in East Gojjam Zone (paper II).
- To identify individual and community level factors associated with household food insecurity in East Gojjam Zone (paper III).
- To determine individual and community level factors associated with child undernutrition (childhood wasting and stunting) in East Gojjam Zone (paper IV).

4. Materials and Methods

4.1. Study area and period

This study was conducted in East Gojjam Zone of the Amhara Regional State, Ethiopia. The area consists of different climatic zones, from Choke Mountain (Blue Nile highlands) to Blue Nile depressions (191).

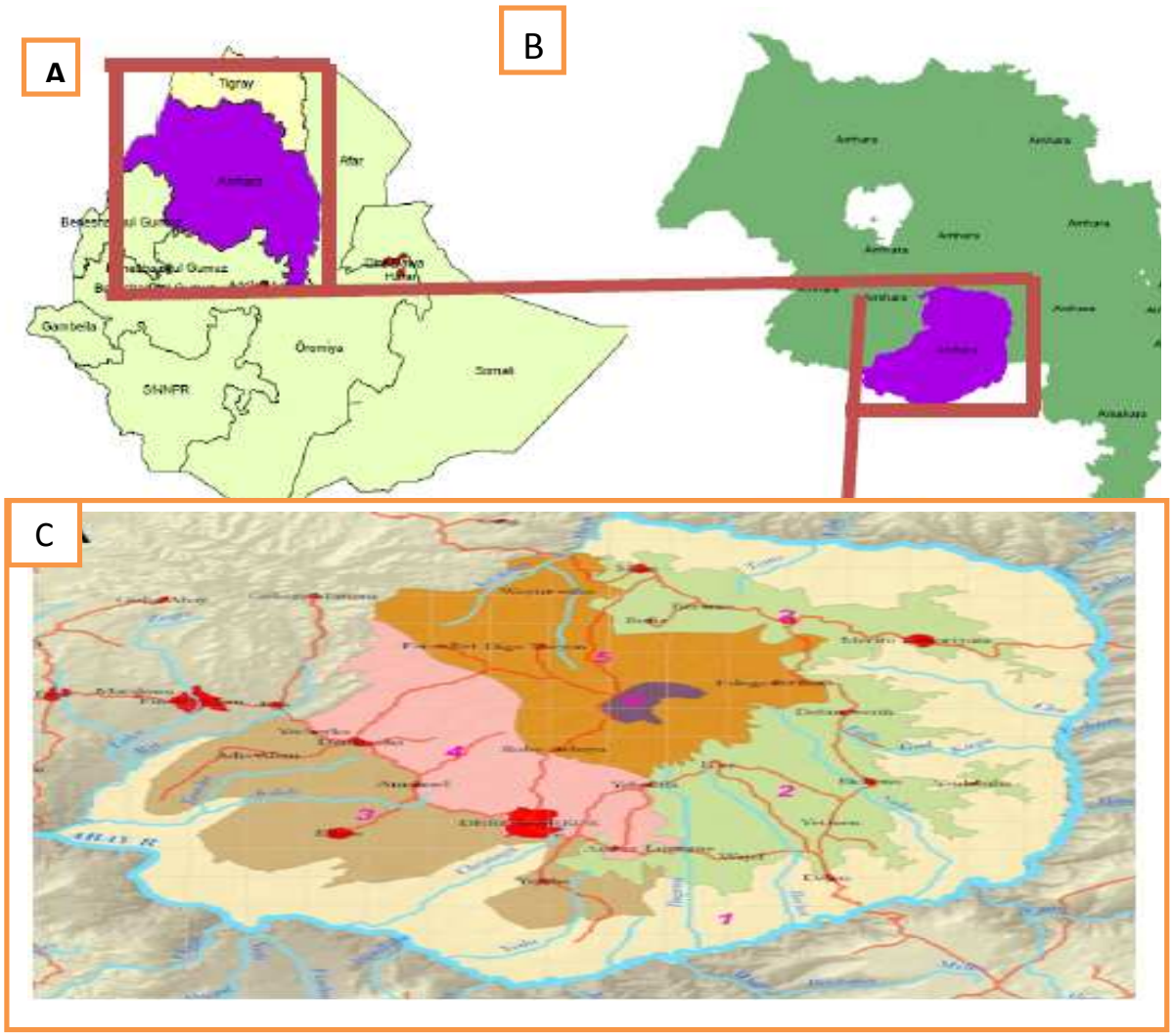


Figure 2:- Map of East Gojjam Zone, in Amhara Region, Ethiopia, 2015 (191).

According to the 2015 Amhara Regional Bureau of Finance and Economics Development Report which was projected based on 2007 census, a total of 381,309 under five children were registered in East Gojjam Zone (192). In the Zone, there are a total of 366,113 households (316, 375 male headed and 46,741 female headed households). The Zone has a total of four town administrations and 16 rural

districts. The area, including the Choke Mountain watersheds is found in the Blue Nile Highlands of Ethiopia, which extends from tropical highlands of over 4000 meters elevation to the hot and dry Blue Nile Gorge to below 1000 meters from sea level (191).

Based on different parameters /characteristics/ like farming system, type of crop produced, temperature, rainfall, soil type, climate change vulnerability and climate adaptation potential and constraints, the area is divided into six agroecosystems with its respective characteristics (191). As indicated in figure 2 of C above, the brown colored area is the lowlands of the Abay Valley (agroecosystem one) marked with number one. This agroecosystem is characterized by lowland areas with unfavorable agro ecological conditions with extensive land degradation (191). The midland plains with black soil (agroecosystem two) colored with light green color indicated with number two, which is characterized with a considerable high agricultural productivity potential (191). The midland plains with brown soil (agroecosystem three) indicated with number three which is suitable for its agricultural productivity since it has a good potential to use mechanized agriculture and irrigation schemes (191). The midland sloping lands with red soil (agroecosystem four) indicated with number four is characterized by low natural fertility with high level of soil acidity, slope terrain and higher rate of water runoff with soil erosion making the crop production potential very low (191). Hilly and mountainous highlands (agroecosystem five) indicated with number five are found in the hilly and mountainous highlands with constrained crop productivity due to erosion and deforestation (191). The last agroecosystem is at the top of the mountain with relatively low agricultural potential due to its low temperature. Since it is a conserved area, it is not used as a residential area (191).

This study was conducted from January to April, 2015.

4.2. Study design

An agroecosystem linked community based comparative cross sectional survey was employed. Linking shared /services/environment, including agroecosystem characteristics with population based cross sectional survey can be considered as one of the stronger investigation approaches to analyze causality in non experimental studies (75).

4.3. Source Population

Households with under-five children (6-59 months) were the source population to determine spatial variations of household food insecurity *(objective I)* and to identify individual and community level determinant factors *(objective III)* in East Gojjam Zone. Also, under five children (6 - 59 months) were the source population used to determine spatial variations of child undernutrition *(objective II)* and to identify individual and community level factors associated with child undernutrition (wasting and stunting) *(objective IV)* from East Gojjam Zone.

4.4. Study Population.

Households with under-five children in the selected kebeles were the study population to determine spatial variations of household food insecurity (*objective I*) and to identify individual and community level determinant factors of food insecurity *(objective III).* Under-five children (6 - 59 months) in the selected kebeles were the study population to determine the spatial variations of child undernutrition *(objective II)* and to identify individual and community level determinant factors *(objective IV)* in East Gojjam Zone. Households with under-five children (6 - 59 months) were considered as study units for analysis.

4.5. Inclusion and exclusion criteria

4.5.1. Inclusion criteria

Households with under-five children (6 -59 months) in the selected kebeles and lived for more than six months were included in the study.

4.5.2. Exclusion criteria

Households with under-five children (6 -59 months) where either the child or/and mother were seriously sick during the data collection period or those who have major physical disabilities to conduct anthropometric assessments were excluded from the study.

4.6. Sample size determination

Different sample size determination methods were used to address each specific objective of the dissertation and then, the maximum sample size, which enhances the power of the study, was considered for all objectives.

Objctive I:- Taking the agroecosystem characteristics into account, as it affects the spatial variations of household food insecurity, household food insecurity prevalence difference between the highland (p_1 =52.3%) and midland agro ecological Zones (p_2 = 63.8%) from the previous study were considered (15). The smallest difference was considered to ensure adequacy of the sample size for all agroecosystem. Then, a double population proportion formula was applied to determine the sample size.

$$n = \frac{\left(Z_{\frac{\alpha}{2}}\sqrt{\left(1+\frac{1}{r}\right)P(1-P)} + \left(Z_{1-\beta}\right)\sqrt{P_1(1-P_1)+\frac{P_2(1-P_2)}{r}}\right)^2}{(P_1-P_2)^2}$$

In this formula, $Z_{\frac{\alpha}{2}}$ is the confidence level, Z_{β} is the power of the study, r is the ratio between two groups, P_1 (prevalence of food insecure households from highland area) and P_2 (prevalence of food insecure households from lowland area) are the expected proportions among "food insecure households" in lowland and midland agro ecological zones, respectively. In the formula, P is the weighted pooled prevalence for P_1 and P_2.

The computation was made using the Stat Cal application of EPI-Info version 3.5.1, with inputs of 95% confidence level ($Z_{\alpha/2}$ = 1.96), 80% power of the study ($Z_{1-\beta}$ =1.28) and one to one ratio of samples between highland and midland agro ecological zones. Finally, assuming 1.5 design effect for its multistage cluster sampling and adding 5% none response rate, the sample size was 481 from each agroecosystem and after multiplying by five, since there are five comparative groups (agroecosystems), the total sample size of the study was 2405 households.

Objective II: - Considering agroecosystem characteristics that affect the spatial variations of child undernutrition and assuming a minimum of 10% difference in the prevalence of child stunting prevalence between any of the two agroecosystems; a double population proportion formula sample size determination method was used. A prevalence of childhood stunting (p_1=52 %) from Amhara Regional

State EDHS 2011 report as a base from better crop productivity agro ecology zone and assuming 10% prevalence difference from an agro ecology with lower crop productivity (p_2 = 62%) (112), the sample size was calculated using the following formula.

$$= \frac{\left(Z_{\frac{\alpha}{2}}\sqrt{\left(1+\frac{1}{r}\right)P(1-P)} + Z_{1-\beta}\sqrt{P_1(1-P_1)+\frac{P_2(1-P_2)}{r}}\right)^2}{(P_1-P_2)^2}$$

In this formula, $Z_{\frac{\alpha}{2}}$ is the confidence level, Z_{β} is the power of the study, r is the ratio between two groups, P_1 (prevalence of child undernutrition among lower productive agroecosystem) and P_2 (prevalence of child undernutrition among higher productive agroecosystem) were the expected prevalence of child undernutrition in lower and higher productive agroecosystems, respectively and P is the weighted pooled proportion for P_1 and P_2.

The sample size calculation was made using the Stat Cal of EPI Info version 3.5.1 application with the following assumptions: 95% confidence level ($Z_{\alpha/2}$ = 1.96), 80% power of the study ($Z_{1-\beta}$ =1.28) and one to one ratio between comparative groups. Finally, assuming 1.5 as design effect, for its multistage cluster sampling and adding 5% none response rate, the sample size from each group was 645 and after multiplying by five, since there are five comparative groups (agroecosystem), the total sample size of the five groups for the study was 3225 under five children.

Objective III: - To identify determinant factors of household food insecurity, a double population proportion formula was used as indicated below.

$$n = \frac{\left(Z_{\frac{\alpha}{2}}\sqrt{\left(1+\frac{1}{r}\right)P(1-P)} + Z_{1-\beta}\sqrt{P_1(1-P_1)+\frac{P_2(1-P_2)}{r}}\right)^2}{(P_1-P_2)^2}$$

In this formula, $Z_{\frac{\alpha}{2}}$ is the confidence level, Z_{β} is the power of the study, r is the ratio between two groups, P_1 and P_2 are the expected prevalences of “food insecure households" in exposed and unexposed groups, respectively. P was the weighted pooled proportion for P_1 and P_2. The computation was made using the

Stat Cal application of EPI Info version 3.5.1, with inputs of 95% confidence level ($Z_{\alpha/2} = 1.96$), 80% power of the study ($Z_{1-\beta} = 1.28$) and one to one ratio between exposed and 'unexposed groups to a factor for household food insecurity. The expected prevalence among exposed and non exposed groups were taken from previous studies conducted in the country (15, 107). Proportion of food insecure households to each exposure variable are given in the table below.

Table 2:- Sample size determination using different potential determinants of food insecurity.

Exposure		Food insecure HHs	Design effect	Sample size with 5% none response rate
Maternal education (15)	No formal education*	60.5%	1.5	1414
	Formal education**	51.0%		
Paternal education (15)	No formal education*	61.4%	1.5	2013
	Formal education**	53.5%		
Access to micro credit (107)	Yes**	30 %	1.5	1480
	No*	39%		
Improved seed use (107)	Yes**	24%	1.5	456
	No*	40%		
Agro ecology type (15)	Highland	52.3%	1.5	945
	Midland	63.8%		

**proportion of food insecure households among exposed group*

*** Proportion of food insecure households among unexposed group*

For this objective, paternal education gives maximum sample size of 2013 study participants.

Objective IV: - The sample size was calculated based on childhood height for age Z score (HAZ) using the mean with a standard deviation between exposed and unexposed group to the factor. Height for age Z score was extracted from EDHS 2011 data set for the Amhara Regional State. The mean height for age Z score (HAZ) with standard deviation was calculated for each exposure variable and double population formula for mean was used to determine the sample size, using Stata version 14. The following assumptions were considered during the sample size estimation: Mean HAZ score with a standard deviation to both exposed and unexposed groups of the exposure variable, one to one ratio between exposed and unexposed group, 95% level of significance, 1.5 design effect, and 5% none response rate. From all exposure variables, agro ecology zone gave the maximum sample size of 2647 considering highland agro ecology as exposed group (mean HAZ score = -1.85 with 1.12 SD) and midland agro ecology as an unexposed group (mean HAZ score = -1.69 with 1.22 SD).

Table 3:- Sample size determination using different potential determinant factors of child undernutrition.

Exposure variable		Mean HAZ (SD)	Design effect	Sample size with 5% none response rate
Child age	<24 months	-1.56 (1.31)**	1.5	1232
	24-59 months	-1.81 (1.18)*		
Child sex	Male	-1.69 (1.32)**	1.5	1477
	Female	-1.46 (1.19)*		
Diarrheal disease	Yes	-1.91 (1.40)**	1.5	1014
	No	-1.62 (1.22)*		
Agro ecology	Midland	-1.69 (1.22)*	1.5	2647
	Highland	-1.85 (1.12)**		

** Childern mean Height for Age Z score (HAZ) among exposed group
* Childern mean Height for Age Z score (HAZ) among unexposed group

For this objective, the maximum sample size calculated was 2647 using agroecology as a determinant factor of child height for age Z score.

Table 4:- Summary of the minimum sample size required for each objective and the assumptions considered.

Objective	Outcome	Assumptions	Formula	Sample Size
Spatial variations of household food insecurity	Food insecurity status	• 95% level of significance • 80 % power of a study • 1.5 design effect • Prevalence of food insecurity (p_1 = 63.5%) among exposed group (midland). • Prevalence of food insecurity (p_2 =52.3%) among unexposed group (highland). • 1:1 ratio between exposed and unexposed • 5 % none response rate	Double population proportion	2405
Spatial variations of child undernutrition.	Child undernutrition	• 95% level of significance • 80 % power of a study • 1.5 design effect • Prevalence of child stunting (p_1 = 52%) among better productive area. • Prevalence of child stunting (p_2 = 62%) among lower productive area. • 1:1 ratio between better productive and lower productive area. • 5% none response rate.	Double population proportion	3225
Determinant factors of household food insecurity.	Food insecurity/ status	• 95% level of significance • 80 % power of a study • 1.5 design effect • Food insecurity (61.4%) among not having formal paternal education • Food insecurity (53.5%) among having formal paternal education. • 1:1 ratio between having formal education and not having formal education. • 5% none response rate.	Double population proportion	2013

Determinant factors of child undernutrition.	Mean Child Height for Age Z score	• 95% significance level • 80 % power of a study • 1.5 design effect • 5% none response rate • 1:1 ratio between samples from midland and highland area. • Midland area mean HAZ score (m_1 = -1.69) • Highland area mean HAZ score (m_2 = -1.85) • SD for midland mean HAZ score (SD_1 = 1.22) • SD for highland mean HAZ score (SD_2 = 1.12)	Double population formula for means 2647

Therefore, for all objectives to the dissertation, a maximum sample size of 3225 households with under five children were considered

4.7. Sampling technique

According to the agroecosystem analysis by Belay et al, agroecosystems which have similar characteristics were identified as sharing common food insecurity and child undernutrition problems. From each agroecosystem, sample districts of the East Gojjam Zone, sample kebeles from each district and sample clusters from each kebele were selected using multistage cluster sampling. In the initial phase, five districts from each agroecosystem were selected purposively. Lowlands of Abay Valley (agroecosystem one) were represented by sample kebeles taken from Dejene District (lowland part). The midland plains with black soil area (agroecosystem two) were represented by sample kebeles taken from the Awabel District (midland part). The midland plains with brown soil area (agroecosystem three) were represented by sample kebeles taken from the Debre Eliyas District (midland part) and midland sloping lands with red soil area (agroecosystem four) were represented by sample kebeles taken from Gozamin District (midland part). Finally, hilly and mountainous highland area (agroecosystem five) was represented by sample kebeles taken from the Sinan District (Highland part).

In the second phase, from each agroecosystem, 38 kebeles were selected using simple random sampling technique. List of all kebeles that represented a particular agroecosystem were listed within a district and then using the lottery method, kebeles was selected randomly. In the third step, from each selected kebele, one got (lowest government administrative level) were selected using simple random sampling. From the kebele, one village as a cluster was selected using simple random sampling. The total clusters (villages), included in the study were 38 from the five agroecosystems and all eligible households with under-five children were considered for the survey. In households where there were more than one under five children within the household, the youngest child was selected to reduce the recall bias and to capture the current state of the problem and associated factors. The schematic presentation of the sampling procedure is presented in the figure below.

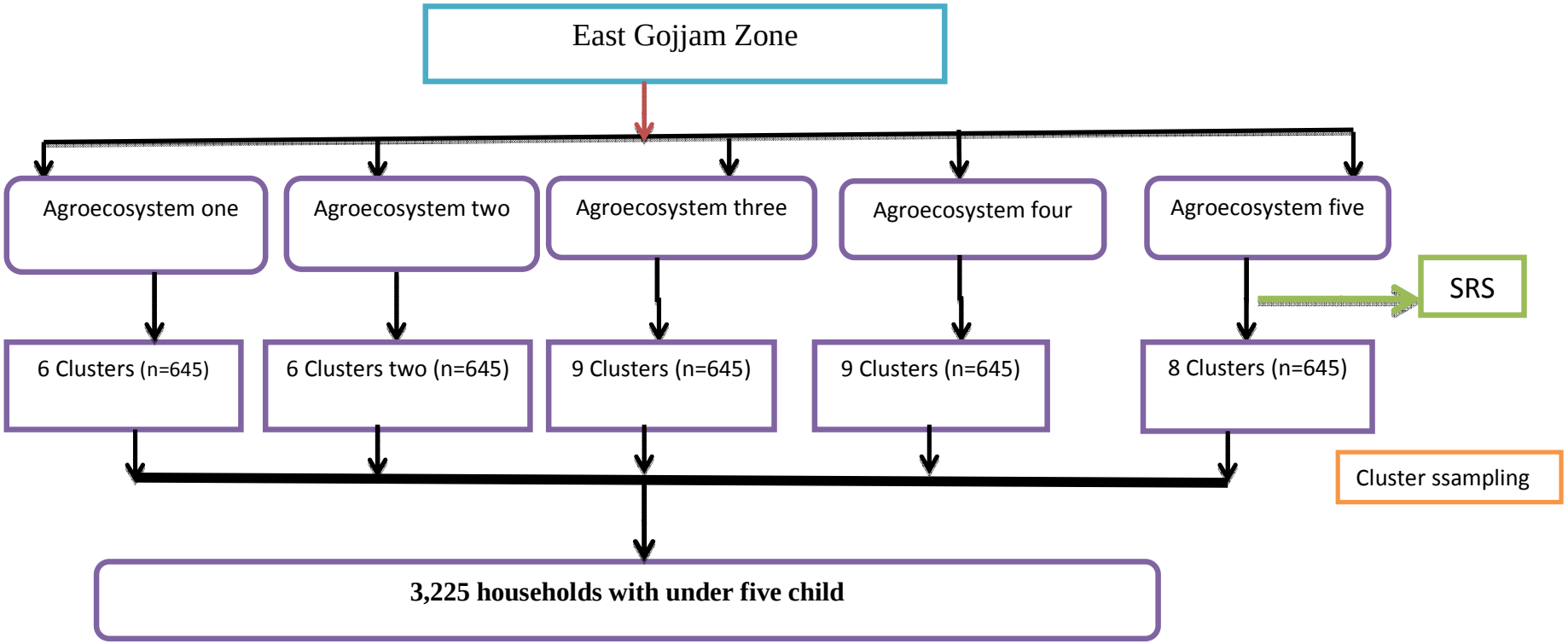


Figure 3:- Sampling procedures for spatial variations and determinant factors of household food insecurity and child undernutrition study in East Gojjam Zone, Amhara Region, Ethiopia, 2015.

4.8. Study variables

4.8.1. Dependent variables

Household food insecurity status *(objectives I and III)* and under five children (6 -59 months) nutritional status indices (Height for age Z score (HAZ), Weight for age Z score and Weight for height Z score (WHZ)) *(objectives II and IV)* were the dependent variables.

4.8.2. Independent variables

The independent variables were considered at two levels: Individual level (lower level determinant factor) and community level (higher level determinant factors).

Individual level determinant factors

- **Socio demographic determinant factors:-** Parents' educational status, gender of household head, number of under five children in the household, family size of the household, women's participation in household decisions, and household wealth status were the independent determinant factors of both household food insecurity and child nutritional status.
- **Child and maternal characteristics and care practice determinant factors: -** Gender of the child, age of the child, child immunization status, and child morbidity prior two weeks of the survey, place of delivery, antenatal care and postnatal care were included in this category as determinant factors of child nutritional status.
- **Diet related determinant factors: -** Maternal nutritional status, breastfeeding initiation time and complementary feeding initiation time, household food insecurity, and household dietary diversity were assessed as determinant factors of child nutritional status.
- **Agricultural related determinant factors:** - In this category, micro credit access, off farm income, irrigation practice, modern fertilizer use and improved seed use were assessed as determinant factors of household food insecurity.

Community level determinant factors:

Agroecosystem characteristics, all season transport access, land size in hectare, distance from the district market center, distance from a health center, latrine utilization, and proper household refuse disposal

practices are considered as community level determinant factors. In this study, land size, household refuse disposal practice and latrine utilization were measured at household level but considered as community level factors. A farmer who have no or limited land size but from areas with better land size have a chance of getting land through rental or other negotiation mechanisms to increase crop production. Similarly, households with poor latrine utilization and household refusal disposal practice have a negative influence on the neighborhood child nutritional status (193).

4.9. Operational definition

Operational definition and measurement of all variables used in this study are indicated in the table below.

Table 5:- Definition and measurement of variables used in the dissertation used to identify determinant factors of food insecurity and child undernutrition.

Variable	Definitions/Measurement of variable
Child undernutrition	Measured using the Z score of the Anthropometric measurements and categorized in to (0) normal (≥-2 SD); (1) undernourished (< -2 SD.
Household food insecurity	Measured using FANTA food access scale and classified as (1) food secure, (2) mild food insecure, (3) moderate food inmsecure (4) and severe food insecure.
Household food insecurity prevalence	Measured using FANTA food access scale and classified as (0) food secure, (1) food insecure (includes mild, moderate and severe food insecurity).
Household dietary diversity score	Measured using 12 food groups consumption in 24 hours prior to the survey and it ranges from 0 - 12 points using food group score.
Mother age at birth	Mother age at birth in years categorized in to (1) 15-19 years; (2); 20 - 29 years; (3) 30 -39 years; (4) 40 - 49 years.
Household head gender	Categorized in to (1) male; (2) female
Marital status	Categorized in to (1) in union; (2) not in union
Family size	Number of family members who lived for more than 6 months with the family and categorized in to two; less than five (1) and five and above (2).

Under five children	Number of under-five children that lived in the household and categorized one (1) and two and above (2).
Educational level of mother	Categorized in to (1) no formal education, (2) can read and write (3) have formal education
Educational level of father	Categorized in to (1) no formal education, (2) can read and write (3) have formal education.
Women participation in decisions	Categorized in to (0) No; (1) Yes
Household Wealth status	Categorized in to (1) lowest quintile; (2) second quintile; (3) third quintile; (4) fourth quintile; (5) highest quintile.
Child place of delivery	Categorized in to (1) home; (2) health institution
Child Immunization status	Categorized in to (0) not fully immunized; (2) fully immunized
Vitamin A supplementation	Categorized in to (0) No; (1) Yes
Child diarrhea illness	Categorized in to (0) No; (1) Yes
Time of breastfeeding initiation	Categorized in to (1) after 1 hour; (2) within an hour
Complementary feeding initiation	Categorized in to (1) recommended time (2) not recommended time
Mother MUAC	Categorized in to (1) < 23.5cm; (2) $\geq$ 23.5 cm
Antenatal Care (ANC)	Categorized in to (0) No; (1) Yes
Postnatal Care	Categorized in to (0) No; (1) Yes
Water source	Categorized in to (1) safe; (2) unsafe
Household level water treatment	Categorized in to (0) No; (1) Yes
Proper latrine utilization	Categorized in to (0) No; (1) Yes
Proper household refuse disposal	Categorized in to (1) disposal site; (2) any where
Land size in hectare per household	Categorized in to: (1) $\leq$ 1.13 hectare; (2) > 1.13 hectare using the mean as a cutoff point.
Having off farm income	Categorized in to (0) No; (1) Yes
Micro credit access	Categorized in to (0) No; (1) Yes
Improved seed use	Categorized in to (0) No; (1) Yes
Fertilizer use	Categorized in to (0) No; (1) Yes
Practicing irrigation scheme	Categorized in to (0) No; (1) Yes
Agroecosystem type	Categorized in to (1) Lowlands of Abay Valley; (2) Midland plains with black soil; (3) midland plain with brown soil (4) midland sloping

	lands with red soils (5) Hilly and mountainous highlands.
Distance from the health center	Measured in kilometer with walking distance and it refers to the distance between village center and health center.
Distance from the market center	Measured in kilometer with walking distance and it refers to the distance between village center and district main market center.
All season road access	Categorized in to (0) No; (1) Yes

4.10. Data Collection

Data were collected using local language translated interviewer (Amharic) administered questionnaire by trained data collectors. Socio demographic data were collected after reviewing similar literature on the topic and adapting from EDHS questionnaire. The socio-demographic variables like sex and age of the child, age of the mother, gender of the household head, religion and ethnicity of parents, educational status of parents, occupation of parents, number of household members, number of under five children in the household and women's participation in decision making on the household resources were collected.

To construct the wealth index as indicator of socio economic status of the community, data were collected on availability of different assets in the household like radio, TV, mobile phone, fixed phone, electricity, and housing condition like type of floor, type of roof, number of windows, separate house for livestock and separate sleeping room and the number of livestock in the household.

Maternal and child health service utilization and care practices data were collected using interviewer administered questionnaire. Child place of delivery, type of delivery, child immunization status using card or history, vitamin A supplementation, child morbidity status in the previous 2 weeks of the survey and child feeding practices data were collected. Maternal health care practices data like antenatal care and postnatal care service utilization were collected.

Also, data were collected on type of water sources; household level water treatment practices, hand washing practice after toilet, latrine availability and proper latrine utilization and proper household refuse disposal practices were assessed. Latrine utilization data were collected using WHO recommended proximate latrine utilization indicator observation checklist. Based on this recommended check list, proper latrine utilization was granted when there was a functional latrine near to the house, safe disposal of child feces into the latrine, no observable feces near to the house, presence of foot path to the latrine

not covered by grass and presence of fresh feces in the squatting hole of the latrine (194). Similarly, household refuse management practices data were collected using an observational checklist focusing on the presence of a pit near to the house to dispose refuses generated from the house.

Agricultural related data like presence of irrigation scheme access, household land size in hectare, micro credit access to the household, modern fertilizer use to increase crop production and improved seed use were collected using an interviewer administered questionnaire. Dietary diversity score data were assessed using Food and Nutrition Technical Assistance (FANTA) guideline version two developed in 2006 using 12 food groups on whether the food groups were consumed or not using 24 hours recall period were assessed (195). Also, household food insecurity access data were collected using Household Food Insecurity Access Scale (HFIAS) of Food and Nutrition Technical Assistance (FANTA) questionnaire developed in 2006 with a recall period of 30 days (3). The respondents were asked about the amount and variety of meals eaten, and the occurrence of food shortage causing them not to eat the whole day or eat at night only, in the past 30 days preceding the survey (3).

Anthropometric measurements of the child and mother data were collected during the survey. Pairs of data collectors were assigned to interview a mother with a child and take anthropometric measurements of children and the mother. A digital scale designed and manufactured under the guidance of UNICEF with 100 gram precision was used to measure body weight. Length/height measurements were taken using a locally produced UNICEF measuring board with a precision of 0.1 cm. Children below 24 months of age were measured in a recumbent position, while standing height was measured for those who were 24 months and older. The Mid Uper Arm Circumstance (MUAC) of the mother was measured on the left arm, at the midpoint between the elbow and the shoulder. Anthropometric measurements of weight and height of the child and MUAC, of the mother were taken twice. The variations between the two measurements of 100 grams were accepted as normal for weight and 0.1 cm in height/length of the children and MUAC of the mother. Finally, the two measure average results were recorded in the data collection questionnaire. However, repeated measurements were carried out upon significantly larger variations which were above 100 grams in weight and 0.1cm in height/length of the child or MUAC of the mother (6). Also, children were evaluated for the presence or absence of edema of the feet before taking child weight.

The Geo-reference coordinate's data were collected at household level using a handheld global positioning system (GPS). Household and child address /location/ GPS data were cross-linked with household food insecurity access prevalence and child undernutrition data using the Arc GIS 10 software (196). After completing the address and data cross-linked to the household with under-five children location, child undernutrition and household food insecurity were characterized using unique latitude and longitude location coordinates.

4.11. Data Quality Control

To assure the quality of the data, care was taken prior to data collection, during data collection, entry and analysis. The data were collected by diploma holder nurses and BSc graduate health officer supervisors after intensive training on the whole data collection process. Also, before the actual data collection, the research team carried out a role play practice on data collection procedures in the training room. Questionnaire understandability, interviewing techniques and all appropriate data collection procedures were tested in another near by community who assumed having similar characteristics during the training as a pretest. Then, all necessary corrections were considered based on the pretest findings before the actual research data collection.

To maintain consistency of measurements, efforts were made to minimize interpersonal and intrapersonal errors among the data collectors and supervisors. The data collectors took the measures of each child weight and height and mother Mid Upper Arm Circumference (MUAC) anthropometry twice independently and results were documented carefully. Then, the averages of the two measures were taken if the two measures difference was in the acceptable range. The weighting scales used to measure the anthropometric variables were calibrated each day prior to the actual data collection, using a 2 kilogram weighing material, before each measurement was taken.

At the end of every data collection day, filled questionnaires were examined for completeness and consistency by the supervisors and the principal investigator. Based on daily assessment of the filled questionnaire, pertinent feedbacks were given to the data collectors and supervisors. The filled questionnaire that missed most important pieces of data like sex, weight, height, and age of the child were not included in the analysis.

4.12. Data Management and Analysis

Data entry, coding and cleaning

Data were cleaned, coded and entered using EPI Info version 3.5 (197) and the necessary part of the data were exported to WHO Anthro 2010 (198), Excell microsoft, SPSS version 20 (199), SaTScan 9.4 (200), Arc GIS 10.1(201) and STATA version 14 (202) for further analysis. Child's age, sex, weight, length/height and oedema status (yes/no) with specific unique identifier were exported to WHO Anthro software. Anthropometric data were used to calculate the height for age Z score (HAZ), Weight for Height Z score (WHZ) and Weight for Age Z score (WAZ) using the WHO Anthro 2010 software (198) to determine children's nutritional status. The WHO anthro result was merged with the main data set using unique identifier to link children nutritional status with other background information for further analysis.

Descriptive statistics using frequency and summary measures like mean, minimum, maximum and outliers were used to clean the data before further analysis. Potential data-entry errors for age, weight, and length/height were checked using the presence of flagged data and either corrected after reviewing the questionnaire or excluded from the analysis. Data containing extreme (biologically unlikely) outliers with Z score (<-6 or >6) for all indices of child nutritional status indicators were excluded. Children whose height for age z (HAZ) score, weight for height Z (WHZ) score and weight for age Z score (WAZ) below minus two standard deviations (z- scores <-2SD) from the median of the reference population were considered as stunted, wasted and underweight (9), respectively.

The multilevel linear regression analysis was done after checking the nonexistence of outliers in the dependent variables and leverages in the independent variables using scatter plots. Outlier is an observation whose dependent variable value is unusual due to either data entry error or other problems. Leverage is a measure of how far an independent variable deviates from its mean and affects estimates of regression coefficients.

Presence of multicollinearity should be checked before running the regression analysis (203). In this study, the presence of multicollinearity was checked using variance inflation factor (VIF) before multivariable multilevel mixed effects regression analysis *(objectives III and IV).* The result indicated that multicollinearity was not a problem using VIF less than 10 as a cut of point (203).

In multilevel linear mixed effects regression analysis, the relationship between the determinant factors and the outcome variable should be linear to estimate the relationship between dependent and independent variables. If linearity is violated, all the estimates of the regression, including regression coefficients, standard errors, and tests of statistical significance may be biased. In this study *(objective IV)*, the assumptions of linearity was checked using scatter plots of standardized residuals against standardized predicted value. Statistical assumptions of normality tests were performed for continuous outcome variables (HAZ and WAZ) *(objective IV)* using graphical methods like the Q-Q plot and kurtosis statistical tests.

Principal Component Analysis

The index of wealth status, as a composite indicator of socio economic statu, was computed by the application of the principal component analysis (PCA). Intially, household asset data were prepared for analysis. Before the PCA, using frequency, important variables that can discriminate households were selected to reduce the number of variables. The binary variables were coded to 0 and 1 and categorical variable options were converted in to binary variables and dummy variable was created as 0 and 1. Missed values of both binary and contionous outcome variables were coded as 0. After data preparation, variables were standardized to change variables in to the same scale for comparision by subtracting the mean from each value and then dividing by the standard deviation. Once standarded, the variables have a mean of zero and standard deviation of 1.

A total of 17 variables were considered for wealth index construction. However, 11 variables were dropped as their communality scores were less than 50%. The rest six variables, including number of cattle in the household, having separate kitchen to prepare food, having corrugated iron sheet roof, presence of wooden or metal chairs in the household, presence of table in the house and modern light use in the household were considered for wealth index construction.

In PCA, the sum of the components with Eigen values greater than one should explain at least 60% of the total variance (204). And in the current study, the components explained 68.3% of the total variance, which was above the recommended minimum value (204). Wealth index values were calculated by summing up the scores for the four components. Finally, the index was developed by categorizing the sum of components in to five equal parts, and the parts were ranked from the poorest to the wealthiest quintile.

Spatial variation analysis

To investigate the spatial variations of household food insecurity *(objective I*) and child undernutrition *(objective II)*, the prevalence with 95% confidence interval (CI) at each agroecosystem were compared. In addition, SaTScan™ software version 9.4 (http://satscan.org/) using the Kulldorf method was used to identify the SaTScan clusters for food insecurity *(objective I)* and child undernutrition *(objective II)* (200). Spatial Scan statistical method is widely recommended that it performs very well in detecting local clusters and has higher power than other available spatial statistical methods (120). The discrete Bernoulli model was used to analyze the spatial SaTScan statistics since the number of food insecure households and child undernutrition in each location have Bernoulli distribution (200).

Spatial SaTScan statistics was used to explore the spatial variations of household food insecurity and child undernutrition. This method was used to identify significant spatial clusters of household food insecurity and child undernutrition at cluster (got) level. SaTScan software uses a circular window moved systematically throughout the study area to identify significant clusters of food insecure households and undernourished children. Cluster analysis was performed with the default maximum spatial cluster size of < 50% of the population and again with a smaller maximum cluster size of < 25% to look for possible sub clusters. Fifty percent was specified as the upper limit which allowed both small and large clusters to be detected and ignored clusters that contain more than 50% of the population (200).

The likelihood ratio (LLR) was used to test the hypothesis that there is elevated food insecurity and undernourished children inside the circular window compared to the distribution outside the circular window. The window sizes and locations with the maximum likelihood defined as the most likely cluster(s) (200). For the Bernoulli model the likelihood function was expressed as:

$$\left(\frac{c}{n}\right)^{c}\left(\frac{n-c}{n}\right)^{n-c} * \left(\frac{C-c}{N-n}\right)^{C-c} * \left(\frac{(N-n)-(C-c)}{N-n}\right)^{(N-n)-(C-c)}$$

where C was the total number of cases, c was the observed number of cases within the window, n was the total number of cases and controls within the window, while N was the combined total number of cases and controls in the data set (200). Monte Carlo replications of the dataset determined the distribution and P-value of the most likely primary and secondary clusters. The aim was to detect clusters of high food

insecurity and child undernutrition cases. The P-value was created using a combination of standard Monte Carlo, sequential Monte Carlo and Gumbel approximation and used 999 replications of Monte Carlo (200).

Multilevel Mixed Effects Regression

Given the hierarchical structure of the sampling procedure, presence of communal factors and neighborhood effects of some independent variables (205), determinant factors of household food insecurity *(objective III)* and child undernutrition *(objective IV)* were identified using two level mixed effects modeling which is the recommended method of analysis (72, 112, 206).

To evaluate the appropriateness of the multilevel mixed effects regression to the data set, a test was done whether the variances of the random part are different from zero over the clusters. The resulting estimates from the models were used to assess the intra class correlation (ICC) and a significant statistically different ICC from zero suggests appropriateness of multilevel mixed effects regression analysis (207). The ICC coefficient describes the proportion of variation that is attributable to the higher level source of variation (208). Also, the multilevel mixed effects regression model fitness statistics was checked using Deviance Information Criteria (DIC) and the lowest DIC value was considered for model construction.

To identify determinant factors of household food insecurity *(objective III)*, a two level mixed effects ordinal regression modeling was applied. Similarly, to identify determinant factors of child undernutrition *(objective IV)*, a two level mixed effects linear regression analysis was used. For both of the objectives, the analysis was done in four steps which indicates the level of heterogeneity and the role of individual and community level factors in reducing level of heterogeneity after adjusting in each step. The intercept only model (empty model) was constructed without determinant factors to check the application of multilevel analysis to the data set. In model two, only individual-level determinant factors were included and in model three, only community level determinant factors were included. The level of heterogienity was evaluated at each model. In the final full model, to control all potential confounders, both individual and community level determinant factors were included at the same time in the analysis. The results of the multilevel analysis were presented as fixed and random effects. The fixed effects were used to model values of the outcome variable, whereas the random effects were used to model the variance across clusters (209).

Fixed effects (Measures of association)

The fixed effects which mainly measures the association between the levels of food insecurity and determinant factors were shown as adjusted odd ratio (AOR) with 95% confidence intervals (CIs) and p value *(objective III).* Similarly, to measure the association between child undernutrition and determinant factors, the regression coefficients with standard deviation and p value were considered *(objective IV).*

Random effects (measures of variation)

Measures of random effects included intra-class correlation (ICC) and median odds ratio (MOR) (210). The dependent variable Y_{ij} depends on individual level explanatory variable X_{ij} and group level (community level) explanatory variable Z_j. If deviation from the average intercept and slope due to community level (level-2) effect are represented by u_{0j} and u_{1j}, respectively. The intercept γ_{00} and slopes γ_{01} and γ_{10} are fixed effects, whereas u_{oj} and u_{1j} are random effects of level two. The intercept only model (empty model) allows us to evaluate the extent of the cluster variation influencing food insecurity and child nutritional status. The intra class correlation coefficient (Rho) was calculated to evaluate whether the variation in the scores is primarily within or between clusters (210).

The intercept only model (empty model) for the four level ordinal outcome (food insecurity) variable was expressed as Logit $p_{ij} = \gamma_{00} + u_{0j} + \varepsilon_{ij,.}$ The full model (with both level one and level two factors) was stated as Logit $(p_{ij}) = \gamma_{00} + \gamma_{01}\ Zj + \gamma_{10}\ X_{ij} + u_{0j} + u_{1j}\ X_{ij} + \varepsilon_{ij}$. In logistic distribution, level one residual variance, ε_{ij}, was standardized and fixed with a mean of zero and variance of $\frac{\pi^2}{3}$ (3.29). Therefore, for a two level ordinal logistic random intercept model with an intercept variance of σ^2_{u0}, the intra class correlation coefficient (Rho) was mathematically given by $\rho = \frac{\delta^2_{uo}}{\delta^2_{uo}+\frac{\pi^2}{3}}$ (160).

The Median Odd Ratio (MOR) showed the unexplained heterogeneity between clusters which was used to translate the area level variance in the widely used odds ratio (OR) scale. The MOR quantified the variation between clusters (the second level variation) by comparing two persons from two randomly chosen, different clusters. Consider two persons with the same covariates, chosen randomly from two different clusters. The MOR is the median odds ratio between the person of higher propensity and the person of lower propensity (211). The MOR is very easy to calculate, because it is a simple function of

the cluster variance, σ^2. Mathematically, the median odds ratio is given: MOR = exp $\sqrt{2 * \sigma^2}$ * Φ^{-1} (0.75), where (·) is the cumulative distribution function of the normal distribution with mean 0 and variance 1, $\Phi^{-1}(0.75)$ is the 75th percentile, and exp (·) is the exponential function. The measure is always greater than or equal to 1. If the MOR is 1, there is no variation between clusters (no second level variation). If there is considerable between cluster variations, the MOR will be large. The measure is directly comparable with fixed-effects odds ratios (211).

Similarly, for the continuous outcome (child nutritional status), the intercept-only model was expressed as $p_{ij} = \gamma_{00} + u_{0j} + \varepsilon_{ij}$ and the full model (with both level one and level two factors) is stated as $p_{ij} = \gamma_{00} + \gamma_{01} Zj + \gamma_{10} X_{ij} + u_{0j} + u_{1j} X_{ij} + \varepsilon_{ij}$. For the continuous outcome variable (child nutritional status), the intra-class correlation coefficient (Rho) was calculated by the ratio of the between cluster variance as level two variance (σ^2_{u0}) to the total variance which was the sum of level one variance ($\sigma^2_{\epsilon ij}$) and level two variance (σ^2_{u0}) (212). Mathematically, it can be expressed as: $\rho = \frac{\delta^2_{u0}}{\delta^2_{u0} + \delta^2_{\epsilon ij}}$.

The ICC commonly takes values between zero and one: the nearer the ICC is to one, the larger the variability between clusters. To interpret the degree of variability, the following ICC values of ICC < 0.1, 0.1–0.199, 0.2–0.299 and $\geq$ 0.3 as cut-off points were used to indicate low, moderately low, moderately high and high clustering, respectively (115, 213).

The proportion change in variance (PCV) in multilevel analysis refers to the percentage of variation in the prevalence of food insecurity and child undernutrition attributable to a particular level in the multilevel analysis (209). Mathematically, the proportion change in variance is given as: proportional change in variance (PVC), $\frac{V_A - V_B}{V_A}$ *100%, where V_A is variance of the initial model without any explanatory variable (empty model) and V_B is the variance of the model with determinant factors (211) i.e. model two with individual level determinant factors, model three with community level factors and model four (full model) with both individual and community level determinant factors.

4.13. Summary of the methods for each specific objective

Table 6:- Summary of the methods used in the dissertation to address each specific objective

No	Objective	Design	population	Sample size	Data collection tool	Data analysis
1	Spatial variations of household food security	Comparative Cross sectional survey	Household with a child	2405	Face to face interview using a questionnaire, geographical data using GPS	Spatial analysis using SaTScan statistics
2	Spatial variations of child undernutrition	Comparative Cross sectional survey	Children (6 -59 months)	3225	Face to face interview using questionnaires, anthropometric measurement and geographical data using GPS data	Spatial analysis using SaTScan statistics
3	Associated factors of house hold food insecurity	Cross sectional survey	Household with a child	2013	Face to face interview using questionnaires and observational checklist.	Multilevel Mixed Effects Ordinal Regression Analysis
4	Associated factors of child nutritional status	Cross sectional survey	Children (6 -59 months)	2647	Face to face interview using questionnaires, anthropometric measurement and observational checklist.	Multilevel Mixed effects Linear Regression Analysis

4.14. Ethical Considerations

To conduct the current study, authorization was secured from different legitimate organizations. Initially, ethical clearance was sought from the Addis Ababa University Institutional Review Board of the College of Health Sciences, Ethics and Research Committee of the School of Public Health. Also, permission letters were obtained from the Amhara Regional Health Bureau, East Gojjam Zone Health Office and from the study districts health bureaus.

Participants of the study were engaged on a voluntary basis and ethical informed oral consent for the adults and assent for children were sought from study participants to confirm their willingness after detailed explanations were provided on the possible benefits and risks in participating in the survey.

Confidentiality of research data were assured to the study participants and codes were used during data processing instead of name of the study participants. The study participants were also assured that the original data will be locked in cabinets after the data analysis carried out and the information will not be used for any purpose, other than what the participants consented for.

The research participants were assured that the research project does not have any kind of physical harm, social discrimination, psychological trauma and economic loss risks. Also, study participants were informed that the research process has not any form of inducement, coercion and the study does not bring any risks that incur compensation.

Maximum efforts were made to increase the beneficence aspect of the study participants during data collection. At the end of each interview, women/care givers received advice to improve child nutritional status. Children found sick during data collection period were urged to seek care in the nearby health facility. Also, in areas where there was health problems, health extension workers and district health offices were communicated to take actions to reverse the problem.

5. Results

From a total of 3225 sample population, 3108 interviewed participants (response rate 96.4%) were included in the analysis. Of the total respondents, 616 (19.8%), 629 (20.2%), 631 (20.3%), 623 (20%) and 609 (19.6%) were from the lowlands of Abay Valley, midlands plains with black soil, midland plains with brown soil, midland sloping lands with red soil and hilly and mountainous highland agroecosystems, respectively.

5.1. Socio-Demographic Characteristics

As indicated in table 7 below, the great majority (91.7%) of household heads' were males, married (90%), Orthodox Christians (99.6%) and Amhara (99.8%). The study indicated, 2492 (80.2%) of the women and 1490 (47.9%) of men did not attend formal education. The majority of the children's mothers (91.9%) and fathers (93.1%) were farmers in their occupation. In the study, 2593 (83.4%) households had only one child and 1589 (51.1%) have a family size of less than five. In the study, in 2683 (86.3%) households, women had participated in deciding on household resources.

Table 7:- Socio demographic characteristics of study participants in East Gojjam Zone, Amhara Region, Ethiopia, 2015.

Variables	Category	Frequency	Percentage
Household head gender	Male	2851	91.7
	Female	257	8.3
Mother marital status	Married	2823	90.0
	Divorced	187	6.0
	Separated	67	2.2
	Widowed	31	1.0
Religion	Orthodox	3096	99.6
	Other*	12	0.4
Ethnicity	Amhara	3102	99.8
	Other**	6	0.1

Father Education	No formal education	1490	47.9
	Only can read and write	1202	38.7
	Have formal education	416	13.4
Mother education	No formal education	2492	80.2
	Only can read and write	304	9.8
	Have formal education	312	10.0
Mother occupation	Farmer	2856	91.9
	House wife	99	3.2
	Merchant	77	2.48
	Daily Laborer	36	1.2
	Employed	16	0.5
	Other***	24	0.8
Father occupation	Farmer	2895	93
	Merchant	86	2.8
	Daily Laborer	58	1.9
	Employed	45	1.4
	Other***	24	0.8
Average family size	< 5 members	1589	51.1
	≥ 5 members	1519	48.9
Number of under five children	One	2593	83.4
	Two and above	515	16.6
Women participation in decision making	Yes	2683	86.3
	No	425	13.7

* Protestant and Muslim, **Tigrie and Oromo, *** have no job

In the study, 1543 (49.65%) were female children. When we observe the age distribution of children (6-59 months), almost more than one fourth of children were in the age range of 12 – 23 months. The age distribution of children is indicated in figure four below (Figure 4).

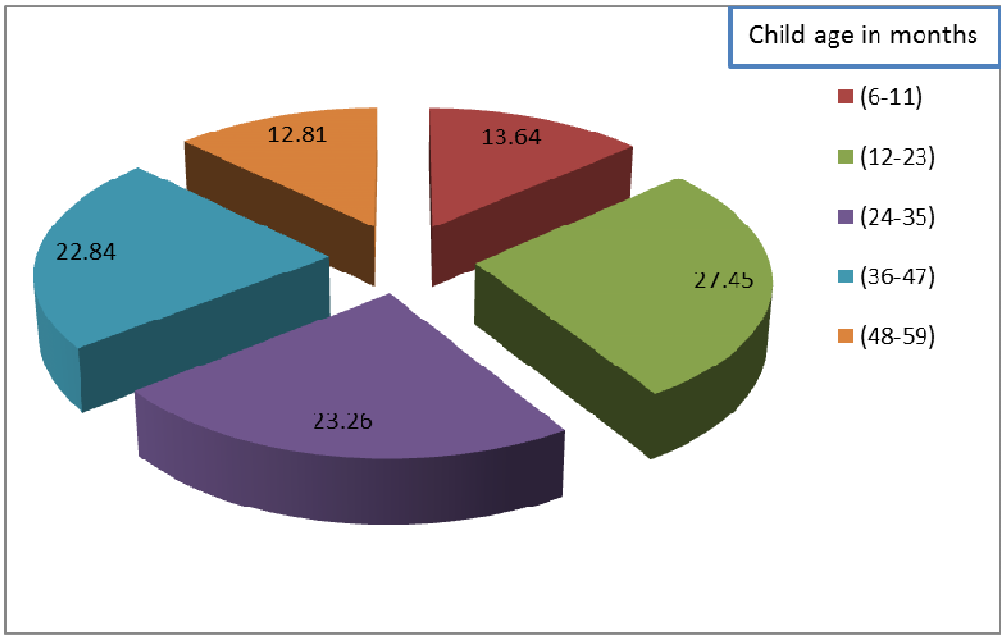


Figure 4:- Age distribution of under-five children (6 - 59 months) in East Gojjam Zone, Ethiopia, 2015.

5.2. Prevalence of household food insecurity

A total of 65.3% (95% CI: 63.5, 67.00) households were found to be food insecure. Of the total study participants, 38.1 % (95% CI: 36.4, 39.7), 23.1% (95% CI: 21.6 - 24.6) and 4.1% (95% CI: 3.3, 4.8) were mildly, moderately and severely food insecure households, respectively.

The study showed that 76.1% (95% CI: 74.5, 77.5) of the households had feelings of uncertainty and anxiety about household food supply prior to 30 days of the survey (Table 8). Similarly, 53.7% (95% CI: 52.0, 55.5) of the respondents perceived that household food supply was insufficient quality and not in a preferred type of food in the last 30 days of the survey. In more

severe conditions, people start to reduce the quantity of food where 26.8% (95% CI: 25.3, 28.4) of the households were taking insufficient quantity of food 30 days prior to the survey.

5.3. Spatial variations of food insecurity

The spatial variations in the domains of household food insecurity were observed based on agroecosystem characteristics in the last 30 days of the survey. The highest prevalence of anxiety/uncertainty in the household food supply 30 days prior to the survey was reported from hilly and mountainous highlands (88.7%, 95% CI: 86.2, 91.2). Also, the highest prevalence of insufficient quantity of food supply 30 days prior to the survey was observed from hilly and mountainous highlands (41.8%, 95% CI: 37.88, 45.71). On the other hand, the highest prevalence of insufficient food quality supply 30 days prior to the survey (57.6%, 95% CI: 53.7, 61.5) was observed from Abay Valley lowlands (Table 8).

Table 8:- Household food insecurity access domains at different agroecosystems in East Gojjam Zone, Amhara Region, Ethiopia, 2015.

Agroecosystem type	Anxiety and Uncertainty	Insufficient Quality	Insufficient Quantity
Abay valley lowland plains	81.8 (78.75,84.85)	57.6 (53.70, 61.50)	20.8 (17.60,24.01)
Midland plain with black soil	67.2 (63.53, 70.87)	47 (43.10, 50.90)	24.2 (20.85,27.55)
Midland plain with brown soil	71.9 (68.40, 75.40)	47 (43.10,50.89)	20.7 (17.54, 23.86)
Midland sloping land with red soil	71.0 (67.44, 74.56)	53 (49.00,56.90)	26.9 (23.40,30.40)
Hilly and mountainous plains	88.7 (86.20, 91.20)	54 (50.00, 57.96)	41.8 (37.88,45.71)
Total sample	76.1 (74.5, 77.5)	53.7 (52.0, 55.5)	26.8 (25.3, 28.4)

As indicated in the figure below, the overall prevalence of food insecurity showed an agroecosystem based spatial variations; where the highest prevalence (70.6%, 95% CI: 66.9, 74.2) was observed from the Abay Valley lowlands (Agroecosystem 1) 30 days prior to the survey. The next highest prevalence of food insecurity (69.8%, 95% CI: 65.9, 73.3) was reported from hilly and mountainous highlands (Agroecosystem 5). There was no statistical significant variation between midland sloping land with red soil (Agroecosystem 4) (61.7%, 95% CI: 58.1, 65.6), midland plains with brown soil (Agroecoystem 3) (63.5%, 95% CI: 59.9, 65.0) and midland plains with black soil (Agroecosystem 2) (61.5%, 95% CI: 57.4, 65.3) agroecosystems.

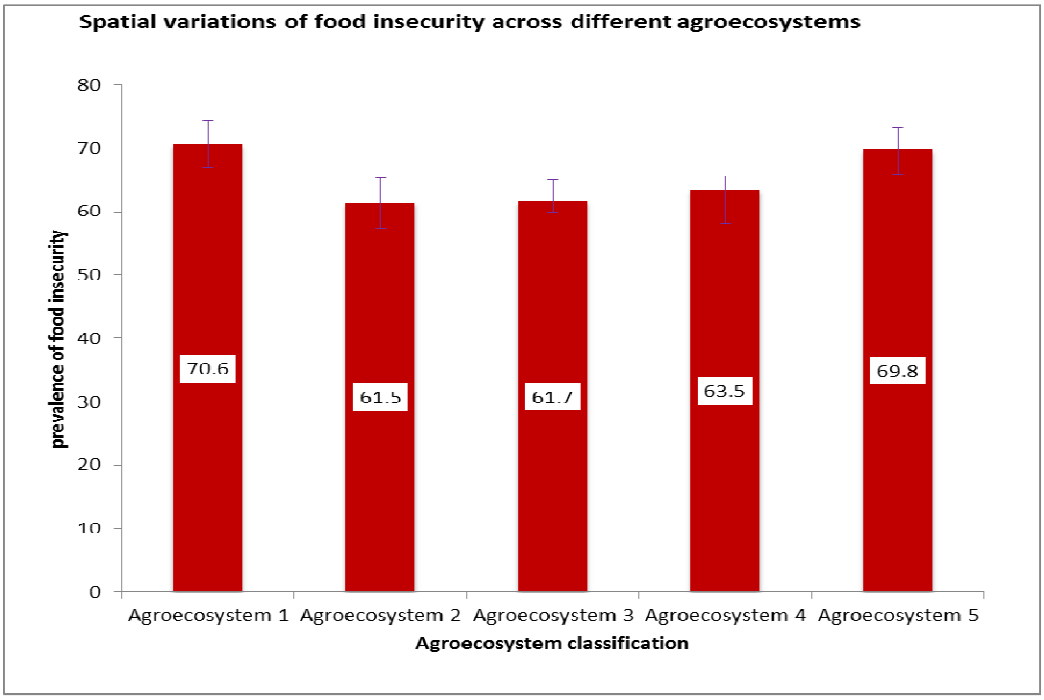


Figure 5:- Spatial variations of household food insecurity across different agroecosystems in East Gojjam Zone, Amhara Regional state, Ethiopia, 2015.

Also, spatial variations were observed in the levels of food insecurity as indicated in figure six below. The highest prevalence of severe food insecurity was observed from hilly and mountainous highland plains (6.9%). Similarly, the highest moderate food insecurity prevalence was observed from hilly and mountainous highland plains (34.81%). The highest mild food insecurity prevalence was observed from Abay Valley lowland plains (Figure 6).

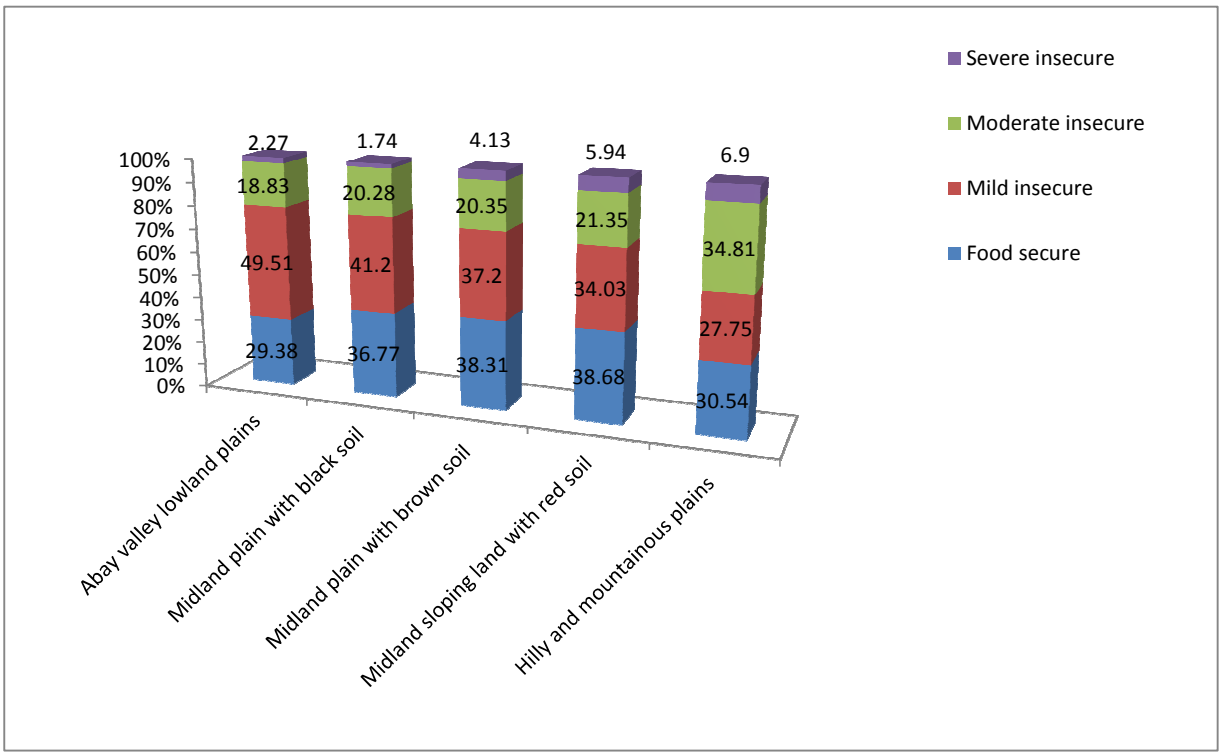


Figure 6:- Household food insecurity levels distribution by agroecosystem characteristics in East Gojjam Zone, Ethiopia, 2015.

As indicated in table 9 below, the SaTScan cluster analysis showed that the most likely primary cluster with the maximum LLR of 11.64 (P<0.01) with geographical location of 10.573N, 37.817E and a radius of 3.53km were found from hilly and mountainous highlands. Also, there were significant secondary most likely clusters detected from the lowlands of the Abay Valley with LLR of 8.218 (p<0.05). Table 9 below summarizes the most likely clusters with their LLR with probability value.

Table 9:- SaTScan analysis of household food insecurity in East Gojjam Zone, Amhara Region, Ethiopia, 2015.

	Cluster location	Coordinate/radius	LLR	P value
1	Hilly and mountionous highlands	(10.573N,37.817E)/3.53km	11.64	0.0088
2	Lowlands of Abay Valley	(10.159N, 38.254E)/1.73km	8.218	0.025
2	Lowlands of Abay Valley	(10.109N, 38.146E)/3.21km	5.983	0.898
2	Midland slopping plains with red soil	(10.321N,37.579E)/0.42km	5.973	0.958
2	Hilly and mountionous highlands	(10.629N, 37.753E)/0.41km	5.545	0.993
2	Midland plain with brown sol	(10.330N, 37.372E)/0.49km	5.545	0.993
2	Midland plains with black soil	(10.237N,38.019E)/0.75km	5.517	0.993
2	Lowlands of Abay Valley	(10.152N, 38.110E)/0.33km	5.198	0.995

AES1:- lowlands of Abay valley, AES2:- Midland plains with black soil, AES3:- Midland plains with brown soil AES4:- Midland sloping land with red soil, AES5:- Hilly and mountainous areas.

As indicated in figure 7 below, a cluster with the maximum LLR (11.64) as the most likely primary cluster colored with red was found from hilly and mountainous highland areas. In addition, there were secondary clusters in the study area. The most likely secondary cluster with the second maximum LLR (8.22) shaded with orange color was found from the lowlands of Abay Valley.

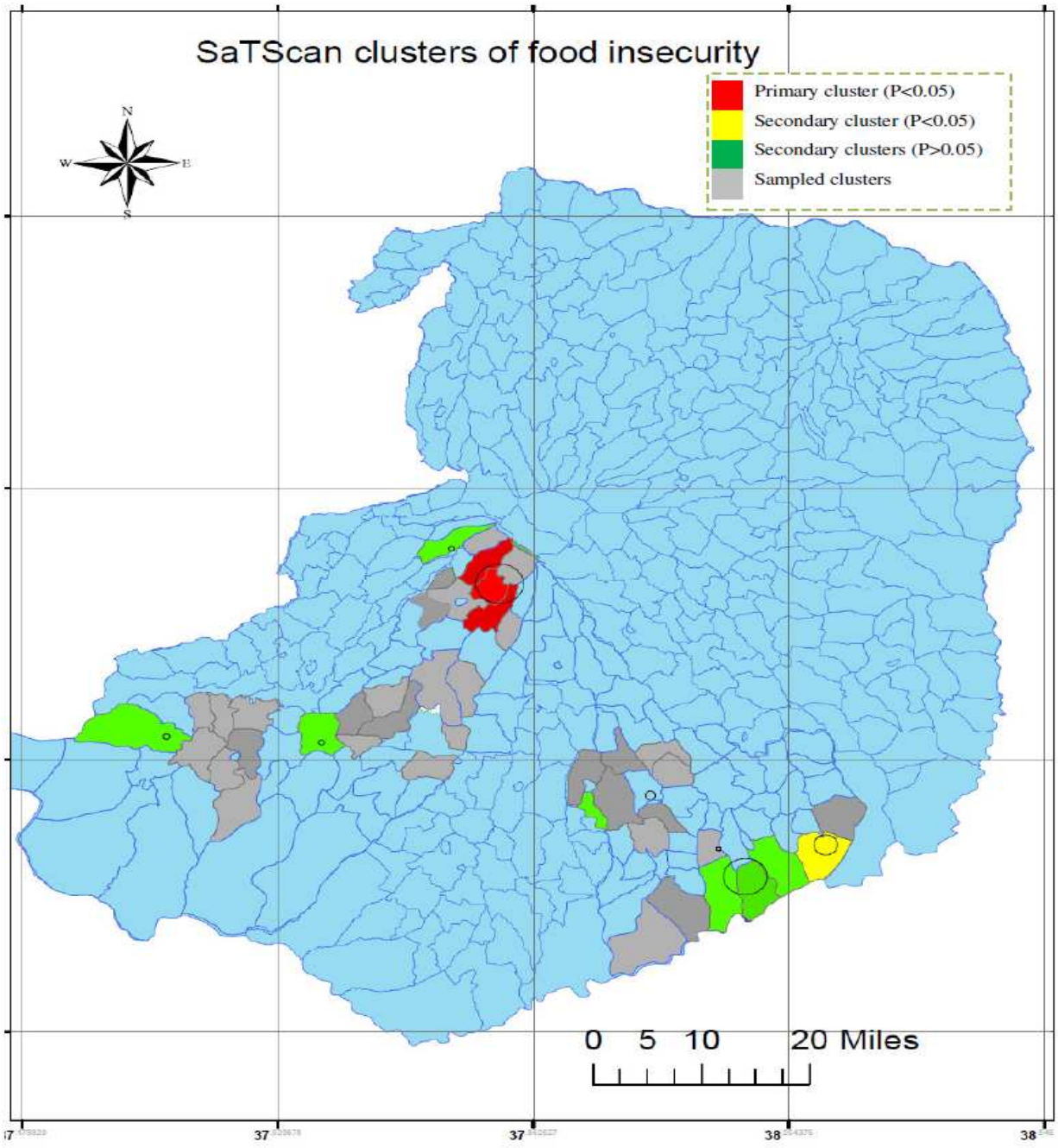


Figure 7:- Map on SaTScan spatial analysis results of household food insecurity in East Gojjam Zone, Amhara Region, Ethiopia, 2015.

5.4. Factors associated with food insecurity

As indicated in table 10 below, the intercept only model (empty model) of the multilevel mixed effects ordinal logistic regression analysis indicated that, of the total variance across the clusters, 4.4% (p<0.001) of the variance was attributable to cluster level. In model two, after adjusting for level one (individual level) determinant factors, the variance attributable to cluster level was reduced to 3.8% (P<0.001). Similarly, after adjusting for level two determinant factors in model three, the variance attributable to cluster level was again reduced to 1.8%(P<0.001). In the final full model, after adjusting for both individual and community level determinant factors at the same time, 1.5% (p<0.001) of the variance were attributable to the cluster level.

As determined by the percentage change of the variance, the full model accounts for about 66.7% of the odds of food insecurity across the clusters. The results of the median odds ratio (MOR) confirmed evidence of cluster level dependent phenomena in determining food insecurity. The MOR for food insecurity was 1.22 in the intercept only model (empty model) and reduced to 1.09 when adjusted to both individual and community level determinant factors in the full model.

Table 10:- Random effects parameters from multilevel ordinal mixed effects model on determinant factors of household food insecurity in East Gojjam Zone, Amhara Region, Ethiopia, 2015.

.Measure of variation	Model 1[a]	P value	Model 2[b]	P value	Model 3[c]	P value	Model 4[d]	P value
Level 2 variance	0.15	P<0.001	0.11	P<0.001	0.08	P<0.001	0.05	P<0.001
ICC (%)	4.4%		3.8%		1.8%		1.5%	
Explained variation	Reference		26.7%		46.77%		66.7%	
Median Odds Ratio (MOR)	1.22		1.18		1.12		1.09	
Model fit statistics								
DIC (-2loglikelihood)	3712		3648		3696		3640	

ICC, intra-cluster correlation, MOR, median odds ratio, DIC deviation information criteria: model 1[a] is the empty model, a baseline model without determinant variable. Model 2[b].is adjusted for individual level factors. Model 3[c] is adjusted for community level factors. Mode4[d] is the final model adjusted for both individual and community level factors.

After adjusting in the final full model for individual and community level determinant factors, household head gender, husband educational status, women's participation in decisions on household resources, having an additional income source, better crop production in the survey year and application of chemical fertilizer on the farm land showed a statistical significant association with the severity of household food insecurity (Table 11).

From community level determinant factors, agroecosystem characteristic was one of the significant determinant factors of household food insecurity. Households from hilly and mountainous highlands had 3.94 (AOR: 95% CI: 2.01, 7.71) higher odds to have a more severe food insecurity compared to households from midland plain area households. Also, households from the lowlands of Abay Valley had 2.11 (AOR: 95% CI: 1.31, 3.39) higher odds to have more severe food insecurity compared to households from midland area households.

In the study, other individual and community level determinant factors determined severity of household food insecurity status. Households headed by females had 1.72 (AOR: 95% CI: 1.24, 2.39) higher odds to have a more severe food insecurity compared to male headed households. Child father in the households with formal education had 23 % (AOR: 0.77, 95% CI: 0.62, 0.96) lower odds to have a more severe food insecurity compared to households with child father who have no formal education. Similarly, households with men who can only read and write had 15 % (AOR: 0.85, 95% CI: 0.73, 0.98) lower odds to have a more severe food insecurity compared to households with men who have no formal education. Households with women who did not participate in household decisions had 1.65 (AOR: 95% CI: 1.36, 2.00) higher odds to have a more severe food insecurity compared to households with women who participated in household decisions.

In the current study, having additional income source, chemical fertilizer use and better crop production per year have significant statistical association with the severity of food insecurity. Households with no additional income source had 1.40 (AOR: 95% CI: 1.14, 1.73) higher odds to have more severe food insecurity status compared to households with additional income source. Households that did not use chemical fertilizer to increase crop production in the survey year had 1.33 (AOR: 95% CI: 1.10, 1.62) higher odds to have a more severe food insecurity status compared to households used chemical fertilizer to improve crop productivity. Households

with 1700kg and above crop production in the survey year had 35% (AOR: 0.65, 95% CI: 0.55, 0.77) lower odds to have a more severe food insecurity compared to households with crop production less than 1700kg. In this study from lower level factors, mother educational status, household wealth status, micro credit access, improved seed use in the survey year and irrigation access to the farm land did not show a statistical significant association with household food insecurity at 5% level of statistical significance.

Similarly, from community level factors, household's land size in hectare has a significant association with the severity of household food insecurity. Households having above 1.13 hectare farm land size had 25% (AOR: 75, 95% CI: 0.63, 0.90) lower odds to have a more severe food insecurity status compared to households having a land size of 1.13 hectares and below. Other community level factors, including all season transport access to the district market center and average distance from the district main market center did not show a statistical significant association with the severity of household food insecurity status at the 5% level of significance (Table 11).

Table 11:- Factors associated with household food insecurity using multilevel mixed effects ordinal regression analysis in East Gojjam Zone, Amhara Region, Ethiopia, 2015.

Variables	Model 2[b], AOR(95 % CI)	Model 3[c], AOR(95 % CI)	Model 4[d], , AOR(95 % CI)
Individual level factors			
Household head sex			
Male	1		1
Female	1.68 (1.21, 2.34)		1.72 (1.24, 2.39)
Marital status			
In union	1		1
Not in union	0.70 (0.49, 1.00)		0.70 (0.50,1.01)
Mother Education			
No formal education	1		1
Can read aand write	0.90 (0.72, 1.13)		0.93 (0.74, 1.17)
Have formal education	0.82 (0.65, 1.04)		0.84 (0.67, 1.08)
Father Education			
No formal education	1		1
Can read aand write	0.85 (0.74, 0.98)		0.85 (0.73, 0.98)
Have formal education	0.77 (0.62, 0.96)		0.77 (0.62,0.96)
Women participation in decisions			
No	1.71 (1.41, 2.08)		1.65 (1.36, 2.00)
Yes	1		1
Wealth status			
Poorest	1		1
Poorer	0.98 (0.79, 1.23)		0.99 (0.78,1.25)
Middle	1.11 (0.87, 1.41)		1.10 (0.86,1.40)
Richer	1.01 (0.77, 1.31)		1.03 (0.79, 1.34)

Richest	0.90 (0.75, 1.08)		0.89 (0.74, 1.07)
Additional income source			
No	1.41 (1.15, 1.73)		1.40 (1.14, 1.73)
Yes	1		1
Micro credit access			
No	0.97 (0.82, 1.14)		1.06 (0.90, 1.25)
Yes	1		1
Improved seed use			
No	0.96 (0.81, 1.13)		0.92 (0.77, 1.09)
Yes	1		1
Chemical fertilizer use			
No	1.43 (1.18, 1.73)		1.33 (1.11, 1.62)
Yes	1		1
Irrigation scheme access			
No	1.04 (0.85, 1.27)		1.10 (0.90, 1.35)
Yes	1		1
Average crop production per household			
< 1700kg	1		1
≥ 1700kg	0.60 (0.51,0.71)		0.65 (0.55, 0.77)
Community level factors			
Agroecosystem type			
Lowlands of Abay Valley		4.60 (2.36, 8.99)	3.94 (2.01, 7.71)
Hilly and mountainous highlands		2.38 (1.49, 3.78)	2.11 (1.31, 3.39)
Midland plain areas		1	1
Distance from district market center			
≤ 12.4km		1	
>12.4 km		0.69 (0.39,1.22)	0.68 (0.39, 1.20)
All season transport access			

No	1	
Yes	1.41 (0.90, 2.19)	1.38 (0.89, 2.14)
Land size in hectare per household		
≤ 1.13 hectare	1	
> 1.13 hectare	0.69 (0.58, 0.82)	0.75 (0.63, 0.90)

Model 2[b].is adjusted for individual level factors. Model 3[c] is adjusted for community level factors. Mode4[d] is the final model adjusted for both individual and community level factors.

5.5. Prevalence of child undernutrition

The overall prevalence of childhood stunting, underweight and wasting were 39.0% (37.32, 40.75), 18.7% (17.32, 20.0) and 12.22% (11.12, 13.42), respectively (Table 12). For all indices of child nutritional status, higher prevalence was observed among males compared to females. As indicated in table 12 below, the prevalence of childhood wasting, underweight and stunting among male children were 14.4%, 21.2% and 41.7%, respectively. Whereas, the prevalence of wasting, underweight and stunting among female children were 10.1%, 16.2% and 36.4%, respectively.

The prevalence of child wasting increased with age up to 24 - 35 months and then declined (Table 12). Children with an age range of 24 - 35 months were with the highest prevalence (15.8%) and children age ranges with 6 - 11 months were with the lowest prevalence (7.2%) of childhood wasting. Child stunting and underweight increased as the age of the child increased (Table 12). The maximum child stunting was observed in the age range of 48 - 59 months (63.8%) and the minimum was from age range of 6 -11 months (21.9%) (Table 12). Similarly, the highest (32.2%) and lowest (8.1%) prevalence of childhood underweight were observed in the age ranges of 48 - 59 months and 6 -11 months, respectively.

Table 12:- Under five children undernutrition prevalence distribution by sex and age in East Gojjam Zone, Amhara Regional State, Ethiopia, 2015.

	Weight-for-length/height (%)	Length/height-for-age (%)	Weight-for-age (%)
Variable	% < -2SD (95% CI)	% < -2SD (95% CI)	% < -2 SD (95% CI)
(6-11)	7.2 (4.4, 11.4)	21.9 (12.9, 34.7)	8.1 (4.5, 14.3)
(12-23)	13 (9.3, 17.8)	33.2 (28.1, 38.8)	12.7(9.4%, 17)
(24-35)	15.8 (11.8, 20.9)	35.8 (30.5, 41.5)	20.1 (13.6, 28.8)
(36-47)	11.7 (7.8, 17.4)	47.2 (39.7, 54.9)	23.8(15.6, 34.5)
(48-59)	11.6 (8.5, 15.7)	63.8 (51.3, 74.7)	32.2 (24.3, 41.2)
Male	14.4 (11.1, 18.4)	41.7 (36.5, 47.1)	21.2 (15.4,28.4)
Female	10.1 (6.1, 16.4)	36.4 (32.4,40.9)	16.2 (10.9, 23.2)
Overall	12.22 (8.9, 16.6)	39.0 (35.1, 43.1)	18.7 (13.5, 25.3)

5.6. Spatial variations of child undernutrition

As indicated in figure 8 below, the highest prevalence of child wasting was observed from hilly and mountainous highlands (Agroecosystem 5) (15.9%) compared to midland sloping lands with red soil (Agroecosystem 4) (8.3%) and midland sloping land with red soils (Agroecosystem 3) (10.6%). Midland plains with black soil (Agroecosystem 2) (11.6) did not show any statistical significant difference in child wasting compared to hilly and mountainous highlands.

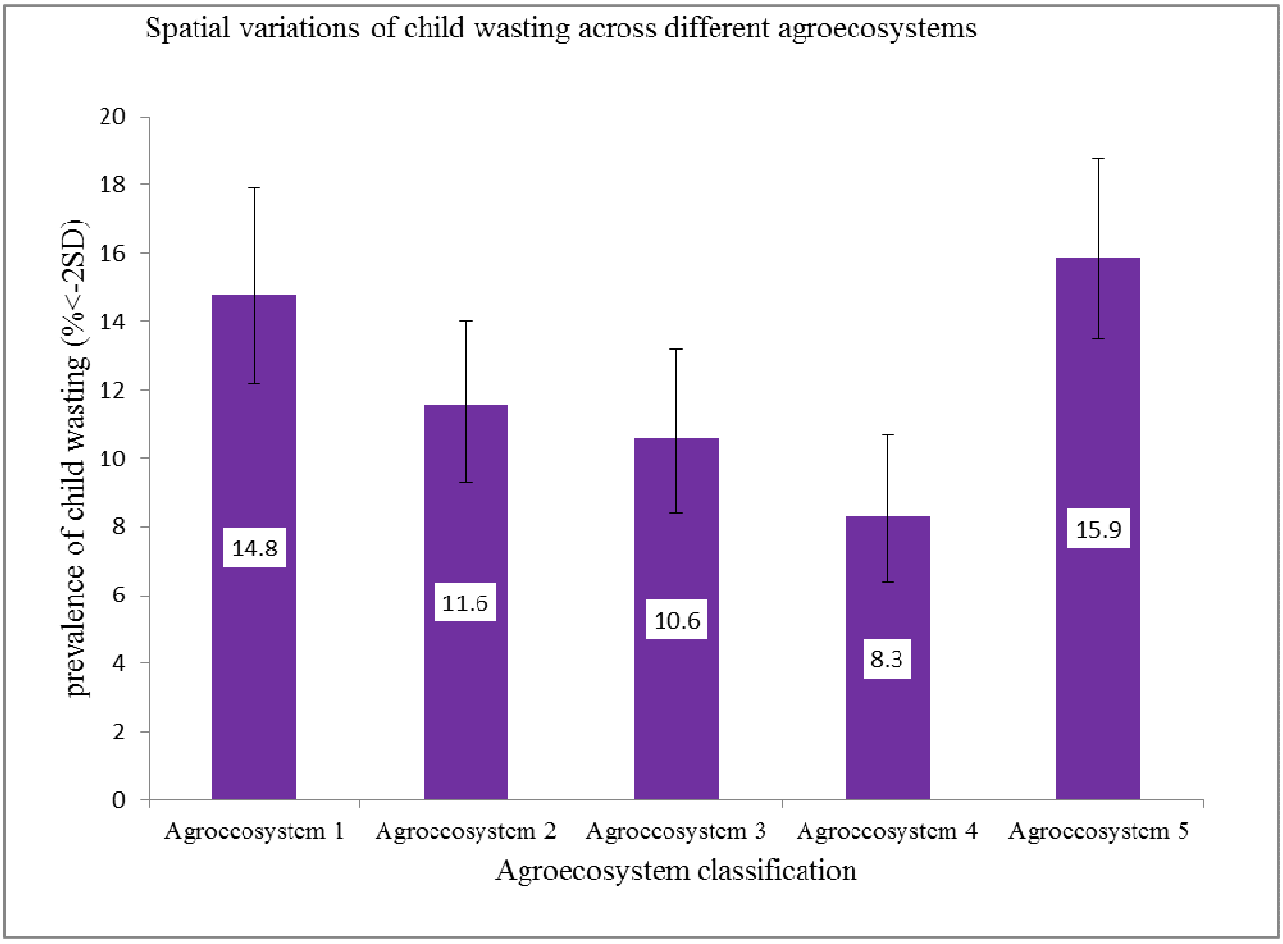


Figure 8:- Spatial variations of child wasting across different agroecosystem in East Gojjam Zone, Amhara Regional State, Ethiopia, 2015.

The highest prevalence of childhood underweight was reported from the lowlands of the Abay Valley (Agroecsosyetem 1) (22.9%) and midland plains with black soil (Agroecosystem 2) (22.3%) compared to midland sloping lands with red soil (Agroecosystem 4) (15.2%) and midland plains with brown soil (Agroecosysstem 3) (12.2%). There was no statistical significance difference between hilly and mountainous highlands compared to the lowlands of the Abay Valley (22.9%) and midland plains with black soil (22.3%) agroecosystems in childhood underweight (Figure 9).

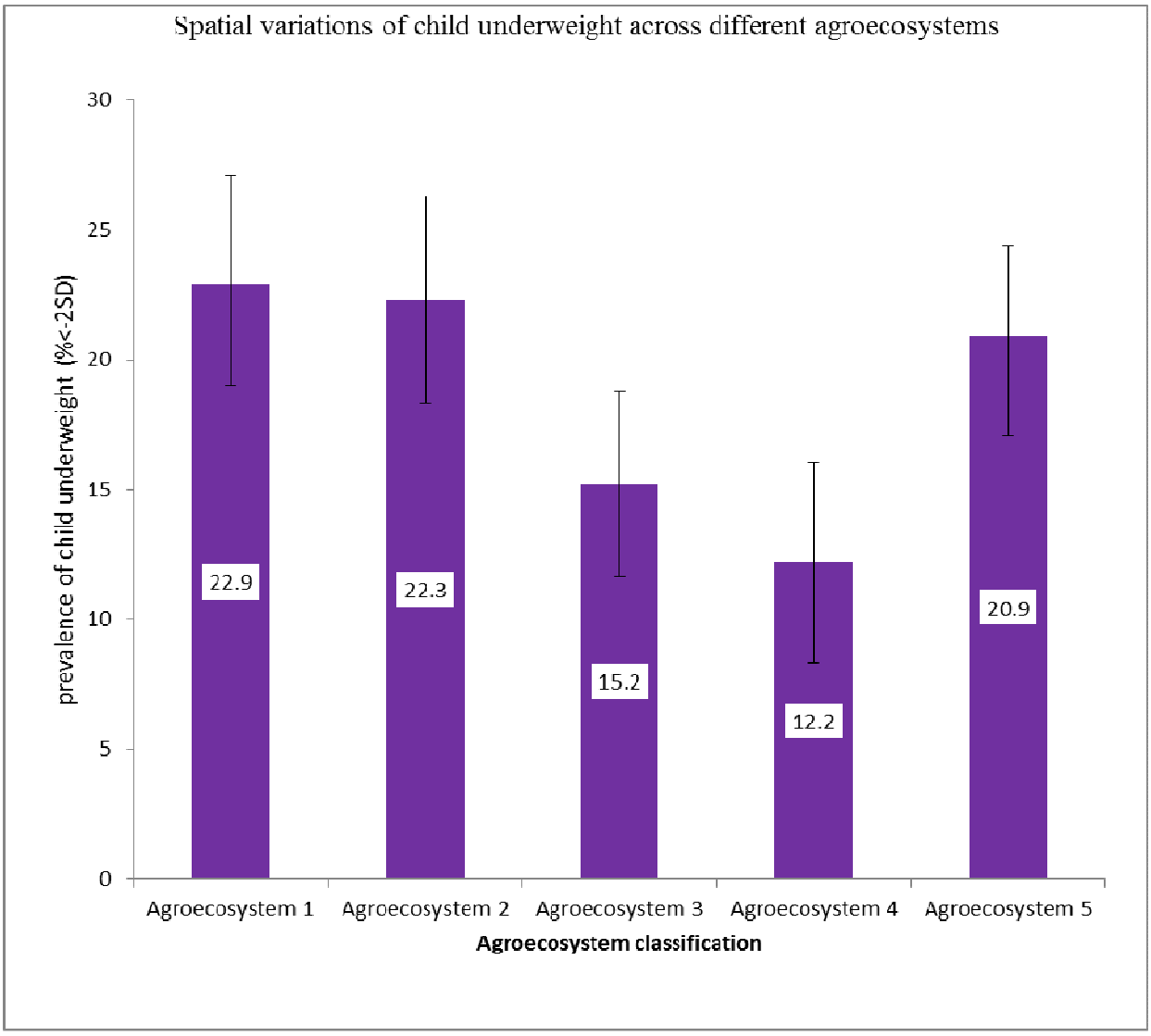


Figure 9:-Spatial variations of child underweight across different agroecosystem in East Gojjam Zone, Amhara Regional State, Ethiopia, 2015.

As indicated in figure 10 below, the highest prevalence of childhood stunting was observed in the lowlands of the Abay Valley (Agroecosystem 1) (42.2%) and the second highest prevalence was from the hilly and mountainous highlands (Agroecosystem 5) (41.1%). The lowest prevalence of childhood stunting was observed from midland sloping land with red soils (Agroecosytem 4) (33.9%) and the second lowest was from midland plain with brown soil (Agroecosystem 3) (38.5%).

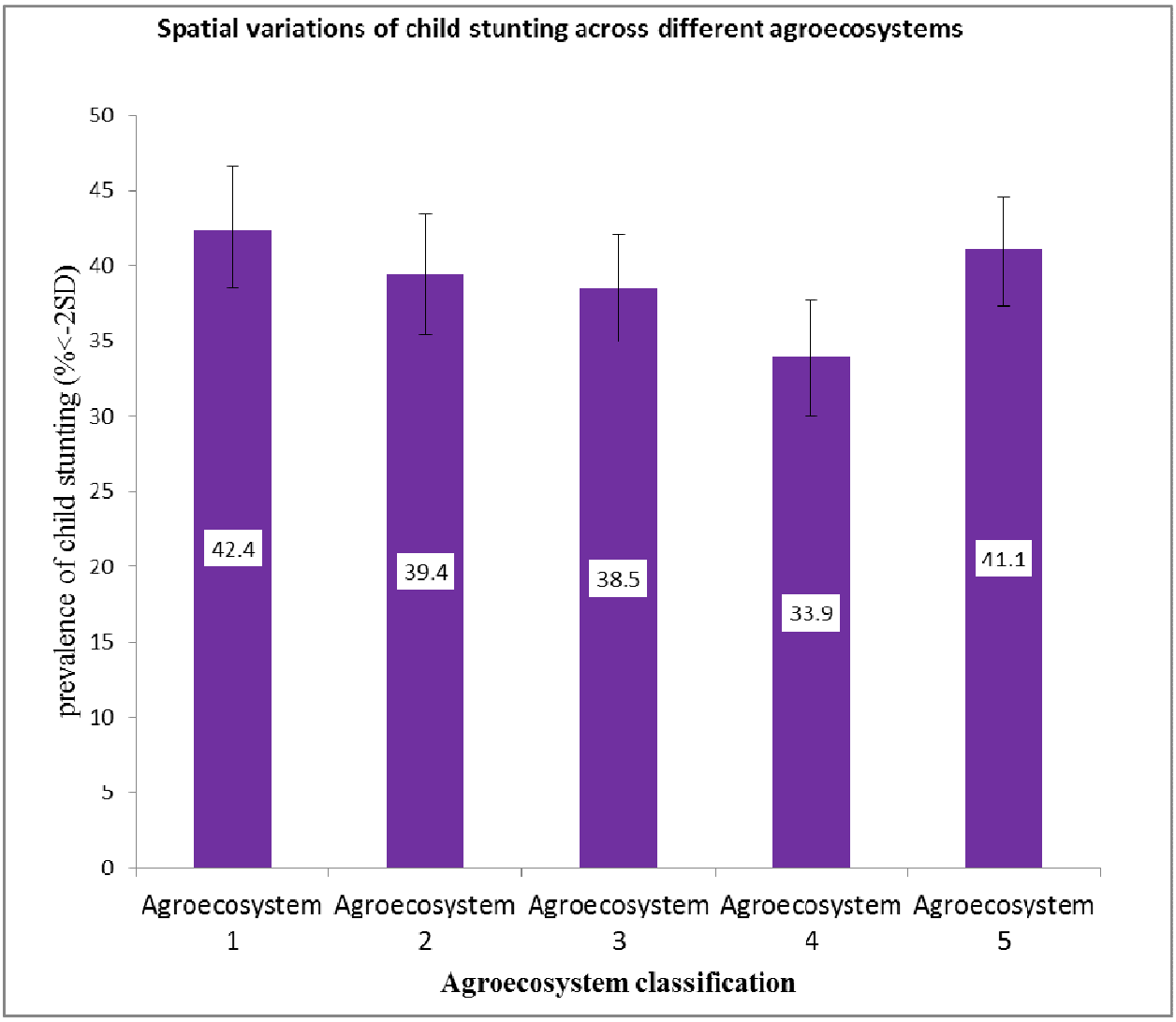


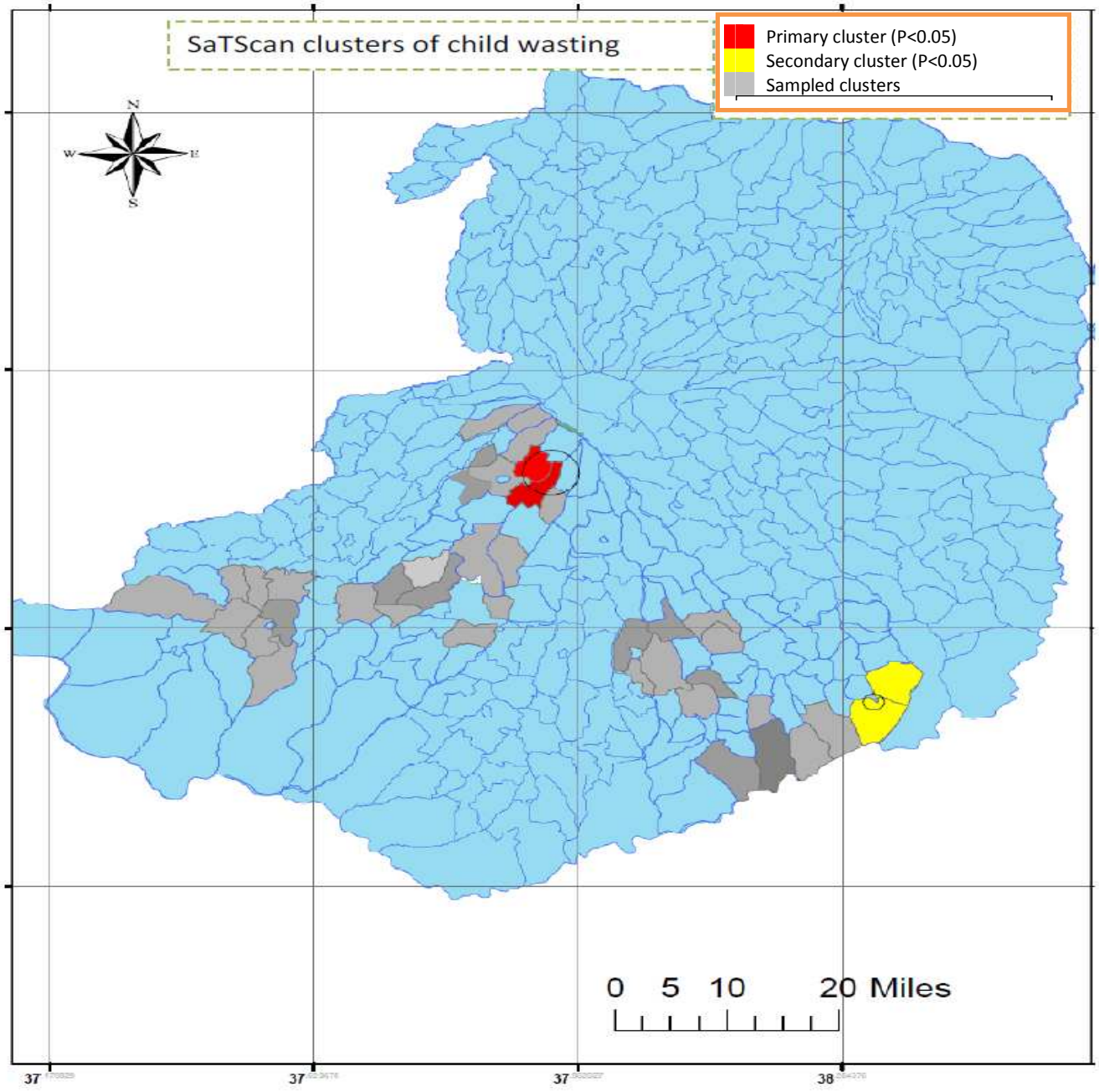
Figure 10:- Spatial variations of child stunting across different agroecosytem in East Gojjam, Amhara Region, Ethiopia, 2015.

The table below summarizes the prevalence with 95% CI of childhood stunting, underweight and wasting across different agroecosystems using less than -2SD as a cut off point.

Table 13:- Agroecosystem based prevalence of child undernutrition in East Gojjam Zone, Amhara Regional State, Ethiopia, 2015.

Agroecosystem	Wasting (% < -2SD (95% CI))	Underweight (% < -2SD(95% CI))	Stunting (% < -2SD(95% CI))
Lowlands of Abay Valley	14.8 (12.2, 17.8)	22.9 (19.7, 26.3)	42.4 (38.5,46.6)
Midland plains with black soil	11.6 (9.3, 14.00)	22.3 (19.0, 25.5)	39.4 (35.4,43.4)
Midland plains with brown soil	10.6 (8.4, 13.2)	15.2 (12.4, 18.0)	38.5 (34.9,42.1)
Midland sloping lands with red soil	8.3 (6.4,10.7)	12.2 (9.4, 14.9)	33.9 (30.0, 37.7)
Hilly and mountainous highlands	15.9 (13.5, 18.8)	20.9 (17.6, 24.0)	41.1 (37.3, 44.6)

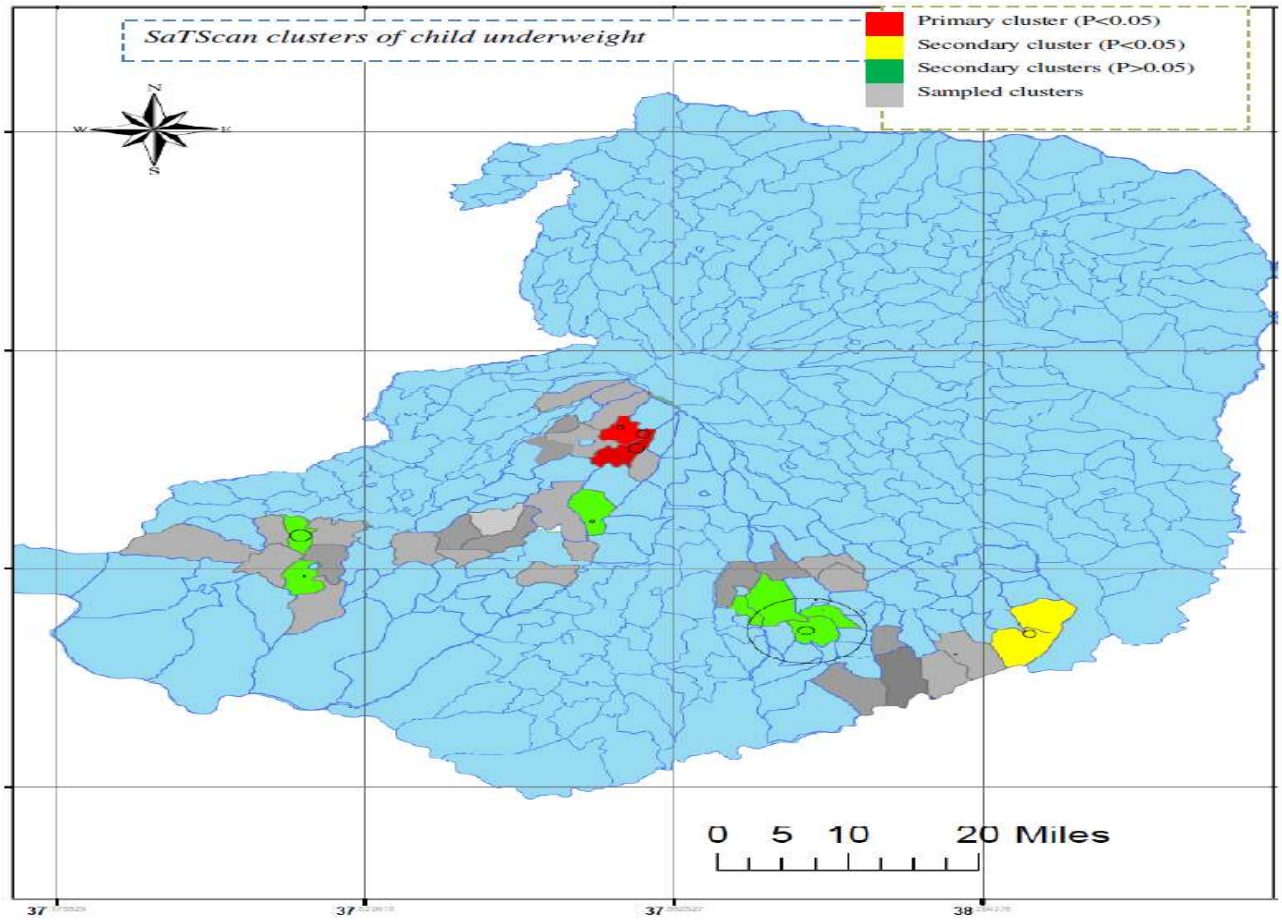
In the SaTScan spatial analysis, the cluster with the maximum Log Likelihood Ratio (LLR) was the most likely primary cluster for childhood undernutrition. As indicated in Table 14 and Figure 11 below, the most likely primary spatial SaTScan cluster for child wasting was detected from hilly and mountainous highland areas (LLR = 13.0 $p < 0.01$). Also, a secondary child wasting cluster was detected from the lowlands of the Abay Valley (LLR = 11.21, $p < 0.05$).



The red color shaded area indicates the location of the most likely primary clusters and the yellow color shaded area indicates the location of the most likely secondary clusters with a statistically significant p value.

Figure 11:-Spatial distribution of childhood wasting in East Gojjam Zone, Amhara Region, Ethiopia, 2015.

As indicated in table 14 and figure 12 below, the most likely primary cluster for child underweight was detected from hilly and mountainous highland area (LLR = 23.16. P< 0.001) shaded with red color. The most likely secondary SaTScan cluster for child underweight was reported from the lowlands of the Abay Valley (LLR = 17.53, p < 0.001) shaded with brown color. Also, there were different secondary clusters detected from different agroecosystems, but did not show statistical significant difference (Table 14).



The red color shaded area indicates the location of the most likely primary clusters and the yellow color shaded area indicates the location of the most likely secondary clusters with a statistically significant p value. Other secondary clusters with green color shaded areas consisted of statistically insignificant most likely secondary clusters.

Figure 12:-Spatial Distribution of child underweight in East Gojjam Zone, Amhara Regional State, Ethiopia, 2015.

Table 14 below indicated the SaTScan spatial analysis results of childhood stunting among clusters. A primary childhood cluster was detected from the lowlands of the Abay Valley (LLR = 10.78, $p < 0.05$). In the SaTScan spatial analysis of childhood stunting, statistically significant spatial variation was observed among clusters. As indicated in figure 13, the most likely primary cluster for childhood stunting was observed from the lowlands of Abay Valley.

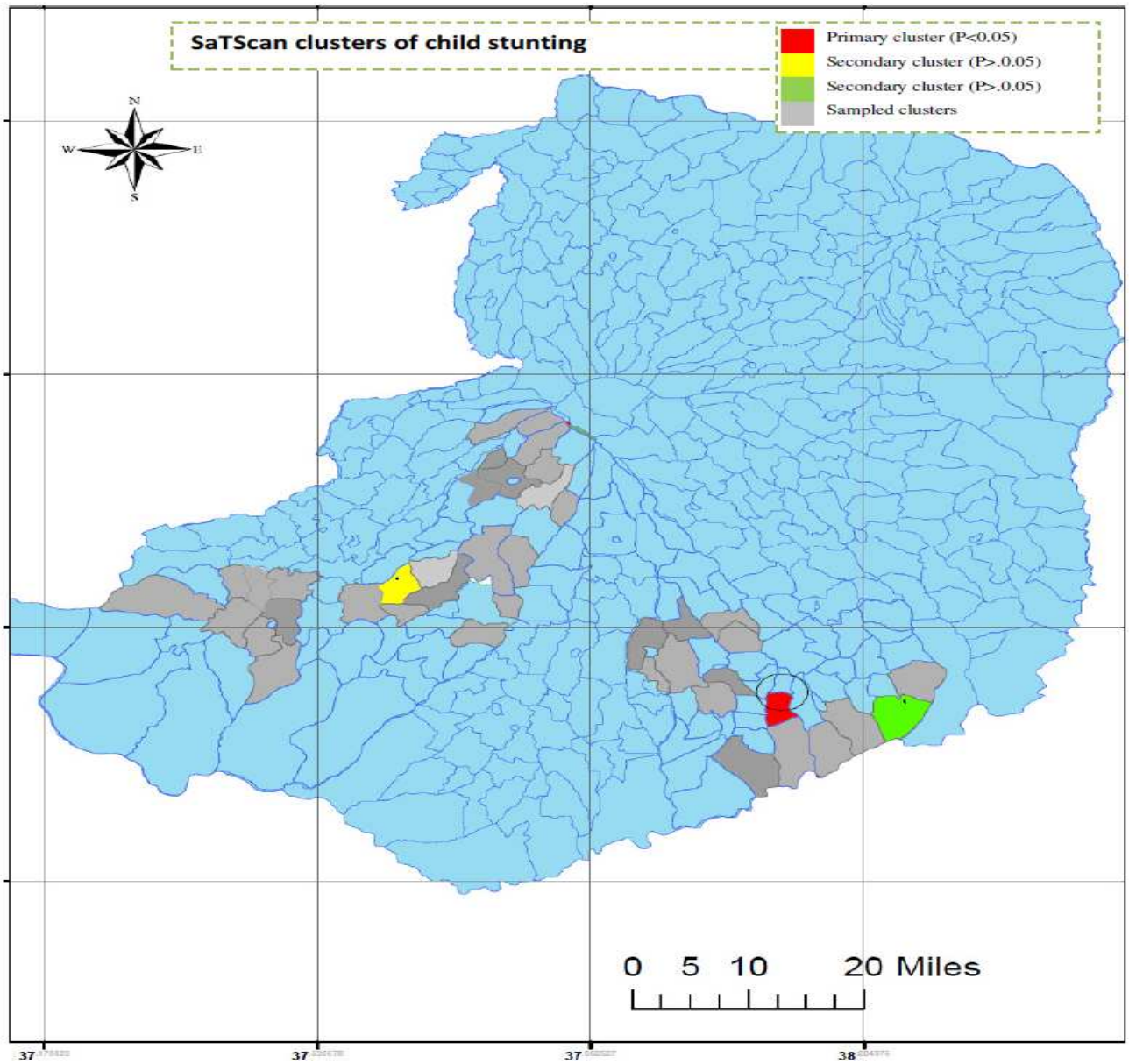


Figure 13:- Spatial Distribution of childhood stunting in East Gojjam Zone, Amhara Region, Ethiopia, 2015.

Table 14:- SaTScan spatial analysis results of child undernutrition in East Gojjam Zone, Amhara Region, Ethiopia, 2015.

	Cluster location	Coordinate/radius	LLR	P value
	Childhood wasting			
1	Hilly and mountainous highlands	10.55N,37.83E/4.06km	13.0	P <0.01
2	Lowlands of Abay Valley	10.17N, 38.24/1.44km	11.21	P,<0.05
	Childhood underweight			
1	Hilly and mountainous highlands	10.53N,37.82E/1km	23.16	P <0.001
2	Low lands of Abay valley	10.17N, 38.25E/0.8km	17.53	P <0.001
2	Midland plains with black soil	10.17N,38.01E/7.2km	9.05	0.14
2	Low lands of Abay valley	10.13N,38.17E/1.11km	8.98	0.18
2	Midland sloping plain with red soil	10.21N, 38.03E/0.11km	7.43	0.61
	Childhood stunting			
1	Low lands of Abay valley	10.18N, 38.10E/1.26km	10.78	0.04
2	Midland plains with red soil	10.38N, 37.62E/1.18km	6.60	0.95
2	Low lands of Abay valley	10.17N,38.25E/1.19km	5.68	0.98

5.7. Factors associated with childhood weight for height Z score (wasting)

As indicated in table 15 in the empty model (intercept only model) of the multilevel mixed effects linear regression analysis of child weight for height Z score, of the total variance across clusters, 3.18% ($p<0.001$) were attributable to cluster level, which suggests the need for multilevel mixed effects linear regression analysis. In model two, after adjusting for level one factors, the variance attributable to cluster level was reduced to 3.12% ($P<0.001$). Similarly, after adjusting for level two determinant factors in model three, the variance attributable to cluster level was reduced to 1.5% ($p<0.001$). Finally, in model four, after adjusting for both individual and community level determinant factors at the same time, 1.2% ($p<0.001$) of the variance was attributable to cluster level.

Table 15:- Random effect parameters of the multilevel linear mixed effects model on determinant factors of child weight for height Z score (wasting) in East Gojjam Zone, Amhara Regional State, Ethiopia, 2015.

Measure of variation	Model 1[a]	P value	Model 2[b]	P value	Model 3[c]	P value	Model 4[d]	P value
Level 2 variance (SE)	0.09	<0.001	0.08	<0.001	0.04	<0.001	0.05	<0.001
Level one variance (SE)	2.74		2.51		2.61		2.43	
ICC (%)	3.18		3.01%		1.8%		1.5%	
Explained variation	Reference		97.0		98.5		98.5	
Model fit statistics								
DIC (-2loglikelihood)	6003		5862		5915		5809	

In the study, the number of under-five children in the household showed statistical significant association with child weight for height Z score. Children from households with two or more under five children, the weight for height Z score decreased by -0.35 (P<0.001) compared to having only one under five child in the household. The child's mother with ANC follow up during pregnancy, weight for height Z score of the child increased by 0.19 (P<0.05) compared to the child's mother without ANC follow up. Complete immunization status of the children increased weight for height Z score by 0.61 (p<0.001) compared to who were not completely immunized. Children who were given to breastfeeding after an hour of delivery, whose weight for height Z score of the child decreased by -0.15 (P<0.05) compared to children who started breastfeeding within an hour of delivery (Table 16).

Children from mothers whose Mid Upper Arm Circumference (MUAC) of 23.5 cm and above, the child weight for height Z score increased by 0.06 (P<0.001) compared to children whose mothers Mid Upper Arm Circumference (MUAC) was less than 23.5cm. When the household level dietary diversity score increased in one food group, the child weight for height Z score increased by 0.08 (P<0.001). In the study, when household food insecurity access score increased in one unit, child weight for height Z score decreased by -0.02 (P<0.05). The presence of childhood diarrheal illness two weeks prior to the survey decreased children weight for height

Z score by -0.60 (P<0.001) compared to who did not report childhood diarrheal illness (Table 16).

From the community level determinant factors, improper household refuse disposal practice decreased child weight for height Z score by -0.53 (P<0.001) compared to households that dispose household refuses properly. Similarly, households that utilized latrine properly increased children weight for height Z score by 0.44 (P<0.001) compared to households that did not utilize the latrine properly.

Children being from the midland plains with brown soils and midland sloping lands with red soils had better weight for height Z score compared to children from Abay Valley lowlands. Children of midland plains with brown soils and midland sloping lands with red soils, whose weight for height Z score increased by 0.32 (p<0.05) and 0.51 (P<0.001), respectively compared to children from the lowlands of Abay Valley (Table 16).

Table 16:- Multilevel linear regression analysis of determinant factors associated with child weight for height Z score in East Gojjam Zone, Amhara Regional State, Ethiopia, 2015.

Variables	Model 2[b] ß**(SE)	P value	Model 3[c] ß** (SE)	P value	Model 4[d] ß** (SE)	P value
Level one factors						
Child age in months	-0.002 (0.002)	p>.0.05			0.001 (0.001)	p>.0.05
Child sex (male*)						
Female	0.10 (0.06)	p>.0.05			0.10 (0.06)	p>.0.05
Number of under-fives (one*)						
Two and above	-0.36 (0.08)	P<0.001			-0.35 (0.08)	P<0.001
Mother education (can't read and write*)						
Only read and write	0.02 (0.10)	p>.0.05			0.004 (0.10)	p>.0.05
Have a formal education	0.004 (0.10)	p>.0.05			0.01 (0.10)	p>.0.05
Wealth index (Lowest *)						
Second	0.01 (0.10)	p>.0.05			0.05 (0.09)	p>.0.05
Middle	0.09 (0.10)	p>.0.05			0.02 (0.10)	p>.0.05
Fourth	0.05 (0.11)	p>.0.05			0.04 (0.11)	p>.0.05
Highest	0.11 (0.20)	p>.0.05			0.02 (0.08)	p>.0.05
Women participation in decisions (No*)						
Yes	0.19 (0.08)	P<0.05			0.12 (0.8)	p>.0.05
ANC follow up (No*)						
Yes	0.16)(0.07)	P<0.05			0.19 (0.07)	P<0.05
Child immunization (Not immunized*)						

Fully immunized	0.70 (0.08)	P<0.001			0.61 (0.08)	P<0.001
Breastfeeding initiation (within an hour*)						
After an hour	-0.22 (0.06)	P<0.01			-0.15 (0.07)	P<0.05
Complementary feeding initiation (on time*)						
Not on recommended time	-0.09 (0.06)	P<0.001			-0.09 (0.06)	p>.0.05
Maternal MUAC (<23.5 cm)						
≥23.5 cm	0.06 (0.01)	p>.0.05			0.06 (0.01)	P<0.001
Household food insecurity access score	-0.02 (0.01)	P<0.05			-0.02 (0.01)	P<0.05
Household dietary diversity score	0.03 (0.02)	p>.0.05			0.08 (0.02)	P<0.001
Diarrhea illness two weeks prior the survey (No*)						
Yes	-0.58 (0.08)	P<0.001			-0.60 (0.08)	P<0.001
Community level factors						
Household refuse disposal practice (Yes*)						
No			-0.57 (0.06)	P<0.001	-0.53 (0.06)	P<0.001
Agroecosystem type (Abay valley lowlands*)						
Midland plains with black soil			0.12 (0.14)	p>.0.05	0.15 (0.14)	p>.0.05
Midland plains with brown soil			0.29 (0.15)	P>0.05	0.32 (0.14)	P<0.05
Midland sloping land with red soil			0.43 (0.14)	P<0.001	0.51 (0.14)	P<0.001
Hilly and mountainous highlands			0.04 (0.14)	p>.0.05	0.24 (0.15)	p>.0.05
Latrine utilization (No*)						
Yes			0.59 (0.06)	P<0.001	0.44 (0.06)	P<0.001

*The reference group

5.8. Factors associated with childhood height for age Z score (stunting)

As indicated in the empty model (intercept only model) of the multilevel mixed effects linear regression analysis in table 17, of the total variation, 3.8% (p<0.001) of the variance were attributable to cluster level, which suggests the need for multilevel mixed effects linear regression analysis.

In model two, after adjusting for level one determinant factors, the variance attributable to cluster level was reduced to 2.7% (P<0.001). Similarly, after controlling for level two determinant factors in model three, the variance attributable to cluster level was reduced to 1.9%. Finally, in the full model (model four), after adjusting for both individual and community level confounding determinant factors at the same time, 1.4% (p<0.001) of the variance were attributable to cluster level.

Table 17:- Random effects parameter coefficients of the multilevel linear mixed effects model on determinant factors of child height for age Z score in East Gojjam Zone, Amhara Regional State, Ethiopia, 2015.

Measure of variation	Model 1[a]	P value	Model 2[b]	P value	Model 3[c]	P value	Model 4[d]	P value
Level 2 variance (SE)	0.16	<0.001	0.08	<0.001	0.06	<0.001	0.04	<0.001
Level 1 variance (SE)	4.04		2.88		3.89		2.85	
ICC (%)	3.8%		2.7%		1.9%		1.4%	
Explained variation	Reference		97.3		98.1		98.6	
Model fit statistics								
DIC (-2loglikelihood)	6606		6077		6538		6054	

As indicated in table 18 below, child gender and age in months were independent determinant factors of child height for age Z score. When, the child's age increased in one month, the height for age Z score decreased by -0.04 (P<0.001). Being a female child improved the child height for age Z score by 0.16 (P<0.01) compared to the male child. Number of underfive children in the household showed a statistical significant association with child height-for-age Z score. Children from households with two or more in number, whose height for age Z score decreased by -0.48 (P<0.001) compared to children from households with one underfive child.

When children got complete immunization, whose height-for-age Z score increased by 1.23 (P<0.001) compared to children who were not fully immunized. Initiating breast milk feeding after an hour of delivery time, height-for-age Z score decreased by -0.25 compared to those children who started breastfeeding within an hour of delivery. Childhood diarrhea illness showed a statistical significant association with child height for age Z score. Children having a diarrheal episode in the last two weeks of the survey, whose height for age Z score decreased by -0.29 (P<0.001) compared to children who did not report diarrheal illness.

In this study, maternal undernutrition showed a positive statistical significant association with child height for age Z score. When the children's mother Mid Upper Arm Circumference (MUAC) was 23.5 cm and above, children height for age Z score increased by 0.12 (P<0.001) compared to children whose mother MUAC less than 23.5cm. The study demonstrated that household dietary diversity score increased by one food group, the child height for age Z score increased by 0.07 (p<0.01). Household level water treatment practices have improved children height for age Z score by 0.25 (p<0.05) compared to households that did not treat water at household level. Household food insecurity access score did not show a statistical significant association with children height for age Z score. As indicated in table 18 below, proper household refuse disposal practice showed statistical significant association with children height for age Z score. Households that properly disposed household refuse, height for age Z score of children increased by 0.20 (p<0.05) compared to those who did not dispose properly. Also, households that used latrine properly, children height for age Z score increased by 0.39 (p<0.001) compared to households that did not use latrine properly.

Agroecosystem characteristics showed a statistical significant association with child height for age Z score. Children from midland sloping land with red soil, midland with brown soil and midland with black soil, whose height for age Z score increased by 0.50 (P<0.01), 0.32 (P<0.05) and 0.52 (P<0.01), respectively compared to children from Abay Valley lowlands. However, children from hilly and mountainous highland agroecosystem, whose height for age Z score did not show a statistical significant difference compared to children from the lowlands of Abay Valley (Table 18).

Table 18:- Multilevel linear regression analysis of factors associated with child height for age Z score in East Gojjam Zone, Amhara Regional State, Ethiopia by, 2015.

Variables	Model 2[b] ß**(SE)	P value	Model 3[c] ß** (SE)	P value	Model 4[d] ß** (SE)	P value
Level one factors						
Child age in months	-0.04 (0.002)	P<0.001			-0.04 (0.002)	P<0.001
Child sex (male*)						
Female	0.16 (0.06)	P<0.01			0.16 (0.06)	P<0.01
Number of under-fives (one*)						
Two and above	-0.48 (0.08)	P<0.001			-0.48 (0.08)	P<0.001
Mother education (can't read and write*)						
Only read and write	0.04 (0.10)	P>0.05			0.004 (0.10)	P>0.05
Have a formal education	0.13 (0.11)	P>0.05			0.14 (0.11)	P>0.05
Wealth index (Lowest *)						
Second	0.09 (0.11)	P>0.05			0.08 (0.11)	P>0.05
Middle	0.09 (0.11)	P>0.05			0.06 (011)	P>0.05
Fourth	0.01(0.12)	P>0.05			0.02 (0.12)	P>0.05
Highest	0.03 (0.08)	P>0.05			0.05 (0.08)	P>0.05
Women participation in decisions (No*)						
Yes	0.11 (0.09)	P>0.05			0.09 (0.09)	P>0.05
ANC follow up (No*)						
Yes	0.05 (0.08)	P>0.05			0.05 (0.08)	P>0.05

PNC follow up (No*)						
Yes	0.09 (0.07)	P>0.05			0.06 (0.07)	P>0.05
Child immunization (Not immunized*)						
Fully immunized	1.35 (0.08)	P<0.001			1.30 (0.09)	P<0.001
Breastfeeding initiation time (within an hour*)						
After an hour	-0.30 (0.07)	P<0.001			-0.25 (0.07)	P<0.01
Complementary feeding initiation (on time*)						
Not on recommended time	-0.10 (0.06)	P>0.05			-0.10 (0.06)	P>0.05
Maternal MUAC (<23.5 cm)						
≥23.5 cm	0.12 (0.01)	P<0.001			0.12 (0.01)	P<0.001
Household food insecurity access score	-0.01 (0.01)	P>0.05			-0.01 (0.01)	P>0.05
House hold dietary diversity score	0.07 (0.03)	P<0.05			0.07 (0.03)	P<0.05
Household level water treatment (No*)						
Yes	0.18 (0.10)	P<0.05			0.25 (0.10)	P<0.05
Diarrhea illness two weeks prior to the survey(No*)						
Yes	-0.27 (0.09)	P<0.01			-0.29 (0.09)	P<0.01
Community level factors						
Household refuse disposal practice (No*)						
Yes			0.26 (0.11)	P<0.05	0.20 (0.10)	P<0.05

Agroecosystem type (Abay valley lowlands)				
Midland with black soil	0.60 (0.19)	P<0.05	0.52 (0.15)	P<0.01
Midland with brown soil	0.48 (0.19)	p<0.01	0.32 (0.16)	P<0.05
Midland sloping land with red soil	0.51 (0.18)	p<0.01	0.50 (0.15)	p<0.01
Hilly and mountainous highlands	0.09 (0.18)	P>0.05	0.18 (0.16)	P>0.05
Latrine utilization (No*)				
Yes	0.84 (0.08)	P<0.001	0.39 (0.07)	P<0.001

* indicates the reference category, ß** it refers to the normal regression coefficient

6. Discussion

An agroecosystem linked to community based comparative cross sectional survey was done to identify the spatial variations of food insecurity and child undernutrition. Also, the study identified individual and community level determinant factors of food insecurity and

child undernutrition using multilevel mixed effects modeling which is recommended where there is multilevel dependency or correlation among the observations (59, 61, 73) as observed in the null (empty) model of the multilevel mixed effects regression analysis. Agroecosystem characteristic of the study area was found from prior published agroecosystem analysis studies in the area (93, 191) which was hypothesized that it affects the geographical distribution of food insecurity and child undernutrition.

6.1. Prevalence of Food Insecurity

In this agroecosystem linked to community based cross sectional study, almost two third of the households (65.3%) were found to be food insecure. Even though maximum efforts were taken through explaining the objective of the study participants, the interpretation of the current study should take in to account the respondents potential bias due to expectations of food aid that might lead to over estimation of the magnitude. This finding was lower than a study from Farta District (70.7%) (87) and higher than e.studies done in East Gojjam Zone (56%) (49) and Sidama Zone (54.1%) (19). This variation might be explained as household food insecurity status varies from area to area, since food insecurity is the product of many predictor variables and it depends on contextual factors which might vary spatially (111, 214). Another possible explanation for the difference could be seasonal variation because seasonal variation has paramount significance on the food security of certain communities. Also, the above findings in the country indicate that there is a variation in the prevalence of food insecurity within the country in different localities.

This high level of food insecurity have public health implications which might lead to poor health outcomes beyond to undernutrition through different pathways, including nutrition, mental health and behavioral pathways (2, 33, 78, 173). For example, food insecurity has the potential to affect child health and care practices (75, 76, 85), the education system, and mental health conditions (33, 173, 181, 215). Literature indicate that food insecurity situation leads to poor self-reported health status (216), high blood pressure and diabetes (217), HIV acquisition risk (218), decrease health care access and weak prevention, management, and treatment of diseases (179).

Another important finding in this study was that more than three fourths of the households (76.1%) had feelings of uncertainty and anxiety about the household food supply. This fact is also indicated that food insecurity might lead to maternal anxiety, depression and other related mental illness during food shortage (2, 184). Women are more responsible to feed the family in most low income countries (219), including the study area. The stress and depression might lead to obesity and other chronic diseases (2). For optimal health, growth and development of human life, adequate quantity and quality of food are required (220).

In the moderate stage of food insecurity, households manage the shortage of food with reduction of diet quality (219). This condition might lead to micro-nutrient deficiencies, especially among children and mothers (219). In addition, poor diet quality increase the burden of non-communicable diseases due to consumption of unhealthy food items (2). In this study, more than half of the households made adjustments to food insecurity by reducing diet quality. A study from Ethiopia indicate that the contribution of poor diet quality as a risk of non-communicable is significant (221). This have an implication on strengthening the integration of none communicable disease control and prevention strategies with food insecurity intervention strategies in areas where there is food insecurity in the community.

As the severity of food insecurity increases, households start to reduce the quantity of food (3) and in this study, more than one fourth of the households (26.8%) compromised the quantity of food served to the family members due to shortage of food. The impacts of household food insecurity burden may not distribute equally among the household members. When there is food shortage in the household, gender, age, birth order and relationship based mal-distribution of food in the household is common in low income countries. This situation might expose children and mothers to undernutrition because these group are high vulnerability to food insecurity and biased food distribution towards male adults in case of food insecurity.

6.2. Spatial Variations of Food Insecurity

To be more efficient in targeting interventions based on level of the problem, spatial analysis is recommended to identify the most affected geographical areas, to design geographical targeted interventions, to allocate scarce resources to the most affected areas, to convince policy and decision makers and program managers using local evidence and to ensure equity in the community (3, 213). In the current study, spatial variations of food insecurity based on different agroecosystems were identified. Households from the low lands of Abay Valley and hilly and mountainous highlands were more food insecure compared to the midland plains. The SaTScan spatial cluster analysis indicated that the most likely primary and secondary clusters were identified from the hilly and mountainous highlands and lowlands of Abay Valley agroecosystems, respectively.

The SaTScan spatial analysis result identified clusters having higher risk than the expected risk for the original at risk population. The current study SaTScan statistics analysis indicated a well-defined agroecosystem based geographical variation of food insecurity. Similarly, the multilevel analysis showed the existence of food insecurity heterogeneity across clusters after adjusting to individual and community level determinant factors. It is documented that agroecosystem characteristics play important role in determining the prevalence of food insecurity, especially for farmers with subsistence farming (97). This might be attributed to poor soil fertility, low rainfall, higher climate change vulnerability, lower climate change adaptive capacity and high human induced land degradation from the lowlands of Abay valley (95). Also, hilly and mountainous area is characterized by low crop productivity due to its low temperature and poor soil fertility, high climate change vulnerability, low climate change adaptive capacity and high human induced land degradation (95).

The geographical location might determine household level poverty and other livelihood conditions of farmers which are among determinant factors of food insecurity. Those findings indicated that agroecosystem based food insecurity interventions should be designed since ecosystem related interventions have a better potential to bring long term food security in the community (97). In such areas, nutritional interventions that do not consider geographical targeting based on vulnerability will not be efficient in reducing the problem to the expected level (222, 223). Geographical targeting of food insecurity interventions through allocating more resources to the risky groups

has the potential to maximize program coverage and minimize leakage (224). Also, targeting food insecurity using geographical approach is easy to implement, has low administrative costs, minimizes the potential for fraud, and requires limited household and individual level information compared with other forms of targeting (213, 225).

Geographical targeting will be effective in contrasting environments where there is high level of variability between clusters and low level variability within clusters (213, 225). Geographical targeting assumes the homogeneity of determinant factors across clusters within the targeted area which is unlikely in the practical world (213, 225). The geographic targeting of food insecurity interventions may lead to excessive leakage of benefits to those at lower risk while leaving many of those at higher risk uncovered within the targeted geographical location. In the current study, as indicated in the multilevel analysis results of ICC, the contribution of higher level variability is categorized under low level of clustering. In areas where there is low level of clustering, geographical targeting alone might not be effective and interventions integrating both household level and geographical targeting may bring better results rather than choosing either of the alternatives in the study area.

6.3. Factors associated with food insecurity

In addition to estimating the spatial variations of food insecurity across different agroecosystem, this study determined both the role of individual and community level determinant factors on household food insecurity using multilevel mixed effects ordinal logistic regression analysis. From the multilevel mixed effects regression analysis of the empty (null) model, nonzero ICC with statistical p value in the current study implies that the observations are not independent and there is heterogeneity across the clusters due to the shared environment (226). Households found at the same geographical location are similar to each other than households that live in different geographical location to food insecurity as they share a number of social, economic, and other characteristics that may condition food insecurity status beyond household level determinant factors. Even though the empty model intra class correlation coefficient (ICC) is categorized in the low range of clustering (ICC<10%) (213) in the current study, it suggests the application of multilevel analysis instead of using the classical logistic regression (226) to identify determinant factors of household food insecurity. In the study, the cluster level variations of

food insecurity decreased in the full model compared to the empty model, which indicates both individual and community level factors have a significant role in determining household food insecurity.

The median odds ratio quantifies variance in terms of odds ratios among clusters which is comparable to the fixed effects odds ratio (226). In the current study, the median value of the odds ratio between the cluster at highest risk and the cluster at lowest risk to food insecurity was 1.22 ($P<0.05$) in the null model. The median odds ratio decreased to 1.09 ($p<0.05$) in the full model compared to the null model when we adjust to both individual and community level determinant factors. This implies that households with identical household level characteristics but from different clusters, the severity of food insecurity increased by 9% in households from high risk clusters compared to households from low risk clusters. This shows that food insecurity is determined by shared environment. This calls to quantifying contextual phenomena using multilevel mixed effects regression to identify determinant factors of food insecurity (226). This implies that both individual and community level determinant factors have a significant role in determining food insecurity. In such conditions multilevel mixed effects regression modeling is recommended over the classical regression analysis (59-61, 226).

Literature shows that in rural households, including in Ethiopia, food insecurity is a common problem in the lowlands and hilly and mountainous highland areas, due to different factors, including low climate change adaptive capacity, high climate change vulnerability and low crop productivity (98). In the current study, households from the lowlands of Abay Valley and hilly and mountainous highlands of Choke Mountain were more severely food insecure compared to midland areas. That might be explained by the fact that most highland and lowland areas are mountainous and hilly, being prone to soil erosion and land degradation, which might reduce crop productivity (51, 95, 227). In the study area, the most highland and lowland areas were identified with low climate change adaptive capacity and high vulnerability (227). Climate change vulnerability of the farmers affects food production and the overall livelihood of farmers which are known determinant factors of food insecurity (228). Similarly, farmers adopting more adaptation practices to climate change have reduced food insecurity levels (229).

In turn, food insecure community back creates pressure on the agroecosystem resources and it aggravates the food insecurity situation to its severe state (97). This study suggests that recognizing the multiple pathways of agroecosystem effects on community food and nutrition security will help to develop sustainable agroecosystem based interventions of food insecurity. Also, decision makers shall give emphasis to support the management of agroecosystem services by taking appropriate policy measures to mitigate food insecurity in collaboration with organizations that are working on natural resources management. In addition to mitigating food insecurity, agroecosystem management can be used to mitigate other food insecurity drivers, including disease distribution and dietary diversity (quality) in the community.

The current study identified other individual and community level determinant factors of household food insecurity in addition to the agroecosystem characteristics. Female headed households were more severely face food insecurity compared to male headed households which is supported by a systematic review and meta analyses somewhere else (230). On the other hand, this study finding contradicts with other studies from Ethiopia, Nigeria and South Africa, which did not show a statistical significant association between household head gender and food insecurity (15, 78, 231). For the inconsistent findings between the current study and studies elsewhere abroad and in Ethiopia, we argue that rural community livelihood depends on agricultural activities and males are more active in cultivating the land and produce more food for household consumptions. Female headed households are disadvantaged when it comes to access to land, markets and extension services. Also, female headed households have limited access to information and unfavorable cultural practices to mitigate food insecurity.

Household heads that were not in union were less likely to be more severe state of food insecurity compared to those who were in union. Similar findings were reported from studies in South Africa (78) and Nigeria (100) which might be associated with an increased family size in households who are in union due to high fertility rate (78, 100). However, a study from Kenya indicated that couples in union were less likely to be more food insecure compared to single headed households (232). The above inconsistency suggests that it is impossible to make conclusions to target interventions in the community based on marital status and it might depend on the local context.

Maternal and paternal educational status make farmers to be familiar with new skills, ideas, modern agricultural technology and other developmental activities (15, 85). This study supported the above facts and statistical significant association between parental education and severity of household food insecurity. Similar findings are reported from Pakistan (101), African study (105) and Malawi (233) studies. This might be related to having a better chance to practice the knowledge they gain from extension service workers education to reduce household food insecurity. Women participation in household decisions showed a statistical significant association with low level of household food insecurity. This suggests that women empowerment to decide on household resources as food insecurity intervention strategy should be strengthened (105).

In countries like Ethiopia, where agriculture production is vulnerable owing to different risk factors, households with off farm activities have a better survival mechanism when the production fails (233). Also, this study witnessed that households with additional income source were less likely to be more severe food insecure compared to households that did not have additional income source. This evidence is supported by studies from Pakistan, Malawi and Nigeria (108, 231, 233). These findings suggest that household having additional income sources should be considered as one of the major coping strategies in communities where there is food shortage (103), including in the current study area. Also, household additional income source increases the probability of the household to use modern agricultural inputs to produce more crop and enable them not to sell the crop they produce to satisfy other family needs (16).

Utilization of modern fertilizer from the right source, with right rate, right time, and right place to increase crop productivity has a significant effect to reduce food insecurity (103, 233). The food needs cannot be achieved without the application of modern fertilizers to increase crop productivity. The current study indicated that households that used chemical fertilizers to increase crop productivity were less likely to be more food insecure compared to farmers who did not use fertilizer. This finding is supported from Malawi (233) and Ethiopia (107).

Micro credit access to farming community has a significant positive effect on household food insecurity (233). Studies from Pakistan and Malawi indicated that better access to micro credit is associated with lower levels of food insecurity (108, 233). However, in the current

study, micro credit access did not show a statistical significant association with household food insecurity. Evidence indicated that there is differential impact of credit on rural Ethiopian households based different parameters (234). For example, for poor households, rather than achieving long term livelihood improvements, access to credit only means short term consumption smoothing with a risk of being trapped into a cycle of indebtedness (234).This implies that the effectiveness of micro credit access to improve the overall livelihood, including household food insecurity of the farmers should be investigated in local contexts.

Farmers access to irrigation scheme for crop production for more than one per year is recognized as one of the strategies for poverty alleviation and it improves household food security, especially for countries, including Ethiopia, where the communities depend primarily on agriculture for their livelihoods (235). However, the current study did not show a statistical significant association between household food insecurity and irrigation access to the household for crop production. This suggests that the effectiveness of irrigation scheme access in improving the household livelihoods needs further exploration in the study area, including type of crop the farmers producing and the market value of the crops produced.

In the current study, households with better land size have reduced the severity of household food insecurity. This means households with larger farm land size can produce more crop for household consumption and for sale and have a better chance to be food secure than those having relatively smaller farm land size. It is documented that land ownership has a significant role in improving the overall livelihood of farmers, including to mitigate food insecurity situation (236). In areas, including the current study, where there is no extra land to be cultivated, increasing crop produced in a limited land size with the application of agricultural technology might be the best solution to reduce household food insecurity. The current study suggested that households with better crop production have reduced the severity of food insecurity status compared to households with lower crop production in the survey year. This could be explained as household food production is often the primary source of food and source of income in developing countries (237), including the study area.

Access to the market center and all season transportation access to the market center were among the strategies to improve household livelihood in the rural communities (107, 235, 237). The community closeness to market centers creates opportunities for additional income

via off-farm/non-farm employment opportunities, easy access to information and inputs and being easy for transportation (57, 107). Also, households nearer to market center have the probability of selling what they produced and purchase food from the market, which increases the probability of having a better livelihood in the household (16). However, the current study did not show a statistical significant association between severity of household food insecurity and all season transport access and district market distance from village. So, to estimate the contributions of market access and all season transport access to the market center in mitigating food insecurity further investigation using longitudinal studies should be done in the local context.

6.4. Prevalence of Child Undernutrition

An overall prevalence of 39.0% (37.32, 40.75) stunting, 18.7% (17.32, 20.0) underweight and 12.22% (11.12, 13.42) wasting were reported in the study area. Childhood stunting prevalence was slightly lower than the Mini EDHS 2014 (42.4%) (111) and EDHS 2016 (46.3%) (25) reports of Amhara Region and other pocket studies from Tigray Region (57.1%) (50), North Shewa Zone (47.6%) (57), Southern Ethiopia (47.6%) (52) Lower prevalence of child underweight was reported in the current study compared to the mini EDHS 2014 (27.9%) (111) and EDHS 2016 (28.4%) (25) reports of the Amhara Region. Also, the current study prevalence of underweight was lower than other pocket surveys of different regions, including studies from Tigray (37.4%) (50), North Showa Zone (30.9%) (57) and Southern Ethiopia (29.6%) (52). Similarly, a lower prevalence of child wasting was reported in the study area, compared to other studies in Ethiopia, like from the Tigray Region (17.8 %) (50), North Shewa Zone (16.7%) (57) Southern Ethiopia (13.4%) (52) and North West Ethiopia (17.1%)(51).

The lower prevalence of child undernutrition indices in the current study might be related with different interventions undergoing in the country, including in the study community. The government with its partners is implementing and strengthening different nutrition specific (200) and sensitive (238, 239) interventions in the country. For example, overall improvements are observed in Water, Sanitation and Hygiene (WASH) interventions, which could reduce child undernutrition by preventing the infectious disease burden (25, 113, 206, 238). Also, improvements in child and maternal health services are observed, which might contribute to the reduction in child undernutrition (25, 113, 206, 239).

Although lower prevalence of childhood undernutrition (stunting and underweight) was reported in the current study compared to the other local studies, based on the WHO undernutrition classification, between 30-39% for stunting, the problem can be considered as a high prevalence and it is a very serious public health concern (240). Child underweight prevalence of 10- 20% can be considered as medium prevalence and prevalence of child wasting 10 – 14% is in the serious public health problem range (240).

This study indicated that the prevalence of undernutrition in the study community have significant public health concerns based on WHO classification (9). The percentage of children with a low height for age (stunting) reflects the cumulative effects of undernutrition and infections since and even before birth. This measure can therefore be interpreted as an indication of poor environmental conditions or long-term restriction of a child's growth potential. This indicates that much effort with multi-sectorial approach is essential to reduce child undernutrition.

This high level of undernutrition in children may increase mental health illness, infectious and chronic diseases morbidity and negatively affects cognitive development and child behavior. In addition to its effect on children, it has negative cumulative effect on the nation economic status, increase the burden on the health system and affects livelihood of families (2, 241).

6.5. Spatial Variations of Child Undernutrition

Studies in Ethiopia at macro level showed spatial variation of child undernutrition (42-44). Similarly, the current study showed an elevated prevalence of child undernutrition from hilly and mountainous highlands and lowlands of Abay Valley compared to the midland plain areas. This study finding contradicts with studies in Ethiopia at country level indicated that midland areas were more affected by stunting compared to lowland areas (42, 43). For this inconsistency, we argue the previous findings that farmers with subsistence farming from highland and lowland areas are more prone to farm land degradation due to the hilly and mountainous nature of the land (95, 227). Also, the most highland and lowland areas have lower climate change adaptive capacity and higher climate change vulnerability which affects child undernutrition through different pathways, including food production, increase water stress in the area and affect other socioeconomic

activities (49, 95, 227-229). The high prevalence of child undernutrition in a certain geographical location has greatly contributed to elevate the overall average prevalence. As, a result addressing the specific geographical location with high prevalence of child undernutrition problem have the potential to reduce the overall prevalence in a short period of time.

Also, the SaTScan spatial analysis indicated that child wasting, underweight, and stunting were not distributed randomly across different clusters. Clusters taken from hilly and mountainous highlands were identified as the most primary cluster for child underweight and wasting. Clusters from lowlands of Abay Valley consisted of the most primary SaTScan clusters for child stunting. This suggests a significant clustering of child stunting, underweight and wasting in the study area. The current study confirms that child undernutrition varies not only across various regions of the world (242) and at national level (42-44), but also within a local context at micro level based on agroecosystem characteristics. The current study child undernutrition spatial distribution variation is consistent with studies in Ethiopia at district level (45) and national level (42, 44).Also, similar findings were reported from elsewhere abroad which showed spatial variations of child undernutrition across different geographical locations (62, 243, 244).

The current study spatial analysis finding implies that planning interventions using macro level aggregated data might undermine national and regional efforts to mitigate child undernutrition due to variations in magnitude of the problem. In such situations, to be effective in interventions geographical targeted at lower level is essential through allocating resources based on level of risk (213, 224). Also, to maximize program coverage, and minimize leakages, geographical targeting of child undernutrition interventions through allocating more resources to the risky groups is recommended (224). So the current study, SaTScan spatial analysis on clustering of child undernutrition suggests considering geographical targeting to improve the effectiveness of interventions on child undernutrition. This type of targeting of interventions is easy to implement, requires lower resource to administer and needs limited information at lower level compared to individual level targeting (213, 225). However, the effectiveness of geographical targeting will be increased based on level of homogeneity with the cluster and level heterogeneity between clusters (213, 225). This may lead to excessive leakage of benefits to those at lower risk while leaving many of those at higher risk uncovered within the targeted geographical location (213, 225).

In the current study area where there is low level but statistically significant heterogienity of child undernutrition, integrating different level of interventions might be a more appropriate method to reduce child undernutrition. As indicated in the multilevel analysis, individual and community level factors have significant role in determining the level of heterogeneity. This suggests that the community level determinant factors could be addressed through geographical targeting and the individual and household level determinant factors could be addressed using individual and household level targeting either through blanket coverage or using screening of children with the highest risk for undernutrition (213). Another approach of integration may focus on households or individual level intervention through a multistage targeting approach. In the first stage, a geographic targeting approach and then household or individual level intervention can be selected using specific criteria.

6.6. Factors associated with child undernutrition

A two multilevel mixed effects linear regression analysis was used to identify determinant factors of child undernutrition which is recommended in nested data structure or spatial dependent data (226). The ICC suggests that the presence of statistical significant heterogeneity across the clusters has important implications for the application of multilevel analysis rather than using the classical regression analysis which produces biased estimates because of the multilevel dependency or correlation among the nutritional status of children (59, 61, 73). Also, the study indicated the level of heterogeneity of child undernutrition across clusters after adjusting for all potential individual and community level determinant factors.

The intra class correlation (ICC) of height for age Z score (HAZ) and weight for height Z score (WHZ) were categorized under low level of clustering (ICC < 10%) (115) but with statistically significant spatial heterogeneity. In the study, reduction of heterogeneity of child height for age Z score (HAZ) was observed in the full model (ICC = 1.5%) compared to models adjusted only for individual level determinant factor in model two (ICC = 3.01%), only for community level determinant factors in model three (ICC = 1.8%) and in the empty model without explanatory variables in model one (ICC= 3.18%).

Similarly, heterogeneity of child weight for height Z score (HAZ) was lower in the full model (ICC = 1.4%, P<0.001) compared to models adjusted for individual level determinant factor in model two (ICC =2.7%), community level determinant factor in model three (ICC = 1.9%, P<0.001) and in the empty model (ICC= 3.8%, P<0.001). This suggests that both individual and community level determinant factors played a significant role in determining the heterogeneity of child undernutrition in the study area. This heterogeneity observed after adjusting for potential determinant factors, might be associated with the study did not account for potential differences across clusters in anthropological and biological factors which needs further exploration in the future.

In addition to measuring the level of heterogeneity in the multilevel analysis, the study identified determinant factors of child undernutrition. In the current study area, child undernutrition was expected in the low lands of the Abay Valley and hilly and mountainous highland agroecosystems due to low crop productivity and high water stress compared to midland plain agroecosystems (95, 227). This could be explained partially due to high climate changing vulnerability and lower climate change adaptive capacity of farmers (95, 227). The current study indicated that children from midland plains showed better height for age Z score, compared to children from low lands of the Abay Valley. Similarly, children from midland plains with black and brown soil agroecosystems had better weight for height Z score (WHZ), compared to children from lowlands of the Abay Valley and hilly and mountainous highlands. These findings can be explained as the agroecosystem characteristics might influence child nutritional status through different pathways, like affecting food security status, disease distribution, safe water source access, type of crop produced and dietary diversity and other social and economic conditions of farmers. Households from lower midland area have better diversified crop production compared to the higher midland areas (245) which have the potential to determine child nutritional status.

The study suggests the need for integrated agroecosystem based geographical and individual level targeting of nutrition programs which is recommended in areas with clear spatial variation of child undernutrition (115). Geographic targeting based on agroecosystem characteristics has the potential to substantially enhance the effectiveness of nutrition programs. Geographical targeting alone might not be

sufficient in areas where there is low level of clustering (115) and integration of it with individual/ household level intervention programs would improve the child nutritional status.

In addition to estimating the association between child weight for height Z score and agroecosystem characteristics, the current study identified other individual and community level determinant factors of child weight for height Z score. A negative statistical significant association was observed between child age in months and height for age Z score. This might be related to as the age increase; the child might start to move independently far from the mother which may expose them to infections from the environment. Also, movement of the child far from the mother might decrease mother to child frequency of contact to give care, including breast milk (152). This study demonstrated the lower height-for-age Z score and weight for height Z score among males compared to females which contradicts with what is expected since lower priority of girls in many cultures would bias food consumption towards boys (168). The possible explanation might be related to the higher proportion of preterm and low birth weights which are common in males compared to females (113, 246). Another possible explanation for this might be related to childhood morbidity is higher among males compared to females in the early life of children (247).

The current study indicated that women's participation in household decisions showed a statistical significant association with child weight for height Z score. There are a number of ways by which women's decision making power might come to be associated with improved child health outcomes, including child nutrition. For example, women who have better participation on household decisions enhance the day to day health enhancing behavior and improve intra household resource allocation, including for maternal and child care practices including nutrition. Women's participation in household decisions affects women's own nutritional status and the quality of care they receive, and in turn, to children's quality of care and nutritional status. Recognizing this, the Ethiopian National Nutrition Program, gives emphasis on women's control over household resources to improve child nutritional outcomes (170). So, the existing efforts to improve women decision making power should be strengthened to improve child nutritional status.

Evidences from Ethiopia and elsewhere abroad indicated that the economic status of households has the potential to improve child height for age Z score through accessing nutritious foods at household level. (42, 74, 145, 159, 248, 249). However, in the current study household with better wealth status did not show a statistical significant association with child height for age Z score and weight for height Z score. A similar finding was reported from southern part of Ethiopia (250). It is documented that the household wealth status might not necessarily help to improve stunting due to different reasons, including the household wealth might not be spent in a way that improves nutritional status of children (251, 252). The contribution of household wealth status on child nutritional status depends on quality foods consumed and amount of resource allocated for food compared to non-food items (251, 252). Another possible explanation might be related to behavior and child care related culture of the community, including intra household food distribution among household members (156). Regardless of wealth status, in most culture, including the study area, mothers and children receive a smaller share of the family's food relative to their nutritional need and simply feed one common kind of food prepared from cereals and pulses (51). In addition, consumption of a balanced diet, including animal products in the study area is very low, except in holidays and festivals (51). These conditions might undermine the household wealth status contribution in reducing child undernutrition in the study area.

Child mother health services utilization, including ANC visit during pregnancy can get information about child and maternal feeding practices, child care practices and health services use (112). Similarly, studies from Ethiopia indicated that ANC follow up has a positive contribution to improve child nutritional status (53, 56). The current study demonstrated that ANC follow up of the mother showed statistically significant association with child weight for height Z score. However, child height for age Z score did not show a statistical significant association with mother ANC and PNC follow up. This needs further exploration using more advanced epidemiological studies to see the effect of maternal health service utilization on child height for age Z score in the local context.

In the current study, mother nutritional status showed a statistical significant association with child height for age Z score and weight for height Z score, which is supported by studies in Ethiopia and elsewhere abroad (42, 145, 249, 253). The interrelationship between maternal and child nutritional status stresses the value of improving maternal nutritional status to make better both maternal and child health outcomes, including reducing undernutrition (253). Early initiation of breastfeeding and exclusive breastfeeding practices have been argued

to be one of the important ways of ensuring better child health outcomes, including nutritional status (254). Initiating breast milk feeding within an hour of delivery (255) contributes to mitigate child undernutrition. The current study indicated that initiating breast milk within an hour of delivery substantially increased child height for age Z score and weight for height Z score. The finding is supported by strong biological plausibility (256) since early breastfeeding initiation reduces the high risk of contamination associated with pre-lacteal feeds (256). Also, breastfeeding appears to both protect and have positive regulatory effects over the intestinal mucosa (257) and its early initiation of breastfeeding has a potential to promote intestinal maturation and epithelial recovery from infection (256). Child immunization status has a strong positive link with child nutritional status (162) and this study indicated that child full immunization status showed a positive statistical significant association with antropometric indices of children (height for age Z score and weight for age Z Score). Consistent findings were reported from studies done in Ethiopia (54, 56) and elsewhere abroad (138, 139, 163).

The other important finding of this study was that better household dietary diversity score improved child height for age Z score significantly, which is supported by a study from the Amhara Regional State (51). Dietary diversity ensures nutrient adequacy (147) and it is a proxy indicator of micronutrient adequacy of human diet (140). These findings suggest that there is an association between child dietary diversity and nutritional status that is independent of other potential determinant factors and that dietary diversity may indeed reflect diet quality.

The associations between Household Food Insecurity and child undernutrition is mixed (258). Literature indicated that household food insecurity is one of the key determining factors of child nutritional status (56, 153, 158, 159, 250, 259-262). Similarly, the current study indicated that household food insecurity access score showed a statistical significant association with child weight for height Z score which is consistent with studies in Ethiopia (258) and elsewhere abroad (169, 263). However, there is no statistical significant association between child height for age Z score and household food insecurity score which is supported by studies from Ethiopia (51, 262). The possible explanation of the result might be related that height for age Z score is an indicator of chronic child undernutrition and the food insecurity situation was assessed 30 days prior to the survey which may not reflect the previous month's food insecurity situation. Child's nutritional

status as reflected in HAZ represents a long term cumulative process, whereas food insecurity information reflects only the previous one month. Another possible explanation is related with that nutritional factors beyond food insecurity may play important roles, including intra household food allocation (258). Food security of the household alone may have a limited effect on the nutritional wellbeing of children unless the reinforcing detrimental linkages between food insecurity, high disease burden, poor sanitation and inadequate education are addressed in the community (2).

Childhood diarrhea depresses appetite, inhibits absorption of nutrients in food, and competes for a child's energy (32). In the current study, diarrhea morbidity two weeks prior to the survey was significantly associated with child height for age Z score and child weight for height Z score, which is supported by studies from Ethiopia (52, 56, 110) and Cambodia (145). The current study result interpretation should take in to account the bidirectional relationship between child nutrition and infection. It is documented that frequent illness can impair nutritional status and poor nutrition can increase the risk of infection (264). Undernutrition lowers the child immunity and increase the risk of infection (264). An infectious disease among children can cause reduced dietary intake (e.g. appetite loss, reduced feeding by parents as an attempt to end diarrhea); increased nutrient loss (e.g. vomiting, mal-absorption) and elevated nutrient requirements caused by increases in metabolism such as those due to fever (265). This bidirectional association suggests programs that combine nutrition intervention with prevention and control of infectious disease is likely to be most effective for improving nutritional status of children.

Lack of access to safe, clean drinking-water and basic sanitation, as well as poor hygiene leads to diarrhea, mainly in children (266). As a result, community safe water source is recognized as an essential component to reduce child undernutrition (168) through reducing frequent infection (52). In addition, household level water treatment and safe handling during transportation, storage or consumption is considered as important water, sanitation and Hygiene (WASH) measures to improve health status, including preventing undernutrition. The current study suggests that household level water treatment practice has a positive significant effect on child height for age Z score. This implies that in addition to measures taken to increase accessibility of safe water sources to the community, education on household safe water handling practices should be strengthened to improve child nutritional status.

This study demonstrated that latrine utilization showed a positive statistical significant association with child height for age Z score and weight for height Z score. The current finding contradicts with a study in Ethiopia that latrine availability for the household did not show a significant association with child height for age Z score (52). The possible explanation for the difference might be related to measurements; in the previous study, only physical availability of the latrine was assessed, whereas in the current study, latrine utilization was measured using WHO recommended indicators (267). The above study suggests the importance of focusing on proper utilization of the latrine in addition to the construction of latrine facilities through changing the behavior of the users. The proper management of refuses generated from the household is very important measure of environmental health services in the community. Improper handling and management of household waste may create breeding places for different vectors and may expose children to infection. In the current study, disposing the household generated refuse anywhere showed negative statistical significant association with child height for age Z score and weight for height Z score.

7. Validity and generalizability

Evaluating the quality of epidemiological studies is very important to use the evidence for decision (268, 269). Epidemiological research quality should be evaluated in terms of both internally and externally to take the evidence for decision and policy making (268). The internal validity refers to the ability to measure variables correctly during the data collection process and focuses on what is supposed to be measured (getting the truth-value) (269, 270) and external validity refers whether the results can be generalized to different measures, persons, settings, and times (268, 269). Also, appropriate data analysis methods were choosen to increase validity of the results. SaTscan spatial analysis was done to identify the local clustering of child undernutrition and food insecurity which is the recommended method for identifying local clustering of the problem (120). Taking the heterogienity of child undernutrition and food insecurity, multilevel analysis was used which is the recommended approach to take into account the spatial dependency of the problem (72, 112, 206).

7.1. Internal validity

Internal validity is the extent to which systematic error is minimized during all stages of data collection process (269, 270) which is concerned with the study's ability to measure and it is a prerequisite for external validity (268, 269). In the current study, to ensure the internal validity of the study; the questionnaire was prepared after reviewing literature from credible sources, including standardized national survey tools (EDHS questionnaire) after adapting to the local context (112) and validated food insecurity access scale tools in the country (271). As a result the possibility of error that could be introduced in association with the measurement tool was minimized.

Information bias is a systematic error arising from inaccurate measurement (or classification) of the subjects of study variable (s) that can arise from the choice of tools one uses to measure as well as the assessor's attitude (269, 270). This type of error commonly occurs during data collection stage in the research process (269), including measurement bias, interviewer bias and respondent bias (270). In this study, to reduce measurement and interviewer biases, training with pretesting was given to data collectors on all measurement issues and interviewing techniques.

In the study, there might be respondents' bias due to food aid and other community support expectations in relation to food and nutrition assessment questions. This condition might over estimate the magnitude of food insecurity in the study area. Also, dietary assessment methods based on self-reports suggest that survey respondents who exhibit social desirability characteristics are more likely to underreport energy and fat intak (272). In surveys taking social desirability bias in to account is an important consideration during design stage of the study, doing the analysis, and interpretation of results. In the current study, to reduce the effect of the above potential biases, efforts were don during designing the questionnaire, and interviewing the respondents (272) .

Also, there may be respondent bias during household asset used to construct the wealth index and land size assessments due to fear of redistribution of land and finance contributions for developmental activities based on assets. This might reduce the amount of land and resource they have and make it very difficult to see the true association between the outcome and determinant factors. As a result, to reduce

the possible biases that might be introduced in relation to the above situations, detail explanations were given to the study participants on the objective of the study. In the study area, farmers used different units to measure the land size and amount of crop produced in different geographical location and the units were converted to the same unit to reduce misclassification bias before analysis. In addition, different variables were used to construct the wealth index to reduce the bias associated with household resources and some of them were assessed usingobservation. This might reduce the bias associated with under estimating the resources they had

Recall bias is one of the challenges that affect the internal validity of epidemiological studies (269). In the current study, some of the independent variables, like age of the child, maternal health service utilization during pregnancy, and child care practices including child immunization where there is no card were measured based on the mother recall ability which might introduce bias. To reduce the recall bias that might be introduced during recall, local events like festivals and holiday dates were used to assist respondents to remember the event of time. However, it is very difficult to resolve the problem totally and this might affect the true association of the independent and dependent variables. So, the interpretation of the current study result should take this in to account.

Data collectors and respondents understanding ability to questions and local terminologies used are among the possible sources of bias. Lack of clear understanding on the message of the questions by data collectors and respondents might affect the estimations we made on food insecurity and child undernutrition spatial analysis. Also, this might affect the true association between independent and dependent variables. So, to reduce the magnitude of the problem and to increase understandability of the questions to the respondents on the terminologies of food insecurity and other dietary behavior related questions, discussions were conducted with health extension workers, extension services providers and nutrition experts in the study area. Based on the discussion results, modifications were done and data collectors were informed during training about the common terminologies the community used locally.

Spatial location measurement errors might be introduced by inaccuracies in the positioning of spatial/geographical locations that will affect the outcome distribution (273). Geographical location measurement errors might be affected by different factors like the data collector measuring ability and weather conditions which might affect the velocity of GPS signals. To reduce the bias that might be introduced in the

current study, intensive training with practical demonstration was given to those who took GPS location data. Also, based on a recommendation (273) detection of at least four satellite signals were used to determine location of a household and in most cases five or more satellite signals were considered for greater precision to reduce the effect of the weather condition. However, in most highland areas, it was challenging to get more satellite signals due to high cloud density as compared to the low land areas. As a result, it might affect the validity of the exact location of the households in current study. To reduce the errors introduced due to the above situation, the data collectors maintain the minimum number of four satellites to register the location data.

Presence of multiple addresses of the studied households due to in or out migration is one of the challenges on spatial analysis of health problems (273). This problem effect on the current study is very low since the community in the study area has low in and out migration practice. To make the effect of the problem very minimal, participants who lived more than 6 months were considered for the spatial pattern analysis of food insecurity and child undernutrition. Another possible bias in spatial analysis is related to utilization of aggregated data at particular political administrative units which led the spatial scan statistic to not only lose power to detect food insecurity and child undernutrition clusters, but also to increase the false detection rate (274). To prevent the bias associated with use of aggregated data on the cluster detection, micro level resolution GPS location data at individual household level was considered in the current study.

The shape file used in the study was based on the local political administrative geographical boundaries. The spatial statistical analysis results may differ wildly according to the scale and pattern of the areal units used and this problem in spatial analysis is known as the modifiable areal unit problem. However, the modifiable areal unit problem might not be a problem for the current study since the spatial location data were collected at individual household level.

In the study, appropriate data analysis methods were choosen to increase validity of the results. SaTscan spatial analysis was done to identify the local clustering of child undernutrition and food insecurity which is the recommended method for identifying local clustering of the problem (120). Taking the heterogienity of child undernutrition and food insecurity, multilevel analysis was used which is the recommended approach to take into account the spatial dependency of the problem (72, 112, 206).

7.2. External validity

On the other hand, external validity is the ability to generalize study results to a more universal population (268, 269). There are three threats to validity of epidemiological research: bias, confounding, and chance (269). Bias is a systematic error that can distort the estimation of an epidemiological measure (269, 270). There are two general types of bias that should be remembered in epidemiological studies: selection bias and information bias (269, 270). Selection bias is due to systematic differences in characteristics between those who take part in a study and those who do not (269, 270).

Selection bias commonly happens during the design phase of the study (269). In the current study, samples were taken during the design phase to represent all agroecosystems which reduced selection bias across different agroecosystems. However, in the current study, households with underfive children were considered for the study. As a result, it is very difficult to give conclusion on food insecurity to the Zonal population. Similarly, if there are two underfive children in the household, the index child was selected to reduce the recall bias in relation to maternal and child care practice. Also, choosing the youngest child can show the recent nutritional problems. On the other side this might lead to selection bias which affects the generalizability to all underfive children in the study area.

None response bias is one of the selection biases when some group of individuals who are invited to the study refuse or not able to participate in relation to specific characteristics to the outcome or risk factors (269). In the current study, the role of selection bias has minimal effect because the response rate was very good (above 96%). To reduce the effect due to none respondents or incomplete questionnaire, 5% none response rate was added as a compensation. Another possible source of bias is related with volunteer based study participant selection (269). In the current study, the study population was selected using probability sampling method using multistage cluster sampling technique. The whole eligible study participants were considered within the cluster. As a result, voluntary study participant related bias in the current study is unlikely to occur. To reduce the errors associated with multistage cluster sampling instead of simple random sampling, a design effect of 1.5 was considered to increase the power of the study through increasing the sample size.

In epidemiological studies, chance has a role in explaining the observed association and should be assessed before making inference (269). In the current study, the possibility of chance as an alternative explanation for the observed result's was evaluated using the statistical significant test using the recommended p value less than 0.05 *(objective I-IV)* or not crossing one (null value for Odds Ratio) *(objective III)* or zero (null value for regression coefficients) *(objective IV)* at 95% confidence level. A large sample size determined using scientific sample size determination method was used to reduce the possibility of the associations and significant clusters due to chance in the current study. In addition, approporaite epidemiological methods, including the spatial analysis using the recommended SaTScan spatial analysis to identify local clustering (120) and multilevel analysis after checking basic assumptions were used. These approaches have the potential to increase the validity of the study.

To be a confounder, the third factor must be associated with the exposure and, independent of that exposure, be a risk factor to the outcome (269). The observed relationship between the exposure and outcome can be attributed, totally or in part, to the effect of the confounder (269). Confounding can lead to an overestimate or underestimate of the true association between exposure and outcome and even can change the direction of observed effect (269). Randomization, restriction and matching during the planning and designing stages and stratified and multivariable regression during the analysis stage can be used to control confounders (269). In this study, multilevel mixed effects linear regression and multilevel mixed effects ordinal regression analysis techniques were chosen to control for potential confounder variables during identification of determinant factors. This method of confounder control was chosen because of the large number of determinant factors considered in the current study. Therefore, the effect of confounders on the current study is minimized and thus; the findings of the current study can be generalized to similar population elsewhere.

8. Strengths and Limitations

8.1. Strengths

One of the major strengths of this study was the use of different methods to understand food insecurity and child undernutrition problems. The study used the application of geographical information system to identify the spatial patterns of food insecurity and child undernutrition. The spatial scan statistics is one of the methods which is highly efficient in identifying local clusters with good accuracy and can help researchers to evaluate and early detection of the problem and to allocate resources based on need (200). As a result, using the application of SaTScan in the current study can be mentioned as one strength of the current study.

The second strength is related to the application of multilevel analysis to identify individual and community level determinant factors of food insecurity and child undernutrition. Multilevel analysis has emerged as one analytical strategy that allows the simultaneous examination of group level and individual level determinant factors. Multilevel mixed effects modeling, is very important to control, for unexplained variations and that prevents the misleading association due to correlation within a cluster, which enables to overcome the limitations of the standard regression analysis done before (72, 112, 205, 206). So, the application of appropriate statistical modeling can be as well considered as the strength of the current study.

Also, this study is an agroecosystem characteristic linked community based cross sectional survey. Linking shared environmental characteristics with population based survey is one of the strongest investigation approaches to analyze causality in non-experimental studies (75). This agroecosystem linked to community based survey can give information to build sustainable food system. The use of large sample size with high response rate can give high statistical power to infer the findings to the source population, and this is also the strength of the study.

The other strength of the study is related to the physical observation of environmental health conditions. Most of the previous studies consider only latrine availability as factor for child undernutrition. However, the physical presence of the facility by itself might not indicate the true association with child undernutrition indicators due to self-reported social desirability bias. Household proper latrine utilization was assessed using recommended proximate indicators of latrine utilization using observation check list (275). Also, to reduce social desirability bias in relation to proper refuse disposal practice and housing condition, they were assessed using observation check lists.

8.2. Limitations

The cross sectional nature of the survey, which makes it difficult to see the temporal variation under different seasons, is one of the major limitations of the survey. Especially prevalence and spatial distribution of acute child undernutrition and household food insecurity might vary seasonally. Also, this study is limited that clusters in the spatial analysis are assumed to be circular and dissimilar in size to areas within a given cluster boundary. This could result in the exclusion or inclusion of clusters that register excess or less risk to food insecurity and child undernutrition.

Because of the nature of the study, recall bias is also a potential limitation of a cross-sectional survey. To reduce the problem, various scientific procedures have been employed to minimize the possible effects, including interviewing the mother who is mostly responsible for care of the child and feed the family and using local festival and holydays to identify the time of event.

Another limitation of this study is related to the proportionality of the sample based on agroecosystem type, since we did not have evidence on the size of the households or number of underfives in each agroecosystem category. This may affect the estimation of food insecurity and child undernutrition. The conceptual framework considered for the current study has three levels which suggest three level analyses. However, the sample design at third level considers agroecosystem with five categories as a cluster. This number of clusters is not suitable to apply three level multilevel analysis and only a two level multilevel analysis was considered.

9. Conclusions

In conclusion, the overall prevalence of household food insecurity was very high. The problem showed spatial variation based on agroecosystem characteristics. Households from hilly and mountainous highlands and lowlands of the Abay Valley were significantly identified as risky areas for household food insecurity compared to midland plain agroecosystems. Similarly, the overall magnitude of childhood stunting, underweight and wasting among under-five children were found to be very high with geographical variations across different agroecosystems. Lowlands of the Abay Valley and hilly and mountainous highlands had higher prevalence of child undernutrition compared to midland plain areas.

The spatial SaTScan analysis showed clustering of food insecurity and child undernutrition. The spatial variation of food insecurity and child undernutrition in the Spatial SaTScan analysis were observed in the multilevel mixed effects regression after adjusting for individual and community level determinant factors. The study showed heterogeneity in the magnitude of household food insecurity and child undernutrition after adjusting for both individual and community level determinant factors in the multilevel analysis. This suggests the need for further spatial analyses concerning the potential factors which influence the spatial distribution.

The determinant factors of food insecurity and child undernutrition operating at individual and community level play a statistically significant role in determining food insecurity and child undernutrition in the study area. The current study have important policy implications which suggest that the challenge to reduce food insecurity and child undernutrition goes beyond addressing individual factors, and requires a better understanding of contextual determinant factors.

Agroecosystem characteristic was found to be one of the community level determinant factors of household food insecurity. Households from the most hilly and mountainous highlands and lowlands of the Abay Valley were more likely to be more severe food insecure

compared to midland area communities. In addition, being male headed household, higher husband educational status, having additional income source, application of fertilizer on the farmland in the survey year, better amount of crop production in the survey year and household's larger land size were identified as independent determinant factors of food insecurity, enhancing better food security.

Also, both individual and community level factors had a significant role in determining child height for age Z score and weight for height Z score. Children from the midland area communities had a better nutritional status compared to hilly and mountainous highlands and lowlands of the Abay Valley. In addition, number of under five children in the household, mother ANC follow up, child immunization status, breast feeding initiation time, maternal nutritional status, household food insecurity, household dietary diversity, presence of diarrheal illness two weeks prior to the survey, household refuse disposal practice and proper latrine utilization showed a statistical significant association with child weight for height Z score. Similarly, child sex, child age in months, number of under five children in the household, child immunization status, breast feeding initiation time, maternal nutritional status, household dietary diversity, household level water treatment practice, diarrheal illness, proper household level refuse disposal practice, and proper latrine utilization showed a statistical significant association with child height for age Z score.

The multilevel analysis implies that there are unmeasured determinant factors other than those included in the analysis that are causing the clustering of food insecurity and child undernutrition. The presence of spatial heterogeneity in food insecurity and child undernutrition suggests further investigation of left out determinant factors. As a result, food insecurity and child under nutrition variation should be promoted in public health research as efficient means of quantifying the importance of the higher level factors for understanding disparities in food insecurity and child undernutrition.

In summary, the spatial variations and determinant factors of food insecurity and child undernutrition in the current study are in agreement with studies and at the same time not in agreement with other studies in the country and elsewhere abroad. In part this variation could be explained the role of determinant factors that influence food insecurity and child undernutrition might vary contextually from area to area.

Another possible explanation for the difference might be associated with the methodological variations across studies, including but not limited to the study design, sample size, sample selection and analysis methods used.

10. Recommendations

To policy and program level

- It is recommended to strengthen the existing efforts to reduce the high level of food insecurity and child undernutrition in the study arear through designing context based interventions.
- The linkages of Agriculture, Nutrition and Health including education should be emphasized in intervention strategies in the study area.
- The current study area, burden specific policies are recommended which can be implemented on a priority basis, keeping in view the nature of inequality in food insecurity and childhood undernutrition problems across the agroecosystems.
- Water, sanitation and hygiene interventions should get the attaention of governmental and non governmental organizations which are working
- Policy and intervention strategies aiming at mitigating food insecurity and child undernutrition should address the effects of lower level and community level determinant factors using individual/household level and geographical targeting, respectively.
- The existing food insecurity and child undernutrition interventions must consider micro level spatial variation in planning and resource allocation to reduce the overall burden of the problem.
- The impact of the agroecosystem characteristics on food insecurity and child undernutrition should be fully understood by the community, program implementers and policy makers during planning and community mobilization activities.
- Food insecurity and child undernutrition intervention strategy and planning designed using aggregated data from the Regional or Zonal level data as evidence may not indicate the true picture of spatial distribution of the problem. So, program level planning should take in to account micro level variation in designing strategies and allocating resources.
- Agroecosystem based sustainable food insecurity mitigation and child undernutrition intervention strategies should be given due attention.

To the Academia research institutes

- In rural communities, where household food consumption depends on own food production from the farmland, the burden of food insecurity and child undernutrition varies seasonally. Understanding temporal variation of food insecurity and acute child undernutrition, in addition to spatial variability in different agroecosystem areas will guide focused interventions. So, further research is recommended to address the spatiotemporal patterns of food insecurity and child undernutrition.
- To fully understand determinant factors of food insecurity and child undernutrition, program level nutrition sensitive and specific interventional studies are recommended.
- Further agroecosystem linked spatial analysis of food insecurity and child undernutrition is recommended to validate the current study results in different geographical locations.
- Researchers should focus in searching for additional risk factors that might account for the unexplained variance of household food insecurity and child undernutrition.
- The effectiveness of different developmental activities like, irrigation access, access of health services, all season road and market in mitigating food insecurity and child undernutrition shall be evaluated using advanced epidemiological study designs.
- Further follow up study is recommended to evaluate the effects of neighborhood and shared environment on food insecurity and child nutritional status.
- To understand the contribution of spatial analysis results evidence in influencing public health policy to mitigate food insecurity and child undernutrition through geographical targeting interventions shall be tested using interventional studies.

To the community

- Since the sanitation situation is one of the strongest predictors of child undernutrition, the community should work to improve the situation using local social and religion institutions.
- Agroecosystem is one of the important factors influencing food insecurity and child undernutrition. As a result, creating healthy ecosystem should be taken as one strategy by the community to improve the food security and reduce child undernutrition.

- The farmers should enhance agricultural inputs use to increase crop production to secure household food consumption
- Crop diversity should be taken as one strategy to increase dietary diversity at the household level.
- Child feeding and care practice practices in the community need improvement

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