Evaluating the level and dynamics of food insecurity in Lake Tana Sub-Basin, North-western Ethiopia

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Ph.D. proposal

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Abstract

Food insecurity is the incapability of households/individuals to obtain enough, nutritious, and socially acceptable food to a healthy life. The problem is determined by the level of their exposure to hazards and their ability to cope with the changing of situation. In the 2000s, 2011 and 2015 estimated 15, 8.5 and 10.1million people of Ethiopia were highly threatened by drought respectively. The problem varies from one area to another depending upon the agroecology, topography, and availability of the natural resources. Complex sets of factors are responsible for food insecurity. i.e. high population pressure, land fragmentation, erratic rainfall, rugged topography, over cultivated land, deforestation, limited off-farm employment, and deteriorating socio-economic conditions. Climate change with inconsistency in rainfall and temperature increases the exposure of the people to food insecurity, poverty and health risks. Since agriculture is the most promising means of livelihood strategy, soil degradation also plays a key role by reducing the average agricultural outcome and increasing the farmer's exposure to food insecurity. Millions of tons of productive soil and nutrients depleted due to soil degradation especially from the highland part of the country where the study area is situated. This, in turn, cause for the decline of crop productivity and enforce farmers to affect other ecosystems in search of productive farmlands. To reduce the problem of food insecurity and achieve the goal of zero hunger in 2030, understanding the multidimensional nature (availability, utilization, access, and stability) of food insecurity is unquestionable. It cannot be evaluated and addressed using one or two drivers and an indicator. Therefore, this study proposed to evaluate the level and dynamics of food insecurity in Lake Tana sub-basin, Ethiopia by linking various drivers to capture the multidimensionality of the problem: household's socio-economic, physical and climatic drivers. HFIAS, DDS, and CSI will be employed to understand the level of farming household food insecurity conditions in various dimensions. To address the impact of climate change, and soil degradation on the wellbeing of households in the study area and identify exposed areas, Remote sensing plays a significant role. It suggests a series of returns like a fairly near real-time report, consistent data, and source of spatially explicit data together with ground truth to assess and monitor hazards. To accomplish the objective various type of time-series satellite images, meteorological data, household surveys, and soil samples will be used to address the problem. Different indices of drought (SPI and SMDI), non-parametric tests, model (Daily based Morgan Morgan Finney model) and statistical analysis will be used to assess the spatial and temporal aspect of drivers, to estimate the loss of soil, and understand the linkage between factors and evaluate their contribution to the household food insecurity in the study area. In that way, the study will contribute a lot to how to use different types of food security indicators to capture all the dimensions, drought index, model, and satellite images in the assessment of food insecurity. In addition, It will add significant value to food security literature in the country.

Key words: SPI, SMDI, DDI, HFIAS, CSI, Daily based Morgan Morgan Finney Mode

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List of Abbreviations

CSA	Central Statics Agency
CSI	Coping Strategy Index
DDS	Diet Diversity Index
DEM	Digital Elevation Model
DMMF	Daily Based Morgan Morgan Model
FAO	Food and Agricultural Organization
FDRE	Federal Democratic Republic of Ethiopia
HFIAS	Household Food Insecurity Access Score
HHs	Households
IPCC	Intergovernmental Panel on Climate Change
MoA	Ministry of Agriculture
OCHA	Office for the Coordination of Humanitarian Affairs
OKP	Orange Knowledge Programme
SMDI	Soil Moisture Deficit Index
SPI	Standardized Precipitation Index
USDA	United States Department of Agriculture
WFP	World Food Program
WHO	World Health Organization

1. Introduction

1.1. Background

According to Food and Agricultural Organization (FAO) (1996), food security is a condition when people have physical and economic access to enough, and nutritious food for a healthy and productive life whereas food insecurity is the situation of uncertain availability of safe and nutritionally adequate food (Coleman-Jensen, Rabbitt, Gregory, & Singh, 2016). It is the incapability of households/individuals to acquire adequate food to remain healthy. In developing countries, food insecurity is a common phenomenon. It is the result of the complex interaction between ecological, social, political and economic events and processes (McGuire, 2015). It indicates that the assessment of food insecurity requires detail identification, investigation, and understanding of the susceptible elements at risk and society at large (World Bank, 2000). The level of susceptibility of community groups, households, and individuals to the food insecurity is determined by the level of their exposure to the risk factors and their ability to cope with the change of situation (FAO, 2010).

In 1996, about 840 million people were threatened by chronic food insecurity (FAO, 1996). This enforces the world countries to ratify the universal declaration that aimed to eliminate hunger and malnutrition by half in 2015. However, the problem is continuing as the fundamental challenges in different parts of the world. In 2003, about 854 million people in the world were undernourished (FAO, 2006). As stated by the World Hunger Education Service (2016) a total of 870 million people were estimated to have the problem of food shortage in 2010-2012. The absolute number of people in the world affected by chronic food deficiency estimated to have increased from 804 in 2016 to nearly 821 million (FAO, 2018). The situation is worsening in South America and most regions of Africa (FAO,2018). As indicated by FAO (2019) report, still 820 million people in the world are living with the problem of food shortage. This shows how much the problem is challenging the attainment of a proposed zero-hunger plan in 2030. It remains one of the important global development challenges.

Food insecurity is not a recent phenomenon in Ethiopia. It disturbs the wellbeing of the community staring from the early 1970s (Bekele & Abdissa, 2015). In 2000, 2011 and 2014 around 15, 8.5 and 2.7 million people of Ethiopia were highly affected by drought respectively (Endalew, Muche, & Tadesse, 2015; Gov, 2004, 2012, 2016). Again in 2015, around 10.2 million people and 238,761 children's required food assistance (Gov, 2016). In 2017, about 5.6 million people in the country require emergency food assistance. In addition, 2.7 million children, pregnant and lactating mothers require supplementary feeding, 9.2 million people need support to access safe drinking water, 1.9 million households need livestock support, and 300,000 children between 6-59 months old are targeted for the treatment for severe acute malnutrition in 2017 (OCHA, 2017). The situation is highly linked to recurring food shortages and famine in the country (FAO, 2010). A large portion of the population has been affected by chronic and temporary food insecurity. As indicated by the IPCC report (2019) about 8 million people of Ethiopia were food insecure due to erratic rainfall, and high food prices. This shows still the problem is deep-rooted and serious in the country and needs attention. Every year, a significant number of people in need of food assistance, some of them being chronically food insecure and others only affected by a transitory form of food insecurity (Kasie, 2017). Even in the normal year, the people in a different part of the country receive food aid from governmental and international organizations. It makes the country one of the aid recipients in the world (A. Teshome & Zhang, 2019).

In Ethiopia, the history of drought goes back to 253BC, However, the worst situation occurred in1984, 2003, and 2015. It put a great scare on the history of the country and still, millions of populations are suffering from the problem. El Niño induced drought in 2015, left millions of country population, particularly the farmers with failed crop and weekend their capacity to feed their family and the country as the whole. The production fall by 10-20% (1.9-3.7 million tons) (National Disaster Risk Management Coordination Commission, 2015).

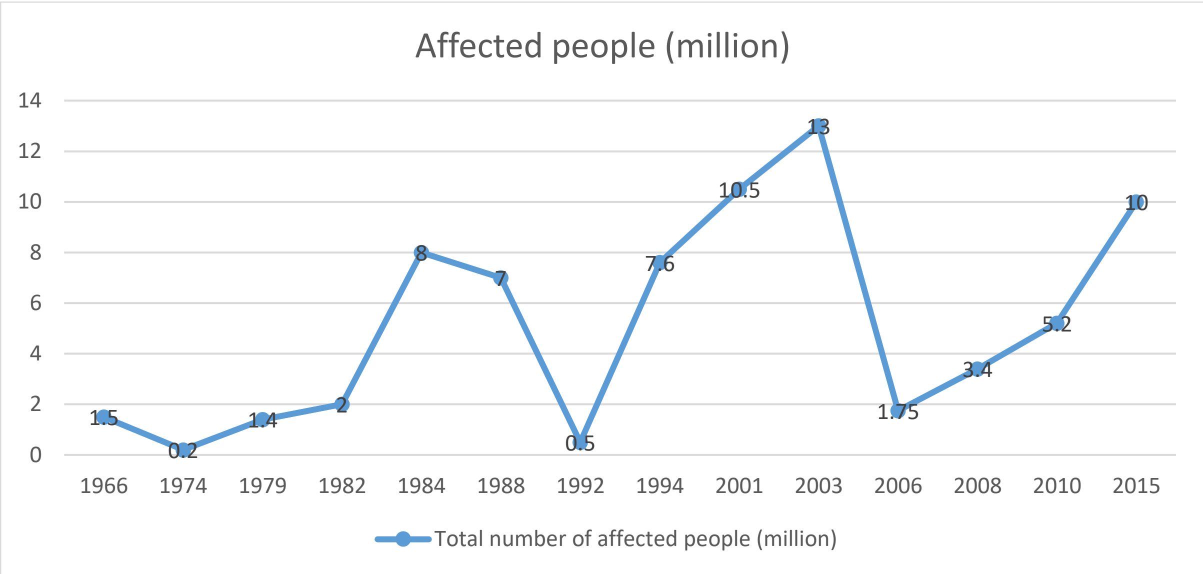

Figure 1.Drought trend in Ethiopia from 1966-2015
Source (Environmental Protection Authority, 1998; OXFAM, 2012)

Agriculture is the most promising and dominant means of livelihood strategy in Ethiopia, particularly in the rural area. It covers 37% of the Gross Domestic Product, 83.9% of foreign exchange earnings, and 72% of the labor force (FAO, 2018a). According to the World Bank report (2016), more than 80.08% of the country's population lives and engaged in rain-fed agriculture. However, due to various human and natural drivers, the sector is characterized by declining productivity and unable to feed the ever-increasing population. The sector is highly dependent on rainfall, dominated by smallholder, and relying on traditional technology and produce crops primarily for consumption. For instance, in 2018, eastern Amhara and southern Tigray seriously threatened by food shortage due to the reduction of the amount of *Belg* rainfall (short rainfall season from February-May). High variability of the onset and cessation of rainfall, reduction of the growing season, high food prices, localized crop failure, displacement and ongoing impact of drought from previous years are cause for the intensification of food shortage in the country (USAID, 2019).

Recently, most highland parts, particularly Amhara region, particularly the study area, have been seriously affected by unseasonal rainfall and desert locust. The rainfall continuous after the end of the summer rainy season (Kermit) and affect the growing stage of agricultural crops.

Around 56 districts of Amhara, Afar, Somalia, Tigray, and Oromia were affected by the problem (WFP & FEWS NET,2019). According to the Amhara region Agricultural office report, more than 75,000ha were affected. This might reduce crop yield at the household level and leads to another phase of food shortage in the area.

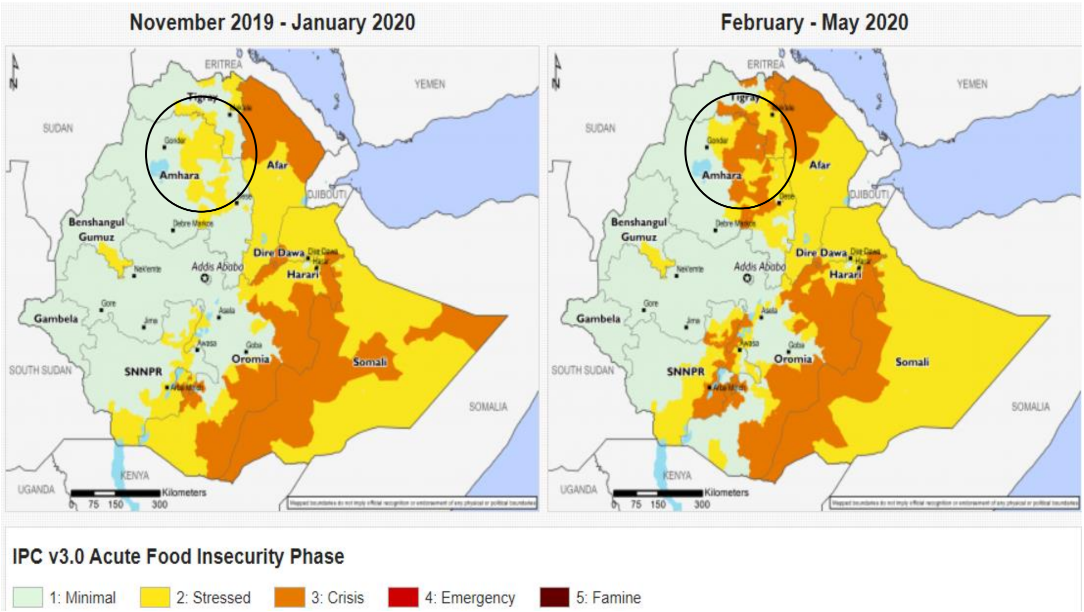

Figure 2.Food insecurity threatened area in Amhara region (Circle used to locate Amhara region)
Source: FEWS NET, 2019

As stated by Alinovi, Mane, & Romano (2010) food insecurity can be detected early using remote sensing output. It provides useful information on crop health, soil moisture condition, the impact of climate on agriculture, the amount of food grown locally/nationally together with field data (Brown, 2015). It enables decision-makers and other concerned bodies to formulate plans and strategies to reduce food insecurity. Therefore, this study planned to use those outputs to evaluate the level and dynamic of food insecurity in Lake Tana sub-basin.

1.2. Problem Statement

Agriculture is the mainstay of rural livelihoods in the Amhara region. Almost all sources of livelihood production and a significant amount of labour market are employed in the agricultural sector (Teshome, 2014). This livelihood is mainly reliant on a rainfed production system where minor changes in weather scenarios can cause profound disruption in overall production. With the frequent existence of weather shocks in the area, almost 14.8% of the community is reported food insecurity (CSA, 2014). Recurrent climate-related shocks (WFP & FEWS NET,2019), coupled with a loss of soil fertility emanated from prevalent soil erosion especially in rugged and mountainous terrain, exacerbated wellbeing of societal livelihood. Accordingly, a report by the World Food Program (2019) has indicated as 36.1% of the population in the region is earning below the national poverty line.

In the study site, an extensive list of studies has been undertaken under the main theme of food insecurity. Though they have brought many empirical findings on some aspects of food insecurity, this study strongly believes that still, the studies were not inclusive enough in terms of used indicators of food security and drought indices. Secondly, beyond climate variability, there is a broad interplay of a range of factors. Among these, soil erosion, land use cover changes were aspects that are less emphasized by previous studies. It strongly argued that, for proper intervention and sustainable livelihood planning, an inclusive study that looks into a multitude of physical, meteorological, and socioeconomic variables that affect food security should be well documented.

Soil erosion is an important factor that results in the loss of topsoil, reduction in crop yield, and food shortage. In the high land area with a slope ranging from 25 to 60%, the annual soil degradation should be between 12 to 42tons/ha/yr (Hurni, 1988). For instance, (Amsalu & Mengaw, 2014; Molla & Sisheber, 2017) have estimated the rate of erosion as 150.1-504.6, and 150-716 t/ha/yr respectively. Are these being true average erosion rates, the area would be quickly turned into bare land where production is impossible. Actual recent rates of soil erosion are not known.

The effect of soil loss on agricultural production is not immediate but long term. This makes quantifying the effect on food security not straightforward. Theoretically, soil loss of topsoil that is richer in organic matter than the subsoil has a long-term decline of fertile. Also, the water holding capacity of the soil decrease and if the degradation takes place thin soil on bedrock there is often an increase in stoniness and outcrop, rendering the soil unfit for agriculture. Later on, the area may change into bare land.

Taking these into consideration, the proposed study is going to investigate the level and dynamics of household food insecurity and its interplay with soil erosion and changes, rainfall variability and land-use changes through integration of socio-economic survey, meteorological observations and times series satellite imagery.

1.3. Objectives

The general objective is to evaluate the level and dynamics of food insecurity in relation to drought and soil erosion in lake Tana sub-basin, Northwestern Ethiopia.

Specific objective 1: To *quantify soil degradation in time and space and its effect crop production*

Research Questions:

1.1. Which parts of the study area are highly threatened by soil degradation?
1.2. What is the temporal change in erosion rate and is this related to drought?
1.3. How soil erosion and land cover of the study area are related?

Specific objective 2: *To assess the spatial and temporal variability of rainfall and its impact on the crop production of household*

Research Questions:

2.1. What is the seasonal and annual variability of rainfall in the study area and its relation to crop production?

2.2. How is the spatial and temporal drought variation analysis over different time scales?
2.3. Is there a relationship between early cessation, length of growing period and farm production of households?

Specific objective 3: ***To examine the food insecurity status of the farming households in lake Tana sub-basin***

Research Questions:
3.1. How is the food insecurity status of the households determined using multiple indicators?
3.2. How is the food security of households related to the crop production of their land?
3.3. What are the spatial relations between vulnerability for food insecurity and drought severity in the area?
3.4. What is the relation between household food insecurity and the land threatened by land degradation?

1.4. Conceptual Framework

As shown in Figure 3, the risk of food insecurity is the result of hazard and hazard probability, the exposure to it and the nature and the degree of vulnerability. Hazard refers to any disruption or stress that society may experience. United Nation Office for Disaster Risk Reduction (Wszolek & Pfeiffer, 2015), define it as a process/human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation. The disturbance may occur naturally/human-induced causes. Topographically, Amhara region as the whole, Lake Tana sub-basin particular (Fig. 4), is found in the high part of the country and the source of major rivers. This makes the area easily affected by soil degradation. Million tons of fertile soil eroded and results in the reduction of crop yield. In addition, due to climate change, the major sector of the area treated by the late or early coming of rainfall. It affects the sowing and germination of agricultural crops. In the end, it leads the farming households to affected by the decline of crop production.

Exposure directly refers to the community/household and their properties that are exposed to hazards. For instance, the household that has farmland in the area where has a steep slope, are more exposed to soil degradation than others then it leads to the loss of soil fertility and crop production. This makes the households to be exposed to the hazard. In the concept of exposure, the degree by which people or property are at risk is defined by how they are exposed. They might be exposed to the problem (IPCC, 2012).

In this study, vulnerability refers to the extent of the availability, access, and utilization of food and household farmlands to be exposed to the hazards. Various social, economic, physical and environmental factors are responsible for the exposure of households for the problem.

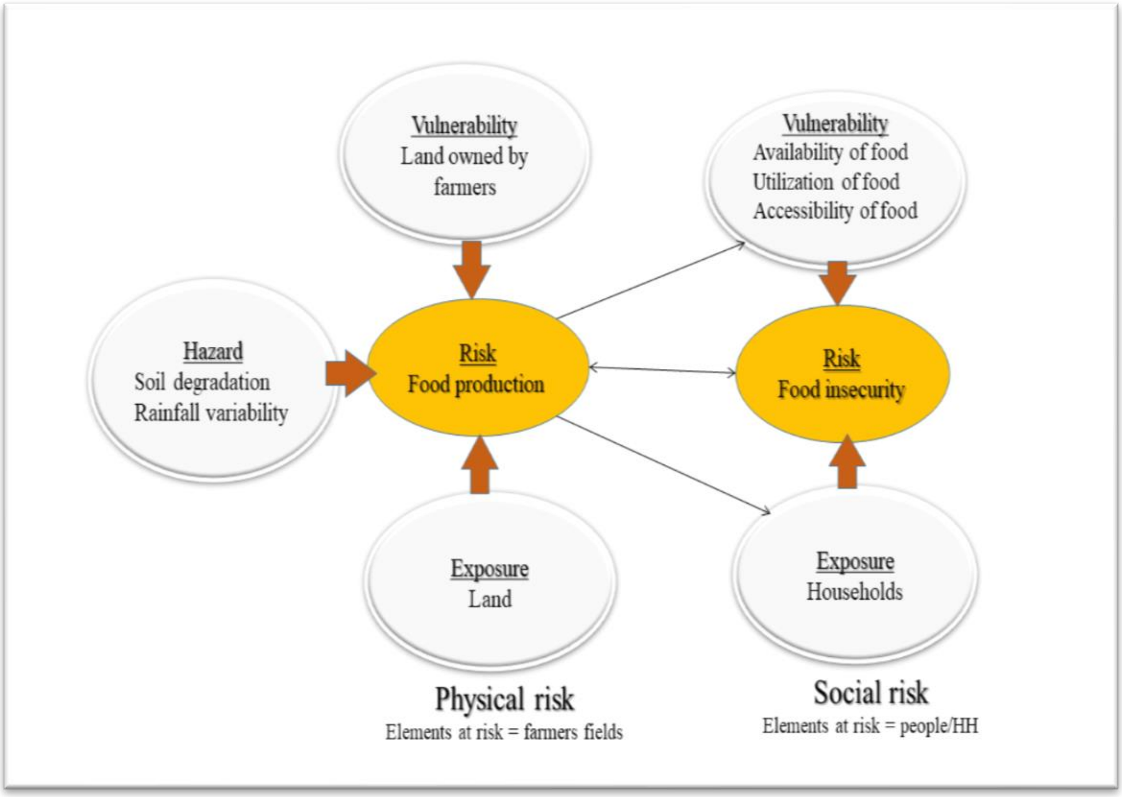

Figure 3. A framework to evaluate the level and dynamics of food insecurity

1.5. Significance of the study

To assure the livelihood of the society/households, attain the country's sustainable development goal of hunger, assess the existing and potential status of at-risk households, and monitor and evaluate programs and policies, studies on the issue of food insecurity play an inevitable part. This study will indicate the significance and explore the strength of employing different indicators of food insecurity and parameters (soil degradation, and rainfall variability) in addressing the issue of food insecurity.

Analyzing the problem of food insecurity from the vulnerability, exposure and hazard standpoint offers forward-looking and multi-dimensional means to search more applicable option to minimize it; the capability to manage it at various level so as to reduce the possibility of households being food insecure in the future; help to improve policy response to food insecurity and search policy options for minimizing vulnerability. Such type of assessment is going beyond to categorizing who is currently food insecure rather it focuses on the ex-ante food insecurity prevention interventions and ex-post food insecurity mitigation intervention. The result of this study is intended to be important for governmental and non-governmental bodies, development experts and policymakers, who are looking to know how to respond to the food insecurity problem by identifying the major determinant which is responsible for. Thus, the result will allow them to revise their documents and policies regarding food security to improve the life of the communities. Moreover, people will aware more about how to reduce exposure or cope with the problem.

3. Research Methodology

3.1. Description of the study area

This study will be conducted in Lake Tana sub-basin of the upper Blue Nile River, found in Amhara Region in the basaltic plateau of the Northwestern highland of Ethiopia (Song et al., 2018). Geographically, it is located between 10°58' - 12°47' N and 36°45'-38°14' E with a total area of 15,320 km^2 and average elevation 2025 m.a.s.l. The sub-basin is flat around lake Tana within a range of 1750 – 1850 m.a.s.l. It is the source of the Blue Nile River. As indicated by (Vijverberg, Sibbing, & Dejen, 2009), 7 permanent and 40 seasonal rivers feed the lake but, Gilgel Abay, Ribb, Gumera, and Megech are the major tributaries that contribute major runoff for Lake Tana.

The average mean rainfall ranges from 1280mm. The Monthly maximum mean rainfall is recorded during the summer season (rainy season) from June to September. The climate of the region is tropical highland monsoon. The sub-basin is one of the most populated areas with a population density of 250 people per square kilometer. The average landholding size of households is less than 2ha, which is comprised of small and fragmented plots (Abera, 2017). According to (Belete, 2013) around 4 million people are residing in the sub-basin. Agriculture is the major means of living for more than 80% of the population followed by other small economic activities like livestock rearing, local alcohol brewing, and small trade. It largely rainfall dependent, only the farmers who live around flood plains, Lake Tana, and Koga reservoir harvest some crops using residual moisture and water for irrigation respectively.

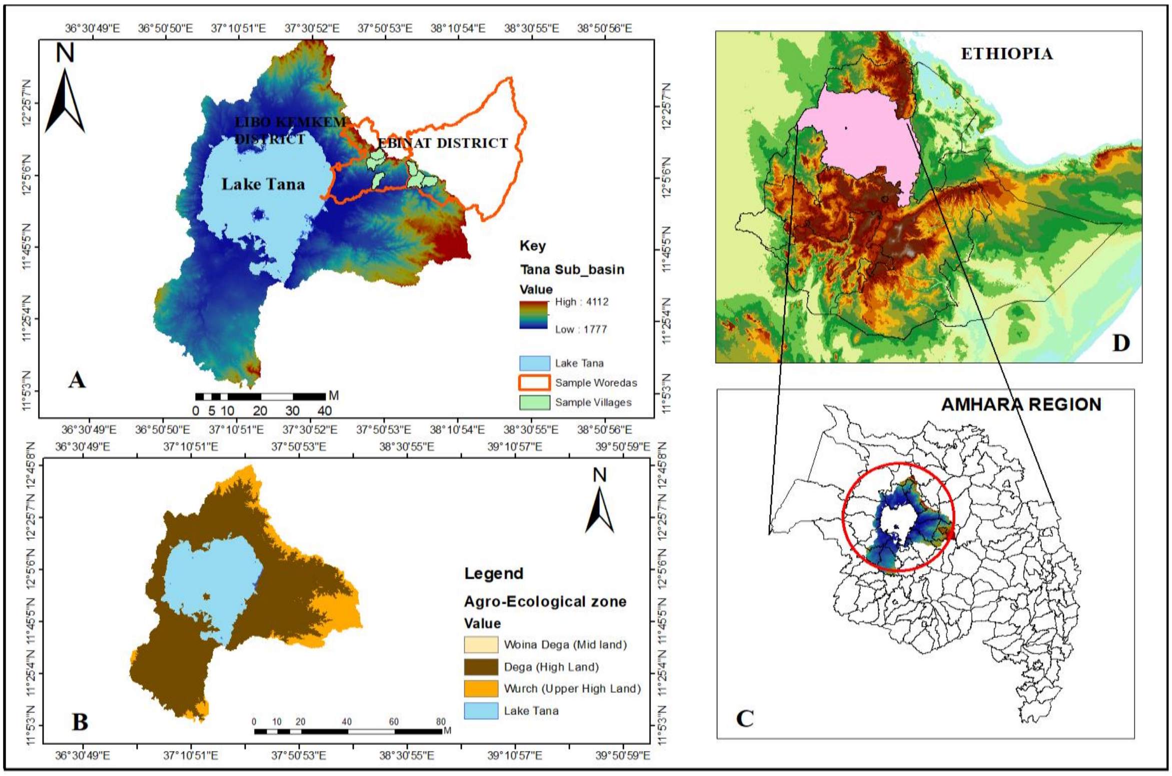

Figure 4.Study area map (A, Map of Lake Tana sub-basin and sample districts); (B, Agroecological zone of the study area). *Woinadega* for midland, *Dega* for highland and *Wurch* for upper highland; (C, map of Amhara region); and (D, Ethiopia in the eastern part of Africa).

3.2. Research Approach and Data Collection Methods

The research approach is an important body of study. It is a strategy that goes from abroad to a comprehensive method of data collection, analysis, interpretation, and discussion. (Chakraborty et al., 2014). It might be selected based on the investigator's experience, an issue being addressed, and the population being studied. In order to shape new insight and triangulate the results, the study will use a mixed research approach. It is the systematic integration of both qualitative and quantitative research methods and used to neutralize the weakness of each form of data.

To examine the multidimensional and complex nature of the food insecurity and understand the level of the problem in the study area, both primary and secondary data sources will be used. Household surveys, key informant interviews, and focus group discussions will be used to obtain information regarding farming household's socio-economic, level of consumption, diet, and dietary information, and coping strategies. Satellite images, meteorological, soil, and field data will be used in this study to address the physical and meteorological drivers of food insecurity. Data regarding crop yield of the study area will be obtained from the respective governmental offices.

3.2.1. Sampling Technique and Sample Size

In this study, a multistage sampling procedure will be used where it starts with the selection of district (Woreda) from Lake Tana sub-basin purposely based on their level of soil erosion and frequent occurrence of rainfall variability and food insecurity. This is known from the prior knowledge, secondary sources (woreda and other reports). The area is highly threatened by land degradation and unseasonal rainfall (see Fig 2). Therefore, Ebinat and Libokemekem districts will be selected, are part of the South Gondar zone in Amhara region (Fig. 4).

Secondly, using stratified sampling three villages (kebeles) from each district will be selected based on their agroecological zones (Wurch, and Dega) and deliberately one village from wurch (upper highland) and two villages (kebeles) from Dega (high land) agroecological zone will be selected. There is an assumption that the households who live within the same agroecological zone share the same livelihoods, land feature and climatic conditions (Atehnkeng, 2007). Accordingly, Darita, Mentagera, and Bira Abo from Libokemkem and Zhina, Mechena and Serawedir from Ebinat district will be selected. The total number of household heads in two districts is about 39,324 and 7205 in the selected villages (CSA, 2007).

As indicated by (Schinca, 2009), based on the asset that they have, farmland and livestock, food insecurity have a different impact on households. The household who have many plots of land and livestock could resist and not easily exposed to food insecurity in the future than others. The study plan to use the result of soil degradation estimation and the wealth of farming households to select the sample population. Therefore, sample households will be selected from severely as well as less threatened areas. The sample size is determined using (Kothari, 2004).

$$n = \frac{z^2 pqN}{e^2(N-1)+z^2 pq}$$

where N is the size of population which is the number of households, n represents the sample size for a finite population p is the population reliability (frequency estimated for a sample of size n), where p is 0.5 which is taken for all developing countries population and p + q = 1 e is the margin of error considered is 10% for this study and Z is 1.96 the level of significance. A total of 73 households will be used as sample respondents for the proposed study (temporary).

The sample for each village will be distributed proportionally based on their population size. A total of six focus group discussions will be conducted (one in each village) and the participants will be selected purposely from the different social groups (community elder, governmental officials, and women) in the study area. For key informant interviews, 18 interviewees (three from each village) will be selected from all sample sites purposively. The interview will be conducted with local elders, development agents, experts working in non-governmental organizations intervening on the issue.

3.2.2. Specific objective 1: To quantify the effect of soil erosion on crop production

In the highland area of the country, the estimated erosion rate is 130 and 35 tons/ha/yr for cropland and other land cover classes respectively. The northern part, where the study area is situated, is the most vulnerable area for soil water erosion than other parts of the country (Berry, 2003). This leads to the destruction of the biophysical characteristic of soil and influence crop performance. It disturbs the top and most productive part of the soil which threatens the level of food security status of the community. There are factors responsible for soil erosion process like topography, type of soil, land cover, surface condition, rainfall amount and intensity (Shrestha, Suriyaprasit, & Prachansri, 2014). Land-use change also highly accelerates the process of soil erosion (Naqvi, Athick, Ganaie, & Siddiqui, 2015).

Erosion Modelling

Based on their characteristics, there are three categories of soil erosion model *viz,* empirical, physical and conceptual. Process-based models such as EUROSEM (Morgan et al., 1998), LISEM (De Roo, Wessling, & Ritsma, 1996), EROSION 3D, WEPP, and ANSWERS (Beasley et.al., 1980) estimate soil erosion rates with well-defined and sophisticated physical equations of mass and momentum conservation laws. A conceptual model like Morgan–Morgan–Finney models use semi-empirical equations with a physical basis to assess annual runoff and soil erosion rates and are designed to possess advantages of both empirical and process-based models (Devia et.al., 2015). In addition, it has been successfully tested for functionality with a variety of climate regions and land use types (Vieira et.al., 2014).

In the model, there are two phases: water and sediment to estimate the loss. The water phase is determined by a soil water balance whereby the runoff is used to calculate the transport capacity used for erosion. The sediment phase uses the transport capacity of overland flow for flow detachment, combines this with splash detachment of rainfall to calculate the soil loss for a pixel or area. However, originally MMF is an annual erosion model, but this ignores the effects of extreme events and dry spells on vegetation cover and it is less suitable for areas that have seasonal rainfall like Ethiopia where a majority of soil erosion occurs due to intensive rainfall events. Therefore, Shrestha and Jetten (2018) created a daily based MMF model that uses daily rainfall, evaporation and a time series of vegetation cover derived from MODIS images. Because of its sensitivity to rainfall fluctuations and vegetation cover. We assume that the model can be well used to assess the effect of antecedent drought on erosion.

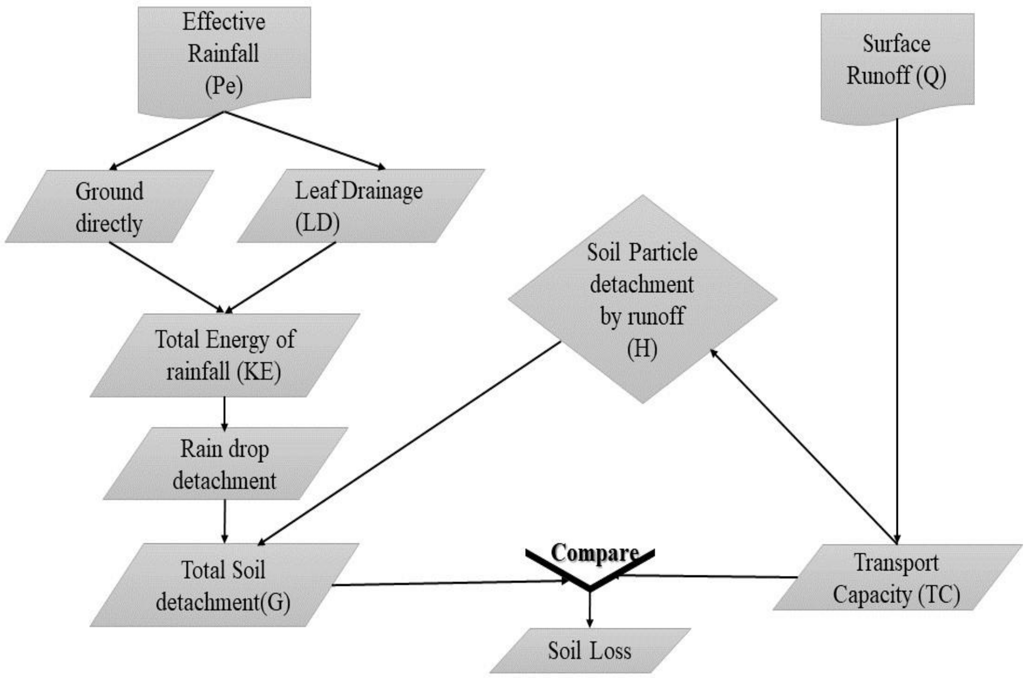

Figure 5.Flow chart depicting the methodology used in the DBMM model
Source: Shrestha and Jetten (2018)

To estimate the erosion rate in the area, the input data like daily rainfall (mm), digital elevation model (DEM) for slope map preparation, land cover, soil moisture storage capacity (Rc), soil texture, cohesion of soil surface (KPa), soil stoniness, porosity, bulk density, wilting point, field capacity, saturated hydraulic conductivity, soil detachability, ratio of actual to potential evapotranspiration (Et/Eo) and effective hydrological topsoil depth (EHD) and others will be used.

The data will be collected from a different source. Accordingly, meteorological data will be obtained from CHIRPS (ftp://ftp.chg.ucsb.edu/pub/org/chg/products/CHIRP/), soil data will be obtained Soil Grid (Hengl et al., 2014) or Agricultural office based on the parameter that needed by daily based MMF model, literature and empirical relation. Digital elevation model will be accessed from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) with a 30-meter spatial resolution to define the slope layer of the study area and MODIS and Sentinel image will be download from USGS with 30m spatial resolution to map the vegetation and land use/cover of the study area.

After the necessary image pre-processing, the Sentinel image will be classified into various classes using supervised classification under maximum likelihood algorisms. In order to assess the accuracy of the classification, a reference sample point per class (randomly) will be collected to compute the confusion matrix. The result will use as input data for the assessment of soil erosion modeling. Regarding the soil data, after it obtained from the soil Grid, it will be organized for further analysis based on the model demand. After the rainfall data accessed from the internet, the daily maximum. minimum and average will be calculated.

Temporal change in erosion and its relation with drought

The deterioration of soil property and loss of organic matter is not an instantaneous problem. Rather it is a slow process and may continue for along without noticed by the farmers/land user. It affects the land until a possible land management measure carried out and if not, the area may be changed into bare land. Again, it creates another burden on farming households and the country population as a whole. In the study area, together with other factors like population density, land and holding, is the major cause for the decline for agricultural production and food shortages. It also causes the reduction depth of Lake Tana which is the source of Blue Nile, out of this study. Investigating the temporal change of erosion in the area is important to its risk in different periods and design plan to minimize the effect. Therefore, the change will assess by the daily base MMF model from 2015-2020. Here, daily rainfall, soil, satellite image will use as input data.

Relationship between Soil degradation and land use/cover

Land use/cover is highly interrelated with soil degradation. It determines the rate of soil loss due to erosion. The increase in the population followed by land-use change play a key role in soil degradation in the area. The problem is highly threatening the highland part of the country in which the study area is situated. The area is most productive and characterized by rugged topography, densely populated and dominated by intensive cultivation (Mushir & Kedru, 2012). Studies indicated that almost all land units around Gojjam area (where the study site situated) have been converted into cultivated land (Zeleke, 2000). It makes the area vulnerable to soil degradation. Therefore, this study proposed to use ordinal logistic regression (Scott, Hosmer, & Lemeshow, 1991) to assess the integration between land use/cover and soil erosion.

To link and understand the combined effect of socio-economic, physical and meteorological factors on the food security situation of the households/society, a multivariant logistic regression model will be used. Therefore, diet diversity, coping strategies, household food insecurity access score, drought, crop yield, and soil degradation will be used as the independent variable and (in)food security of households as an independent variable. The result will be shown as the condition of household food security in the study area.

3.2.3. Specific objective Two: Assess the impacts of rainfall variability on the production of agricultural crops

Rainfall Variability

Climate change is manifested by the variability of rainfall and temperature spatially and temporally. The variability is revealed by the increasing/decreasing in its amount from the normal, early/late arrival and continues beyond the expected time. This variability also has a great impact on the water and agricultural sector, especially in developing countries. The seasonal and annual rainfall fluctuation has an impact on agricultural productivity. It is cause for severe drought, crop failure, soil degradation, and increment of temperature. In terms of meeting the water necessary for agricultural crops, rainfall plays a great role especially in the area where irrigation technology underdeveloped.

In the study area, the majority of the population lives in rural areas and highly engaged in rain-fed subsistence agriculture (Berry, Olson, & Campbell, 2003). This makes the farmers highly exposed to the reduction of crop production due to the erratic nature of rainfall. As stated by Sunil & Sujeet (2015) erratic rainfall and drought have been the major cause of food deficit and famine. The impact of rainfall variability on crop production varies with the types and properties of soil, and types of crops cultivated.

Understanding the variable nature of these elements is advisable to improve the productivity of farming households, make a wise decision on agricultural water management, locate drought phone area, and achieve sustainable development. Rainfall and crop production will be used to assess the variation as well as its impact on the wellbeing of the households. To assess the rainfall variability, the study proposed to use the non-parametric Mann-Kendall trend test (Bevan & Kendall, 1971). This test is widely used, less sensitive to missing values, and robust in the assessment of trends (Siraj, Mohammed, Bam, & Addisu, 2013).

Rainfall variability and crop yield relationship

The irregular nature of rainfall has an immense impact on crop production. Therefore, having a better understanding of the relationship between rainfall variability and crop production is good to minimize its effect. Annual crop production data spanning a 30-years period from 1990-2020, will be obtained from the central statistical office. It used to establish trends in interannual and inter-seasonal rainfall distribution.

Examine the relationship between rainfall onset, cessation, and its impact on crop yield

Providing information on the rainfall onset, cessation and length of the growing season is an important thing to maximize agricultural productivity. It enables the farmers to plan the right sowing date, use less risky crops, and plan their activities. The false start season of the growing season might lead to crop failure and food shortage. Unlike other economic sectors, agriculture needs timely and accurate information on rainfall onset, and cessation, especially in the area where rain-fed agricultural dominant.

The onset of rainfall will be measured by investigating the depth of rainfall on the top-up to 0.25m field capacity during the maximum of 4days using the DEPTH method. As indicated by (Raes, Sithole, Makarau, & Milford, 2004), 20% probability level of soil moisture are acceptable to evaluate rainfed agriculture. Cessation is quantified by considering the date when the water stress in the root zone of the dominant crop exceeding a threshold value. Soil water content in the root zone will be simulated using the water soil water balance module of RAIN software by taking the daily rainfall data as an input. The dominant crop (Teff and wheat) will be used to examine the cessation period in the study area. Water stress will be assessed by using the water stress coefficient (Ks) (Allen, Pereira, Raes, & Smith, 1999). The length of the growing season is the difference between the onset and cessation of rainfall and their relationship will run using RAIN software.

In this activity, the rainfall onset and cessation of the study area will be assessed from 1990-2020. It used to understand whether the number of rainy days increases or deceased and the early/late fall of rain. Summer season is the only rainy and sowing period. However, the starting and ending of rainfall show variability. It affects crop productivity of the area. Investigating information regarding it, useful for the farmer to plan, select appropriate crops, save their time and efforts. In addition to meteorological data, information that will collect from a farmer during the interview will be used to narrate it

Analyzing drought over a different period

Drought is the slow-moving and most challenging form of natural hazard. Unlike others, determining of the onset, termination, intensity, and duration of drought is not an easy task and vary from place to place based on topographic and climate condition of the area (Mirabbasi, Anagnostou, Fakheri-Fard, Dinpashoh, & Eslamian, 2013). It occurs due to the shortage of water for a long period of time over a wider area and led to crop failure, food shortage, and poverty.

Standardized Precipitation Index (SPI)

There are different types of indices that used to monitor, quantify and identify the condition of drought. In this study, the Standardized Precipitation Index (SPI) (Thomas B. McKee, 1993) and soil moisture deficit index (Narasimhan & Srinivasan, 2005) will be used to assess the meteorological and agricultural drought in the study area respectively. Over the other drought indices, SPI is widely used, probabilistic, simple, spatially consistent, and preferred to simulate drought both in spatial and temporal scale. It is important to achieve risk management activities in the area of agricultural production. It suggested by the World Meteorological Organization as the best index to monitor meteorological drought (Hayes, Svoboda, Wall, & Widhalm, 2011). Thus, this study aimed to use the temporal scale of -3, -6 and -12 months to investigate the situation of drought in short, medium and longer ranges from 1990-2020 in the study area. The time series SPI will be generated by using the R for Statistical Computing program (R Core Team 2019, 2019) using the data that obtain from CHIRPS.

Soil Moisture Deficit Index (SMDI)

In the study area, food insecurity could be directly associated with agricultural drought. Due to its dependence on soil moisture and water, agriculture is the first sector to be affected by the onset of drought in the study area. However, there is debate on whether meteorological drought indices can be effectively monitored agricultural drought (Halwatura, McIntyre, Lechner, & Arnold, 2016). As indicated by Hao & AghaKouchak (2013) the shortage of precipitation may not be the only cause for agricultural drought. Therefore, in this study, the soil moisture deficit index will be used to assess agricultural drought in the area.

To compute the potential evapotranspiration, the Hargreaves method will be used (Sivapravasam, Murugappan, and Mohan, 2011). It requires radiation and temperature as an input.

$$PE = 0.0023 * R_n * (T_{mean} + 17.78) * (T_{max} - T_{min})^{0.5}$$

where PE is the potential evapotranspiration (mm/month); R_n is the solar/extra-terrestrial radiation (MJ m^{-2} $month^{-1}$); T_{max} is the maximum monthly air-temperature (ºC); T_{min} is the minimum monthly air-temperature (ºC); and T_{mean} is the mean monthly temperature (ºC). Monthly potential evapotranspiration (ET_0), dominant soil type and soil depth with 60cm will be used to compute monthly soil water content (SW_i) using Aqua crop model 4.0v. Then the monthly soil deficit will be computed as

$$\mathrm{SD_i} = \left(\frac{\mathrm{SW_i} - \mathrm{MSW_i}}{\mathrm{MSW_i} - \mathrm{SW_{mini}}}\right) * 100, If\ \mathrm{SW_i} \le \mathrm{MSW_i}$$

Where, SD_i is monthly soil water deficit, SW_i is mean monthly available soil water in a soil profile in mm, SW_{mini} is long-term minimum available soil water in the soil profile in mm, SW_{max} is long-term maximum available soil water in the soil profile in mm, and MSW_i represent the long-term median available soil water in the soil profile. SMDI will be computed based on SD_i as

$$\mathrm{SMDI}_j = 0.5{*}\mathrm{SMDI}_{i-1} + \frac{\mathrm{SD_i}}{50}$$

Where, SMDI_j is soil moisture deficit index for a jth week/monthly, SD_i is soil moisture deficit (%) for the *i*th month of a particular year, and SMDI_i is the soil moisture deficit for *i*th month week. Lastly, the spatial distribution of severe drought will be calculated after the sum of drought severity (DI_d) value below zero for each year and probability (P) of drought occurrence will be computed by dividing the number of months that have the value (DI) less than zero by 12 months of the year.

$$S = \sum_{N=1}^{N} \mathrm{SMDI}_d * P$$

Where, S is annual drought severity for a defining year, $\mathrm{SMDI_d}$ is the sum of drought severity values below zero during a particular year, and P is the probability of drought occurrence for the defined year.

Due to the presence of limited meteorological stations, inconsistency/missing value and limited length of observation, the study planned to use satellite-derived rainfall and temperature data to assess the problem. Therefore, Climate Hazard Group InfraRed Precipitation with Station data version 2.0 will be used at 0.05º resolution (5.4km) which is available in the Tagged Image File Format(tiff) file format (ftp://ftp.chg.ucsb.edu/pub/org/chg/products) (Funk et al., 2015). It is available from 1981-present provides that relatively is finer than other satellite-based precipitation data both temporally (daily, decadal, and monthly precipitation data). It combines combined data from satellite images and ground stations and is useful for drought monitoring and climate change assessment. Such data plays a vital role particularly in geographic areas where long-term data are not available.

Data regarding the crop yield of dominant crops in the area from 1990-2020 (tentative) will be acquired from the regional Ministry of Agriculture. Then, the data will be converted into yields (tons/ha) so as to understand the impact of rainfall and temperature variability on crop production.

3.2.4. Specific objective one: Examine the food insecurity status of the farming households in the sub-basin

Currently, food security indicators are widely used in measuring the level of food insecurity at the national and local levels. Because they enable identification of the household with the problem, address facets of food security (see appendix 8.1), examine food insecurity and show the gap on food policy (Daniel Maxwell, Coates, & Vaitla, 2013). This sub-objective will examine the level of farming household's food insecurity using multiple indicators so as to measure the pillars and its relationship between crop production, drought and soil degradation. The method per specific objective is given below.

Household Dietary diversity score

Dietary Diversity Score is a robust and easy index to measure the diversity and quality of food consumed by each household. It computed by classifying the food items (types) into the food group for the last specific time/days. As proposed by FAO (2010), around 12 food group are specified to measure it: cereals, root and tubers, vegetables, fruits, meat, poultry, and offal, eggs, fish and seafood, pulse/legumes/nuts, milk/milk product, oil/fat, sugar/honey/and miscellaneous. The score ranges from 0 to 12, where 0 means no food was consumed and 12 indicate high dietary diversity. Basically, there is no standard cut-off line to determine adequate or inadequate dietary diversity. FAO (2010), suggests guidelines to classify the household as low (0-3 foods), medium (4-5 foods), and high (6-12 foods) dietary diversity.

Regarding the recall time, some suggest the previous 24hrs as the best to measure the diet diversity of a given community (Kennedy, Regina, Chiara, Nantel, & Brouwer, 2007) and 1-15days recall (Ruel, 2003). This study planned to use 7days recall to measure the dietary diversity score of farming households. To obtain accurate data and come up with an acceptable result, the survey will be conducted twice (post and pre-harvest season). Post-harvest is the period when food is relatively cheap and plentiful while pre-harvest when food is expensive and scarce. In the study area, the number and quality of food consumed by the households are quite variable in different seasons.

Control Strategies Index

This index assesses the behavior and methods used by the households to reduce the problem while they face food shortage. It is simple, easy, low cost and quick in measuring food insecurity (Maxwell et al., 2013). It mainly depends on the response given by the households /individuals about their coping strategies. As indicated by (Maxwell and Caldwell, 2008) measuring CSI depends on the question, "What do you do when you don't have enough food or enough money to buy food?". The adoption and frequency of using various type coping methods indicate the level of household food insecurity. It will measure by using 7days recall as a reference by (Maxwell, Caldwell, & Langworthy, 2008). The CSI will be calculated by multiplying the severity score which will be obtained from the survey (FGD).

First, the type of method used by households locally identified, compared with the already proposed by (FAO, 2010) and ranked during the discussion with the sample population. The positive response shows the severity of the problem. The level of food (in)security is determined by computing the rank (high and low CSI score).

Household Food Insecurity Access Scale

This indicator of food insecurity will be used to understand households' behavioral and psychological manifestations of insecure food access. It used to measure the access domain but the questions that included to address it indirectly measure the worry and uncertainty about the household food supply (availability), insufficient quality (utilization) and food intake and its physical outcome. Therefore, in this study, the HFIAS of the household will measure by taking 30days as reference (one month) (Chakraborty et al., 2014). As indicated by Maxwell and Coates (2012) this indicator is widely used and important to address the level of the problem within the households.

The study will use the Rasch model (Wolins, Wright, & Rasch, 1982) to analyze the household food insecurity access score. It is one parameter logistic item response model approach and best for dichotomous and (yes/no) and polytomous (multiple or Likert types) responses. The model is widely used in the food security measurement scale. It assumes that the households will give a response to a question based on their experience for the food insecurity. Therefore, households might give negative responses to a more difficult question than a less difficult one (see appendix 8.2). The model assumes that households might give a response based on the extent of the problem and level of food insecurity taken by the questions. For instance, if the extent of food insecurity of the household and level of the question is equal and extent less than the level, the household probably chooses "yes" to the question and the revers (Wright & Mok, 2004).

The response given by each household for HFIAS questions will convert into a single indicator. Then two indicators will be derived from the analysis of the indicator: HFIAS scale and categories. To estimate the HFIAS scale, the occurrence will be coded as 0, 1, 2, 3 (no occurrence, rare occurrence, some time and often). Their position on the scale from 0-27 shows the food insecurity level of the households. The problem might be severe when positive response increases. Lastly, households will be grouped into four food security categories as highly food-secure, marginally food insecure, low food secure and very low food security (Chakraborty et al., 2014). Spearman's correlation coefficient will be used to investigate the relationship between three indicators in measuring the food insecurity status of the farming households.

Food insecurity and Crop yield

Farming household food insecurity is directly related to the amount of crop production that produces annually or seasonally. It is the main source of income and food for farming households in the study area. In Amhara region, particularly in the study area, crop production flows unimodal (Summer season) rainfall. Teff (Eragrostis tef), wheat (Triticum Vulgare), and barley (Hordeum Vulgaris) are the dominant crops. Therefore, understanding the relationship between crop yield and household food insecurity is vital to understand and reduce the problem. Logistic regression, therefore, will be used to analyze the association between farming household's food insecurity and crop production.

Agricultural drought and Crop production

Drought is the major cause of malnutrition and food insecurity (Kulkarni, Gedam, & Dhorde, 2017). The risk is getting worse when it occurs during the growing season. It reduces agricultural production and exposes the households to food insecurity. Because it causes crop failure, water stress, and death of livestock. Therefore, detecting the drought-prone area gives insight into the food insecurity situation of farming households. To minimize the effect other non-climatic factors and make the comparison of yield effective, original crop yield time series data will transform standardized yield residual series (SYRS) (Potopová et al., 2016) using:

$$SYRS = \frac{yd - u}{\sigma}$$

Where yd represents the residual of the de-trended yield obtained using the linear regression model, u is the mean of the de-trended series, and σ is the standard deviation of the de-trended yield. The relationship between agricultural drought index and SYRS will be assessed by calculating a polynomial correlation coefficient.

Soil degradation and Food insecurity

In the area where population growth and a need for more agricultural land, often agriculture expand onto the area that is already degraded or have a low potential production, which aggravates the problem. There may be a strong link between soil erosion and food insecurity: if the area has overexploited, and vegetation cover is low, the erosion effect of subsequent rainfall may be more than in normal years. It is therefore important to assess erosion in the context of food insecurity. In the study area, soil degradation has a direct association with food insecurity. Because agriculture is the main source of income for the society. To understand the relationship between food insecurity and soil erosion in the area, logistic regression will be employed.

Table 1.Summarized data and possible sources

Data	Description	Data	Source
Climate	Temperature, Rainfall, Radiation, Evaporation	Secondary	Ethiopia Meteorological Agency, Gridded data (CHIRPS) and GIOVANNI (EARTHDATA)
Crop production	Temporal yield statistics of crop	Secondary	Central Statistical Agency, Agricultural office, Survey
Soil	Soil moisture, depth, bulky, porosity, texture	Secondary	Literature, Soil Grid, World Soil Database

Household data		Primary	Survey (Questioner, interview, FGD, and Observation)
Satellite Images	Digital Elevation Model, MODIS, Sentinel	Secondary	USGS

4. Expected outcome

Researches in the area of food insecurity contribute a lot to improve the state of food security in the country, particularly in the study area. This study believed that food insecurity is not only the result of one or two factors rather structural factors are involved in the intensification of the problem in the study area. Thus, it will show how different drivers and food security indicators are combined in the evaluation of household food insecurity i.e. economic, meteorological, and physical drivers in Lake Tana sub-basin. It will provide the following valuable information for governmental, policymakers, development agents, regional, district officials, and international organizations who engaged in reducing the problem i.e which households are at risk of food insecurity, proportions of households experiencing food insecurity, which part of the area is highly threatened by soil degradation and drought-prone and what measures should be taken.

In addition, the study will show how multiple indicators are effective in measuring the pillars of food security, contributes a lot to the reduction of crop yield and weakened the resilience of farming households, enables decision-makers to integrate drought characteristics in the policymaking, formulate priority adaptation, identify priority activities, build capacity, monitoring policy effectiveness.

5. Expected Potential Outputs

Table 2.Research outputs

Specific Objectives	Publication title	Journals
To examine food insecurity status of the farming households in lake Tana sub-basin	Evaluate the status of farming household’s food insecurity using multiple indicators	Agricultural and Forest Meteorology / World Medical and Health Policy/Agriculture and food security journal
To assess the spatial and temporal variability of rainfall and its impact on the farm production of household	Analysis of the spatial-temporal variation of drought based on Satellite-derived climate data over the past three decades in Lake Tana sub-basin	Journal of Geophysical Research: Atmosphere/ Climatology and Water Management
	Assess the rainfall onset, cessation and length of the growing season in Lake Tana sub-basin	Agricultural and Forest Meteorology/ Journal of Geophysical Research:

		Atmosphere/ International Journal of Climatology
Assess the effect of soil degradation on crop production	Investigate the changes in soil erosion and its impact on crop production from 2015-2020)	Environmental Earth Science/ European Journal of Soil Science

6. Research Time Table

Table: 3. Research Time Table

Activities	2019							2020												2021												2022												2023			
Months	**J**	J	A	S	O	N	D	J	**F**	M	A	M	J	J	A	S	O	N	D	J	**F**	M	A	M	J	J	A	**S**	O	N	D	J	F	M	A	M	J	J	A	**S**	O	N	D	J	F	M	A
Proposal preparation	■	■	■	■	■	■	■																																								
Qualifier								■																																							
Organize Satellite images									■																																						
Literature Studies									■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Tools preparation & field data collection for obj-1									■	■	■																																				
Organize data analysis &write up (Obj-1)												■	■	■																																	
Field observation, tool preparation (obj-3)														■	■	■																															
Pre-test data collection tools																■	■																														
Second round data collection (survey data obj-3)																		■	■	■																											
Organization & analysis																					■	■	■																								
Taking Training and course (ITC)																					■	■	■	■	■																						
Write up obj-1																						■	■	■	■	■	■	■																			
Organize data for obj-2																													■	■	■																
Data analysis &Writing up (Obj-2)																																■	■	■	■	■	■	■									
Thesis writing																																							■	■	■	■	■	■	■	■	
Finalize and Submit																																													■	■	
Defense																																															■

6. Reference

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8. Appendix

8.1. Food security indicators and dimensions

Pillars of food security	Indicators of food security
Availability	Household food insecurity access score, diet diversity score, and Coping strategy.
Access	Household food insecurity access score, diet diversity score, and Coping strategy.
Utilization	Household food insecurity access score, diet diversity score
Stability	Household food insecurity access score, diet diversity score, and Coping strategy.

8.2. Rasch model

$$In\left(\frac{P_{in}}{(1-P_{in}}\right)=B_i\text{-}D_n$$

$$P_{in} = \left(\frac{exp(B_i-D_n}{[1+exp(B_i-D_n)]}\right)=B_i\text{-}D_n$$

where, P_{in} is the probability of household i with experience B_i, giving an affirmative answer to question n that has a food insecurity level D_n. The indicator variables D_n are assumed to be independent of each other.