Jimma University
College of Social Science and Humanities
Department of Geography and Environmental Studies

Assessments of environmental determinants of the spatial distribution of *Enset* wilt disease in Yem Special *Wereda,* Southwest Ethiopia.

M.Sc. Thesis

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October, 2017
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We hereby certify that we have read and evaluated this thesis entitled "Assessments of environmental determinants of the spatial distribution of *enset* wilt disease in Yem Special *Wereda*, Southwest Ethiopia", prepared under our guidance by Ashenafi Woldeyohannes. We recommend that it be submitted as fulfilling the thesis requirement.

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Certification of the Final Thesis

I hereby certify that all the corrections and recommendations suggested by the board of examiners are incorporated into the final thesis entitled as “Assessments of environmental determinants of the spatial distribution of *enset* wilt disease in Yem Special *Wereda*, Southwest Ethiopia” by Ashenafi Woldeyohannes.

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Dedication

I dedicated this manuscript:

To my dear late friend Ato Dese Amano who was my best friend and passed away on September, 01, 2017. He was a wonderful man and I shall all miss him very much. I was saddened to miss him. Rest in Peace!

Statement of the Author

I hereby declare that the thesis entitled "Assessments of environmental determinants of the spatial distribution of *enset* wilt disease in Yem Special *Wereda*, Southwest Ethiopia" has been carried out by me under the supervision of Dr. Kefelegn Getahun, in Jimma University, College of Social Science and Humanities, Department of Geography and Environmental Studies during the year 2017. It is submitted for the partial fulfillment of a Master of Science in Geography and Environmental Studies with the Specialization of GIS and Remote Sensing.

By my signature below, I declare and affirm that the thesis is entirely my own work and that all source of materials used for this thesis has been fully acknowledged. I have followed all ethical and technical principles of scholarship in the preparation, data collection, data analysis and compilation of this thesis. Any scholarly matter that is included in the thesis has been given recognition through citation.

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Acronyms/Abbreviations

^{0}C	Degree Celsius
AdjR^2	Multiple R-Squared
AICc	Akaike's Information Criterion
BXW	Banana *Xanthomonas* Wilt
CABI	Common wealth agricultural Bureau and Biosciences International
CHIRPS	Climate Hazards Group Infrared Precipitation with Stations
CSSH	College of Social Science and Humanities
CI	Confidence Interval
CSA	Central Statistic Agency
CSR	Complete Spatial Randomness
DAs	Development Agents
DEM	Digital Elevation Model
DRC	Democratic Republic of Congo
EXW	Enset *Xanthomonas* Wilt
GIS	Geographic Information System
GITs	Geospatial Information Technologies
GLM	Generalized Linear Model
GPS	Global Positioning System
HHs	House Holds
ISRIC	International Soil Reference Information Centre
JB	Jarque-Bera
KIIs	Key Informants Interview
Km^2	Square Kilometer
KML	Keyhole Markup Language
Kms	Kilometers
LWC	Linear weighted combination
m	meters
m.a.s.l	meters above sea level
MLE	Maximum Likelihood Estimation
mm	millimeters

MoA	Ministry of Agriculture
NGO's	Non-Governmental Organizations
NMA	National Meteorological Agency of Ethiopia
OLS	Ordinary Least Square
OR	Odd Ratio
R^2	Adjusted R-Squared
RS	Remote Sensing
SARI	South Agriculture Research Institute
SGS	School of Graduate Studies
shp	shapefile format
SNNPR	South Nation, Nationalities and People Region
UTM	Universal Transverse Mercator
SRTM	Shuttle Radar Topography Mission
VIF	Variance Inflation Factors
Xcm	*Xanthomonas campestris* pv. *Musacearum*
WGS	World Geodetic System

Abstract

Enset (Ensete ventricosum Welw. Cheesman) is a perennial crop, cultivated by millions of smallholder farmers in South, Central and Southwestern Ethiopia. However, its production has been endangered by one of the overwhelming Enset bacterial wilt (EXW) disease caused by Xanthomonas campestris pv. musacearum (Xcm). Although EXW has been described in Ethiopia for about five decades, the current disease burden and geographical distribution; and main causing environmental factors are not precisely known. Understanding the geographical distribution and identifying the environmental correlation of the disease distribution is important. Therefore, this study aims to determine the magnitude of Enset bacterial wilt (EXW) and identification of biophysical factors, which affect its spatial distribution using spatial statistical analysis techniques Yem Special Wereda, Southwest Ethiopia. Representative Kebele administrations were selected using purposive sampling method and spatial random sampling method was used to determine the households or enset plots. Data on EXW prevalence and incidence was collected from 135 enset plots found in 11 selected Kebeles. EXW prevalence and incidence were tested for spatial autocorrelation using the global Moran's I and Getis-Ord G statistics. The relationship between EXW and predicting environmental variables was modeled using logistic and linear regression analysis. Logistic regression was used to model the relationship between EXW prevalence and response variables, whereas both Ordinary Least Square (OLS) and Generalized Linear Model (GLM) were used to analyze the relationship between EXW incidence and response variables. 95% confidence interval and p-values, 0.05 were considered as significant. In the study area the EXW disease was widely distributed at varied degree of intensity. 135 enset plots assessed, 87 of them were found to be infected by EXW disease. The overall EXW prevalence and incidence rate in the study area was 64.4% and 20.11%, respectively. The highest prevalence was recorded for Kerewa Kebele (89%) and lowest for Asher Kebele (29%). The scale of EXW incidence ranges from 0% – 100% at enset plots, and 6.20% – 38.86% at Kebele level. Based on the spatial analysis results, the pattern of EXW prevalence and incidence were clustered and the null hypotheses were rejected. Predicting variables such as relative humidity, altitude, total annual precipitation and silty texture were positively correlated with EXW prevalence and significantly contributed to the model. Relative humidity, total annual precipitation, altitude, silty texture, soil pH and insect vector (leafhopper) were positively correlated with EXW incidence and significantly contributed to the model. Other variables such as agro-ecology, clayey soil textures and soil type were not significant predictors of EXW prevalence and incidence in the study area. Based on the finding, the concerned bodies should provide management options to control the spread of disease, for more vulnerable areas due to environmental factors. Particularly, providing insecticide where leafhopper is found. In addition, it could be concluding that the findings contribute to the growing research on the aetiology of EXW, and provide new starting points for further exploration of EXW aetiology using laboratory studies.*

Key words: *Enset, GIS, Enset Bacterial Wilt, Prevalence, Incidence, Spatial auto correlation analysis, Correlation analysis, Regression analysis.*

Chapter 1: Introduction

1.1. Background

Enset (Ensete ventricosum *(Welw.)* Chessman) is a perennial and monocarpic herbs belonging to the banana family and originated in Ethiopia (Vavilov, 1951). *Enset* is a wonder food and income security crop, cultivated by millions of smallholder farmers in South, Central and Southwestern Ethiopia. It is a source of food, cash, feed, medicine, fuel wood, construction and ornament for smallholder farmers in Ethiopia (Africa RASING, 2015).

The area of *enset* cropping correlates well with mid and high altitudinal delineations, which ranging from 1,500 to 3,100 m a. s. l (Birmeta, Nybom & Bekele, 2004). However, the elevation between 2000 and 2750 m.a.s.l. with an average annual rainfall of 1100 to 1500 mm, a mean temperature of 10^0C -21^0C and a relative humidity of 63-80% are favorable for *enset* cultivation (Brandt et al., 1997). Moderately acidic to alkaline (pH of 5.6 to 7.3) soils are favorable for *enset* cultivation (Bezuneh & Feleke, 1966).

Geographically, *enset* crop distributed as a wild species in various parts of Africa and Asia (Simmonds, 1962). *Enset* grows wild or maintained as an ornamental plant due to its showy leaves, in many parts of the world (Bizuayehu & Ludders, 2003). Nevertheless, it cultivated as food and fiber merely in its indigenous farming systems of South and Southwest Ethiopia, predominantly (Brandt et al., 1997).

Enset is the most important traditional staple and co-staple food crop contributing to food security and rural livelihoods for over 20% of people in the South and Southwest Ethiopia (Karin, 2002; Tariku, Kassahun, Endale & Mengistu, 2015). It estimated that about 224,400 hectares of land in Ethiopia covered with e*nset*, whereas 145,800 and 78,600 hectares of land found in Southern Nations Nationalities and Peoples' Regional State (SNNPRS) and Oromia Regional State, respectively (Central Statistical Agency of Ethiopia [CSA], 1997).

However, the productivity and area coverage of the crop shows continuous declining due to various environmental and management factors (Anonymous, 2013, 2014;

Birmeta et al., 2004). *Enset* bacterial wilt disease is prior threatening or problem to *enset* production system in Ethiopia (Anonymous, 2013; 2014).

Enset bacterial wilt disease, which is commonly known as *"Banana Xanthomonas Wilt (BXW)", "Enset Xanthomonas Wilt (EXW)"* or *"Enset wilt"* is a devastating disease caused by the bacterium *Xanthomonas campestris* pv. *musacearum (Xcm)* (Yirgou & Bradbury, 1968). This bacterium affects *enset* and banana plants. According to Welde-Michael et al. (2008b) report, *enset* wilt disease yellowing the edge of *enset* leaf and wilting the leaves, progressively and then all the leaves wilt, bend over and decline, finally killing the plant.

The bacterial pathogen is very critical as it kills the plants at all growth stages and regularly causes total fatalities (Kidist, 2003; Bizuayehu, 2008). The disease is widely distributed and presently found in almost all *enset* growing regions by causing significant losses on production (Ashagari, 1985; Welde-Michael & Fikre, 2007). Currently, it reported that up to 80% of *enset* farms in *enset* growing area of Ethiopia infected by EXW, which directly affects the livelihood of more than 20 million *enset* farmers in the country (Anonymous, 2014). This shows that, the disease is most economical and needs an accurate research to overcome. To control and manage the disease, research should focus on factors such as socio-economic and environmental, which are possibly playing important roles in the distribution and spread of the disease. Mainly, understanding the relationship between environment and *enset* wilt should play an important role in the processes of controlling and managing the spread of disease (Mekuria, Amare, & Alemayehu, 2016; Shank & Chernet, 1996; Smith et al., 2008).

To understand the correlation between environmental determinants and EXW, Geospatial Information Technologies (GITs) tools and techniques play a great role. These tools are Global Positioning System (GPS), Remote Sensing (RS) and Geographic Information System (GIS), which used to map and analyze spatial distribution, pattern, and process of a set of features or disease in space. Analyzing the spatial distribution, or pattern of disease can help to identify and quantify its patterns and to look at relationships between features in space, then the underlying cause of the distribution can be determined (Fotheringham, Brunsdon & Charlton, 2002).

Therefore, this research initiated to investigate environmental determinants that can affect spatial pattern of distribution of *enset* bacterial wilt.

1.2. Statement of the problem

Enset is considered as one of the importance crops for food and livelihood security in *enset* growing part of Ethiopia, for its tolerance to drought and its high productivity in small area. In addition, *enset* can be grown with minimum spadework and using only farmyard manures (without the need of chemical fertilizer), as soils under *enset* production are known to display a positive nutrient balance. However, as a number of researchers Birmeta et al. (2004); Shank & Chernet (1996); Welde-Michael & Fikre (2007) reported, the productivity and area coverage of the *enset* is declining in Ethiopia and EXW disease is mostly the reason behind the problem. For instance, Bizuayehu (2008) reported that the EXW is the most serious threat to enset production in Sidama Zone.

Most of farmers in *enset* growing areas could have information about EXW disease from their profound indigenous knowledge that they were experienced with disease. They might be not new to the EXW, but in recent years, its incidence rates became high and highly affected the *enset* production (Anonymous, 2014). There have been some attempts to develop controlling options against the disease via identifying some disease tolerant clones, developing cultural practices, creating awareness on available management practices and others. In addition, most research activities on EXW focus on characterization of the disease and verification of tolerant/non-tolerant enset clones. However, still the disease spread is high and farmers are unable to control the disease. Therefore, there is an urgent need to determine and identify the spatial correlation between the spread of disease and environment.

According to Desalegn and Addis (2015); Mekuria et al. (2016) report, indicated that there might be a relationship between the disease and environmental variables. Particularly, research on *enset* conducted so far is mainly limited to mapping the distribution of the disease (Mengistu et al., 2014). Equally, the environmental factors that can determine *enset* bacterial wilt under different agro-ecological conditions remains largely underestimated. This in turn hinders adequate prevention and control of the disease. Understanding the relationship between various environmental factors and *enset* wilt disease, play an important role in the processes of controlling and managing the spread of disease (Mekuria et al., 2016; Shank & Chernet, 1996; Smith et al., 2008).

This study is important by providing information about the relationship between EXW and environment, since little or no research outputs focus on investigating their relationship at local as well as national level. Therefore, this study tries to obtain a better understanding of the environmental complex in which the host and pathogen associated. Especially, the focus is on how the interaction between and among biophysical entities in this complex affect host-pathogen relationship in *enset* farming systems.

1.3. Objectives of the study

1.3.1. General Objective

The overriding objective of this study is to assess environmental determinants of the spatial distribution of *enset* wilt disease in Yem Special *Wereda*, Southwest Ethiopia.

1.3.2. Specific Objectives

In order to address the general objective, the following specific objectives are considered:

- To understand the magnitude of the EXW prevalence and incidence.
- To investigate the spatial distribution of EXW disease in the study area.
- To investigate the link between prevalence and incidence of EXW and biophysical factors.

1.4. Research questions

The following basic research questions were set to address the objectives of the study:

- What is the impact of EXW disease on *enset* production in the study area?
- What is the distribution of the disease pattern in space? Where is hot and cold spots of EXW prevalence and incidence? Is there any spatial concentration in the EXW prevalence and incidence?
- Can biophysical variables predict the pattern of distribution of EXW?

1.5. Significance of the study

To control EXW, knowledge regarding the distribution and incidence of EXW is essential. Explaining the distribution of EXW in relation to environmental factors provides a rationale for interventions and helps to predict transmission intensity in places in which it has not been measured.

GIS-based analysis of spatial distribution, prevalence and incidence of EXW disease and its correlation to environmental determinants is the most precise technique to understand the forces and processes behind the disease. It also helps to obtain better understanding of the environmental complex in which the host and pathogen coevolved. The influence of environmental factors on disease incidence and spread was investigated, particularly, by looking at the role of topographic, climatic and ecological conditions and insect vectors on the disease system. To looking the role of these factors on the disease system, both GITs and other statistical analysis computer program (STATA) tools and techniques were applied.

Therefore, this study is helpful in bringing the known biophysical factors or the ecological complex in which the host and pathogen coevolved. In turn, this would necessitate effective management of *enset* bacterial wilt problem and aid the advance deployment of resources for raising awareness. The output from this research is essential for farmers and socio-economic development planners in order to have understanding on appropriate controlling and managing methods. It is also essential for researchers as a baseline or an input to precede related research. In general, this study will become important in order to develop sustainable strategies for strategic and tactical management of disease.

1.6. Scope of the study

Spatially, the study has undertaken in Yem Special *Wereda* in SNNPR state of Ethiopia. This study was limited to develop spatially explicit analysis of EXW distribution and its correlation with biophysical variables. Methodologically, the research utilized different environmental variability descriptors, and spatial statistical techniques for analysis purpose to yield a vivid account on a problem under investigation in a comprehensive way.

1.7. Limitations of the study

The study has some limitations. These are lack of time and secondary data particularly related literature and the base-line data in the study area. Old references are widely used due to lack of related to scientific literatures, which published recently. Since the degree of disease intensity is not similar throughout the year, it could reveal other important hidden events in relation to disease if its data was continuously recorded. However, student researcher was unable to continuously record, the intensity of the disease at least for a year. Even though there was limitation of time, historical occurrence of disease had been collected through survey at *enset* farm plots.

1.8. Definition of terms and concepts

In order to avoid any misleading understanding by the reader or user of the research output, the investigator briefly defines the following important terms in view of the research:

Agro-ecology: a defined spatial group of ecological factors (climate, soil, altitude etc.), that contribute to the classification of distinct agricultural system.

Kebele**:** the smallest administrative units in Ethiopia, which is found with in a *Wereda.* It is also known as Peasant Association.

Wereda**:** an administrative group of *Kebeles;* usually bounded by common geographic features and rarely having a common ethnic background. It could be equivalent of "district".

Special *Wereda:* an administrative group of *Kebeles;* usually bounded by common geographic features and having a common ethnic background. Special *Wereda* is neither part of Zone nor *Wereda* rather considered as an administrative subdivision, which is similar to an autonomous area. Special *Weredas* are directly responsible to regional state in SNNPRS, just like Zones while *Weredas* are responsible to Zones.

Spatial distribution: a spatial array of objects or events, especially, the geographic occurrence or range of a natural or manmade features or phenomena.

Spatial autocorrelation: the correlation among values of a single variable strictly attributable to their relatively close locational positions on a two-dimensional surface, introducing a deviation from the independent observations assumption of classical statistics (Griffith, 2000).

1.9. Organization of the thesis

The thesis divided in to six chapters. Chapter one incorporates introduction, which include background, statement of the problem, objectives, research questions, significance, scope, and the definition of key terms or concepts. Chapter two describes related literature review that includes the theoretical information about EXW disease and causing environmental factors and spatial analysis. Chapter three provides the methods and materials, which includes description of study area (geographical location, topography, climate and socio-economic characteristics), methods for data collection, sampling, and data analysis. Chapter four presents the results while chapter five presents discussions. Finally, chapter six presents conclusion and recommendations of the study based on the major findings.

Chapter 2: Review of Related Literature

2.1. *Enset* bacterial wilt diseases in Ethiopia

Enset bacterial wilt disease was for the first time reported from Ethiopia in 1968 (Yirgou & Bradbury 1968). EXW is a devastating disease and the most important biotic constraint to *enset* cultivation in Ethiopia (Welde-Michael & Fikre, 2007; Welde-Michael et al., 2008a).

EXW has the greatest impact on *enset* production. Due to EXW disease, there is severe decline in *enset* cultivation, changes in cropping and dietary patterns, genetic erosion and catastrophic impacts on livelihoods (Anonymous, 2014). The pathogen of *enset* bacterial wilt is very destructive as it kills the plants at all growth stages and causes total losses (Bizuayehu, 2008; Brandt et al., 1997; Kidist, 2003).

Bacterial pathogens enter plants through wounds, principally produced by adverse weather conditions, humans, tools and machinery, insects, and nematodes, or through natural openings such as stomata's, lenticels, leaf scars, etc. (Dereje, 1985). It mainly spread through contaminated farm tools, infected planting materials, animals and possibly insects feeding on the foliage (Welde-Michael et al., 2008b). Once the bacteria enter into the plant grow in the intercellular space and pass through the tissues, then cell death of the plant may follow (Manners, 1993).

Until 2001, *enset* bacterial wilt was only confined in *enset* and banana in Ethiopia (CABI, 2016). However, since 2001 it was found causing epidemic disease in several cultivated varieties of banana in other parts of eastern Africa and Northeastern corner of the Democratic Republic of Congo (Biruma et al., 2007; Smith et al., 2008; Tripath et al., 2009). Surveys conducted in the 1980s in major *enset* growing Zones of Ethiopia revealed the occurrence of *enset* bacterial wilt disease in all Zones with different degree of severity (Brandt et al., 1997). Although the current status and distribution of the EXW disease in Ethiopia is not well assessed, there is believe that it is to found in all *enset* growing regions, and spreads rapidly and results in total yield loss in an area (Welde-Michael et al., 2008a). Westphal (1975) reported a serious outbreak of the disease of with losses up to 70%. On the other hand, Shank and Chernet (1996) reported as it exhibited losses up to 100%, under severe damage.

The rate of multiplication of the pathogen determines the rate of spread of the disease, its motility and ability to produce pectolytic enzymes and the structure of the host (Manners, 1993). According to Kidist (2003) once it appears in a field, it easily transmits from infected *enset* plant to healthy plants through different mechanisms. Under the severe condition of the disease, farmers are obliged to abandon the whole field and replace it with another crop (Kidist, 2003).

2.2. Environmental factors associated with bacterial wilt of *enset*

2.2.1. Topographic factors: Elevation and Slope

It is obvious that, topographic factors affect local environmental conditions, especially temperature and rainfall, which in turn influences suitability for growth of *enset* and pathogen. The topographic factors, particularly, elevation would be expected to influence the spread of the disease. *Enset* bacterial wilt disease has shown increasing rates with high altitude areas (Maina et al., 2006). *Enset* farmers reported that the bacterial wilt is more severe at high altitudes (Brandt et al., 1997). This could indicate the cooler temperatures of the higher areas will have higher effect on disease expression.

Although there is scant, experimental evidence for survival and movement in soils, *enset* wilt is thought to survive in soil only for short periods and is capable of dispersal in contaminated soils and runoff water (CABI, 2016). The role of water, if any, is not known, although it has long been suspected that water may carry infection from upper to lower contour plantations (Smith et al., 2008). This could reveal the movement in infected soils and water to the disease free *enset* plants or farm fields has possible role in transmission, which determined by the slope.

2.2.2. Climatic factors: Temperature, Rainfall and Humidity

Environmental disturbances alter the normal physiology of a plant, activity of pathogens, and host-pathogen interactions (http://www.britannica.com). The bacterial diseases are greatly influenced by temperature and moisture (http://www.britannica.com).

The bacterial pathogen requires humid condition for survival (Maina et al., 2006; Mekuria et al., 2016). Generally, moisture is required for the multiplication and penetration of bacteria, and the initiation of infection (http://www.britannica.com). Therefore, these notions lead to assumption that temperature, rainfall and humidity could be correlated with *enset* bacterial wilt.

2.2.3. Ecological factors: Soil

High or low soil moisture and/or soil types may be a limiting factor in the development of certain diseases (http://www.britannica.com). According to Mwebaze et al. (2006), the survival of the pathogen in soil can be influenced by soil moisture and soil treatment. Therefore, understanding the relationship between soil types, soil texture, soil pH and *enset* bacterial wilt is necessary.

2.2.4. Insect vectors

Xanthomonas campestris pv. musacearum bacteria has been released from the ooze through cracks or wounds in the infected part, or through natural openings or present in the infected area (http://giasipartnership.myspecies) . Some of insect vectors would contribute to the spread of some bacterial pathogens of plants when they carry bacteria on their body and land on a fresh wound or on an open natural opening, the bacteria may move into the plant and begin a new infection (Shivani, 2016). The insect vectors would probably transmit disease from infected *enset* plants to health plants. However, the influence of insect vectors was undermined. Therefore, understanding of the role of insect vectors in *enset* bacterial wilt disease transmission would be important.

2.3. Application of GIS in crop disease mapping, surveillance, and modelling

GIS is a decision support computer based systems for collecting, storing, presenting, analyzing, modeling, and displaying spatial information, and it offers capabilities of integrating multi-sector, multilevel and multi-period database (Anji, 2008). The application of GIS has emerged as the core of spatial technology, which integrates wide range of dataset available from different sources including Remote Sensing (RS) and Global Positioning System (GPS).

Mapping of disease is an activity closely related to disease surveillance and cluster detection to bring out hidden relationships among variables (Oluwafemi, Babatimehin, Oluwadare, & Mahmud, 2013; Brown, McLafferty & Moon, 2010). It is widely used to identify patterns of geographical variation in diseases and to develop new ideas about the causation of disease or to reflects the environmental conditions that affect risk, susceptibility, social interaction and behaviors that facilitates occurrence (Oluwafemi et al., 2013). Moreover, maps reveal visually the existence or the absence of spatial patterning, which in turn leads to the elaboration of hypotheses about associated factors (Brown et al., 2010).

The idea of spatial autocorrelation in spatial analysis is based on the notion from Waldo Tobler “everything is related to everything else, but near things are more related than distant things” (Tobler, 1970). Positive spatial autocorrelation occurs when events of similar value are adjacent to each other, while negative spatial autocorrelation occurs when high values are located adjacent to low values (Gatrell, 2002).

Indeed, GIS is used to capture, map, transform, and analyze data for use in disease atlases; to model disease in relation to environmental variables; to predict the effects of density-related factors in disease distribution; and to focus and drive infection control programs by identifying areas of endemic disease or populations at risk (Brooker et al., 2000). For instance; GITs have been applied in plant pathology to improve the accuracy of disease assessment, diagnostics and pathogen detection (Nwauzoma, 2016), to detect the sugar beet disease (Laudien, Bareth & Doluschitz, 2004), and to identify recurring patterns of plant disease (Merritt, Thomas, Ramon & Athar, 1999). Shimwela et al. (2016) used GITs to examine relationships between EXW hotspots and environmental variables. Bouwmeester et al. (2010) used GITs to determine the spatial extent of a banana disease, to identify spatial patterns of the disease and to demonstrate how disease observations correlated to spatial environmental data. In addition, Bouwmeester et al., (2015), used geostatistical methods to map banana bacterial wilt disease incidence.

Therefore, this research used geospatial information tools and techniques to visualize the spatial distribution of EXW disease, to analyze its prevalence and incidence and to investigate the spatial relationship of the disease to various environmental factors.

Chapter 3: Methodology

3.1. Description of the study area

Yem is one of the four Special *Weredas* of the Southern Nations, Nationalities and Peoples' Regional States (SNNPRS). The total area of Yem Special *Wereda* is about 724.5 km^2, which accounts for around 0.65 % of the total area of the SNNPRS (Kassahun, 2011). The Yem Special *Wereda* has 35 *Kebele* administrations, 4 of them are categorized as town and 31 are rural *Kebele* administrations (Appendix 5). Fofa town the former administrative center of the Yem Special *Wereda,* situated in the central part of the *Wereda* and the road to it branches off at Saja from the main Addis Ababa -Jimma asphalt road. However, since 2011 its administrative center was shifted from Fofa to Saja.

3.1.1. Location

Relatively, Yem Special *Wereda* is located in the northwestern tip of the SNNPRS. It bordered by Hadiya and Gurage Zones (SNNPRS) in the east and south, and Jimma Zone (Oromiya Region) in the north and west. The Gibe River marks the border between Yem and Hadiya Zone. Geographically, the Yem Special *Wereda* is located between 7º 35ˈ N to 8º02ˈ N and 37º 24ˈ E to 37º37ˈ E.

Currently, Saja is the principal town of the *Wereda*, which is located in northwestern part of the *Wereda*. Saja is situated to the southwest of Ethiopia at a distance of about 252 km from Addis Ababa (capital of Ethiopia).

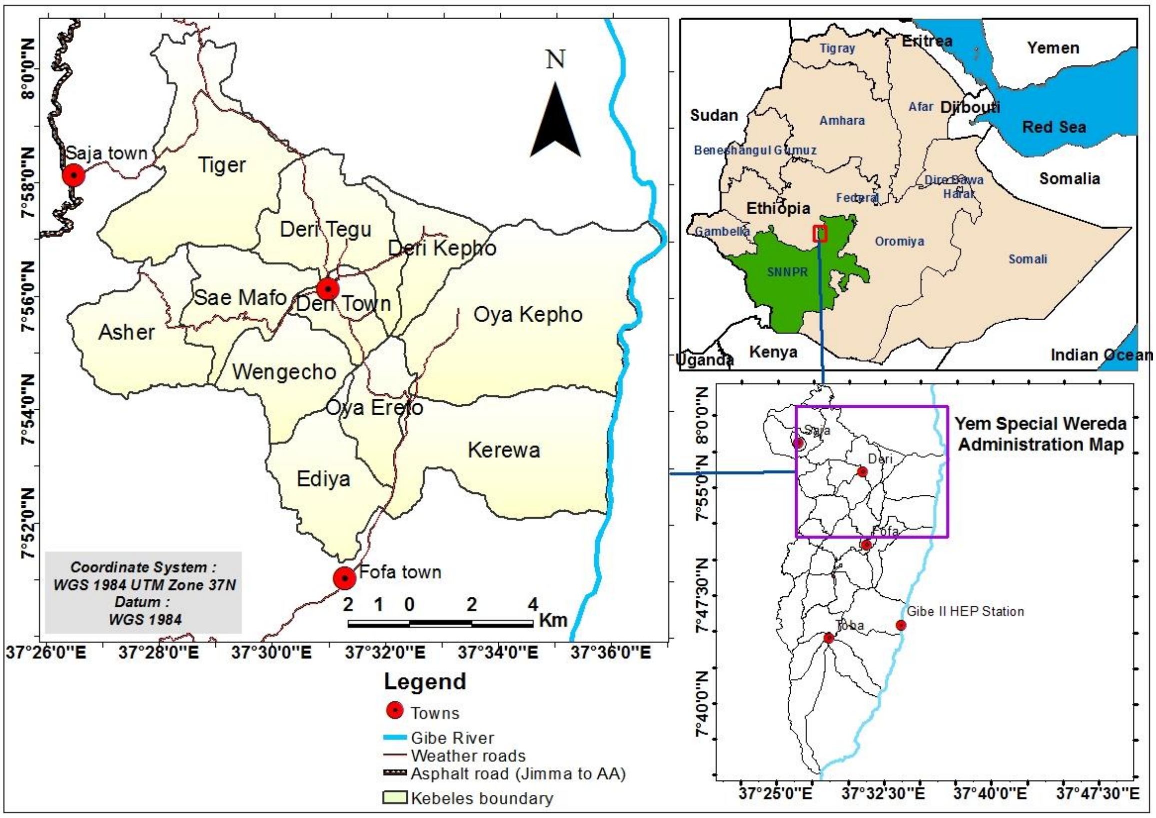

Figure 1: Location of the study area

3.1.2. Topography and Agro-ecology

The Yem Special *Wereda* has different landscape, which varies considerably from one part of the *Wereda* to another, but mostly hilly. Its topography is characterized by rolling mountains, steeply sloppy areas and flat to undulating plateaus (Kassahun, 2011). The lowest point of elevation is 817m.a.s.l, which located at north east (Gibe lowland) and the highest peak is 2940m.a.s.l (mountain Bora) which located in the central part of the *Wereda*.

The area has two agro-ecological zones, namely, warm sub-humid lowlands, which cover the central apex and southwestern part and tepid sub-humid highlands, which cover eastern and northwestern part of the *Wereda*.

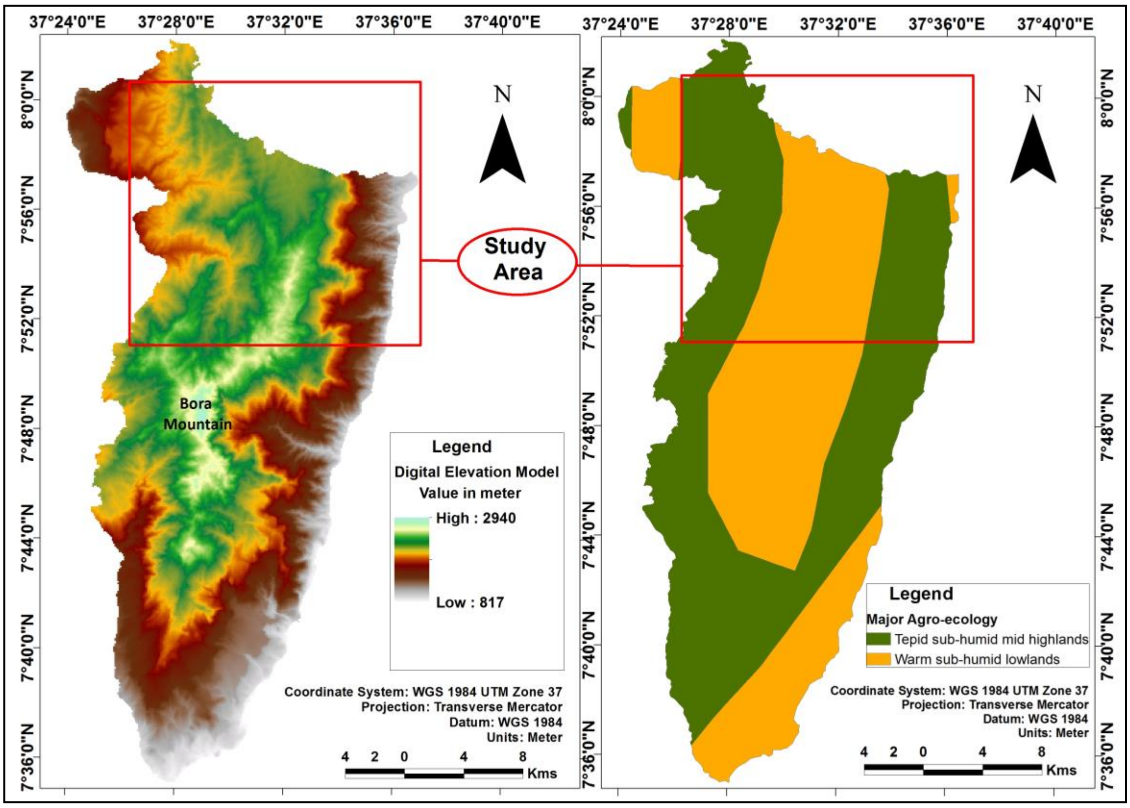

Figure 2: Digital Elevation Model (left) and Agro-ecology (right) of the study area.

3.1.3. Climate

Mean annual temperature is between 20ºC - 30ºC in the lowlands (*Kola*), 16ºC - 20ºC in the temperate (*Woyina Dega*) and 12ºC - 16ºC in the highlands (*Dega*) areas of the *Wereda* (Kassahun, 2011).

Rainfall in the *Wereda* is mostly bimodal with short rainy season ("*Belg*") and long rainy season ("*Meher*"). The short rainy season usually appears during the months of mid of February or April while the long rainy season is in the months of June or September (Kassahun, 2011). Sometimes the rainfall pattern considered as one and overlapping long rainy season with rainfall duration of 7-8 months per annum with a short dray period. In general, the area estimated to receives adequate precipitation of total annual rainfall ranging from 800mm - 2200 mm (Kassahun, 2011).

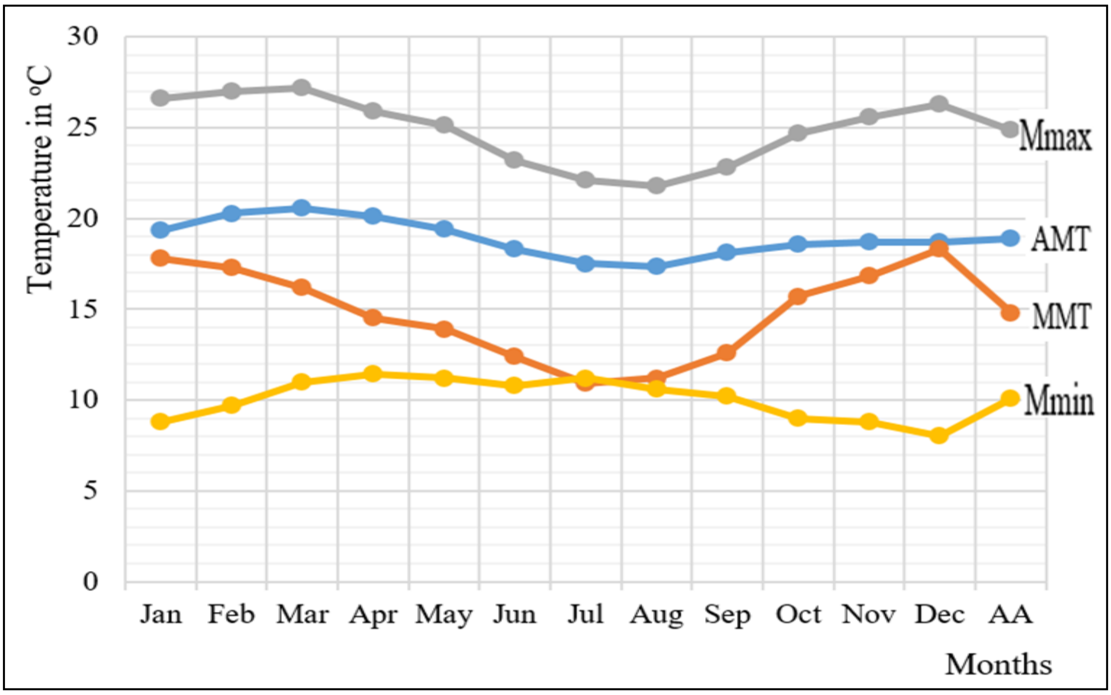

Figure 3: Temperature of the study area. Mmax (Monthly maximum), AMT (Average Monthly Temperature), MMT (Mean Monthly Temperature), Mmin (Monthly minimum) and AA (Annual Average). (Source: Computed from WorldClim data (1970 – 2000))

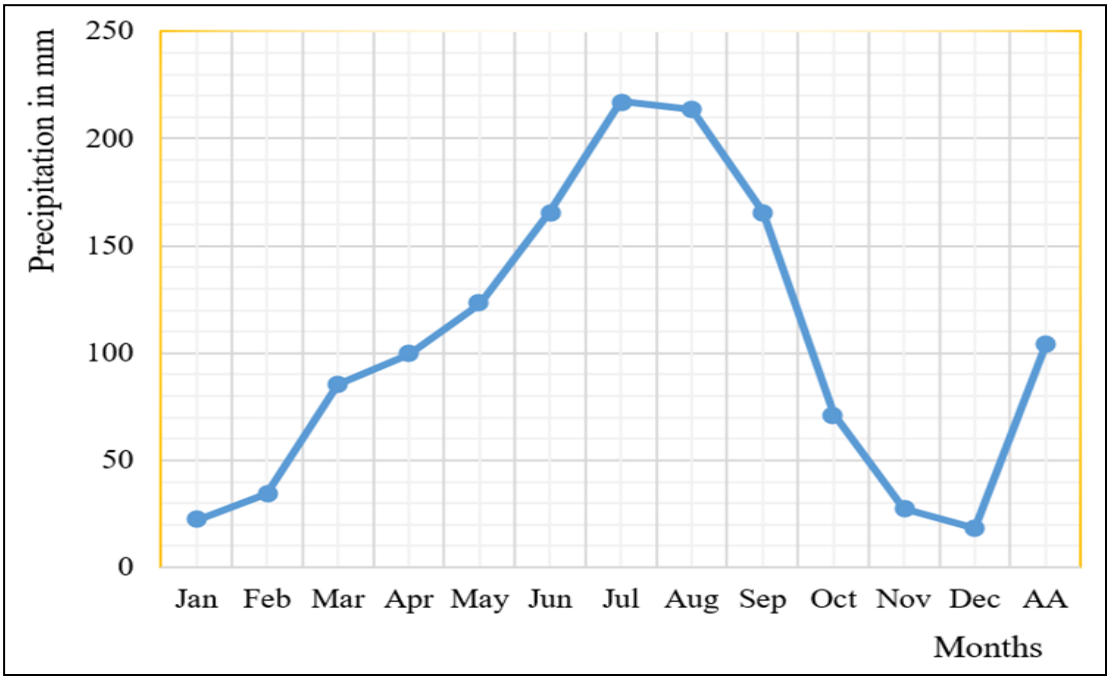

Figure 4: Precipitation of the study area. AA (Annual Average). (Source: Computed from WorldClim data (1970 – 2000)).

3.1.4. Demographic and Socio-economic Characteristics

According to CSA (2007) population and housing census report, the total population of the Yem Special *Wereda* is 80,687, of whom 40,566 are men and 40,121 are women. The *Wereda* has a population density of 124.54. From total population 72,629 (90%) are rural inhabitants, while 7,952(9.86%) are urban inhabitants and 106 (0.13%) are pastoralists (CSA, 2007). *Yemsa* was native language of Yem that mostly spoken by the inhabitants, while *Oromiffa* and *Amharic* were the second and third dominant languages, respectively (CSA, 2007).

The altitudinal variation in temperature gives rise to a variety of vegetation types and suitability of land for agriculture. The sophisticated agro-climate and fertile large amount of land is suitable for farming. *Enset* and cereal cultivation is the dominant cropping system in the area.

3.2. Methods and Materials

For this study, a cross-sectional research design, which includes qualitative and quantitative data collection methods, was implemented. The research emphases on the cross-sectional survey design to collect qualitative and quantitative data (Creswell, 2009). More focus was given for quantitative approach while together with recognizing qualitative procedures (Burke et al., 2007). The quantitative or technical phase was associated with the identification of EXW prevalence and incidence predicting variables and modeling their relationships. Then, qualitative approach was used for the sake of analyzing and describing the qualitative data for interpretation.

3.2.1. Sample size and sampling techniques

3.2.1.1. Reconnaissance survey

Before determining sampling procedures, the base-line information about the *Wereda* was collected from the Yem Special *Wereda* Agriculture and Natural Resource Development Office. Discussions were made with experts regarding selection of the representative study *Kebeles*. The Yem Special *Wereda* has 35 *Kebele* administrations. In most of the *Kebeles*, farmers cultivate *enset* mainly to meet their livelihood needs. Although 4 *Kebeles* are categorized as a town, three of them have high *enset* production (Appendix 5). Unfortunately, in most of them, *enset* bacterial wilt disease was observed in 2016/17 with varied degree. Beside *enset* growing potential and EXW prevalence or incidence, the agro ecology condition and geographical adjacency of *Kebeles* were identified. In order to assume better sampling methods, pilot field visit was made prior to the actual fieldwork in the single *Kebele,* which has not been included in the actual survey.

Finally, resulting the discussions and available secondary data, purposive sampling method was used to determine *Kebeles*. Based on the result of preliminary field visit, spatial sampling (grid system) method was used to determine the households.

3.2.1.2. Sampling techniques

From a total of 35 *Kebeles* found in Yem Special *Wereda*, 11 *Kebeles* were selected for the study, purposively (Appendix 5). *Enset* growing potential, EXW prevalence or incidence, the agro ecology condition and geographical adjacency of *Kebeles* were used as a sampling frame to select *Kebeles*. Selected 11 *Kebele*s areal coverage is about 31.4% of total area of the *Wereda* or 38% of potentially *enset* growing *Kebeles*.

Households who have *enset* farm were taken as sampling unit of the study. The households sample size was determined from the selected *Kebeles*, based on point features that were generated randomly by using ArcGIS tool (create random points). Before generating random point features, index was created at 1km^2 grids from sampled *Kebeles* feature by using ArcGIS tool (Grid Index Features). The area in which random points generated was defined by constraining index. The number of point parameter specified to generate random point features was one for each 1km^2 grid. Then, **207** random point features were generated for the sampled *Kebeles*.

In order to confirm whether the point features represent households with *enset* farm plots or not, the following techniques were used. First, the boundary line of the study area, grids (1km^2) and generated points were changed from their original shapefile (.shp) format (ArcGIS) to Keyhole Markup Language (KML) format of Google Earth via using ArcGIS conversion tool. Secondly, all converted point features retrieved in Google Earth™, to evaluate whether they are placed on households with *enset* plots or not. Thirdly, point features, which have fallen on *enset* growing households, were considered part of the study unit. Whereas, those point features, which were placed on non-enset households, were considered to be part of the sample by placing them to the next nearby *enset* growing household. On the other hand, some point features were ignored due to total absence of *enset* farm plots with in 1km^2 grid. Finally, from 208 randomly generated point features, 135 (households) were selected and remaining 73 were ignored due to absence of *enset* farm plots.

In addition, all key informants were selected from *Kebeles* agriculture extension workers or Development Agents (DAs), *Wereda* agricultural officers, farmers and experts, purposively. One expert (crop science) from *Wereda* Agriculture and Natural Resource Development Office, and one DA's (crop science officers) from each sampled *Kebeles* were selected for interview. Based on information, gathered from DA's and *Wereda* agricultural expert, 11 farmers i.e., one from each *Kebele* were selected for interview.

The farmers selected from *Kebeles* for key informant interviews (KIIs) were experienced and knowledgeable with the *enset* bacterial wilt disease. In addition, three experts (1 *enset* breeder and 2 well experienced with the *enset* bacterial wilt) were selected from South Agriculture Research Institute (SARI), Hawassa University College of Agriculture and Veterinary Medicine and Areka Agriculture Research Center. In the process of expertise's selection, officers from South Agriculture Research Institute (SARI) were consulted. In total, 26 respondents were participated in key informant interviews (KIIs).

3.2.2. Data Collection

3.2.2.1. *Enset* wilt disease

Enset wilt disease was collected via semi-structured questionnaire, Key Informants Interview/KIIs, GPS survey (GPS recorder), digital camera, and field observations.

Questionnaire survey was going through semi-structured questionnaires. Both close-ended and open-ended questions were involved in questionnaire. Questionnaire was prepared in *Amharic*, *Yemisa* and *Oromifa* languages. All target households selected from each *Kebeles* were involved in questionnaire survey. It was carried out together with trained enumerators (DAs) who should securely been identifying the symptoms of EXW, fluently speaking local language (*Yemisa* and *Oromifa*) and closely working with the communities in the respective selected *Kebeles*. Data collectors were identifying, counting and recording total number of *enset* plants and diseased (symptomatic) *enset* plants from each sampled *enset* farm plots.

Key informant interviews (KIIs) was also going through semi-structured questionnaires. KIIs was carried out together with student researcher and trained enumerators (DA's). Email and phone were also used to carried out expert's interviews when impossible to found expert's physically who selected from out of *Wereda*.

In addition, open questions and free-listing approaches were followed, in order to collect supplementary data on *enset* wilt disease, particularly, to assess farmer's perception (indigenous knowledge) about disease and its correlation with environment. Informal discussions with pioneer pathologists were also carried out to validate the analysis result.

Handheld GPS receiver was used to tag the geographic coordinate of each of the sampled *enset* plots. Digital camera was used to capture the scene of disease events in the study area during the field observations of EXW disease appearance.

Field data collection procedure

Field survey of EXW disease was carried out in the rainy season during the mid of March - June 2017. During rainy season, the leaves of *enset* plants become green except the leaf of diseased or wounded *enset* plants due to different factors. Rainy season is favorable to identify disease symptoms.

To found selected households position on the ground, the student researcher used Google Earth™ image of the study area. The point layers that represent sampled households who own *enset* plots were added to Google Earth and Map It application on the Android Mobile. Then, data collector searched the locations of sample household on the ground through online search (Google Earth™ image) by using mobile internet data on Android Mobile Phone. In some parts of study area, where there was limitation of internet connection, the student researcher used GPS location tracer and Google Earth™ satellite image that was downloaded and prepared (including some marginal information of map) on ArcMap. All surveys employed a common semi-structured household questionnaire through face-to-face interviews and EXW field inspections by researcher and enumerators (DA's).

Based on the previous research reports (characteristics of EXW symptoms in situ enset farming), farmers and enumerator's profound knowledge and experiences, the diseased and non-diseased *enset* plants were identified at surveyed *enset* farm plots. Then, at an *enset* stand level, both diseased and non-diseased *enset* plants were counted and recorded from each surveyed enset farm plot, Table 3.

3.2.2.2. Biophysical data

a. Topographic variables: Elevation and Slope

The elevation data of the study area was extracted from a gridded digital elevation model (DEM) produced by the Shuttle Radar Topography Mission (SRTM) at 30 m resolution and was processed to generate the slope using spatial analyst tool in ArcGIS 10.5. Both elevation and slope pixel values were extracted based on collected field data of EXW. Then after, the relation with EXW incidence was investigated by using spatial statistics tools in Arc GIS.

b. Climatic Variables: Temperature, Rainfall and Relative Humidity

The temperature and rainfall data layer were accessed from WorldClim (http://www.worldclim.org/) and CHIRPS (http://earlywarning.usgs.gov) database and National Meteorological Agency (NMA). The creation of the WorldClim dataset is a considerable advance in terms of global environmental characterization as it provides high resolution (i.e. nearly 1 km) climatic surfaces derived from historical records from a number of weather stations across the globe (Hijmans et al., 2005).

The WorldClim freely provides climate data layers in different data format, which contain 12 data layers (one for each month from year 1970 to 2000). Therefore, average annual temperature, average annual maximum and minimum temperature data in degree Celsius and precipitation in millimeters with spatial resolutions of 30 seconds for each month were downloaded. Similarly, the Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) data archive provides precipitation data (time series data) with the resolution of 0.05 degree, from 1981 to near-real time.

Next, annual values for each of variable were computed by overlaying data layers of the past 12 months in ArcGIS. The “weighted sum overlay” tool was used to generate single layer (annual) for both temperature and precipitation.

To generate near recent climate data, the mean monthly temperature and precipitation recorded at Agaro, Areka, Bedele, Butajira, Giyon and Jimma meteorological stations were collected along with their geographical coordinates from National Meteorological Agency (NMA) of Ethiopia. These stations were selected due to their proximity to the study area and availability of climate data for needed time.

As can be seen in the figure 5, on the left side map, the point features indicate meteorology stations (observed data) with their annual precipitation values and surface (raster) indicates the annual precipitation data accessed from WorldClim data base (modeled data). Except Butajira station, others were well matched with the surface data. Similarly, on the right side map, the point features indicate meteorology stations with their average annual temperature values and surface (raster) indicates the average annual temperature data accessed from WorldClim database. Except Areka station, others were well matched with the WorldClim data.

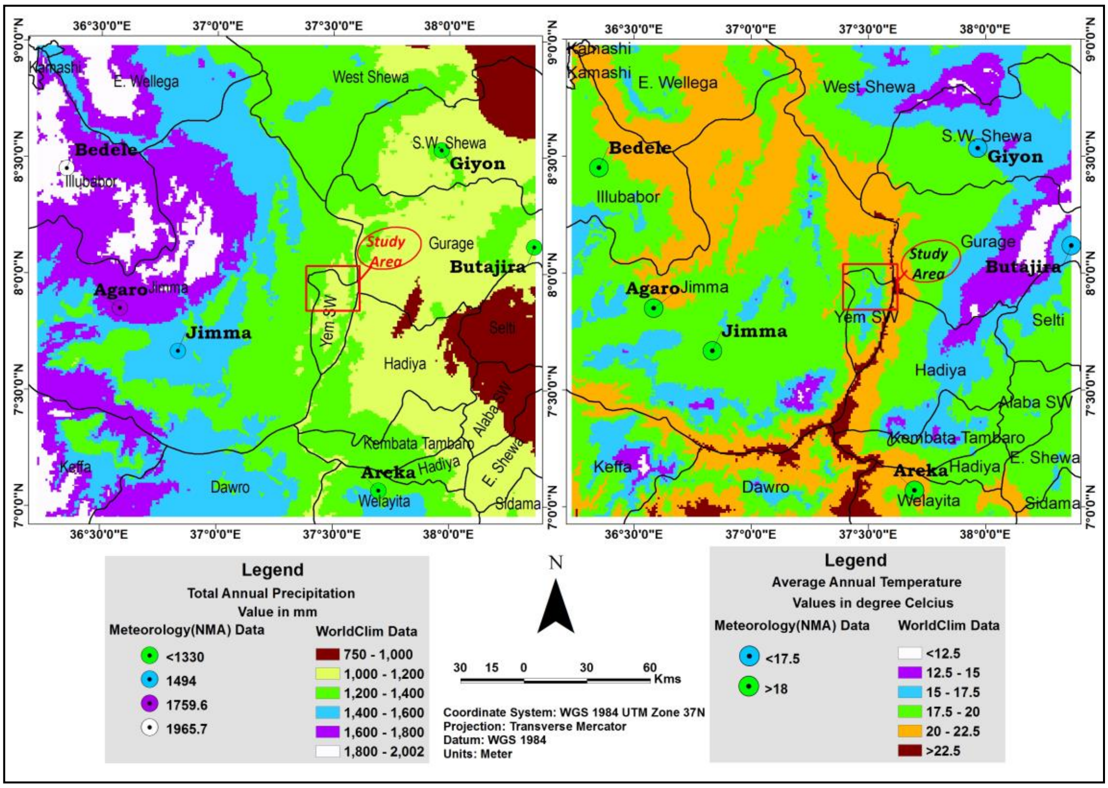

Figure 5: Total annual precipitation (left) and average annual temperature data(right).

There was no significant variation in observed and modeled climate data. Therefore, the climate data accessed from both WorldClim and CHIRPS database, and meteorological stations were used for the analysis, as needed.

Finally, temperature and precipitation values were extracted to the points (field data) by using ArcGIS 10.5 spatial analyst tool (extraction). Then, temperature values extracted to each point was divided in to 12 (months) while total annual precipitation directly recorded as it was.

The relative humidity data was generated based on data provided by above-mentioned meteorological stations as a point data. Then, by using ordinary kriging interpolation technique, its continuous surface was created. Finally, annual relative humidity value was extracted to the points by using ArcGIS spatial analyst tool (extraction).

c. Ecological factors: Soil

Soil data including soil texture, pH values, and dominant soil type at seven standard depths were accessed from ISRIC database (http://www.isric.org/). ISRIC provides the most recent and improved version of the Soil Grids system at 250m resolution. Soil Grids provides global predictions for standard numeric soil properties at seven standard depths (0, 5, 15, 30, 60, 100 and 200 cm) (Hengl et al., 2017). Then, there values at each depth were extracted to the points by spatial analyst tools in Arc GIS.

d. Insect vectors

Experts assume an insect vector, specifically leafhopper as EXW disease transmitter. Leafhopper is highly distributed and found to contribute for the spread of EXW disease in the study area. Therefore, the leafhopper data was recorded based on its availability in the *enset* farm plot as presence or absence.

3.2.2.3. Sources of data

The data for this study was collected from both primary and secondary sources. Primary source of data was collected from sampled respondents (farmers and experts) through semi-structured questionnaires and interviews. Primary data collection also includes field observation. The secondary source of data was collected from published and unpublished documents, articles, books, spatial data provider agencies and different web page (online access for both spatial and non-spatial data), table 1.

All spatial data retrieved from different sources were examined through its meta data and prepared with the same coordinate system. Finding the right neighborhood distance should be trustworthy, since the study focused on spatial relationships. A Projected Coordinate System was used for the study so that distance calculations would be accurate. Therefore, a projected coordinate system WGS 1984 UTM Zone 37N with the unit of meter was used in the study.

Table 1: Characteristics of spatial data used in the study

Variables	Data format		Resolution	Data sources & acquisition date
	Original	Converted	Original	
EXW	Point	-	-	Field/own
Altitude	DEM	DEM	30m	SRTM (http://www.usgs.gov/)
Slope	DEM	DEM	30m	
Temperature	Raster	Raster	30 second	WorldClim (1970-2000)
Precipitation	Raster	Raster	30 second	(http://www.worldclim.org/)
Precipitation	Raster	Raster	0.05^0	CHIRPS (2016 - 2017) (http://earlywarning.usgs.gov)
Temperature*	Point	-	-	National Meteorology
Precipitation*	Point	-	-	Agency(NMA) of Ethiopia
RH	Point	Raster	250m	
Soil texture	Raster	Raster	250m	ISRIC-World Soil Information
Soil PH	Raster	Raster	250m	(http://www.isric.org/)
Soil type	Polygon	Raster	250m	
AEZ	Polygon	Raster	250m	
Boundary line	Polygon	-	-	Ethio-GIS (2004)

* (the clime data used to validation). RH (Relative Humidity), AEZ (Agro-ecology zone)

3.2.3. Data Analysis and Interpretation

3.2.3.1. Disease assessment and data preparation

EXW at each plot was assessed and recorded through GPS and direct field observations. Then, *enset* plots with bacterial wilt symptoms and free from bacterial wilt symptoms were identified. *Enset* farm plot with at least one *enset* plant that showed visible EXW symptom was regarded as infected. Similarly, number of *enset* plants with bacterial wilt symptoms and free from bacterial symptoms were identified and counted in each sampled *enset* plot. Then, the following equation by Bhopal (2002), was applied to calculate the prevalence and incidence of EXW:

EXW Prevalence = (SP/TP) × 100……………………..............………………...*Eq. - 1*

where,
SP (Symptomatic Plot) = the number of *enset* farm plots with EXW symptoms,
TP (Total Plots) = the total number of *enset* farm plots assessed at *Kebele* level or in the study area, totally.

EXW Incidence = (SEP/TEP) × 100……......…...……...……...……………... *Eq. - 2*

where,
SEP (Symptomatic *Enset* Plants) = the number of *enset* plants with bacterial wilt symptoms in sampled *enset* farm plot,
TP (Total *Enset* Plants) = the total number of *enset* plants assessed in sampled *enset* farm plot.

3.2.3.2. Descriptive statistics

Collected households field survey data were subjected to simple descriptive statistics (frequencies, percentages, and average) using STATA 14.0. Computed results stated as frequencies and percentages in tables and figures with elaboration.

3.2.3.3. Spatial Analysis

Although there are many approaches to analyze spatial data, creating adjusted rate maps of disease events and using spatial statistics to determine whether or not the rates are spatially auto-correlated are the typical methods to approaching spatial analysis (Wilson & Fotheringham, 2007). Detecting and identifying the locations of clusters, hot spots, cold spots, and outliers, and assessing why clusters, hot spots, cold spots, and outliers exist where they do are also common methods (Wilson & Fotheringham, 2007).

i. Mapping EXW disease distribution, prevalence and incidence

Enset production

In order to reveal the spatial pattern of *enset* bacterial wilt disease, mapping geographical distribution of *enset* plant farming is important. To visualize the actual potential of *enset* crop productions in the area, the model that depicts geographical distribution of *enset* crop production was prepared by using ArcGIS 10.5 spatial analyst tool, i.e. Inverse Weighted Distance (IWD) interpolation technique. The model was derived from 207-point data, which was collected during field survey and the point features that generated randomly and omitted due to absence of *enset* farming in the area were included in the interpolation.

The value of total number of *enset* plants counted within a farm fields was assigned for 135-point features. Whilst the value of zero was assigned for remaining 72 point features (randomly created but omitted due to absence of *enset* plants around there). The absence of *enset* plants or farm plot at these points was approved via field observation. IDW determines cell values using a linear weighted combination (LWC) of a set of sample points. The weight is a function of inverse distance. As this method assumes that the variable being mapped decreases is influenced with distance from its sampled location, the search radius variable is specified with only 4 points to increase the accuracy of prediction. To control the significance of known points on the interpolated values based on their distance from the output point, default value used in power parameter.

EXW distribution and prevalence

EXW distribution was indicated in point patterns as absent and present of disease while prevalence map was computed with the aggregate occurrences of disease at *Kebele* level based on observed *enset* cultivated gardens.

EXW incidence

EXW incidence model was generated based on the degree of incident rate or strength recorded at each surveyed *enset* farm plot by using ArcGIS Geostatistical Analyst (simple kriging) tool. Local interpolation methods are ideal in the presence of a sufficient number of observations and small-scale spatial inconsistency (Auchincloss et al., 2012). One such local interpolation procedure that uses a weighted linear combination of nearby observations to obtain an exact best linear unbiased predictor is kriging (Goovaerts, 1997).

The kriging geostatistical method or technique used because it can describe and model spatial patterns (variography or semivariogram), predict values at unmeasured locations, and assess the uncertainty associated with a predicted value at the unmeasured locations. In addition, this tool uses mathematical forms to express autocorrelation (strength of statistical correlation as a function of distance) such as either semivariogram or covariance, use transformations, and allow for measurement error.

ii. Analyzing patterns of EXW prevalence and incidence

In spatial data analysis, it is frequently needed to determine whether or not identifiable spatial patterns exist (Ord &Getis, 1995). A spatial statistic test was used to quantify each unit's spatial pattern and compare that value to the one predicted by the null hypothesis (Goovaerts & Jacquez, 2004). Some of commonly used spatial statistics analysis techniques to detect spatial patterns of a disease in a certain area are Global Moran's I statistics, Getis-Ord Gi* statistics and Reply's K function (Pfeiffer *et al.,* 2008). Areas of positive or negative clustering can be identified when their values deviate from the null hypothesis by showing increased variability in disease rates (Elliott, Cuzick & English, 1996). If the null hypothesis is rejected, the variable is said to be spatially autocorrelated (Ord & Getis, 1995). Therefore, the result is the identification of how unlikely an observed spatial pattern is under the null hypothesis (Gustafson, 1998).

In this study, spatial autocorrelation analysis (Global Moran's I) and Getis-Ord Gi* statistics were used to determine clustering of EXW prevalence and incidence in the study area. Both of them are inferential statistic with a null hypothesis of complete spatial randomness (CSR). Global Moran's I statistics to examine the spatial pattern of EXW prevalence and incidence while Getis-Ord Gi*statistics was undertaken to determine where significant spatial clustering of EXW prevalence and incidence occurred in the study area. In the case of spatial statistical analysis, the EXW prevalence refers to the presence or absent of disease at surveyed *enset* farm plots in study area, while incidence refers to ratio between symptomatic and asymptomatic plants at surveyed *enset* farm plots.

One of important parameter in such kinds of statistics analysis is conceptualization of spatial relationships. The hot spot analysis (Getis-Ord Gi* statistics) was used to determine the spatial clustering event with respect to each other within a pre-defined distance threshold (Getis et al., 2003). Fixed distance band with defined threshold distance used to specifies how spatial relationships among features are defined. The distance threshold at which spatial autocorrelation of EXW prevalence and incidence most pronounced was identified by using Incremental spatial autocorrelation tools in ArcGIS. This tool measures spatial autocorrelation for a series of distances and indicate distances where spatial processes promoting clustering are most pronounced.

a. Spatial Autocorrelation (Moran's I) Analysis

The global Moran's I statistic measure the degree of spatial association between features across the study region as a whole by evaluating whether the pattern expressed is clustered, dispersed, or random. A global Moran's Index value close to -1 indicates the presence of strong negative spatial autocorrelation (dispersion) between the features in the study area. A value close to +1 indicates strong positive spatial autocorrelation between features and a value near 0 indicates spatial randomness between features (Anselin, Syabri, & Kho, 2006).

A *Z*-score and *P*-value calculated through global Moran's I indicate whether or not to reject the null hypotheses. In this case, the null hypothesis states that EXW prevalence and incidence is randomly distributed across the study area. The overall pattern and trend of EXW prevalence and incidence were measured with global Moran's I statistic whether or not to reject the null hypotheses. The Moran's I statistic for spatial autocorrelation is calculated as:

$$I = \frac{n}{S_0} \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{i,j} z_i z_j}{\sum_{i=1}^{n} z_i^2} \quad \text{……...……………...………………} \textit{Eq. - 3}$$

Where,

$\mathbf{z}_i$ is the deviation of an attribute for feature *i* from its mean (x_i – X),

$w_{i,j}$ is the spatial weight between feature *i* and *j*,

n is equal to the total number of features,

S_0 is the aggregate of all the spatial weights.

However, global Moran's I statistic do not indicate exactly where clustering found. Therefore, hot spot analysis (local or regional statistic) was used to know where the clusters found in the study area.

b. Hot Spot Analysis (Getis-Ord Gi*)

Local statistics like hot spot analysis tool assess each feature within the context of neighboring features and compare the local situation to the global situation. The hot spot analysis tool assesses whether high or low values cluster spatially. It tests not only tests for regional clustering. It can also show the presence of significant spatial clusters or dispersion. Identification of significant spatial pattern is serves as the starting point for further investigation and the creation of hypothesized relations between the environment and health outcomes. Therefore, the EXW prevalence and incidence was analyzed to know where spatial clusters are by using the hot spot analysis tool. The Getis-Ord local statistic was defined by Getis and Ord (1992) given as:

$$G_i^*(d) = \frac{\sum j\, Wij\,(d)\, xj - Wi * \chi}{S\,\{[NS1i * - Wi * 2]/\,(N-1)\}\;1/2} \quad \text{..................................... } Eq. - 4$$

Where;

W a weights matrix used to determine spatial structure and association among locations in a data set,

i is the cell of analysis in which all other cells (*j*) must fall within a distance (*d*) to be included,

x is number of EXW cases,

N is the total number of locations,

S is the standard deviation,

χ is the mean of all EXW cases.

Finally, to know where the clusters are formed, from the hot spots statistic analysis result *Gi-Bin* values was interpolated through ArcGIS Geostatical analyst tool (simple kriging) was used to interpolate the observed EXW incidence to the study area.

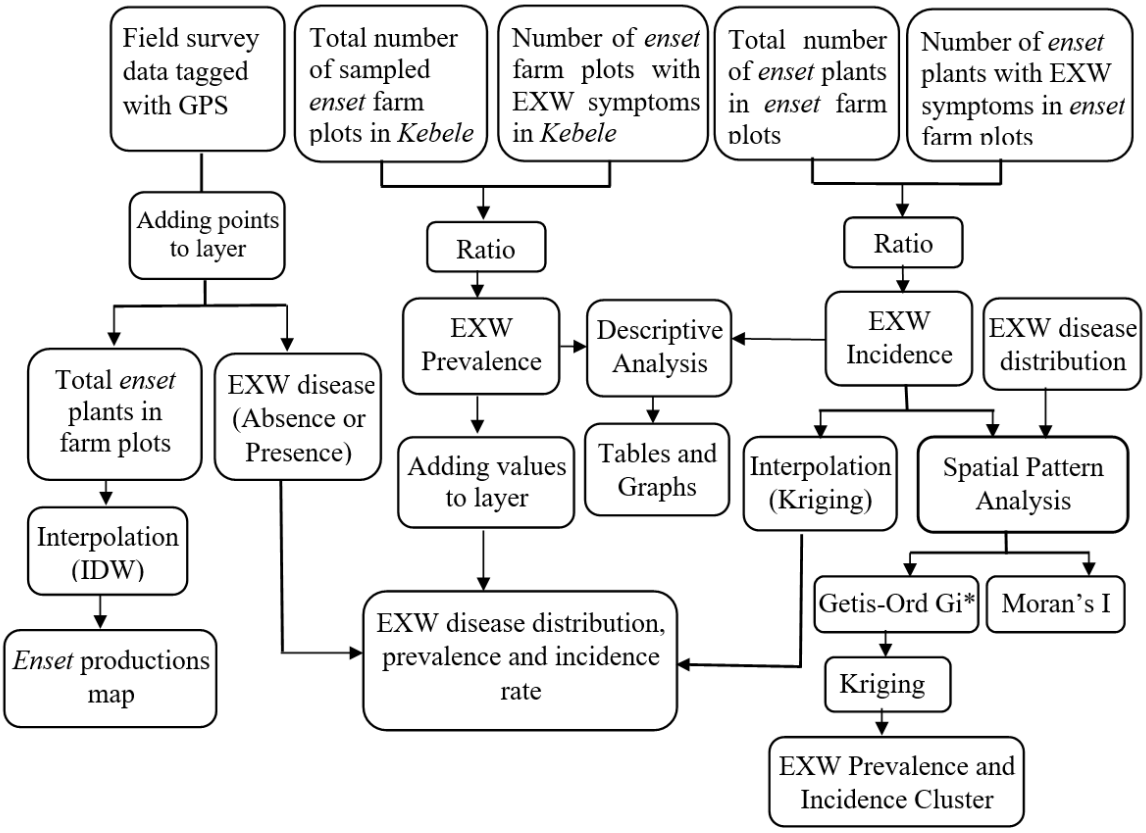

Figure 6: Workflow for mapping and spatial pattern analysis of EXW disease.

iii. Modeling spatial relationships

After determining the patterns of disease, the next question should be assessing causing factors. Statistical approaches like simple or multiple linear regressions and logistic regression allow us to look at relationships between variables. Some of advanced spatial statistics tools in ArcGIS and statistical analysis tools in other related computer programs like STATA are important. Particularly, regression analysis tools in ArcGIS are important to determine hidden spatial process. However, the regression analysis tools, such as Ordinary Least Square (OLS) in ArcGIS can compute normally distributed data. Therefore, the distribution of variables was analyzed for normality and prepared prior to using OLS approach and then analyzed through OLS regression in ArcGIS. EXW incidence was also computed using generalized linear model

(GLM) in STATA, while EXW prevalence was analyzed through logistic regression analysis in STATA since prevalence was expressed as in the form of absent or present.

a. Correlation Analysis

The association between EXW prevalence or incidence; and environmental variables were examined using the nonparametric Spearman's correlation coefficient (p value $\leq$ 0.05) using STATA 14.0. Variables found to be significantly associated with EXW prevalence and incidence in bivariate analysis was included in regression analysis.

b. Regressions Analysis

Regression analysis allows us to model, examine, and explore spatial relationships and can help explain the factors behind observed spatial patterns. Spatial regression adds spatial weights into a regression analysis to include space into the model. In this analysis, logistic and linear regression analysis and techniques were used for EXW prevalence and incidence, respectively.

Logistic Regression

Logistic regression has been widely used to predict geographic distribution of plant diseases (Yuen & Mila, 2015). It can be used to predict the probability of occurrence of an event as a function of the explanatory variables (Hosmer & Lemeshow, 2000). The logistic regression model also allows evaluating the importance of multiple independent variables that affect the response variable (Yuen et al., 1996). The logistic regression model was chosen for EXW prevalence (presence or absence) analysis because it has the capacity in predicting binary variables by nominal and ratio variables at the same.

Logistic regression generates the model statistics and coefficients that predict a logit transformation of the probability that the dependent variable is 1 (probability of occurrence of a EXW event). Logistic regression involves fitting a dependent variable using the following equations:

$Y = \text{logit}(p) = \ln(p/1-p) = \beta o + \beta_1 X_1 + \beta_2 X_2 \ldots + \beta_n X_n)$ …………………….… *Eq. - 5*

Where;

p = the probability that the dependent variable (Y) is 1,

βo = intercept,

$\beta 1$= coefficient,

X = predictors (environmental variables).

General Linear Regression

General linear model usually refers to conventional linear regression models for a continuous response variable given continuous and/or categorical predictors and which can be computed in much statistical analysis software including ArcGIS 10.5. These models are fit by Ordinary Least Square (OLS) approach, which can be visualized as the process of finding the line that best fits the data. Ordinary least square provides a global model of the variable or process that someone's are trying to understand or predict and creates a single regression equation to represent that process (Scott and Pratt, 2009). Ordinary Least Square in ArcGIS can compute linear regression with ratio data and assumes such data as normally distributed and variables have linear relationship. However, the EXW incidence data has shown significant right skew*,* meaning the mass of cases are bunched at lower values (many zero rates).

Providentially, it is possible to transform such kind of data to make it normal. Logarithmic transformations are a convenient means of transforming a highly skewed variable into one that is more approximately normal (Benoit, 2011). On the other hand, some environmental variables have shown nonlinearity nature. Logarithmically transforming variables in a regression model is a very common way to handle situations where a non-linear relationship exists between the independent and dependent variables. Therefore, ladder of power statistics in distributional plots and tests tool in STATA 14.0 was used to explore the adequacy of the fit and to transform data. The ladder searches a subset of the ladder of powers for a transform that converts variable in data set into a normally distributed variable (Tukey 1977). Then after, linear regression analysis technique was used to explore the relationship between EXW incidence and predicting environmental variables. Linear regression involves fitting a dependent variable using the following equations:

$$\gamma = \beta_0 + \beta_1\chi_1 + \beta_2\chi_2 + ... \beta_\eta\chi_\eta + \varepsilon \quad \textit{Eq. - 6}$$

where;

γ is dependent variable (EXW incidence),

β_0 is the intercept,

$\beta_1, \beta_2,$ and β_η are regression coefficients of independent variables,

χ_1, χ_2 and χ_η are independent variables,

ε is residual/random error.

Each independent variable was associated with a regression coefficient describing the strength and the sign of that variable's relationship to the dependent variable. An OLS regression model was tested. The potential relevant variable for EXW incidence prediction was screened through the process of collinearity analysis.

The residual of the regression model was analyzed for the presence of spatial pattern. The method to investigate spatial pattern (spatial autocorrelation) of the error residual values was global Moran's I statistic. If spatial autocorrelation is present in the error residuals of a model, it is an indication that the explanatory variable is unable to explain the inherent spatial structure of the dependent variable and therefore the model is missing one or more explanatory spatial variables (Anselin et al., 2006).

Generalized Linear Model (GLM)

Generalized linear models can handle more complicated situations and analyze the simultaneous effects of multiple variables, including mixtures of categorical and continuous variables. There is no need to transform the response Y to have a normal distribution in GLM. It does not assume linear relationship between the dependent variable and the independent variables, but it does assume linear relationship between the transformed response in terms of the link function and the explanatory variables. It uses Maximum Likelihood Estimation (MLE), unlike general linear regression, which uses the Ordinary Least Squares (OLS) approach (McCullagh and Nelder, 1989). Therefore, EXW incidence data was also regressed with GLM logistic model.

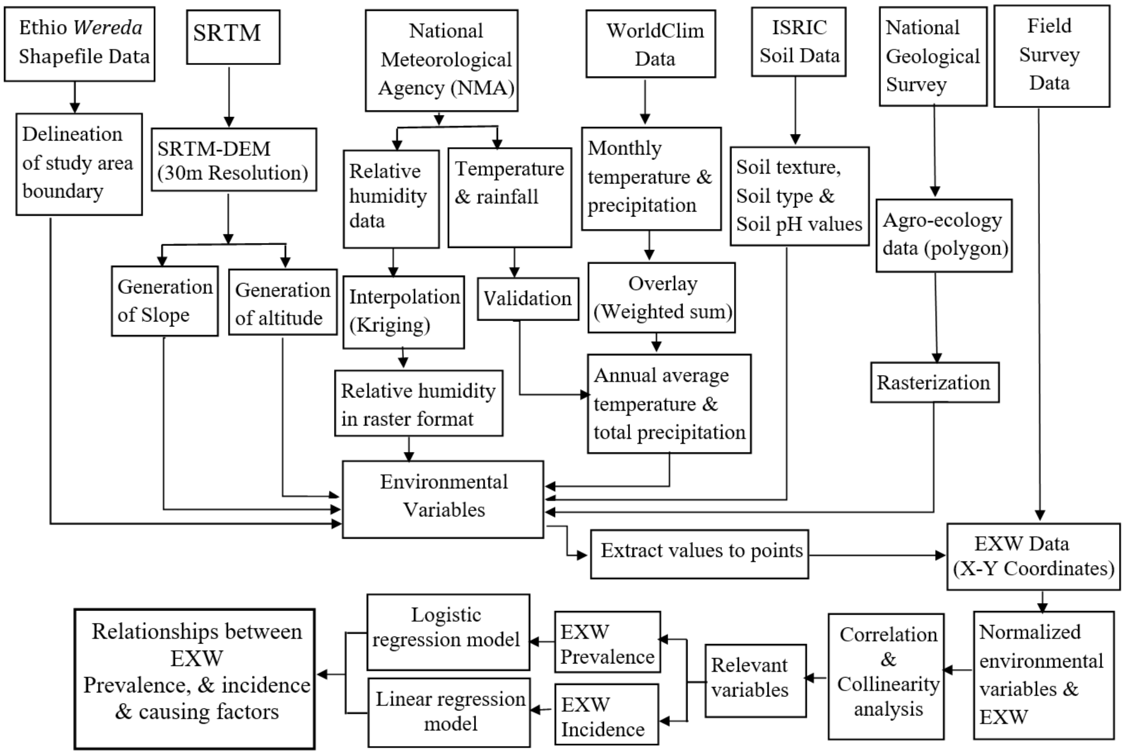

Figure 7: Workflow for modelling spatial relationships between EXW prevalence and incidence and environmental predicting variables.

3.2.4. Data Quality Controlling Procedures

In order to keep the quality of data to its highest possible level, data collectors were trained on issues related to data collection procedures and EXW symptoms identification. Moreover, data collection instruments were pretested to estimate the time needed to complete and implement them to assure whether they are capable enough to conduct the actual study. The chief investigator (researcher) reviewed the completed questionnaires on daily basis. Computer data cleaning was under taken to check for the completeness, consistency and accuracy of data and to identify errors that might have occurred during data coding process.

3.2.5. Ethical Consideration

Verbal consent was presented to both households and key informants groups to confirm their participation in the interview processes i.e. the interviewee was informed about the objectives and outcomes of the research quite adequately.

Beyond the ethics on human subjects, research ethics were also considered acknowledgement of data generated by others and appropriate citations of scholarly research outputs, books, websites, and any other related documents in order to assure intellectual and scientific integrity of the research/researcher.

Chapter 4: Results

In this chapter, the results are presented, and interpreted in line with the research objectives and research questions, and the methodology used in the study.

4.1. Overview of preliminary information

4.1.1. Household characteristics

Since the household survey data used for the study, describing the basic information about respondents is important to understand the research process. Totally, from 11 *Kebele* administrations, 135 respondents were participated in the field survey, Appendix 4(a). 56% of respondents were male and remaining 44% were female. About half (50.4%) of respondents were unable to write and read, while about 43% of respondents were either read and write or attended primary school education and only 6% of respondents have attended high school or above. Agriculture is the occupation of all respondents. 81.5% of respondents were married, whereas 3.7% were single, 8.1% were divorced and 6.7% were widowed. Total family size of respondent was 789, from those 51% were female and 49% were male. The mean age of the respondents is 42 years, Appendix 4(a).

On the other hand, 26 individuals from farmers (42%), *Kebele* agriculture extension officers (42%) and experts (16%) from *Wereda* and research centers or institutions were participated in key informant interviews. From those, 21(81%) were male and 5(19%) were female. All DA's and experts have education status of at least college diploma and above, while all farmers can read and write, at least, Appendix 4(b).

4.1.2. *Enset* production

Before discussing about the intensity of *enset* bacterial wilt disease, an overview of current condition of *enset* production and visualizing its distribution in the study area should be important to understand overall process of research.

Of course, the potential of *enset* production in the study area was described in the unit three and list of *kebeles* data was depicted in Appendix 3. However, there was no map that could depict the distribution of *enset* crop productions in the area rather generalized statistical data. Figure 8 visualize, the model that indicate the *enset* production in the study area, which was generated from collected field data.

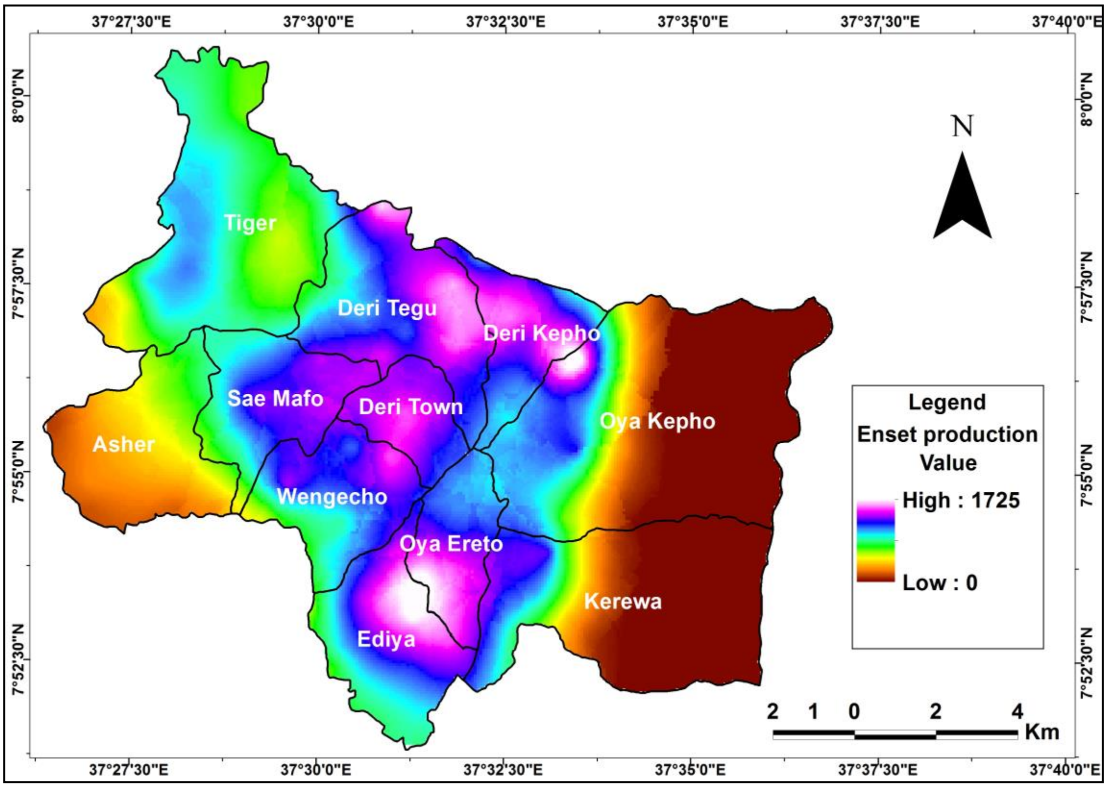

Figure 8: The Inverse Weighted Distance interpolation of *enset* crop production.

The values in figure 8 indicate the total number of *enset* crops in the *enset* farm plot. For instance, the high value 1,725 is highest number of *enset* crops that counted during field survey. The low value zero indicates total absence of *enset* crops at representative point features and was ignored during field survey but included in the interpolation to indicate the area with no *enset* production.

South, central and north parts of the study area are potentially suitable for *enset* cultivation than southwest and eastern parts, Figure 8. In the western part of the study area, there is low *enset* production and no *enset* production in eastern part. Potentialities variability in *enset* production at the study area is mainly due to *enset* farming system and elevation variation. Although *enset* is most widely cultivated crop in midland and highland areas of Yem, its farming system is only maintained in home-garden ring. Cultivated *enset* are located in human settlements near dwellings as a home-garden crop. This is similar with the *enset* farming system in Wolaita Zone which reported by Temesgen et al. (2014). However, based on the field observation, the pattern of human settlement in the study area is clustered at the center while sparsely distributed at western and no settlement at the eastern part. On the other hand, in the eastern part of the study area, the elevation is mostly found between 817m – 2000m above sea level. This area is boarded by Gibe River, which experienced high temperature and low rainfall, relatively. Conceivably, this can prove that as the elevation and climate can determine the *enset* crops production or farming system.

4.1.3. Current status of *enset* productions and yields

According to the respondents, the *enset* production is highly decreased in the area. As indicated in Figure 9, about 107 (79%) of respondents were responded as the *enset* crop production decreased in their farm gardens, whereas 15 (11%) of respondents were replied as it increased and 13 (10%) were replied as it was remained the same.

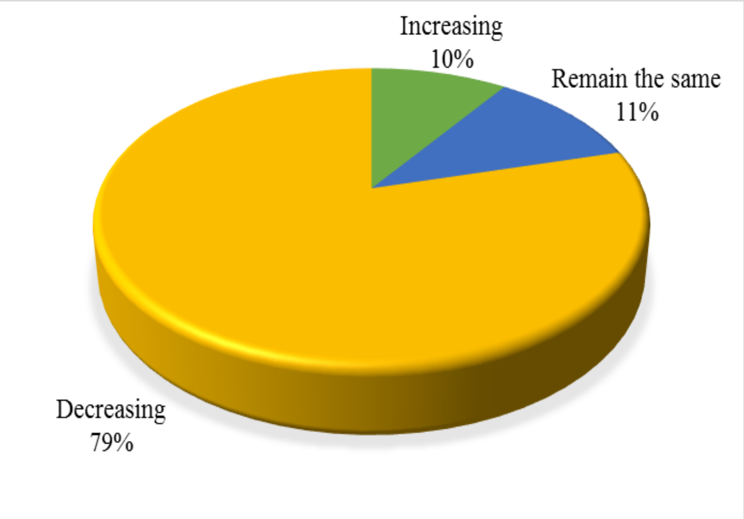

Figure 9: The recent *enset* production status.

In addition, all the interviewed key informants explained that the declining trends of the *enset* production and productivity and as it was not only about size or/and amount at farm gardens, but also its yields were highly declined.

4.1.4. Major constraints of *enset* production

There are different factors that hindered *enset* production in the area. According to the respondents, EXW, leafhopper, dry conditions and aging are some of the major factors that could affect *enset* production in the area. As indicated in Table 2, for 51%

of respondents, EXW disease is major constraint that hindered *enset* crop production. According to 25% of respondents, leafhopper had high impact on the *enset* production, while dry conditions and others (aging, corm rout, porcupine) are the major constraints for 14% and 10% of respondents, respectively.

Table 2: Proportion of respondents who ranked major enset production constraints.

Major Constraints	Frequency of respondents					
	In number			In precentage		
	1st rank	2nd rank	Total	1st rank	2nd rank	Total
EXW	70	17	87	65.4	27	51
Leafhopper	22	21	43	20.6	33	25
Dry Condition	8	16	24	7.5	26	14
Others	7	9	16	6.5	14	10
Total	107[a]	63[b]	170	100	100	100

a: indicates respondents who responded as the enset production is decreased (Figure 9) and
b: indicates respondents who had more than one constraint at the garden and ranked the second constrain, from 107 respondents.

From 107(79%) respondents, 65.4% responded that as EXW is the major (first ranked) constraints for the *enset* production, while leafhoppe is for 20.6%, dry condition is for 7.5 % and others are for 6.5% of respondents, Table 2.

In general, EXW disease had greatly contributing for the decline of *enset* crop production, for more than half (51%) of respondents. Dry conditions is the other major constraints affecting its productions that responded by 14% of respondents. This indicate how much global climate changes, could affect the *enset* production. For 25% of respondents, leafhopper is major constraint for *enset* productions, Table 2. Although leafhopper can affect *enset* productions merely, its influence is more severe with the presence of EXW disease.

In addition, according to key informants, the responsible constraints for *enset* production are population pressure, *enset* bacterial wilt disease attacks, declining soil fertility, primitive food/*kocho* processing, insect pest, etc. Particularly, most of interviewed key informants indicated that EXW is the most important constraint to attack *enset* in all *enset* growing areas causing serious losses to the crop.

4.2. EXW disease distribution, prevalence and incidence rate

4.2.1. Geographical distribution of EXW

Bacterial wilt disease symptoms were observed in the majority of the inspected *enset* cultivated gardens. The area with the EXW symptoms (symptomatic) and free from the EXW symptoms (asymptomatic) were illustrated in Figure 10.

EXW is widely distributed in the all sampled *Kebeles*, high in area where *enset* crops production is high and vice versa. Of the 135 surveyed *enset* cultivated gardens, 87 had EXW disease symptoms and 48 were free from the EXW disease symptoms.

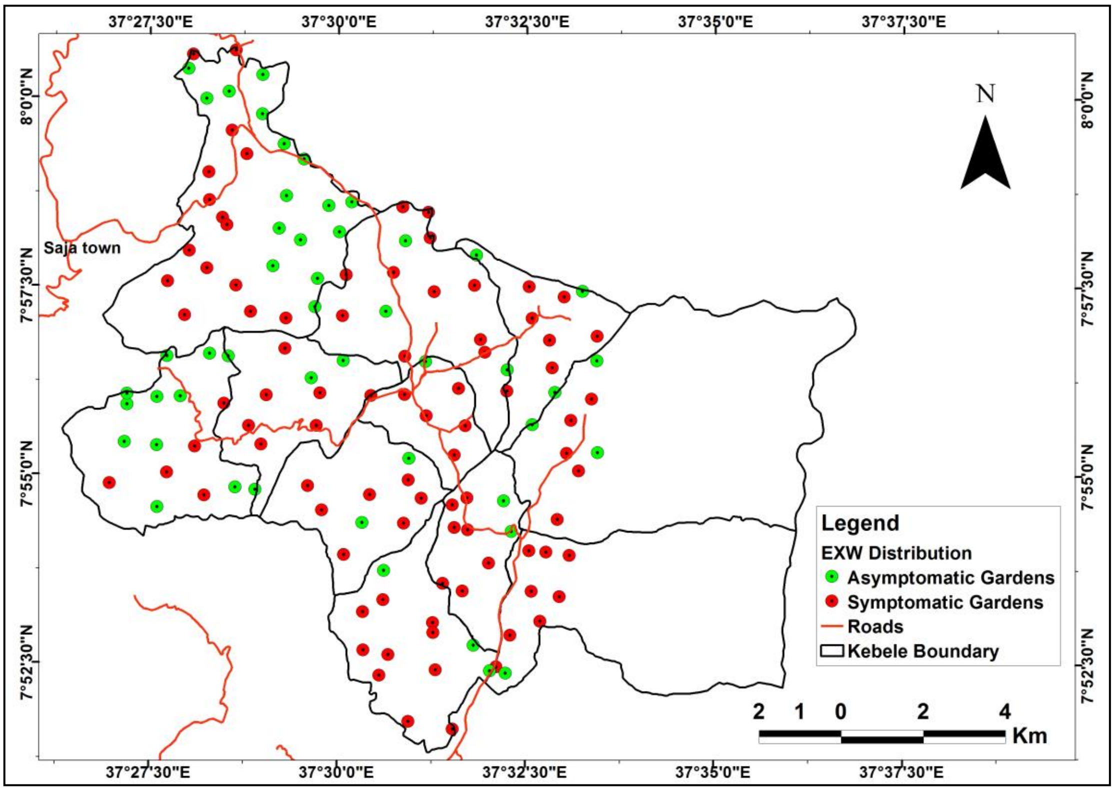

Figure 10: Spatial distribution of EXW in the study area.

According to respondents, the distribution of disease is varying from place to place and time to time. As about 70% of farmers responded, most of time the disease occurred at the summer season. However, about 30% of participant farmers responded, there is no specific time or season for the occurrence of disease, it would occur at any time or any season.

4.2.2. EXW disease prevalence

EXW disease prevalence was calculated as the ratio of the number of positive (symptomatic) *enset* farm plots and the total number of *enset* farm plots observed in *Kebele's* or/and study area. There was significant geographical variation in the EXW prevalence. Based on the analysis of 11 *Kebeles*, no *Kebele* had zero prevalence, only one *Kebele* had below 50% and 10 *Kebeles* a prevalence of ≥50 %, (Table 3, Figure 11). Note, reader to be understand from Figure 11 is, it shows only the degree of EXW prevalence ratio but not the distribution or patterns of EXW prevalence at the study area.

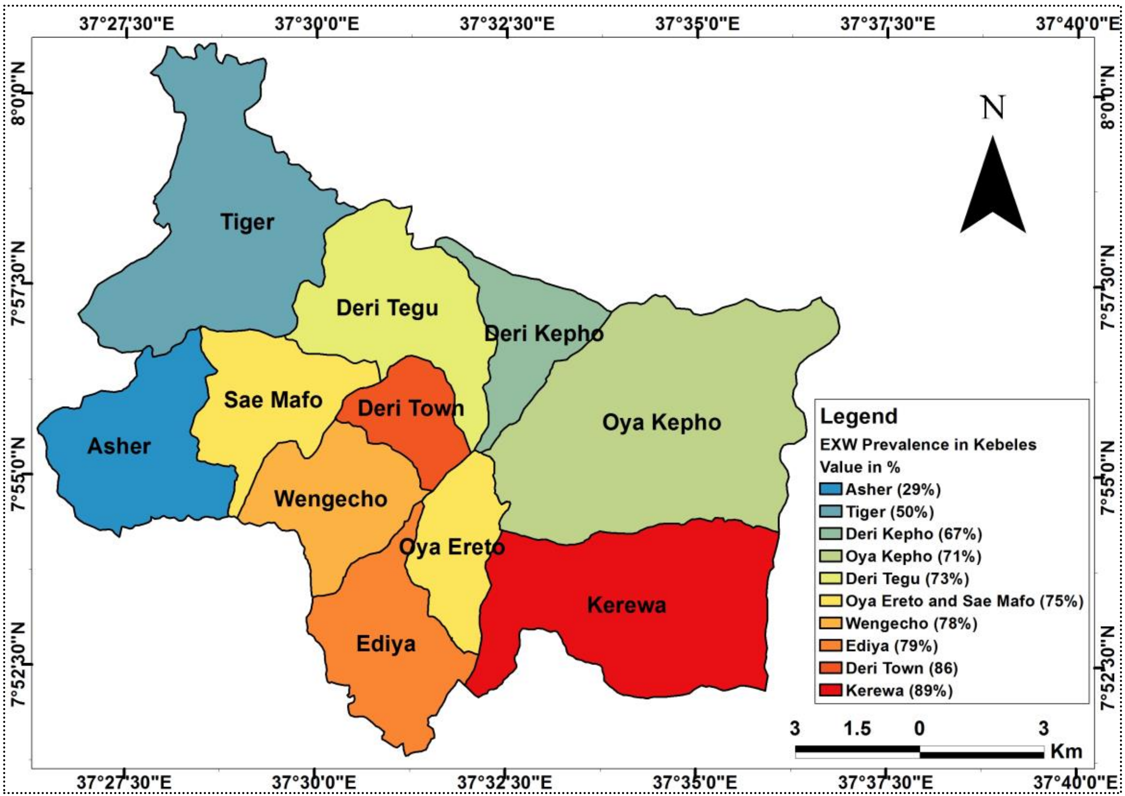

Figure 11: The EXW prevalence rate.

High prevalence of EXW recorded in the central and southern parts of the study area. The highest prevalence was recorded in Kerewa *Kebele* (89%) and lowest in Asher *Kebele* (29%). In general, EXW prevalence in the study area is 64.4%, Table 3. The source of the difference for EXW prevalence was described below under discussion section of the paper.

4.2.3. EXW disease incidence

EXW incidence was calculated as the ratio of the number of positive (symptomatic) *enset* plants and the total number of *enset* plants observed. The incidence of EXW disease was computed in three areas, such as at farm plot, *Kebele's*, and study area, entirely.

Thus, the scale of EXW incidence range from 0 – 100% at a cultivated garden, while 6.20 – 38.86% at a *Kebele* levels and 20.11% in the study area, generally. The disease was totally (100% losses) disappearing *enset* plants from *enset* cultivated gardens for some of surveyed farmers. The highest incidence was recorded in Oya Ereto *Kebele* (38. 86%) and lowest in Asher *Kebele* (6.2%).

Table 3: Intensity (prevalence and incidence) of EXW disease per Kebele

Kebeles	OP	SEP	AEP	Prevalence in %	SE	AE	TE	Incidence in %
Oya Ereto	8	6	2	75	1286	3309	4595	38.86
Kerewa	9	8	1	89	1077	4586	5663	23.48
Oya Kepho	7	5	2	71	291	4614	4905	6.31
Deri Kepho	9	6	3	67	365	3520	3885	10.37
Deri Tegu	15	11	4	73	918	8464	9382	10.85
Wengecho	9	7	2	78	1032	4997	6029	20.65
Asher	17	5	12	29	190	3064	3254	6.20
Deri Town	7	6	1	86	1176	3268	4444	35.99
Sae Mafo	8	6	2	75	411	3729	4140	11.02
Ediya	14	11	3	79	1890	7360	9250	25.68
Tiger	32	16	16	50	2823	10058	12881	28.07
Total	135	87	48	64.44	11459	56969	68428	20.11

OP (Observed Enset Farm Plots), SEP (Symptomatic Enset Farm Plots), AEP (Asymptomatic Enset Farm Plots), SE (Symptomatic Enset Plants), AE (Asymptomatic Enset Plants), TP (Total Enset Plants in the Plots).

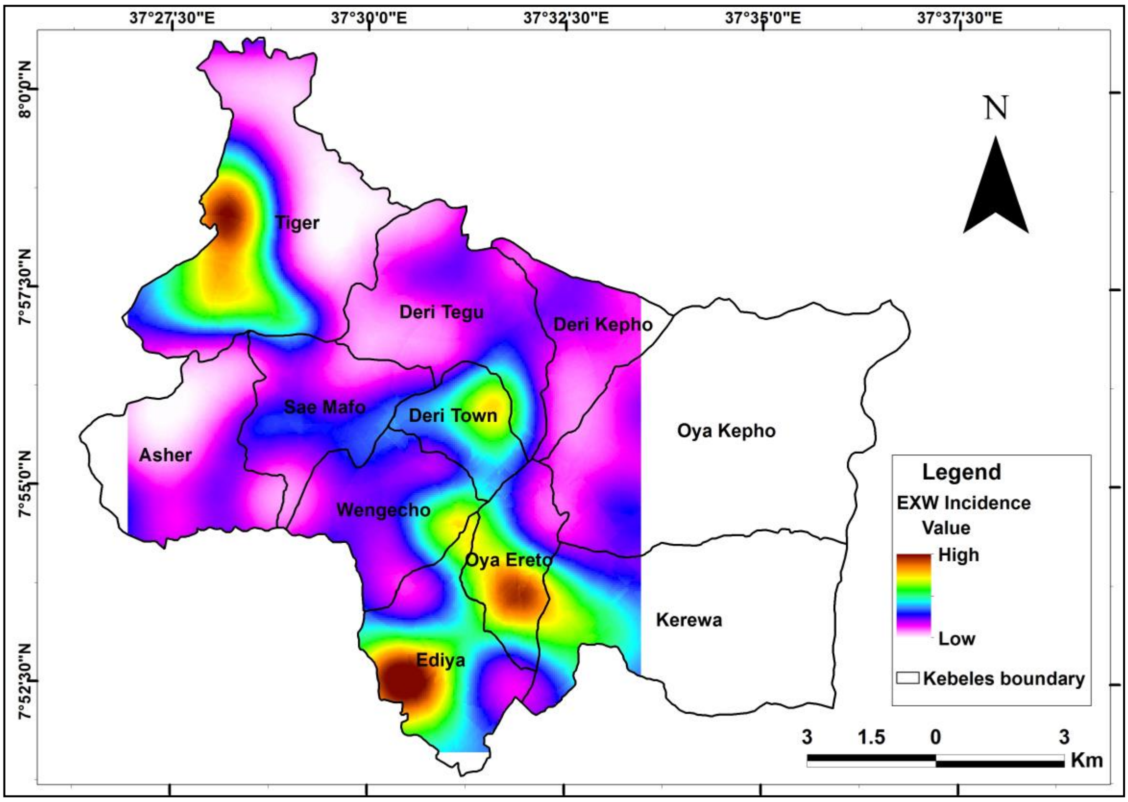

Figure 12: Kriging interpolation of EXW incidence distribution.

Figure 12 shows the magnitude of EXW incidence rate in the study area that interpolated from observed incidence rate values of the study area, totally. The model indicated the high EXW incidence rate at Ediya, part of Tiger and Oya Ereto *Kebeles* whereas the medium rate at Deri Town, Wengecho and Kerewa *Kebeles*. The low EXW incidence rate was located at remaining *Kebeles* such as Asher, Deri Tegu, Deri Kepho, Oya Kepho and Sae Mafo. There might be variation in distribution or pattern of EXW incidence rate, which identified based on descriptive statistic analysis (Table 3) and modeled (Figure 12) based on observed incidence rate of the study area. Because descriptive analysis indicates the ratio of EXW incidence at *Kebele* level based on the rate of EXW incidence recorded at such *Kebele* only while the interpolation considered the rate of EXW incidence recorded at the study area or across *Kebele*.

4.3. Analysis of pattern of EXW prevalence and incidence

Analyzed appropriate distance threshold for point features was 1884.17 m. Then, to detect EXW prevalence and incidence, both Moran's I and hot spots analysis were performed using EXW prevalence and incidence per point features with fixed distance bands of 1884.17 m in ArcGIS.

EXW prevalence has a Global Moran's I value of 0.1300, z-score of 3.4138 and a p-value of 0.0006, while incidence has a Global Moran's I value of 0.1642, z-score of 4.4453 and a p-value of 0.0000. The diagnostic indicates, there is less than 1% likelihood that this clustered pattern for both prevalence and incidence could be the result of random chance. Based on the result, it could be concluded that the pattern of EXW prevalence and incidence were clustered and the null hypothesis could be rejected.

It is apparent that a test for hot spots could be used to serve the same role as a focused test, in that the hot spot should emerge from the pack if its local structure is sufficiently unusual (Ord & Getis, 1995). Furthermore, such an approach affords some protection against the biases that may arise when only selected areas are tested. The hot spot analysis indicates the clustering of EXW prevalence and incidence.

The spatial pattern of EXW spots in the study area varied from *Kebele* to *Kebele* and as in most of epidemiological cases, the number of surveyed households under hotspots is greater than the number under cold spots but less than the number of surveyed households under not significant spots. The models clearly indicated where the EXW prevalence and incidence clusters found in the study area, Figure 13.

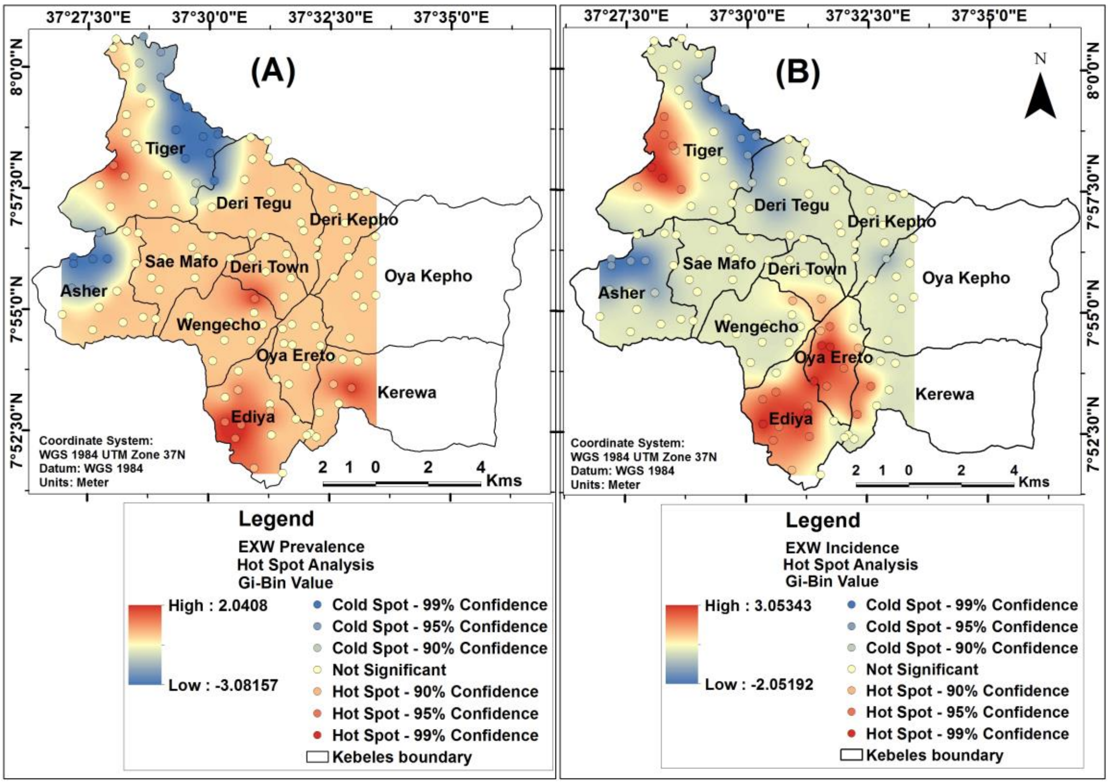

Figure 13: Kriging interpolation of the hot spot cluster of EXW prevalence (A) & incidence (B).

As illustrated in Figure 14, the semivariogram model fit to the empirical data, which pass through the center of the cloud of binned values, pass as closely as possible to the average values (blue crosses), pass as closely as possible through the middle of the local polynomials (green lines). Since these indicate performance of model, therefore, it is possible to say the models fit for both EXW incidence and prevalence.

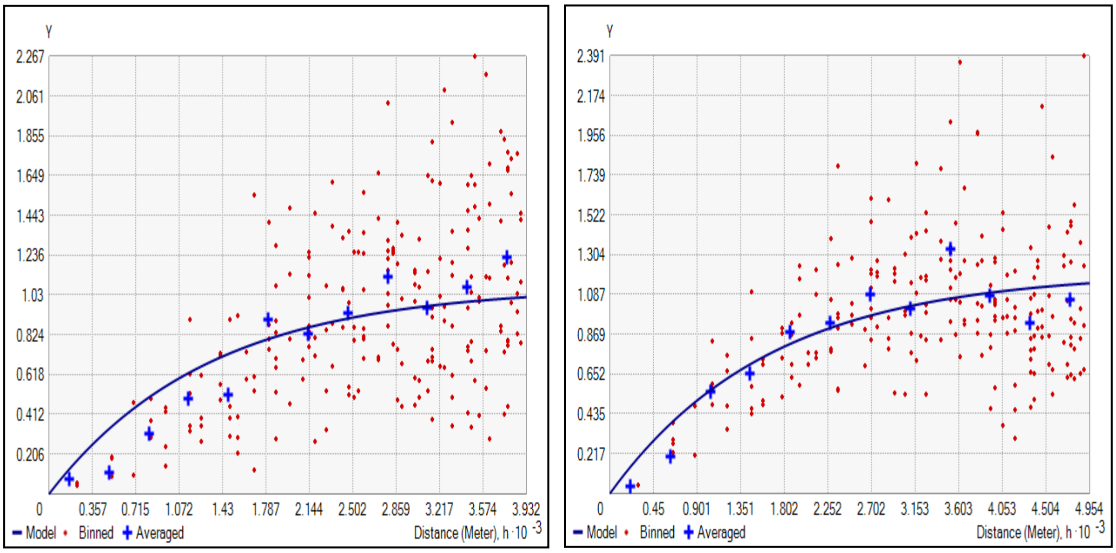

Figure 14: Semivariogram fitted with an exponential model for the hot spot cluster of EXW disease prevalence (left) and incidence (right) rate.

Based on the hot spot analysis of spatial pattern of EXW prevalence, significant clustering of hot spots was found in south (Ediya *Kebele*), west (Kerewa *Kebele*), central (at Deri Town and Wengecho *Kebele* boarder) and north-west (west part of Tiger *Kebele*), whereas cold spots found in north (north part of Tiger *Kebele*) and southwest (Asher *Kebele*), Figure 13. On the other hand, the significant clustering of EXW incidence was observed and hot spots were located in south (Ediya and Oya Ereto *Kebeles*) and northwest (west part of Tiger *Kebele*), and cold spots found in north (north part of Tiger *Kebele*) and southwest (Asher *Kebele*). Both EXW prevalence and incidence were commonly shown hot spot clustering in Ediya and west part of Tiger *Kebeles*, while cold spot clustering in Asher and west part of Tiger *Kebeles.*

Identification of clusters, however, does not address issues related to identifying the environmental determinants or causes of disease. The presence of spatial variation in the underlying environmental risk factors and the estimation of their effects remains a substantial area of further research. In part, this reflects the underlying effect of spatial autocorrelation of environmental conditions. Therefore, the identification of significant clusters then serves as the starting point for further investigation and the creation of hypothesized relations between the environment and health outcomes.

4.4. Analysis of relationship between EXW disease and underlying factors

As mentioned above (section 4.3), the spatial statistical analysis of the patterns of disease in the space was not randomly distributed, and then reject null hypothesis that the spatial processes promoting the observed pattern of values is random chance. The next question should be what underlining factors would determine the observed patterns of the disease.

4.4.1. Variables screening and collinearity test

Elevation, slope, agro-ecology, temperature, precipitation, relative humidity, soil type, soil pH value and soil texture are variables possibly considered as important EXW predicting factors by experts and literature. Whereas insect vector (leafhopper) is possibly considered as important EXW transmitter agents. However, as in many epidemiological studies, before the integration of disease causing factors, they must be pre-analyzed to evaluate their importance and pre-processed for their compatibility (Anamzui-Ya, 2012). Not all the variables that have been explored on the above are equally important and it is necessary to decide about the ones, which could play a considerable role in EXW prediction.

Therefore, the associations between EXW prevalence and incidence, and individual predicting variables were investigated. Highly correlated predicting variables were determined and removed by performing pair wise Spearman's correlation tests in to avoid multicollinearity. There should be no high correlations among the predictors. This can be assessed by a correlation matrix among the predictors. Tabachnick and Fidell (2012) suggest that as long correlation coefficients among independent variables are less than 0.90 the assumption is met. Variables with a correlation > 0.90 were removed, resulting in the selection of temperature (long time mean annual temperature, annual minimum and maximum temperature, average annual temperature of year 2016 and average spring season (March – May) temperature in year 2017) and precipitation (long time total annual precipitation, average annual precipitation of year 2016 and spring season total precipitation in year 2017). In general, most of predicting variables had low correlation coefficients but significant *p*-values at ($p \leq 0.05$). The correlation analysis result of variables is presented in Appendix 5.

Correspondingly, in statistical modeling, it is important to avoid the inclusion of related variables that can reflect the same reality leading to the issue of information duplicate or multicollinearity (Field, 2009). For this reason, collinearity was checked between all possible pairs of potential environmental variables. Temperature and altitude have high correlation coefficient ≥ 0.95 with significant $p = 000$, temperature was excluded from the model. Altitude was included because it has strong correlation coefficient with both EXW prevalence and incidence and it would control the temperature. On the other hand, sandy and clayey soil texture had correlation coefficient > 0.90, with significant $p = 0.000$. Sandy soil texture was excluded from final model due to its high contribution for collinearity and low correlations with EXW prevalence and incidence. Variance Inflation factors (VIF) was used as the next step to test collinearity. There was no potential redundancy among variables. All variables have VIF < 7.5 and therefore, collinearity was not a problem, Table 5.

Predicting variables such as altitude, total annual precipitation, relative humidity, agro-ecology, soil pH values, soil textures and soil types were screened for EXW prevalence. Whilst, altitude, total annual precipitation, relative humidity, slope, soil types, soil textures, soil pH values and leafhopper were screened for EXW incidence. Leafhopper was not included in EXW prevalence analysis because there was no theoretical assumption that it could cause the EXW. However, it was included in EXW incidence model since there was possible assumptions that insects could transmit bacterial disease from diseased plants to healthy plants.

4.4.2. Regression Analysis

The associations between screened environmental variables and EXW prevalence and incidence were further assessed using logistic regression and linear regression, respectively. Variables contributing to the model based on the statistical significance (probability) test and model performance were retained in the final model, for both EXW prevalence and incidence, specifically. *P*-values, 0.05 were considered significant.

Logistic regression

The relationship between EXW prevalence and its underlying factors was analyzed through a stepwise regression where the Odd Ratio (OR) proved their significance. For each predictor, the Odd Ratio, 95% confidence interval (CI), and *p*-values were recorded. Number of tried was made until to found better-fit model based on the log likelihood, Pseudo R^2 and significant x^2 value. Of screened predicting environmental variables, soil type, soil pH values, agro-ecology and clayey soil texture were not good EXW prevalence predictors ($p > 0.05$) in the model and were not therefore included in the final model, Table, 4.

Predicting variables such as relative humidity, altitude, total annual precipitation and silty soil texture were positively correlated and significantly contributing to the model and retained in final model. In a logistic regression, odds ratios are commonly employed to measure the strength of the partial relationship between one predictor and the dependent variable (in the context of the other predictor variables). Compared to all important response variables, relative humidity was strongly related with EXW prevalence than the others such as altitude, total annual precipitation and silty soil, Table 4.

Table 4: Output of logistic regression of environmental predicting variables and EXW prevalence, in the study area.

EXW predicting variables	OR	Std. Err	*Z*	*P*>|z|	[95% Conf. Interval]	
Relative Humidity	8.855	7.284	2.65	0.008*	1.766	4.401
Elevation	1.717	.4314	2.15	0.031*	1.049	2.809
Precipitation	1.024	.0123	2.03	0.043*	1.001	1.049
Silty Soil texture	1.283	.1285	2.49	0.013*	1.054	1.561
_cons	1.15e-70	6.61e-69	-2.81	0.005*	2.0e-119	6.62e-22

* Significant at $p < 0.05$

Together, relative humidity, altitude, total annual precipitation and silty soil texture account for 13.74 % of the variance in EXW prevalence. The final regression model show, a low predictive power (R^2 = 13.74%). This explained the variables included in the model are not the only EXW prevalence underlying factors in the study area. There could be other variables, which can determine the EXW prevalence in the area.

Linear regression

The relationships between environmental variables and incidence was assessed using linear regression with the approaches of ordinary linear square (OLS) in ArcGIS and maximum likelihood estimation (MLE) approach in STATA.

As indicated in the Table 5, based on OLS regression analysis, relative humidity, total annual precipitation, soil pH value, silty soil texture, altitude, slope, and leafhopper were significant predictors of EXW incidence in the model. Other variables such as agro-ecology and soil type were not significant predictors of EXW incidence at 95% CI and *p*-value < 0.05. All variables have positive coefficients, which indicated positive relationship found between them and EXW incidence.

Table 5: Result of OLS regression of predicting variables and EXW incidence.

EXW predicting variables	Coefficient	StdError	*t*-Statistic	*p*-value	VIF
Intercept	-183.996	49.054	-3.751	0.000*	-----
Relative Humidity	2.252	0.722	3.118	0.002*	2.514
Precipitation	0.031	0.011	2.900	0.004*	5.600
Altitude	0.474	0.227	2.090	0.039*	3.973
Soil pH	0.196	0.960	2.054	0.042*	1.375
Silty soil	0.288	0.133	2.167	0.032*	1.490
Slope	0.583	0.253	2.304	0.023*	1.049
Leafhopper	3.356	0.420	7.100	0.000*	1.111

* Significant at $p < 0.05$

Table 6 illustrates the diagnostic value results for the OLS regression models. Model was generated based on all statistically significant values in the EXW incidence dataset and has an Akaike's Information Criterion (AICc) value of 606.125 and an adjusted R^2 value of 0.44841. Model has a Jarque-Bera (JB) statistic value of 0.2647 and a JB p-value of 0.876 indicating that the JB statistic is statistically not significant at a > 95% CI.

Table 6: OLS Regression Diagnostic Values

Diagnostic	Statistic value	*p*-value
Akaike's Information Criterion (AICc)	606.125745	----------
Adjusted R-Squared(R^2)	0.448409	----------
Multiple R-Squared (AdjR^2)	0.477224	----------
Joint F-Statistic	16.561968	0.000000*
Joint Wald Statistic	159.369271	0.000000*
Koenker Statistic	10.917915	0.142240
Jarque-Bera (JB) Statistic	0.264725	0.876023

* Significant at $p < 0.01$

The Koenker test was also no statistically significant, which illustrate the relationships between some or all of explanatory variables and dependent variable are stationary. This means that the strength of the relationship could not change based on the geographic location. As a rule, when Koenker test is statistically significant (p < 0.01), the relationships modeled are not consistent (either due to non-stationarity or heteroscedasticity). However, it was not a problem in this study.

The Jarque-Bera (JB) test was not significant which illustrate that the model could be not missing variables or model is unbiased by examining whether the error residuals not deviate from a normal distribution but the R^2 value indicated that model only explained about 44.84 % of the variance in EXW incidence rate.

It was also checked by analyzing error residual value in spatial autocorrelation (Global Moran's I) statistic tool, results are presented in Appendix 6. Model has a near zero Global Moran's I value of 0.037 and a p-value of 0.266, indicating that the distribution of the error residual values is random, i.e. no spatial autocorrelation was present in the error residual values. Based on the above result it could be concluded that explanatory variables adequately explain the inherent spatial structure of EXW incidence in OLS model.

Table 7: The relationship between EXW incidence and predicting variables based on generalized linear models(GLM) with family(Gamma) link(log)

EXW predicting variables	Exp(Coef.)	Std. Err	z	P>|z|	[95% Conf. Interval]	
Relative humidity	3.160	1.503	2.42	0.016*	1.244	8.027
Precipitation	1.016	.006	2.69	0.007*	1.004	1.029
Altitude	1.465	.204	2.74	0.006*	1.115	1.926
Slope	1.455	.237	2.30	0.022*	1.057	2.003
Silty soil	1.162	.079	2.19	0.028*	1.016	1.330
Soil pH	1.164	.069	2.54	0.011*	1.035	1.309
Leafhopper	5.073	1.099	7.49	0.000*	3.317	7.759
_cons	2.31e-43	7.71e-42	-2.95	0.003*	9.94e-72	5.39e-15

* Significant at p-value < 0.05

Table 7, illustrate the statistical analysis results based on generalized linear model (maximum likelihood estimation approach). Based on GLM regression, total annual precipitation, altitude, relative humidity, slope, soil pH value, silty soil texture and leafhopper correlates positively with EXW incidence and contributes significantly to the model, yet some variation in analysis of variance. Other variables such as agro-ecology, clayey soil textures and soil type (99% CI, p-value > 0.05) were not significant predictors of EXW incidence.

In both OLS and MLE approaches, relative humidity, precipitation, altitude, slope, silty soil texture, soil pH and leafhopper were shown statistically significant relationships with EXW incidence and contributing to the model. Whereas agro-ecology, soil type and clay soil texture correlates negatively, but they seem not to be contributing to the model. As a result, agro-ecology, soil type and clayey soil texture were excluded from final model in both OLS and MLE approaches.

Chapter 5: Discussions

Although EXW has been described in Ethiopia for about five decades, the current disease burden and geographical distribution is not precisely known. EXW is gradually attracting national attention, and as the profile of the disease increases, understanding the geographical distribution and environmental factors affecting this distribution will become important. Identifying the environmental correlates of disease distribution/prevalence and incidence should the first step to control the disease spread, and producing risk and distribution maps to guide decision making for interventions.

5.1. *Enset* production and constraints

In fact, *enset* is the most economically, socially and environmentally important crop in the study area. *Enset* is widely cultivated in Yem Special *Wereda* and staple food for the society. *Enset* is source of food, medicine, mat, house constructing material, animal feed, etc. in day-to-day life for resource poor farmers in the area, since it is drought tolerant crop. Yem society and *enset* has strong relationships, *enset* is more than crop for them when compare to the other crops. In addition to aforementioned importance, *enset* is the indicator of wealth status of farmers for Yem society.

However, since a decade, the *enset* production is highly decreased in the area. The productivity and yields of *enset* is decreased due to different factors. According to 79% of respondents, the *enset* production was shown continuously decreasing trends since last 15 years. Similarly, all interviewed key informants reflect the declining trend of *enset* production, productivity and yields in most of *enset* growing areas. Likewise, many researchers such as Anita et al. (1996), Endale et al. (2003), Tsegaye et al. (1998), Anonymous (2014) reported that both the area coverage and the productivity of *enset* is declining continuously in *enset* growing areas.

According to the respondents, the major responsible factors for the declining trends of *enset* production are *enset* wilt disease, leafhopper, climate change, low soil fertility, population pressure.

For 65.4% of respondents, EXW is major constraints for *enset* production. This is in line with Brandt et al. (1997); Anynomous (2013; 2014); and Teshome (2016) report, *enset* bacterial wilt, is the most important biotic constraint to *enset* cultivation. Particularly, due to frequent impacts of EXW in the area, many farmers are obligated to replace the *enset* farming by other crops and have given low attention for *enset* production. In addition, shift towards a market-oriented economy those have a high market values and can be mature within a short period of time or seasonal crops are another observed factors affecting *enset* farming system in the study area. Bizuayehu (2008) obtained similar report. Dry condition (drought) is the another major constraint affecting *enset* productions for 7.5 % of respondents. This indicate how much global climate changes, could affectting the *enset* crop production. Similarly, Teshome (2016) reported climatic factor as major enset production constrain in Gamo highland. For 20.6% of respondents, leafhopper is major constraint for *enset* crop productions, Table 2. Although leafhopper can affect *enset* productions alone, its influence is more severe with the presence of disease.

5.2. *Enset* bacterial wilt identification

Plants get sick, and sick plants grow and produce poorly, they show various types of symptoms, and, often, parts of plants or whole plants die (Agrios, 2005). Evident EXW disease symptoms observed in survey fields showed on diseased *enset* plants were the yellowing of the leaf at margin side and tip, wilting (related with failure of turgor and petiole wrinkling; and leaf), dry leaf and also yellowish secretion of a bacterial ooze from cut tissues of the plants. Which are the characteristics of EXW in agreement with the prior reports on *enset* bacterial wilt assessment in *enset* farm plots by Twaites et al., (2000), Tushemereirwe et al., (2004), Mengistu et al., (2014) and Alemayehu et al., (2016).

According to farmers, for long period the disease was known as the cause of occasional and scattered infections in *enset* in the study area. The farmers described as the disease causes considerable losses of *enset* in the area, sometimes causing farmers to abandon severely affected gardens for up to two to five years. As a result, farmers were tried to control and manage the disease via applying different cultural management systems such as burning or buried the infected plants, taking care in using farm equipment. Farmers always observing their *enset* farm plots to identify if *enset* plants are either diseased or not and apply immediate controlling options. The farmers of study area have a profound knowledge about *enset* wilt disease. In addition, the educational and work experiences of enumerators (DAs) were provided other good opportunity to identify diseased and non-diseased *enset* plants, easily.

5.3. Magnitude of EXW prevalence and incidence rate

In the study area the EXW disease was widely distributed at varied degree of intensity. Out of surveyed 11 *Kebele* administrations, except Asher *Kebele* (29%), all other *Kebeles* had the EXW prevalence of greater than 50%. Totally, the EXW prevalence in the study area is 64.4%. This is higher than the EXW prevalence reported in Borena mid altitude 56% by Desalegn and Addis (2015) and less than the EXW prevalence reported in Gedeo Zone 75.5% by Anonymous (2014) and in Tikur Inchini *Wereda* 89.3% and Jibat *Wereda* 86.7% by Mengistu et al. (2014).

On the other hand, the EXW incidence was also varied from *enset* farm plot to plot and *Kebele* to *Kebele*. It ranges from 0 – 100% at *enset* cultivated garden, 6.20 – 38.86% at a *Kebele* level. In general, the EXW incidence rate in the study area is 20.11%. The disease totally devastated *enset* plants from *enset* farm plots for some farmers. This is in agreement with the report that the losses due to EXW disease can reach up to 100% under severe damage of plant by the pathogen under favorable condition for disease development (Gizachew, 2000; Kidist, 2003; Tsehay, 2009; Mengistu et al., 2014). Although its degree of intensity varied from place to place, the observed EXW prevalence and incidence in the study area was severe. It leads the society to be threatening for their future food security and livelihood security.

5.4. The relationship between EXW disease and environmental variables

Environmental factors are not yet adequately investigated, however, obviously altitude, slope, temperature, rainfall, relative humidity, soil type, soil texture, soil pH, agro-ecology and insect vectors are factors associated with disease developments and spread. This assumption was supported by 81% of interviewed key informants, where as 19% were opposing it and believed as EXW was not determined by above-mentioned environmental factors, rather not known.

The availability, growth stage, succulence, and genetic susceptibility of the host plants may have affected by environment. It may also affect the survival, vigor, rate of multiplication, and ease, direction, and distance of dispersal of the pathogen, as well as the rate of spore germination and penetration (Agrios, 2005). In this study, the analysis result indicates strong positive associations between EXW prevalence and response variables such as relative humidity, altitude, precipitation and silty soil texture.

Altitude, precipitation and relative humidity are highly related to each other. Obviously, altitude determines rainfall in Ethiopia i.e. when altitude increase, rainfall also increase as well as relative humidity increases. The extent of altitude, precipitation and relative humidity covered in this study were 1899 - 2641 m.a.s.l, 1070 - 1254mm and 56 - 58%, respectively. There was only 742m vertical variation in altitude, 184mm variation in precipitation and 2% variation in relative humidity. However, the disease was widely distributed in observed range of altitude, precipitation and relative humidity and they show statistically significant relation with both EXW prevalence and incidence. The observed wide distribution of disease in different altitude at a study area is in line with Anita et al. (1996) report that the disease was widely distributed in high, mid and lower altitude areas of the Central, the Southern and Southwestern *enset* growing regions of the country. Similarly, Mengistu et al. (2014) reported the wide distribution of disease in *enset* growing area in West Shewa.

Although the disease was widely distributed in observed range of altitude, precipitation and relative humidity in the study area, its intensity (prevalence and incidence) varied with the variation of these predicting variables. When comparing the variation of the disease intensity with the range of altitude, precipitation and relative humidity, it has high intensity with increasing altitude, precipitation and relative humidity and vice versa, though no clear cut-off where the variation was started. Previous studies have documented association of altitude and rainfall with occurrence of EXW in Borena (Desalegn and Addis, 2015). Similarly, many researchers such as Mekuria et al. (2016); Brandt et al. (1997); and Maina et al. (2006) reported the associated of elevation and EXW disease. In addition, the positive association between slope and EXW incidence, may strengthen the influence of topography (altitude) on pathogen multiplication.

Ashagari (1985) reported the association between EXW and relative humidity and Maina et al. (2006) as the pathogen requires humid condition for survival. Although the temperature was not included in regression model due to its high correlation with altitude, it does not mean there is no association between EXW and temperature. Because temperature and altitude has inverse relationship and temperature has shown statistically significant negative correlation with EXW prevalence and incidence. This indicated that there is low disease intensity with increasing temperature and vice versa. Therefore, low temperature might be favorable for pathogen multiplication than high temperature. The pathogen may require high moisture and lower temperature (Mekuria et al., 2016).

Moisture and temperature are some of the most important environmental factors that affect the development of plant disease epidemics. The continued high moisture abundant whether in the form of rain, dew, or high humidity, is the dominant factor in the development of most epidemics of diseases caused by oomycetes and fungi, bacteria, and nematodes (Agrios, 2005). He also explained that moisture not only promotes new succulent and susceptible growth in the host, but, more importantly, it increases multiplication of bacteria. Also according to him, moisture facilitates the oozing of bacteria to the host surface, and it enables spores to germinate and zoospores, bacteria, and nematodes to move. The presence of high levels of moisture and low temperature may allow the spread of EXW prevalence and incidence. In line with the analysis, about 92% of interviewed key informants believe that the diseases onset occurs mostly during rainy or wet seasons.

Contrary to researcher expectation, agro ecology, soil type, and clayey soil texture were not to be significantly contributed to the both EXW prevalence and incidence models. While insect vectors (leafhopper) found to be very strongly correlated with EXW incidence and has significantly contributed to the model.

Though agro ecology was expected to be associated with disease, it has insignificant association with EXW prevalence and incidence. The disease was detected in all agro ecologies. There could be variation in extent of disease occurrence in different agro ecology yet there is no clear cut off occurrence on them. Anita et al. (1996); Ashagari

(1985); and Mekuria et al. (2016) also reported the variation in disease occurrence with different agro-ecology.

Silty soil texture in 0 - 30 cm depth indicates strong positive associations between EXW prevalence and incidence and contributed to the models, while soil pH only shown positive association with incidence and contributed to the model. The silty soil content is high in upper part of soil particularly in 0 - 30cm depth and then decreasing toward lower depth (lower part), in the study area. During the wet season, more than 70% of the total fine root mass of *enset* was distributed in the upper 0 - 20 cm soil depth (Solomon, Masresha and Olsson, 2008). Since the survey data was collected during rainy season, the high root mass might be concentrated at the upper depth of soil and may enter more than mentioned depth. The root damage caused by nematodes creates wounds that act as entry avenues for *Xcm* from the surrounding soil (Shehebu et al., 2010). The silty soil texture has capability to holding water, whereas sandy and clayey soil textures have poor capability. Therefore, the available nutrients content in silty soil and its water (moisture) holding capability could probably favor bacterial multiplication. Because *Xcm* is soil borne and possibly soil is believed to associated with pathogen by including suitable nutrients. The soil moisture and temperature, and soil nutrients (nitrogen, carbon and others) allocation patterns to different plant parts and its association with *Xcm* should need further investigation in the laboratory.

Some of insect vectors do contribute to the spread of some bacterial pathogens of plants. However, generally, the importance of insect transmission of plant diseases has been overlooked and greatly underestimated (Agrios, 2005). This is true in the case of EXW disease, there was no or little study, which investigate the association between Xanthomonas wilt in *enset*, whereas little Xanthomonas wilt in bananas is transmitted by insect vectors via moist male flower cushions and bract scars (Tinzaara et al., 2007). Surprisingly, from all investigated predicting variables of EXW incidence in this study, insect vector (leafhopper) was shown high association with EXW incidence. There was leafhopper in all EXW incidence hot spot clusters. Contrary to this, there was no leafhopper in all EXW incidence cold spot clusters in the study area. In fact, leafhopper cannot be causing factor for EXW disease rather it would probably worsen the spread of EXW incidence as a transmitter.

Many insects facilitate the entry of a pathogen into its host through the wounds the insects make on aboveground or belowground plant organs. Finally, in many cases, insects make possible the existence of a plant disease by obtaining, carrying, and delivering into host plants pathogens that, in the absence of the insect, would have been unable to spread, and thereby unable to cause disease (Agrios, 2005). EXW diseases caused by *Xcm* which are produced within or between plant cells, released masses of sticky bacteria exudates (ooze) through cracks or wounds in the infected area. Then, bacteria are likely to stick on the legs and bodies of all sorts of insects, like leafhopper and others that land on the plant and met the bacterial exudates (Shivani, 2016). Actually, many of insects attracted by the sugars contained in the bacterial oozes and feed on it, thereby further smearing their body and mouthparts with the bacteria-containing exudates (Shivani, 2016).

A leafhopper is the common name for any species from the family Cicadellidae. Leafhoppers can transmit plant pathogens, such as viruses, bacteria (Ing-Ming et al., 2000). The insects like leafhopper could wound the host plant organs particularly leave, by feeding or place the bacteria with their mouthparts, in or around wounded plant cells. Where a suspension of nutrients in the absence of active host defenses and where they can multiply rapidly and subsequently infect adjacent healthy tissues surround leafhopper, increase the probability of transmission of plant pathogenic bacteria (Shivani, 2016).

According to respondents (whose *enset* farm plot was affected by leafhopper), the leafhopper is seasonal and most of time it presents at the beginning of rainy season and disappearing when rain become strong. This could probably due to low temperature and high rain may not favorable for leafhopper. Agrios (2005) explained that the low temperatures reduce the number of vectors (insects). The activity of these vectors is reduced drastically in rainy weather (Agrios, 2005). This all may strengthen the possible association of insect vectors (leafhopper) with EXW incidence rate. Therefore, further investigation would be very important to minimize the gap related to the importance of insect vectors in the spread of EXW incidence.

Chapter 6: Conclusion and Recommendations

6.1. Conclusion

This study set out to establish the relationship between EXW disease and environmental variables. Understanding of the factors that are associated with EXW incidence is critical for the design of intervention strategies aimed at reducing EXW prevalence as well as incidence.

To establish the correlation between environmental variables and EXW prevalence and incidence in study area, the regression model was adopted using cross sectional data. Correlation of the observed geographical distribution of EXW with selected environmental variables was investigated. The disease incidence is high in the certain part of the study area. The possible association of environmental variables and EXW prevalence and incidence was modeled. Regression results indicated some of potentially predicting environmental variables of EXW disease. Topography (altitude and slope), climatic conditions (relative humidity and precipitation), silty soil texture and soil pH, may contribute or influence pathogen survival, which in turn probably influences the distribution of EXW. However, there was no a clear trend of increasing incidence as relative humidity and precipitation increases. The EXW incidence is highly associated with leafhopper.

Regression results indicated no relationship between EXW and agro-ecology, soil type and clayey soil texture. However, there is need for further investigations using disaggregated data, time series EXW data, and adding more control variables to regression model to identify the factors that are associated with EXW incidence in *enset* growing area of Ethiopia.

In general, the findings of this study support some of the preexisting assumptions that link EXW occurrence with the higher elevation, higher rainfall, humidity and lower temperature. Based on the finding, the concerned bodies should provide management options to control the spread of disease, for more vulnerable areas due to environmental factors. Particularly, providing insecticide where leafhopper is found. In addition, it could be concluding that the findings contribute to the growing research on the aetiology of EXW, and provide new starting points for further exploration of EXW aetiology using laboratory studies.

Finally, this work is in progress and the results presented here will be refined in future work. Because plant disease models are developed for specific climates and regions for different seasons to verify that it will change in spatio-temporal dynamics.

6.2. Recommendations

The present study identified that the disease was influenced by biophysical factors. Understanding disease epidemiology as affected by different variables is useful to design sustainable EXW management strategies. Identifying other variables influencing prevalence/incidence might be achieved through wide area coverage in future analyses. Deciding on a threshold for classification of geographic region as endemic or non-endemic for EXW will be a priority in targeting intervention to where the disease is prevalent.

The identified EXW prevalence and incidence in this study were based on cross-sectional data, which may have considered just single season and small areal coverage. The effect of the disease at different growing seasons in wider geographical area should be assessed. Particularly, geographical area coverage should be included all elevation limits, which covered with *enset* farming or suitable for *enset* plant growth. A comprehensive understanding of the occurrence of EXW needs investigation of both the socioeconomic-level and environmental level correlates. Therefore, the status and distribution of the disease should be further determined.

Finally, the analytical model used for this study was regression with dependent variable EXW prevalence and incidence with screened predicting environmental variables. This may not enough to identify or model the relationship between EXW and environmental variables that could predict EXW distribution. Therefore, using different modelling techniques and method would important to achieve better results. The quality of data and multidisciplinary approach should be essential and need high focus.

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Appendix 1: Questionnaire to be filled by households

Jimma University
College of Social Sciences and Humanities
Department of Geography and Environmental Studies

The aim of this questionnaire is to gather information from local household regarding *enset* bacterial wilt disease of the study area. Purpose of this research is purely for the problem solving and the academic award. Thus, the fact that you have been selected is quite systematically and your participation in this questionnaire is voluntary. The information you provide will be treated as confidential. It will be processed in computer in such a way that no personal identification will be possible. Since your response is valuable for the mentioned objective, the writer politely requests you to give your answers to the stated questions as much as possible as you can. To obtain reliable and scientific information it is necessary that you answer the questions as honestly as you can.

I greatly appreciate your cooperation in advance!

I. General Questions. ***NB:*** *Respondent should be head of household (HHH)*

Instruction: Fill in blank space & encircle letter for multiple choice, accordingly.

No.	General questions		Responses/Answers for the questions	
1	Geographic location of respondent's	Region:	SNNPRS	
		Wereda:	Yem Special Wereda	
		Kebele		
		Village/ Cluster:		
		GPS Point ID No.		(in number)
		X-Coordinate		(in decimal degree)
		Y-Coordinate		(in decimal degree)
		Elevation		(in meter above sea level)
		Temperature	Min: Max: Av:	(in degree Celsius)
		Relative humidity		(in percentage)
		Precipitation		(in inch)
		Others	Visibility:	Dew point:
2	Personal information of respondent's	Name		
		Sex	A. *Male* B. *Female*	
		Age		
		Responsibility	A. *Husband* B. *Wife* C. *Daughter/Son* D. *Others*	
		Academic status	A. Unable to r*ead & write* B. *Read & write* C. *Grade 1-4* D. *Grade 5_8* E. *Grade 9_10* F. *Grade 11_12* G. *College*	
		Occupation	A. *Agriculture* B. *Wage Labor* C. *Both A&B* D. *Others*	
		Marital status	A. *Single* B. *Married* C. *Divorced* D. *Widowed*	
		Family size	A. *Male:* B. *Female:* C. *Total:*	
		Length of time living in this area	A. 1-5 years B. 6- 10 years C. 11-15 years D. 16-20 years E. 21and above	

II. Questions related to *enset* farming and *enset* bacterial wilt disease

Instruction: Give answers for short term questions and encircle letter for multiple choice, accordingly.

1. Do you have *enset* in your farm?

   A. Yes **B.** No

2. How many *enset* plants do you have on the *enset* field (number)?__________
3. What is the trend of *enset* production in the past 15 years?

   A. Increasing **B.** Remain the same **C.** Decreasing

4. List out the major constraints of enset production in your farm in their order of importance (use code)? _____, _____, _____, _____, _____, ______, ______

   1. *Enset* Bacterial wilt 2. Enset mealy bug
   3. Leaf hopper 4. Mole rate
   5. Porcupine 6. Wild pig
   7. Corm rout 8. Others (Specify)____________

5. Did you get any information about the EXW diseases from locality?

   A. Yes **B.** No

6. If yes, what information did you get about the disease?______________________

   ____

7. Which part of the plant shows the first symptoms when attacked by the disease?

   A. Corm **B.** Pseudo steam **C**. Leaf

   D. Others specify____

8. Is there *enset* bacterial wilt in your farming garden in 2008/2009?

   A. Yes **B.** No

9. If yes (3), how many *enset* plants infected by EXW disease at your field?_______

   ____

10. Do you identify EXW infected enset early?

    A. Yes **B.** No

11. How do you identify whether it is EXW or not? You can choice more than one.

    A. Yellowish leaf **B.** Wilted leaf

    C. Wilting upper part of the leaf **D.** Yellowish leaf and strange smell

    E. Shoot bud and entire leaf wilted **F.** Excrete outh on the psuedostem.

    G. List if any other____

12. Is it regularly observing your farm fields?

A. Yes **B.** No

13. If yes (5), when the EXW occur at your *enset* farm garden (E.C)?______________

____

14. Do you believe that EBW problem was season dependent?

A. Yes **B.** No

15. If yes, for question 20 which season is more favorable for EBW?

A. Wet season **B.** Onset of rain season **C.** Dry season

16. Do you believe that an EBW disease correlated with environmental factors?

A. Yes **B.** No

17. If yes (7), which environmental factors are correlated? ______________________

____

18. In which climatic condition BXW frequently occurring?

A. Hot **B.** Cold **C.** Cool **D.** Humid

19. In your opinion, what are the causal agents of the BXW disease?______________

____

____

Thank you for cooperation!

Appendix 2: Interview questions filled by key informants

Jimma University

College of Social Sciences and Humanities

Department of Geography and Environmental Studies

The aim of this interview is to gather information from expertise/ experienced individual regarding *enset* bacterial wilt disease. Purpose of this research is purely for the problem solving and the academic award. Thus, the fact that you have been selected is quite purposively based on your experience and knowledge with the case as nomination from your colleague's. Your participation in this interview is voluntary. The information you provide will be treated as confidential. It will be processed in computer in such a way that no personal identification will be possible. Since your response is valuable for the mentioned objective, the researcher politely requests you to give your answers to the stated questions as much as possible as you can. To obtain reliable and scientific information it is necessary that you answer the questions as honestly as you can.

I greatly appreciate your cooperation in advance!

I. General Questions (Personal questions)

Instruction: Fill in blank space on the table, please.

Questions	***Responses/Answers for the questions***
Region	
Zone/Wereda	
Kebele/City/Town	
*Name**	
Sex	
Age	
Marital status	
Academic status	
Working place/Organization	
Occupation/Position	
Work Experience	

**(Writing name is not mandatory, but it might help the researcher to quote directly the idea/ response will be given for the questions by you if it is necessary. So, writing your name in the table should be considered as your agreement/commitment to be cited in the paper as an expert).*

II. Interview Questions

Instruction: Give answers for short term questions as you can & encircle letter for multiple choice.

2. How do you explain enset in relation to its importance to the society?__________
____

3. What is the trend of *enset* production in the past 10 years?

   A. Increasing **B.** Remain the same **C.** Decreasing

4. If decreasing/remain the same (3), list out the major constraints of *enset* production based on your experience of observation?________________________
____

5. Do you have any information about *enset* bacterial wilt disease?

   A. Yes **B.** No

6. If yes (5), how do you explain enset bacterial wilt disease?___________________
____

7. Do you identify EXW infected enset, early?

   A. Yes **B.** No

8. How do you identify whether it is EXW or not? ____________________________
____

9. When the diseases onset occurs? ____
____

10. Do you believe that EBW problem was season dependent?

    A. Yes **B.** No

11. If yes (10), which season is more favorable for EBW? Why (possible assumptions)? ____
____

12. Do you think that an EBW disease correlated with environmental factors?

A. Yes **B.** No

13. If yes (11), which environmental factors are correlated? How?

A. Elevation____

____

B. Slope____

____

C. Soil (type or texture or PH value):____________________________________

____

D. Temperature: ____

____

E. Rainfall:____

____

F. Relative humidity:____

____

G. Others:____

____

14. Do you think that an EBW disease correlated with socio-economic factors?

A. Yes **B.** No

15. If yes (11), which socio-economic are correlated? How?______________________

____

16. In your opinion, what are the causal agents of the BXW disease?_______________

____

Thank you for cooperation!

Appendix 3: The *Kebele* administrations of Yem Special *Wereda*.

No	Name of *Kebele*	Enset crop production	EXW symptoms in 2016/17	Degree of Prevalence	Remark
1	Saja Town	Not potential	Observed	Moderate	Not Selected
2	Ashe	Not potential	Observed	Low	Not Selected
3	Saja Laften	Not potential	Observed	Low	Not Selected
4	Konar	Not potential	Observed	Low	Not Selected
5	Asher	Potential	Observed	High	Selected
6	Tiger	Potential	Observed	High	Selected
7	Deri Town	Potential	Observed	High	Selected
8	Deri Tegu	Potential	Observed	High	Selected
9	Deri Kepho	Potential	Observed	High	Selected
10	Sae Mafo	Potential	Observed	High	Selected
11	Wengecho	Potential	Observed	High	Selected
12	Oya Ereto	Potential	Observed	High	Selected
13	Oya Kepho	Potential	Observed	High	Selected
14	Kerewa	Potential	Observed	High	Selected
15	Ediya	Potential	Observed	High	Selected
16	Fofa Town	Potential	Observed	High	Not Selected
17	Gorumina Angry	Potential	Observed	High	Not Selected
18	Meleka	Potential	Observed	High	Not Selected
19	Shemu Metelo	Potential	Observed	High	Not Selected
20	Azgi Zemda	Potential	Observed	High	Not Selected
21	Gesi	Potential	Observed	Moderate	Not Selected
22	Nuba	Potential	Observed	High	Not Selected
23	Lower Kesheli	Potential	Observed	High	Not Selected
24	Upper Keshelu	Potential	Observed	High	Not Selected
25	Samo Awasho	Potential	Observed	High	Not Selected
26	Shoshorina	Potential	Observed	High	Not Selected
27	Shosher Alimama	Potential	Observed	High	Not Selected
28	Kerezi Doyo	Potential	Observed	Low	Not Selected
29	Toba Town	Potential	Observed	High	Not Selected
30	Faya	Potential	Observed	High	Not Selected
31	Soro Goni	Not Potential	Observed	Low	Not Selected
32	Weira	Potential	Observed	Moderate	Not Selected
33	Wogero	Not Potential	Observed	Low	Not Selected
34	Kelechi	Potential	Observed	Moderate	Not Selected
35	Ezo Zeta	Potential	Observed	Moderate	Not Selected

Source (Yem Special Wereda Agriculture and Natural Resource Development Office, 2017).

Appendix 4: Participants information.

a) Background information of the households (N= 135)

Variables	Descriptions/Category	Frequency	Percentage
Sex	Male	75	56
	Female	60	44
Education Status	Unable to write and read	68	50.4
	Read and write	5	3.7
	Primary school (Grade 1- 4)	26	19.2
	Primary school (Grade 5- 8)	27	20
	Secondary school (Grade 9 – 10)	7	5.2
	Secondary school (Grade 11 – 12)	1	0.7
	Certificate and above	1	0.7
Occupation	Agriculture	135	100
Marital Status	Single	5	3.7
	Married	110	81.5
	Divorced	11	8.1
	Widowed	9	6.7
Family size	Male	386	49
	Female	403	51
	Total	789	100

b) The interviewed key informants

Variables		Farmers	DAs[1]	Experts[2]	Experts[3]	Total
Sex	Male	10	7	1	3	21
	Female	1	4	-	-	5
	Total	11	11	1	3	26
Education Status	Can read and write	9	-	-	-	9
	Primary school	1	-	-	-	1
	Secondary school	1	-	-	-	1
	College Diploma	-	8	-	-	8
	Degree	-	3	1	-	4
	Master Degree & above	-	-	-	3	3
	Total	11	11	1	3	26

1: DAs (Development Agents or Kebele agriculture extension officers),
2: Experts from Wereda Agriculture and Development office,
3: Experts from Research Institutions and Higher Education

Appendix 5: The Correlations of EXW with selected explanatory variables.

Predicting variables	Incidence		Prevalence	
	Spearman's Correlation	Sig.(2-tailed)	Spearman's Correlation	Sig.(2-tailed)
Elevation	.187*	.000	.187*	.026
Soil type	.253**	.000	.169*	.050
Agro-ecology zone	-.170*	.048	-.227**	.008
Relative Humidity	.185*	.032	.281**	.001
Slope	.191*	.027	.063	.470
Mean Annual Temperature	.182*	.035	-.177*	.040
Average Annual Temperature	-.144	.095	-.182*	.034
Annual Minimum Temperature	-.195*	.024	-.193*	.025
Annual Maximum Temperature	-.190*	.027	-.184*	.032
Average Annual Temperature in 2016	-.169*	.050	-.201*	.019
Spring Season Average Temperature in 2017	-.178*	.038	-.204*	.018
Total Annual Precipitation	.133*	.023	.231**	.007
Total Annual Precipitation in 2016	.120*	.047	.186*	.031
Spring Season Total precipitation in 2017	.127	.141	.005	.950
Soil PH value_depth1	-.193*	.038	-.189*	.028
Soil PH value _depth 2	-.197*	.046	-.191*	.026
Soil PH value_depth 3	-.057	.512	-.150	.083
Soil PH value_depth 4	-.026	.761	-.129	.134
Soil PH value_depth 5	-.001	.989	-.093	.284
Clay soil_depth1	-.237**	.006	-.276**	.001
Clay soil_depth 2	-.231**	.007	-.281**	.001
Clay soil_depth 3	-.265**	.002	-.308**	.000
Clay soil_depth 4	-.278**	.001	-.322**	.000
Clay soil_depth 5	-.269**	.002	-.309**	.000
Silty soil_depth1	.162	.060	.158	.067
Silty soil_depth 2	.183*	.034	.209*	.015
Silty soil_depth 3	.232**	.007	.255**	.003
Silty soil_depth 4	.257**	.003	.273**	.001
Silty soil_depth 5	.307**	.000	.295**	.001
Sandy soil_depth1	.171*	.048	.215*	.012
Sandy soil_depth 2	.168	.052	.204*	.017
Sandy soil_depth 3	.180*	.037	.203*	.018
Sandy soil_depth 4	.195*	.023	.229**	.007
Sandy soil_depth 5	.193*	.025	.234**	.006
Leafhopper	.621**	.000	.478**	.000

** Correlation is significant at the 0.01 level
* Correlation is significant at the 0.05 level

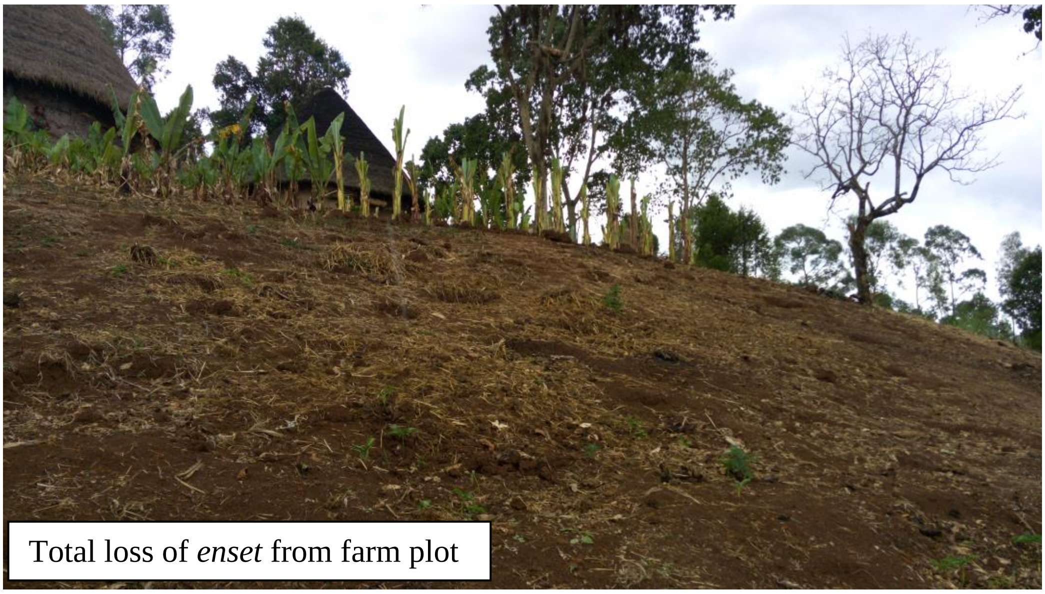
Appendix 6: Error Residual Global Moran's I Summary Results

Indicators	Values
Moran's Index	0.013755
Expected Index	-0.007463
Variance	0.001603
z-score	0.529873
p-value	0.596200

Appendix 7: List of pictures

Field data collection (A), (B) and (C)

Infested *enset* farm plot

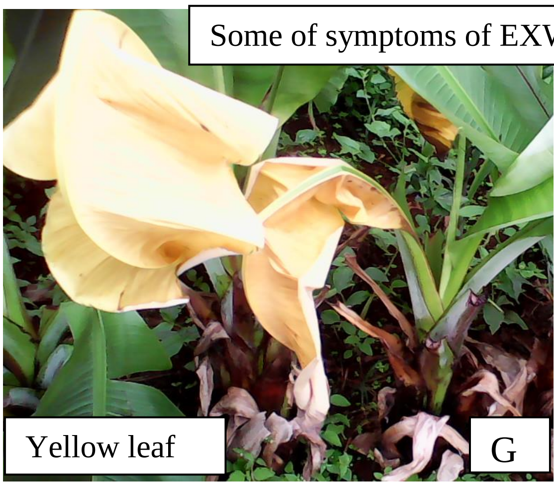


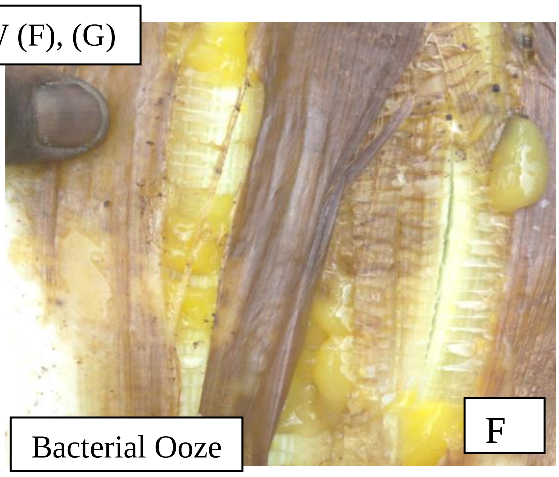
Total loss of *enset* from farm plot

Total loss of *enset* from farm plot

Identification of diseased enset plants (D), (E)

Some of symptoms of EXW (F), (G)





Leafhopper observed at enset farm plots