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Assessment of Desert Locust Infestation by Using GIS and Remote Sensing Technology: A Case Study in Dire Dawa and the Northern Part of Somali Region, Ethiopia

A Thesis Submitted to the School of Civil and Environmental Engineering in partial fulfillment of the Requirement for the Degrees of Masters Science in Geodesy and Geomatics Program (Specialization in Geomatics)

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Declaration

I certify that this study work entitled **"Assessment of Desert Locust Infestation by Using GIS and Remote Sensing Technology: A Case Study in Dire Dawa and the Northern Part of Somali Region, Ethiopia"** is my own work and has not been presented for a degree in any other university. Where material has been used from other sources has been properly acknowledged.

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As Master research advisor, I hereby certify that I have read and evaluated this MSc thesis prepared under my guidance.

Dr. Tibebu Kassawmar -------------------------- --------------------

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Table of Contents

List of Figures

List of Tables

List of Abbreviations

ASF	Alaska Satellite Facility
AVHR	Advanced Very High-resolution Radiometer
CNES	Centre National ’Études Spatiales
DEM	Digital Elevation Model
DLIS	Desert Locust Information System
EC	European Commission
ECMWF	European Centre for Medium-Range Weather Forecasts
EROS	Earth Resource Observation and Science
ESA	European Space Agency
ESDA	Exploratory Spatial Data Analyst
ESRI	Environmental system research institute
EVI	Enhanced Vegetation Index
FAO	Food and Agricultural Organization
GCS	Geographic coordinate system
GeoTIFF	Geo-referenced Tagged Image File Format
GES DISC	Goddard Earth Sciences Data and Information Services Center
GIOVANNI	Geospatial Interactive Online Visualization and Analysis Infrastructure
GIS	Geographic Information System
GPM	Global Precipitation Measurement
GPS	Global Positioning System
GRD	Ground Ranging detection
IDW	Inverse Distance Weighted interpolation
IMERG	Integrated Multi-Satellite Retrievals for GPM
IRI	International Research Institutes
ISRRO	Indian Space Research Organization
JAXA	Japan Aerospace Exploration Agency

LAI	Leaf Area Index
LIDAR	Light Detecting and Ranging
LPDAAC	Land Processer Distributed Active Archive Center
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation index
NETCDF	Network common data form
NOAA	National Oceanic and Atmosphere Administration
RADAR	Radio Detecting and Ranging
RAMSES	Reconnaissance and Management System of the Environment of Schistocerca
SAR	Synthetic Aperture Radar
SNAP	Sentinel Application platform
SRTM	Shuttle Radar Topographic Mission
SWARMS	Schistocerca Warning Management System
TIFF	Tagged Image File Format
TRMM	Tropical Rainfall Measurement Mission
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
VH	Vertical- Horizontal
VV	Vertical-Vertical
WGS	World Geodetic System

Abstract

Desert locust (Schistocerca gregaria, Forskal) is the most serious insect pest devastating and damaging agricultural products of cropland areas and pastureland during the invasion of locust. The main cause of desert locust outbreaks is the trigger of rainfall occurring and the growth of green vegetation expands the area and the population of locust density leads to an upsurge and possibly develop plagues. The aim of the study is to assess desert locust infestation using GIS and remote sensing technology. The open-source satellite data of EVI from MODIS with 250 m, sentinel-1 SAR data from Copernicus 10 m, DEM from SRTM 1 arc seconds, precipitation data from GPM 0.1 degree spatial resolution, and ground survey data were applied to analyze the effect of desert locust environmental variables of rainfall, vegetation, and digital elevation model (DEM), damaged vegetation assessment of desert locust and determine whether kriging interpolation correctly predict the unobserved area using the surveyed site. The methodology of the study was Preprocessing, reclassification, zonal attribute analysis, and geostatistical analysis of kriging, and (IDW) method of interpolation was performed. The distribution of locusts in September and October 2019 and September 2020 occurred in the Northern part of the study with low vegetation levels and low rainfall amount. However, in November 2019, October, and November 2020 desert locust infestations occupied and migrated to the southern part of the study area with high vegetation and rainfall. The lower mean pixel reflectance value of EVI data produced in September 2019 is 0.11 and a higher mean pixel value reflectance of 0.23 was produced in October 2020 damaged vegetation of desert locust infestation. Whereas the sentinel-1 SAR data value of lower mean pixel backscatter value of damaged vegetation (vertical-horizontal (VH -20.86 dB) and (vertical-vertical (VV -14.25 dB) produced October 2019) and higher mean pixel backscatter value (VH -17.78 dB and (VV -11.48 dB produced in September 2020). the kriging interpolation was applied to predict un-surveyed areas by the survey team using a surveyed site of spherical modeling. the regression value between measured and predicted of 2019 square r = 0.24 with p-value = 0.0003 and 2020 square r = 0.0084 and p-value = 0.26. The result indicates kriging interpolation need randomly distributed and accurately measured data.

Keywords: Desert locust, Damage assessment, Geo-statistical, GIS, MODIS EVI, sentinel-1 SAR data, RS

Chapter one

1. Introduction

1.1 Background of the study

The desert locust (Schistocerca gregaria, Forskål) is one of the dozen species of short-horned and periodically swarming grasshopper in the family of Acrididae. It differs from grasshopper, based on the ability to change behavior and physiology with morphological properties (color, shapes) and change responsibility to density (Symmons and Cressman, 2001). The phase of the desert locust is classified into two groups, those are solitaries and gregarious. The phase changes from solitaries to gregarious or gregarious to solitaries is known as the transient phase. During the transient phase, the number of locust increase means from solitaries to gregarious is called congregants and the reverse one is dissections (Cressman, 2008). The difference between the solitaries and gregarious phases is revealed in behaviors and external color. The solitaries phase lives at low density and does not endamage the vegetation or crops in the agricultural product but they can assemblage and outbreeding occur due to suitable ecological conditions with the growth of vegetation cover in the high and widespread successive amount of rainfall leading to form a hopper or swarms of desert locusts (Tucker et al., 1985). The gregarious phase increases the number of locusts and forms a swarm of high density from place to place and damaged the crops and green vegetation. The locust swarm destruction of rangeland and croplands around the world. according to (Uvarov, 1977) the medium-sized locust swarm contains expressed in several thousand million locusts with 20 square kilometers damaged three thousand tons of vegetation per day.

The desert locust is found and distributed usually in arid and semi-arid desert areas of northern and eastern Africa, Arabia, and the near east and southwest of Asia with annual rainfall receiving less than 200mm(Mohamed et al., 2004). This vast area is known as the recession area and covered 16 million square kilometers consisting of 30 countries during the period of the desert locust plague. according to(Showler, 2002) listed in (Figure 1.1), the desert locust spread over a large demarcation area of 29 million square kilometers extending over 60 countries more than 20% of the total land surface in the world and damages a tenth of the world population livelihood (FAO, desert locust information service, 2004).

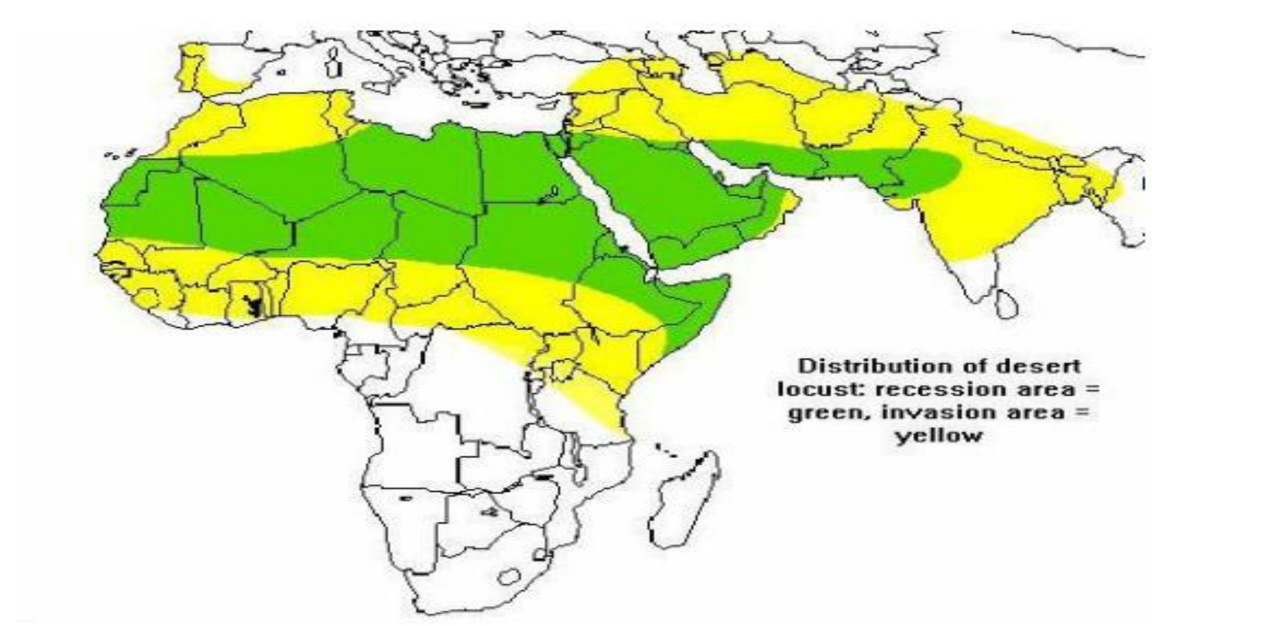

Figure 1.1 Recission and invasion area of the desert locust

Source: Showler 2002

According to the food and agricultural organization (FAO) The recession area affected by the desert locust is classified into three parts those are western, central, and eastern. The western region includes countries located in Africa including Algeria, Chad, Libya, Mali, Mauritania, Morocco, Niger, Senegal, and Tunisia. The central region includes countries along the Red Sea: Djibouti, Egypt, Sudan, Somalia, Ethiopia, Saudi Arabia, Oman, Eritrea, and Yemen and the eastern region includes the southwest Asian countries of Iran, Pakistan, India, and Afghanistan (FAO, desert locust information service, 2004)

The amount of rainfall increase is the main cause of desert locust outbreaks and create suitable for breeding development and band forms of locusts (Rabie & Moustafa, 2011). The outbreak of desert locust leads to several problems. Locust damages agricultural products, vegetables for a human being food and pastures for animal feeding vegetation, bushes and shrubs for habitat of birds, ecological processes (e.g., carbon and water cycles). furthermore, the locust swarm rapid loss in vegetation cover can result in soil erosion and increased runoff. Crop damages could result in catastrophic losses to farmers, and this problem could be acute for small, subsistence farmers throughout the world and especially for those in developing countries(Latchininsky, 2010).

The prevention of desert locust out breading and distribution of locust monitor in different geospatial technology. To manage the locust distribution and timely warning there is a need for a structured geospatial database in geographic information systems (GIS) and remote sensing in the satellite image information. GIS and remote sensing technology are the ability to monitor and forecast the desert locust outbreed through effective manipulation of the large covered area of spatially referenced and descriptive data (Dutta et al., 2003) Ethiopia is one of the African countries affected by desert locusts in various periods especially the worst in 25 years (Wang et al., 2021). The invasion or development of locusts is high and adopted frequently occurred in eastern, southeastern, and northeastern parts of Ethiopia is very favorable for locust development and invasion simply to extend the other parts of countries. The distribution and expansion of desert locusts occurred over in different period of time. In this study, the area selected was where the desert locust was recorded frequently and the movement of locust widely spread in the harvest (spring) season from September to November during the agricultural product and pastureland or vegetation cover preferable to desert locust with suitable weather conditions.

The present study was carried out to assess the desert locust infestation, investigate the driving factors of desert locust environmental variables like rainfall, green vegetation and the Digital Elevation Model (DEM), vegetation damage assessment and predict the surveyor doesn't cover the area developed a method of zonal statistics, geostatistical analysis in arc GIS and SNAP toolbox for sentinel-1 data preprocessing.

1.2 Statement of the problem

Desert locust is one of the most dangerous insects that move in swarms and cover large square kilometers of areas devastating pest within the recession area appears in various parts of the world. The desert locust mostly damages and affect African contents in east and west Africa, the middle east, and southwest Asia threatening crop and vegetation or serious risk to food security in different period (Wang et al., 2021). The infested area of the desert locusts is green vegetation when desert locust occurred during invasion and breeding time(Cressman, 1997). The desert locust movement also increases in early 2020 highly damaging and expanding the worst infestation in 10 years some parts of East Africa and some parts of West Asia countries such as Kenya, Ethiopia and Pakistan several hectares of the land were damaged green vegetation and cultivated land by desert locust(Wang et al., 2021).

Ethiopia is one of the frontline countries of eastern Africa the desert locust was attacked in various periods and having suitable areas for locust breeding and gregarization in eastern Africa. In the last years, 2019/2020 Desert Locust invasion in Ethiopia affected seven regions like afar, Amhara, Oromia, SNNPR Dire Dawa, Somali, and Tigray damaging different types of crops. the major things that initiate to study of desert locust infestation occur in different parts of the country over a consecutive period. The locust infestations in Ethiopia are a serious problem and damage the economic aspects of the country, the survey team didn't address the whole infested vast area by several problems such as may be the economic case, due to bad weather conditions, the difficulty of topography to take measurements, and so on. To solve this kind of problem, estimate the infested area determination, investigate the environmental variables support to take a decision and survey target to next observation within a short period cover a large green vegetation area and vegetation damage assessment to consider and understand the condition of desert locusts' distribution in several months applied of ArcGIS and SNAP toolbox.

1.3 Objective of the study

1.3.1 General objective

The main objective of this study is the Assessment of desert locust infestation by using GIS and remote sensing technology: a case study in Dire Dawa and the Northern part of Somali Region, Ethiopia.

1.3.2 Specific objective

- To investigate the effect of environmental variables like rainfall, green vegetation, and elevation levels with the interaction of ground survey data on desert locust distributions.
- To assess the vegetation damaged area by desert locust infestation using MODIS EVI and sentinel-1 SAR data with the help of ground survey data.
- To predict un surveyed area and estimate the potential area of desert locust infestation using geostatistical analysis.

1.4 Research Questions

1. What is the contribution of rainfall, green vegetation, and digital elevation model (DEM) parameter for desert locust infestation and expansion within the study area?
2. Is possible to detect vegetation damaged areas using satellite data of MODIS EVI and sentinel-1 SAR data?
3. Can the infested areas and the potential invasion areas identify correctly by geostatistical analysis of kriging interpolation using ground survey data?

1.5 Scope of the study

The scope of the study is focused on the assessment of desert locust infestation in Dire Dawa and the northern part of the Somali region by using geographic information systems (GIS) and remote sensing techniques. The aim of this study predicts the area of desert locust infestation when the observer doesn't collect information about desert locusts due to terrain difficulties and shortage of time using geostatistical analysis of point data, determine the difference between the infested area and non-infested area by using zonal statistics method mean values of vegetation damage using open-source satellite data and investigate/analyses the parameter of desert locust expansion area using satellite data, rainfall data and DEM data.

1.6 Significance of the study

The importance of this study is to assess the capacity of satellite data to detect damaged vegetation with ground survey data, to measure and estimate the non-surveyed site of desert locust infestation of the survey team which area is potentially locust distributed. Assess the locust distribution and invasion in different months with related to environmental variables of rainfall, green vegetation and elevation levels. This study is also used as to reference for future studies about desert locust infestation and it is important to the plant protection directorate department in the ministry of agriculture as an input to analyze the information on desert locusts related to climatic conditions and to improve the quality of data.

1.7 Limitation of the study

The limitation of this study was listed below:

1. The climatic data from the Ethiopian national metrology agency is not consistent and not obtained quality data of monthly rainfall, lack of clear information about rainfall station and difficult to obtain the current information on rainfall condition with desert locust occurrences periods.
2. Difficult to directly determine the damaged area by desert locust using an open-source satellite with the limitation of spatial and temporal resolution of satellite image quality.
3. The optical satellite data is affected by weather conditions and difficult to interpret the radar satellite data and simply identify the impact of locust infestation.
4. The quality of ground survey data collected by the survey team does not include all over the study area.

1.8 Organization of the thesis

This thesis consists of five chapters and is summarized as follows. Chapter One: describes the background of the study from the world to Ethiopian distribution of desert locusts, the statement of the problem, the objective of the study (general and specific), the research question, the scope of the study, the significance of the study, limitation of the study and organization of thesis structure. Chapter Two presents a review of literature of previous work based on related topics and describes appropriate common methods with problem-solving explanation papers. Chapter Three explains the material and methodology, data type, the study area, and software used to accomplish the present study are described in this chapter. Chapter Four deals the result analysis and the discussion of the overall study describe with maps and charts of output results based on methods. Chapter Five describe the conclusion and recommendation of the general study performed in the present study and advise the future works based on this topic and Reference include the list of sources used in the present study.

Chapter Two

2. Literature review

2.1 Definition of terms and concepts

The desert locust (Schistocerca gregaria (Forskal).) is a kind of locust species and the most dangerous pest flying from a great distance by forming swarms from place to place and damaging the green vegetation of agricultural products and pasturelands on the earth's surface. (FAO, Desert Locust Guidelines, 1994). The locust swarm is the most disastrous pest in the world and affects green vegetation (Yao et al., 2017). The recession area of desert locusts includes 16 million square kilometers from west Africa to western India and also expands to the north, south and eastern part of the world. The recession area of the desert locust consists a small number of hoppers and adults present (Hemming et al., 1979). Sometimes desert locusts breed and an outbreak occurs when the low-density desert locust population change to the recession area and accidental or seasonal rainfall happened. The outbreak of desert locusts is depending on the weather condition and the movement of locusts from place to place when the rain brings out (Rabie & Moustafa, 2011). It also affected the world greater than 60 countries at different levels during the infestation development of gregarious phase moves in high density and damaged green vegetation and croplands(Dutta et al 2003). The outbreak of desert locust level is uncontrolled and spread over a large area based on heavy rainfall expand to neighborhood area and several successive seasons of locust breeding development with the formation of hopper bands and adult swarms is referred to as upsurges. The number of desert locust population increases, the size of the area expands, the ecological condition is very suitable for breeding, the duration of time takes one or more years, the movement of upsurge is difficult to control and the infestation occurs in bands and swarms attacked two or more area at a time is known as plague (Desk, 2020).

According to (Symmons & Cressman, 2001) the desert locust damages the vegetation, agricultural products and food security in large parts of Africa, East and southwest Asia happened during the locust plague that occurred since1986-89 and successive locust upsurges 1990s expanding the invasion with the historic pest.

2.2 Life cycle of the desert locust

The life cycle of the desert locust is fragmentary metamorphosis and it consists of three stages such as egg, hopper and adults. The desert locust is similar to grasshoppers' eggs are laid in moist or bare sandy soil by female locusts about mature male locusts. the female locust laid the egg into clusters known as egg pods(Rabie & Moustafa, 2011). The female desert locust identifies the soil moisture is 5 to 10 centimeters to lay and deposit the egg pods 3-4 centimeter long and laid the egg 5-10 centimeter below the surface.(Symmons and Cressman, 2001)(Mohamed et al., 2004). The desert locust incubation period of eggs time taken is different from a breeding area of one place to another breeding area and depending on temperature, the summer season required breeding areas 9-25 days, based on the rain of short and long-time breeding areas required time in Africa 10-22 days and coastal areas around the red sea and the Gulf of Aden 10-29 days (Roffey, 1982; Steedman 1990). The green vegetation is used as a food for the development of the hopper depending on the moisture content of soil and temperature helping to the development of eggs and leading to the first hopper instars. After the first instar converted to second instars by using molting process. after seven days change to third and fourth instars the fifth instars led to gregarious phase and six instars solitary hoppers.(Symmons and Cressman, 2001). The development of desert locusts required several stages and a long time depending on the temperature and availability of suitable conditions in the life cycle ranges of locusts between 34 and 90 days and the average duration of time is 40 to 50 days (Bennett, 1976)

The maturation of adult locusts required different times based on climatic and nutrition influences, in a suitable and favorable climatic condition the adult locust sexually matured time required 3-8 weeks. on the other hand, the condition is harsh and not favorable for the development of desert locust time required for sexually matured more than 40 weeks (Pedgley, 1981). The desert locust development of the hopper and the total time required duration period vary from 24-57 days and an average of 36 days depending on temperature. and suitability of climatic conditions (Wardhaugh, K, Ashour, Y, Ibrahim, A, & Khan, A, 1969). The adult maturation of desert locust development depends on climatic conditions associated with rains, vegetation, and a maximum temperature of 35^{o}c lay within 3 weeks of fledglings, and the adult locust survives for 6 months or more in dry conditions(Mohamed et al., 2004). In general, the progress of hopper stage development the time taken from the first stage to the last stage of instars is 35 days. in the end, the molting produces soft wings of fledged adult insects and develops their length and time of flying and transferring from sexually immature to sexually matured with help of suitable climatic conditions.(Symmons and Cressman, 2001)

The life cycle parameters of desert locusts discussed by (Symmons and Cressman, 2001) are classified into three stages and time of duration based on the date and month listed in the following (Table 2.1)

Table 2.1 life cycle parameter and duration time

	Life cycle parameter	Duration
Stage	Egg	10-65 days
Larval molts	Hopper	24-95 days (36 days average)
	Adults	2.5-5 month
	Laying-fledging	40-50 days
	Adult maturation	2-6 months
Phase	Solitaries, transients, gregarious	
Affected area	16 million km^2 (recession),	29 million km^2 (invasion)

The life cycle of desert locust from egg stage to adults' development listed in the form (Figure 2.1)

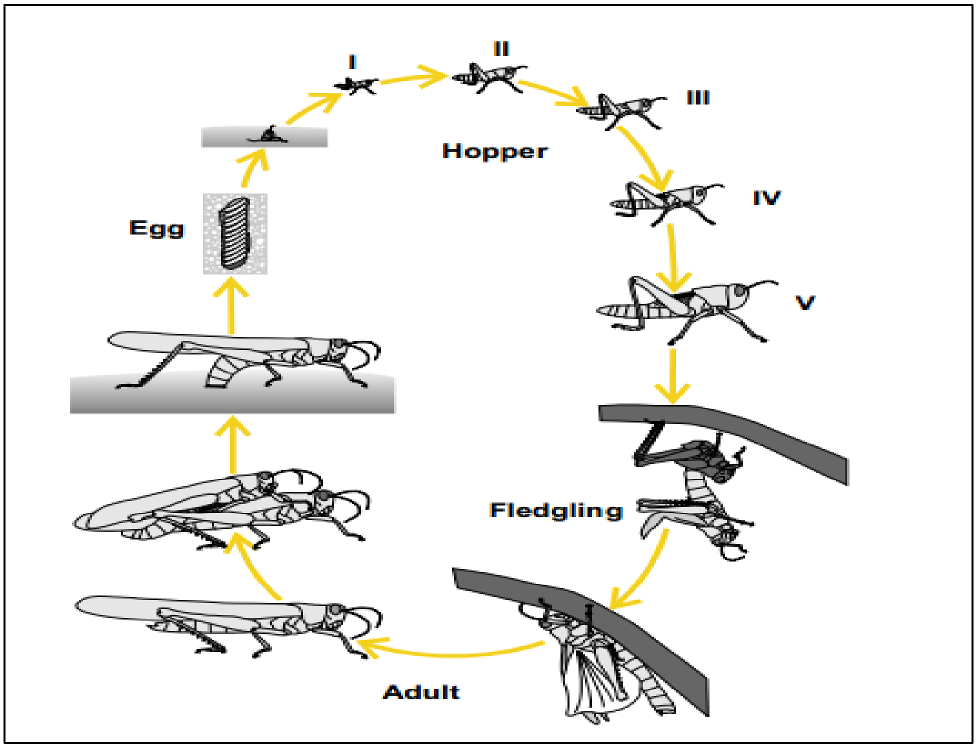

Figure 2.1 Life cycle of the desert locust

Source: Symmons and cressman (2001)

2.3 Survey operations

The survey operation of the desert locust control strategy is used to minimize and prevent the formation of large hopper bands and swarms(Cressman, 1997). It also requires the breeding area of desert locusts monitoring based regularly and taking continuing small scale control operations (Cressman, 1998). This essential part of the controlling method of survey operation was adopted in 1960 during the occurrence of the desert locust outbreak, plague and upsurge for the first time(Magor, Lecoq and Hunter, 2008). To control the disaster of the desert locust, locate and map the potential area of reproduction and grangerization study to improve the real-time detection of ecological conditions mainly green vegetation(Mohammed et al., 2015). Affected countries are performed the survey operation of ground control survey based on the ministry of agriculture and plant protection department to control habitats of desert locusts and damage assessment by using global positioning system(GPS) instrument to record the location of infestation occurrence area, the condition of green vegetation when desert locust infestation occurred and non-infestation, the soil moisture content, greenns, the rainfall situation and detect the favorable and available areas of potentially the development and invasion of desert locust in ground survey method. (Krall & Herok, 1997).

The operation of the survey collected information at the beginning, mid, and the end of the rainy season in suitable habitats of desert locusts present to control the outbreak, plague, and upsurge. The survey assessment performed during the operation of the survey determines the green vegetation status when the desert locust is infested and the recent amount of rainfall in the area infested, identification of area suitable for breeding and finding mostly desert locust present in potential, estimates the survey infestation size of identified locust area, environmental conditions, and information about the collected data in the field with a description of attribute data(Symmons & Cressman, 2001)(Rabie & Moustafa, 2011). The survey operation was used to conduct the information on desert locusts using in-ground and aerial survey methods. The ground survey methods used instruments like GPS for reference location, vehicles, and food used to transect from place to place and collect important information about desert locusts based on filling standard reporting forms. In addition to this, the survey team required available equipment used to collect reliable information about desert locusts such as e locust3 or FAO form, handle-held GPS, and maps with a scale of (1:200-500,000), paper and pen, and first aid kits (FAO, Standard Operating Procedures (SOP) for Desert Locust Ground Survey, 2021). the second is the aerial (aircraft) survey conduct information at the beginning of rain which area have high green vegetation and the amount of rainfall in the areas and update the habitat situation in the mid and end of the season (Osman, 2011). This collected information about desert locust data of survey operation used for many purposes, for example, to forecast the situation of desert locust invasion, interpret damaged area and basis of prediction from place to place, undertake control method, estimate the damaged area from time to time, identification of how to match destruction of cropland and pastureland area, economic and environmental crisis of desert locust occurred in the country level or the world level.

2.4 The Effect of Environmental variables on the desert locusts

The environmental variable also factor affects the spatial distribution of desert locust breeding and infestation. In many studies explained before, the environmental variable that supports the development and movement of locusts from egg stage to gregarious or swarm stage affect rainfall, vegetation cover, temperature, wind, soil moisture, soil type, and relative humidity. The main factor that affects the breeding and expansion of locusts is rainfall to provide important water amount to the vegetation growth used as food and shelter of the desert locust, increase the moisture content to breeding the pests, egg development and hatching simply based on the content of soil moisture(Hielkema and Roffey, 1986) (Skaf et al., 1990). Moreover, the rainfall is the main factor during an outbreak of desert locust occurs when the rainfall amount is not adopted, heavy and widespread rainfall support the growth of vegetation and leads to food and shelter for hoppers and adults, increasing the population of locust (White, 1976). According to (Magor et al, 2008) the outbreak of desert locusts occurs during the heavy and widespread seasonally rainfalls. The minimum rainfall amount required for the development, shelter, and feeding plants of locust successful breeding and increase the locust number from maturation to adults of rainfall is 25 mm(Bennett, 1976). The relationship between the desert locust abundance area and the rainfall amount is directly related to the breeding and expansion of desert locust when the rainfall amount increases the breeding of locust also increase and the rainfall amount weakens the locust movement and breeding all so similar movement in a different part of the world when desert locust occurred area in different study article explanation.

The other most important factor next to rainfall provides the development of desert locust expansion and used as food, shelter, and habitats of the locust is green vegetation. The green vegetation is used to protect itself from natural enemies, protect against harsh weather conditions or unsuitable conditions, and used as food and shelter for the development of locust insects with temperature values of high and low temperatures amounts(Symmons & Cressman, 2001).

The temperature affects the different phases of locust development like the incubation period of eggs, the development of hoppers adult, and other activities. In addition to this, the temperature used for locust movement of gregarious adults during the day and the solitary desert locust movement during the night (Symmons and Cressman, 2001) The other important environmental variable used in the development of desert locust breeding is sandy soil very suitable and the moisture content of soil used to lay the egg of female locust identified the favorable moisture content of soil upper 12 cm(Cherlet et al., 2001). The effect of wind is also used to migrate swarm locusts from one area to another area simply a hundred kilometers per day with the help of wind direction(Ibrahim et al., 2000). The topography of earth surfaces also an issue with the distribution and movement of desert locust infestation.

2.5 Damage Assessment of desert locust using vegetation of different satellite images

The earth observation satellite of remotely sensed data is mostly used to obtain the repetitive measurement of large coverage area with a short interval and consistencies of image quality. In the previous studies, the researchers used earth observation satellite data of optical imagery like Aqua and Terra MODIS data of NDVI and EVI, Landsat and radar satellite (sentinel data), thermal infrared sensor temperature, precipitation and soil moisture contents data-based studies applied in many articles to describe the desert locust habitat, breeding, expansion, and infestation (Katel et al., 2021). In the review about desert locusts few studies quantify the damage assessment of desert locust detection using very high spatial resolution imagery or hyperspectral remote sensing data and environmental variable data like precipitation temperature and wind(Klein et al., 2021). To detect the damage amount of desert locusts, the satellite observation of vegetation conditions provides important information about the infestation and damage by the pests (Wójtowicz, and Piekarczyk, 2016). Damage detection of the desert locust is difficult to quantify with the help of earth observation satellite data because the nature of desert locust infestation is localized and sporadic characteristics, migratory from one place to the other, agroclimatology and timing event with limitation of spatial and temporal resolution of images(Adams et al., 2021). However, the earth observation satellite data support the ground-based survey data to take control measures, identify the potential area for the movement and distribution of desert locusts, and collected information from the ground by reducing time, power, and economy. The survey team of data observers accessed the hot spot of desert locusts when the vegetation is suitable for breeding and expansion of pests(Adams et al., 2021). Sometimes the hot spot area of the desert locusts is remote from high rainfall occasion sites, in this Case, the MODIS EVI images were identified. To determine damaged vegetation areas remote sensing technology capability to obtain quickly and successive information on the temporal and spatial resolution of vegetation cover in large areas (Eltoum, 2014). change detection technique used to compares the variation of vegetation cover with different times, the desert locust plague occurrence level, scope, size of occurrence (extent area), the damaged level (highly damaged, moderately damaged, and lowest damage), predict for the future hypothesis using the optical and radar satellite data of remote sensing technology(Zhao et al., 2020) The spatial resolution of 250 km MODIS datasets is more significant than the 1 km resolution dataset to detect the damaged vegetation by desert locust(Eltoum, 2014). The spectral signature of sufficient spatial resolution is used to identify the damages of desert locusts in plant species, but there are no systematical methods to identify the desert locust damage to pastureland and croplands (FAO, desert locust information service, 2004). In addition to the spatial resolution the temporal resolution also the most important criterion to detect vegetation damage assessment by desert locusts. Landsat and sentinel data spatial resolution are more significant than MODIS EVI spatial resolution in order to perform vegetation damage assessments. However, the Landsat and sentinel-2 data are limited by cloud cover in different seasons. In recently studies sentinel-1 SAR data was used to detect vegetation damage with the integration of ground survey data performed zonal statistics analysis because of having high spatial and temporal resolution and freely accessed to any weather condition (Bell et al., 2020, Adams et al., 2021). Damage detection also depends on the seasonal and annual characteristics considered the significant factors to increase the level of accuracy in vegetation damage detection (Chen, Fedosejevs, & Tiscareño-LóPez, 2006).

2.6 The Role of Remote Sensing in Desert Locust Monitoring

Remote sensing is an art science and a technology used to acquire information about large geographical areas without physical contact (Campbell, 2006). Remote sensing can be classified into active and passive depending on the source of electromagnetic radiation. In passive remote sensing, the sensor records the information radiation reflected or emitted by the earth’s surface features and limited by weather conditions and dependents on illumination. Active remote sensing uses its source of electromagnetic radiation and record the information targeted objects without limitation of weather condition and accessed the information at any time datasets like radio detecting and ranging (RADAR) and light detecting and ranging (LIDAR) images acquired in a specific region of data in bad weather condition like cloudy day and night(Latchininsky, 2010).

Remote sensing data collected from airplanes and satellites have been used to map the distribution of locusts, habitats of locusts and assess the damage to vegetation following the outbreak of desert locusts. to cover the wide and large geographic area the coarse spatial resolution of AVHR and MODIS data are available for coverage of several thousand square km(Eltoum, 2014). Remote sensing data used for tactical application including vegetation damage assessment following locust outbreaks and strategical applications includes identifying the potential area of desert locust habitat and undertaking suitable prevention measurement like chemical treatment (Showler, 2003). Under pest management, remote sensing has been used for damage detection of vegetation and measurement of several metrological parameters. The first satellite data applied to desert locust habitat monitoring was pedgly 1974. Tucker 1986 recognized the capacity of remote sensing satellite data used for locust survey and locust forecasting principles used Landsat satellite data to map the vegetation of gregarization areas locusts occurred in west Africa(Tucker et al., 1985). in order to control the desert locust requires knowledge about areas and conditions of vegetation after rainfall in which area is suitable for locust oviposition, egg hatching and development of hopper. The remote sensing of NOAA AVHR data was tasted by calibrating different vegetation indexes consists NDVI integrated with ground survey data from Niger (Cherlet, M & Di Gregorio, A., 1993) The Landsat data is difficult to distinguish the vegetation and bare land in studies of Mauritania using NDVI and authors conclude that in sparse vegetation density of Saharan and Sub-Saharan countries the Landsat data is not allowed to control locust habitat (Showler et al., 2021). after this conclusion the desert locust information system (DLIS) of FAO used the 1 km SPOT-VGT imagery to overview the ecological condition of locusts in breeding areas and designed specifically sensor to vegetation monitoring of 250 m spatial resolution imagery of MODIS data with 16 days temporal resolution.

The earth observation satellite cannot detect the population of the desert locust. But they can provide information about the environmental factors of ecological conditions over a continuous period of time to lead the desert locust at the country level or region with real-time data. (Cressman, 2008). remote sensing imagery is used to control the environmental factors that influence desert locust population development. The main environmental factors to drive the development of desert locusts and population can be a dynamic from place to places, such as vegetation condition, rainfall, temperature, soil type, and moisture content of the soil. (Pekel, P. Ceccato, C. Vancutsem, & Cressman, 2011). To control the desert locust the specialist, need information about elevation, temperature, soil moisture and rainfall in addition to vegetation in order to adjust effective survey to assess the distribution of locust condition in egg-pod.(Latchininsky, 2010). The vegetation cover is considered the essential environmental factor to derive the development of desert locusts because the locust is used as habitat, food, and shelter and is significant for the nutrition of insects(Latchininsky, 2010). To detect the green vegetation and movement of desert locusts the affected countries and FAO used the remote sensing product regularly data records by computing the NDVI using the red and near-infrared spectral band to detect the vegetation change in different periods of time to reduce observation area and to increase the priority of ground survey checking (Cressman & Hodson, 2009). The NDVI is maybe influenced different factors like structure of vegetation canopy, atmospheric condition, and soil type. Due to this case the modification of enhanced vegetation index (EVI) in MODIS data performed with a spatial resolution of 1 km, 500 m, 250 m and temporal resolution in 16 days and 1-2 days of global coverages to monitor the desert locust in real-time data (Ji et al., 2004).

Besides vegetation data, DLIS used rainfall data also the significant parameter of desert locust forecasting and damage assessments. DLIS rainfall is derived from METEOSAT, visible and infrared channel, in order to understand the spatial distribution of rainfall in desert locust breeding areas, the image is available in 15 minutes and estimated at three hours. DLIS also used the cumulative of 24-hours of daily or decadal estimate and processed in Colombia university international research institutes (IRI) for climate and society with ground survey data to forecast and control the movement of the desert locust (Latchininsky, 2010). Active remote sensing of radar imagery was also used to monitor the distribution and movement of desert locusts in a previous study due to the difficulty of weather conditions and observation of desert locust flights direction, orientation and speed of solitaries and gregarious desert locusts in vertically looking radar (Hemming et al., 1979).

2.7 The Application of Geographical Information System (GIS) in Desert Locust Management

GIS is a spatial system that creates, manages, analyzes and maps all types of data (ESRI, what is GIS, n.d.). It is a computer-based system used to store, retrieve, manage, manipulate, integrate, analyze and display geographic data in the form of maps, and communicate in different sectors in the same format structure(Bernardi, 2001). GIS also used to analyze the locust population of spatial patterns and is capable to store, organize and analysis of geographic data such as the number of egg pods, hopper band or swarm density and area, rainfall, temperature, received and vegetation of a given district of geographic location (Latchininsky, 2010). GIS technology is utilized to produce a map of layers that can be georeferenced data like insect density, soil type and crop type location incorporated, analysis and interpretation of spatial pattern insect populations (Virginia,1993). During the integration and combination of information of physical and environmental variables for several applications users simply accessed a query tool in GIS software and update and generate results in a short period of time due to changes in physical and environmental condition information stored in the GIS database (Latchininsky, 2010). At the national level geographic information system is used to access locust information from locust attacked countries and integrated with the food and agricultural organization (FAO) about desert locust information service (FAO-DLIS) and its objective is to manage and analyze locust and environmental data. SWARMS (Schistocerca Warning Management System) was the first time operating on a UNIX workstation using the oracle database and arc info software was introduced in 1996. The system was used to manage and analyze received from locust occurrence countries data including locust population, ecological conditions rainfall and soil moisture content (Cressman and Hodson, 2009). Furthermore, the food and agriculture organization (FAO) also provided a GIS to monitor locust information department in the country of recession area called RAMSES (reconnaissance and management system of the environment of Schistocerca) system used in national level introduced in 2000. This software is used to integrate ground survey data and remote sensing images with analysis and display information about desert locust monitoring of the daily situation of locust environmental conditions (Symmons & Cressman, 2001) (Ceccato et al., 2007). The two systems used to combine data with various sources such as MODIS imagery, NOAA rainfall station data, seasonal rainfall, temperature prediction and historical ground survey data from 1930 to the present to assess the situation, forecast the scale, timing and location of breeding and migration (Cressman & Hodson, 2009).

According to (Rosenberg, 2000) RAMSES is a personal computer-based system designed to control and assist national locust units in storing, analyzing, and disseminating locusts related to environmental information derived from their data capturing network (Figure 2.2)

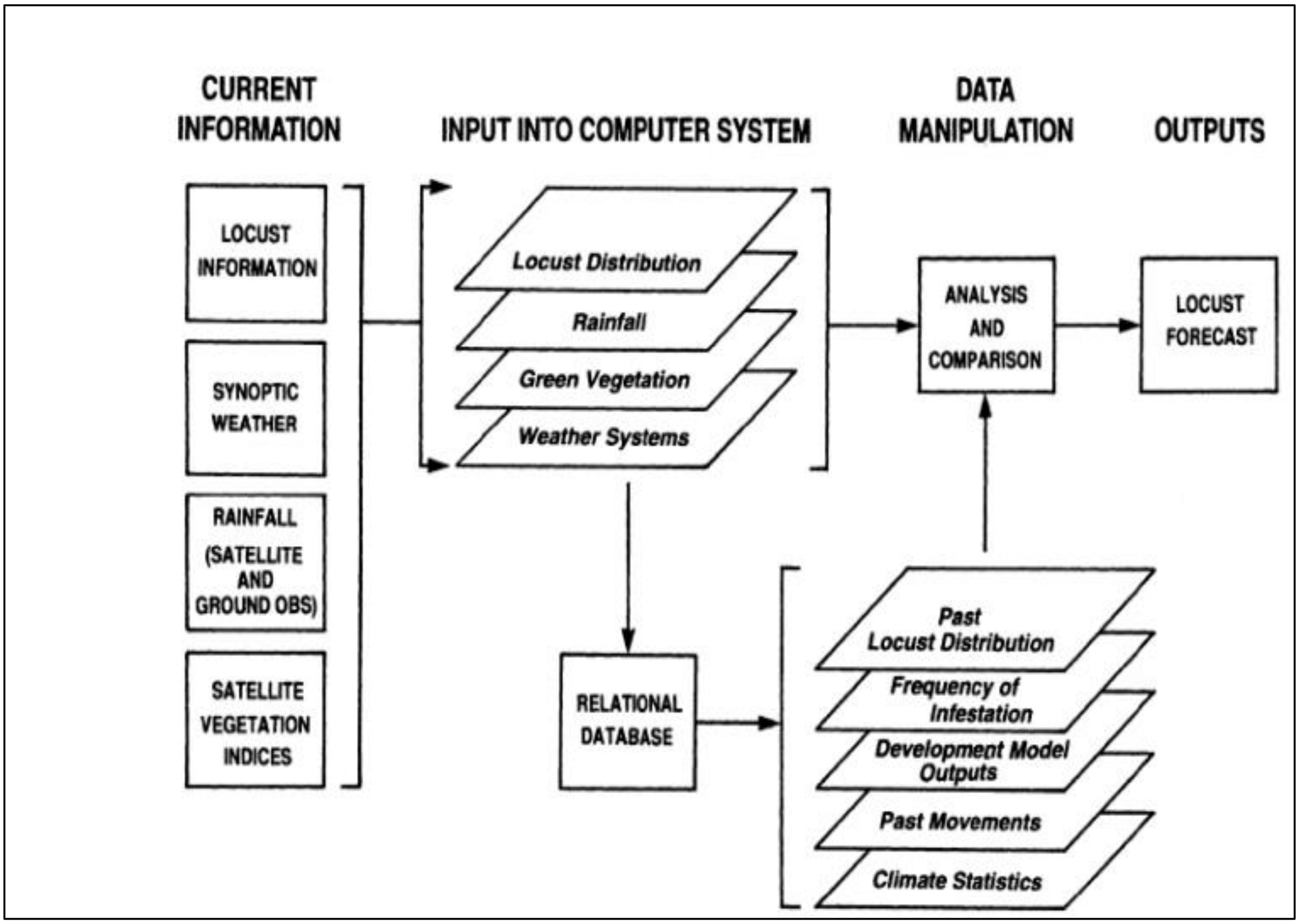

Figure 2.2 GIS, Remote sensing and related data process in the desert locust management system

Source: (Rosenberg, 2000)

2.8 Application of GIS forecast and predicting the distribution of desert locust

In the last time the method of forecasting desert locust were applied by mapping collected monthly ground survey data used to observe geographical relationship momentary result and change over time (Healey et al. 1996). Currently, the forecasting method of FAO information system DLIS uses the GIS of SWARM to create database system collect information of desert locust of survey data, meteorological data, and historically captured data from several countries when desert locust occurred. it also forecast the correlation of metrological data and ancillary survey data with satellite data of vegetation and rainfall for short and medium time forecasting the condition of desert locust in recession area (Cressman, 2008). This means the locust attacked countries use short term forecast to control the movement of desert locust operation and the long-term forecast use the country to prevent and plan to defend the locust before outbreak on the countries(Cressman, 1997). To develop the forecasting condition and analyze data of desert locust information system by (SWARM) using GIS software applied the two models. The first was used to estimate the egg and hopper development in days, received and understand the information of any condition, determine the normal and detecting egg-laying performed with the prediction of flaying occur. The second model of forecasting and analyzing data using GIS is the trajectory model. This model estimates the movement of desert locusts in forwarding and backward time at the given point. It also used six-hour metrological data forecast 10 days from the European center medium-range weather forecast (ECMWF)(Cressman, 2008). The most effective methods of forecasting the desert locust are the transformation of the collected data in the field survey to national locust center in real-time. GIS software creates the relational database system of attribute and spatial data used to monitor and forecast habitat of locust (Yao et al., 2017). In addition to forecast GIS software used to estimate desert locust infestation based on sample data of observed site to predict non surveyed site of locust potential infestation area using geostatistical analysis. The estimation of desert locust density is difficult to obtain reliable information when the locust distribution is variable. The main problem with controlling the locust population in several habitats with a patchy distribution of locusts is how can estimate the density of locusts in unvisited sites from nearby surveyed sites(Woldewahid, 2003). The geostatistical method was adopted to explain the spatial variation of desert locust density and used to predict locust occurrence in unobserved locations by the survey team(Woldewahid, 2003). The origin of geo-statistics is invented in earth science to explore and describe the natural resource of the earth(Society, 2017, Society and Monographs, 2011) applied in ecology. Used to analyze the spatial analysis of insects e.g., (Schotzko & O'Keeffe, 1990). The kriging interpolation method was found higher estimation of unsampled area compression than other methods of prediction like Thiessen polygon and trend surface analysis(Tabios and Salas, 1985). the kriging maps were found for the distribution of grasshoppers used to determine high-density zones and used to assess the area of grasshoppers in Mauritania(Kemp et al., 1989). The geostatistical methods were used to determine the spatial pattern and estimate the desert locust density of the un observed area of desert locust invasion. kriging method used to estimate the locust density of survey teams do not cover or un surveyed area of desert locust area delineating. kriging map in which site is locust density high and low occurrence in addition to this the relationship between the intensity sampling and the variance explore. The kriging method was used to assist the optimization of sampling efforts in which area desert locusts frequently and densely occurred.

2.9 The contribution of GIS and Remote sensing in the study

The above description of the review literature includes the assessment of desert locust initiation to infestation. It also assesses the purpose of GIS and remote sensing for the management of desert locust control and monitoring the combination of GIS and remote sensing application. in current study also assessment of desert locust using different data, identifying the desert locust infestation area various data types preferable for determination infested and outbreed area. The data used for this purpose like vegetation cover data, digital elevation model data (DEM), rainfall data, sentinel-1 SAR data and ground survey data. In addition to this, mentioned the effect of desert locust occurrence in different periods of time, vegetation damage assessment and estimate the hot spot area by using geostatistical analysis covered by green vegetation data with remote sensing technology and application of GIS forecasting and predicting the desert locust using ground survey data.

Chapter Three

3. Material and methods

3.1 Description of the study area

The study area is located in the eastern part of Ethiopia, which includes Dire Dawa administration, and the Northern part of the Somalia region (Figure 3.1). The study area focused on desert locust infestation that occurred frequently and many times with breeding and invasion of locusts in different weather conditions. The study area covers a latitude of 8° 40' 55" − 11° 06' 54" N and longitude of 40° 53' 04" − 43° 41' 32" E, and the total area covered 40026 km^2 with an elevation between 337 m and 2650 m based on the DEM data. The season selected in this study is the spring (harvest) season months consists of September, October, and November) seasons in 2019 and 2020 desert locust upsurges occurred in eastern Ethiopia.

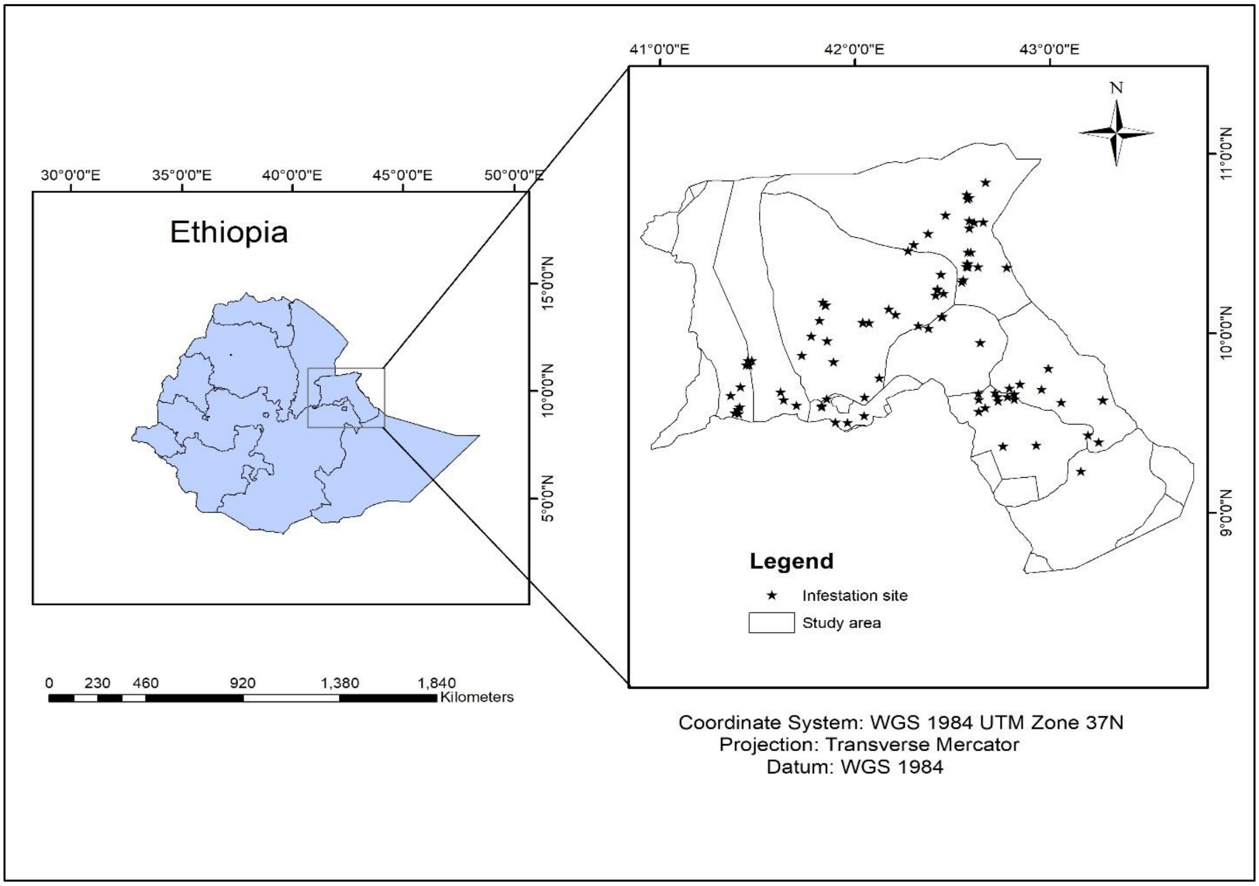

Figure 3.1 Location map of study area

3.2 Data and Data source

3.2.1 The Ground survey data collection

The ground survey data of desert locusts was collected by the survey team of the plant protection directorate (PPD) department from the Ethiopian ministry of agriculture (MOA) received in a Microsoft Excel spreadsheet. The data were recorded in the form of food and agricultural organization (FAO) standard control form (Appendix) (Symmons and Cressman, 2001). The survey team recorded and collected the data from the field measurement of the following information.

1. The observer's name (author), the location name, the geographic coordinates (latitude and longitude) with measurement units like degree, minute, and second, date of the survey with month, year, and dates.
2. The situation of environments, the type of ecological habitats (plain, crops, pasture Hillis, plateau, and wadis), the area surveyed by the survey team in hectares, the indicator of metrological condition, and the amount of rainfall last rain started to date and end date, the vegetation in the area (greening, drying, low, medium and dense), the soil humidity (dry and wet) (Ghaemian, 2002)
3. The major crops in the study area attacked by DL include maize, sorghum, wheat, barley and vegetable (FAO et al., 2020).
4. The desert locusts (present or not present) if the locust presents infestation type swarms, hoppers, adults, and eggs, and the method of data coding/entry like manual and elocust3(el3)

3.2.2 Satellite data collection

The satellite data were collected from remote sensing imagery of optical and radar satellite images like Enhanced vegetation index (EVI) computed from MODIS/Terra 13Q1 (Moderate Resolution Imaging Spectroradiometer), digital elevation model (DEM) from shuttle radar topographic mission (SRTM), sentinel-1 synthetic aperture radar (SAR) Copernicus data form Alaska satellite facility (ASF), and rainfall from global precipitation measurement (GPM).

i. MODIS Enhanced Vegetation Index (EVI) of satellite image

The terra moderate resolution imaging spectroradiometer (MODIS) data downloaded from land processer distributed active archive center (LPDAAC) obtained at united states geological survey (USGS) earth resource observation and science (EROS) used to derive vegetation layer (https://ladsweb.modaps.eosdis.nasa.gov). Twenty-four layers were downloaded from the (USGS) earth explorer. The (MODIS, EVI) data spatial resolution of 250m with 16 days of a temporal resolution was used in this study. The mod13Q1 version06 products have two primary vegetation layers. Those are the normalized difference vegetation index (NDVI) and (EVI). In this study, the EVI was chosen because the EVI doesn't simply saturate by chlorophyll and is not simply attacked by cloud cover, increasing the sensitivity of vegetation signal over high biomass regions (Huete.A, et al., 2002) (Evrendilek & Gulbeyaz, 2008). The indexing measurement uses the red and near-infrared band and is also used in the visible of a blue band which allows an extra correction of aerosol scattering. In addition, this is used to monitor the vegetation through decoupling the canopy background signal and reducing the atmospheric influence and variable soil background influence (Alfredo, 2005). The (EVI) is computed by the following formula (equation 3.1).

$$EVI = G \frac{\rho NIR - \rho RED}{\rho NIR + C1 * \rho RED - C2 * \rho blue + L} \qquad (3.1)$$

Where, ρ are atmospherically corrected or partially corrected (Rayleigh and ozone absorption reflectance. L is the canopy background adjustment which addresses the nonlinearity difference between NIR and red radiant transfer through the canopy. C1 and C2 is the coefficient related to aerosol correction used the blue band is used to remove residual contamination caused by smoke and subpixel thin clouds. G is the gain factor; The enhanced vegetation index coefficient algorithm adopted in MODIS data L = 1 C1 = 6, C2 = 7.5, and gain factor G = 2.5 (Huete.A, et al., 2002), (Huete. A,, Justice. C, , & Liu. H, 1994)

ii. Sentinel-1 synthetic aperture radar (SAR)

The Copernicus program was established by the European space agency (ESA) and the European Commission (EC) for the accessibility of the world's largest space data information of the earth observation satellite mainly sentinel data with high spatial and temporal resolution covering a wide range of applications in free access. The sentinel-1 mission has two polar-orbiting satellite sentinel-1A and sentinel-1B which performs day and night sensing of the C-band synthetic aperture radar (SAR) operating at the center of frequency 5.405 GHZ. The acquisition of data without any limitations like weather conditions and illumination. The sentinel-1 ground range detection (GRD) product-focused SAR data have been detected multi-looked and projected to ground range using an earth ellipsoidal model (ESA, Level-1 GRD Products, 2014) The sentinel-1 SAR data of C-band high resolution of ground ranging detection (GRD HD) data was chosen in this study to detect the damage assessment of desert locusts due to high spatial resolution and high temporal resolution of freely available satellite product.

The Copernicus sentinel-1 C-band high-resolution SAR of GRD-HD data were downloaded from the ASF at (https://vertex.daac.asf.alaska.edu). The characteristics and filtration methods of the raw dataset of sentinel-1 SAR have L1 detected high-resolution dual-pol GRD-HD with sensor mode of the interferometric wide swath (IW) and dual-polarization of (VV+VH) in the flight direction of descending sentinel-1A and sentinel-1B subtype image from 2019 to 2020 of sensing period and the study area. 30 layers were downloaded from ASF of sentinel-1(SAR GRD-HD) data of full swath approximately 250 km in length with pixel spacing 10 m*10 m spatial resolution at 6 days temporal resolution in two satellites. The sentinel-1SAR data of Level-1 GRD products consist of focused SAR data that has been detected, multi-looked, and projected to the ground range using an Earth ellipsoid model (ESA, Level-1 GRD Products, 2014).

iii. Digital elevation model (DEM)

The digital elevation model (DEM) data downloaded from the United States geological survey (USGS) earth explorer was obtained from a shuttle radar topographic mission (SRTM) of Twelve data tiles to cover the study area with Geo-Tiff extension by using the following website (https://earthexplorer.usgs.gov) to investigate the effect of desert locust infestation in what elevation is occupied.

iv. Rainfall data

The global precipitation measurement (GPM) mission is used to provide the global observation of rain using the international network of satellites carrying of very advanced radiometer system to measure the rainfall/precipitation from operational satellites measured between the space and reference. GPM was launched by NASA and Japan Aerospace Exploration Agency (JAXA) on February 27th, 2014 from "Tanegashim" center space in Japan. It is the extension of the tropical rainfall measurement mission (TRMM) non-sun synchronous orbit utilized the passive and active microwave instruments to provide the global precipitation in higher latitude coverage (GPM, 2014). It is a collection of international space agencies consists the Centre National d'Études Spatiales (CNES), the Indian space research organization (ISRRO), the national oceanic and atmospheric administration (NOAA), the European organization for the Exploitation of Metrological satellite (EUMETSTAT) and initiated by NASA and (JAXA) as a global successor to tropical rainfall measuring mission (TRMM) (GPM, 2014).

The integrated multi-satellite retrievals for GPM (IMERG) algorithm are used to estimate the precipitation of the earth's surface by combining information from different satellite constellations operating around the earth's surface. This algorithm was available in lack of precipitation measures of the earth's surface on the ground GPM, 2020). The study used precipitation measurement with the platform of GPM and the 30 day temporal resolution, as well as the high spatial resolution of 0.1 degree*0.1 degree data of (GPM_3IMERGM v06), which was collected by Geospatial Interactive Online Visualization and Analysis Infrastructure (GIOVANNI) of a web-based tool, developed at the Goddard Earth Sciences Data & Information Services Center (GES DISC), to facilitate access, evaluation, and exploration of Earth science datasets/plotted precipitation information of accumulated map downloaded in network common data form (NETCDF) format and monthly data of spring season in an area of interest. (https://giovanni.gsfc.nasa.gov/Giovanni/).

The following (Table 3.1) the dataset, data type, data source, spatial resolution & purpose.

Table 3.1 data and data source

Data Set	Data Type	Data Source	Spatial resolution	Data Purpose
desert locust ancillary ground survey data	Point data	Ministry of agriculture (plant protection directorate)	-	For identifying desert locust infestation occurrences area
Vegetation cover data	raster data	http://earthexplorer.usgs.gov (MODIS)	250 m*250 m	Generate the Enhanced vegetation index (EVI)
DEM	raster data	http://earthexplorer.usgs.gov (SRTM)	30 m*30 m	For determining the movement of locusts in what topography
Sentinel-1 (SAR) data	Raster data	Alaska satellite facility (https://vertex.daac.asf.alaska.edu)	10 m*10 m	Used to damage assessment of desert locust
Rainfall	raster data	(https://gpm.nasa.gov/mission/GPM	0.1 degree* 0.1 degree	For identifying the effect of rainfall in desert locust movement

3.3 Software and instrument used in this study

The software used to collect, store, process, and analyze data applied in this study (Table3.2)

Table 3.2 List of software used in this study

software	Version	Production company	Purpose/function
Arc GIS	10.7.1	Environmental system research institute (ESRI)	Datastore, management presentation, analysis, and display of a map in this study
SNAP toolbox	8.0	European space agency (ESA)	Used to preprocessing the sentinel-1 SAR data
Google earth pro	7.3.3	Google	For extracting the study area.
Microsoft offices	2019	Microsoft	To arrange and reorganize the document and compute the statistical analysis

3.4 Data Processing, Methods, and Analysis

3.4.1 Extracting Ground Survey Data

The ancillary ground survey point data received from the ministry of agriculture in a Microsoft Excel spreadsheet of dessert locust observation assessment from 2019 to 2021. The survey data covered all over the country of Ethiopia when the desert locust observation assessments were collected by the survey team. The ground survey data were extracted and converted to the save as format (CSV) comma-delimited in excel sheet to fit the ArcGIS software and the ground survey data were selected and extracted using the study area in the years 2019 and 2020 of the spring “tseday” seasons. The ground survey point data was used to determine the location area of desert locust distributed area, coverage area, and boundaries of locust found at the time of occurrence.

The method of extraction of the ground survey point data in ArcGIS

- The ground survey data were converted to the projection coordinate system (GCS) world geodetic system (WGS_1984, UTM Zone 37N, Datum D_WGS_1984 to coincide with reliable projection system or adjust the reference system of the datum used in the data
- Clipped with study area in order to separate and categorized the infestation type applied to the attribute table and selected from the locust present and non-present.
- Classification of ground data based on monthly file (according to the date of surveys)
- Symbolizes the locust infestation data represented by a black star and the infestation absent represent by tourmaline green colors.

3.4.2 Processing Vegetation layers of MODIS data

Image processing is used to extract the necessary information to increase the quality of the image to perform for finding activity process of image input and information output or getting the enhanced image. Under the image processing, several steps and procedures would be applied depending on the input data study of the research. In this section, the green vegetation index processing was used to obtain the damage assessment of desert locusts, and the environmental variable of deriving force desert locusts in the spring (harvest) season of 2019 and 2020 by extracting the EVI using ArcGIS software and performed some procedures.

1. The data of vegetation index layer from MODIS data were reprojected from the SIN (from sinusoidal projection) to projected coordinate system of world geodetic system 1984 universal transverse Mercator zone 37N (WGS1984 UTM 37N) which is similar to the other layers used in this study (Ian, & Heywood, 2010)
2. Extract the Enhanced vegetation index by using the extraction by mask within the boundary of the study area in spatial analysis.
3. The temporal resolution of enhanced vegetation index layers is 16 days with 250m spatial resolution combined with monthly data.
4. Computed the EVI layers by using the scale factor of 0.0001 to derive the real EVI values based on the study area.
5. The compound EVI layers were classified into different ranges of values based on reclassifying in a spatial analysis toolbox (Rabie & Moustafa, 2011).

3.4.3 Sentinel-1 (SAR) Data processing

The preprocessing of sentinel-1 level-1 GRD data was performed ESA production for sentinel data processing software of the sentinel application platform (SNAP) toolbox developed for process and analysis of earth observation data to remove error propagation in successive step (ESA, science tool boox explotation platform, 2020). The sentinel-1 data operates in a single wavelength of 5.6 cm which corresponds to a frequency of 5.4 GHZ unlike the multispectral satellite mission of Landsat 8 and sentinel-2 (Nagler et al., 2015). However, the sentinel-1 operates in dual-polarization mode, which means the vertical wave emitted from the sensor and both the vertical and horizontal waves are measured when returning to the sensor leading to backscatter intensity of VV and VH. Sentinel-1 is an ESA mission that is made up of two polar-orbiting satellites (Sentinel-1A/1B) each equipped with a C-band SAR 5.6 cm(Nagler et al., 2015). The pre-processing steps of sentinel-1 data were applied by using the SNAP toolbox looks like below.

1. **Slice assembly**

The slice assembly tools are used to remove the gap or duplicated lines, with no geometric, radiometric, or phase discontinuity between the consecutive image during the SAR mosaic data and easily manage a large amount of data in the SNAP toolbox (ESA, Product Slice Handling, 2014). The sliced product contains metadata into an assembled product. In order to perform the assembly product, the three technical rules applied to including, merging and concatenating different slice products.

2. Apply orbit file

The orbit auxiliary data contain information about the position of the satellite during data acquisition. The orbit state vectors SAR product metadata information is not correct(Filipponi, 2019). due to this reason applying the orbit file is to provide the accurate satellite position of the metadata of the original image and obtained the correct velocity information of sentinel-1 SAR image in a SNAP toolbox.

3. bordar noise removal

The level-1 GRD-HD sentinel-1data bordar noise removal perform to compensate for the change of earth curvature, azimuth, and range compression leads to radiometric artifacts and used to remove low-intensity noise and invalid data from the scene(Ali et al., 2018).

4. Thermal noise removal

The fundamental step of preprocessing in sentinel-1 data is thermal noise removal used to get the correct radiometric calibration of SAR data. the thermal noise removal comprises two sources antenna pattern and varies in range direction and scalloping noise varies along azimuth direction.

5. Radiometric Calibration

Radiometric calibration is the ability to convert digital numbers recorded by a satellite imaging system into radiometrically calibrated SAR backscatter(Filipponi, 2019). The information required to apply the calibration equation is included within the Sentinel-1 GRD product specifically, a calibration vector included as an annotation in the product allows simple conversion of image intensity values into sigma naught values.

6. Speckle filtering

The speckle filtering used to increase the quality of the image by reducing the interference of noise in the wave reflected by the elementary scatter. It is not propagated in an ongoing process and processing early stage before and after terrain correction. The filtering type used in this image is lee sigma of 3*3 target window size and 7*7 window size from the drop-down table created the speckle data(Qiu et al., 2004).

7. Range Doppler Terrain correction

Terrain corrections are applied to observed values obtained in the geophysical survey to remove the effect of variations in observation due to topography and used to compensate for these distortions. so that the geometric representation of the image will be as close as possible to the real world. The range doppler terrain correction is a correction of geometric distortion caused by various topography. such as foreshortening and shadows, using a digital elevation model to correct the location of each pixel (Filipponi, 2019). In this stage, the digital elevation model used SRTM 1sec HGT (Auto download) with the DEM and the image resampling method used bilinear interpolation. And the map projection selected the (WGS84 UTM zone 37N). The range-Doppler terrain correction operator available in SNAP implements the Range Doppler orthorectification method for geocoding SAR scenes from images in radar geometry.

8. SAR Mosaics

The fundamental step of performing remote sensing images of satellite data is mosaicking. This step is used to merge multiple orthoimages which have overlapped areas between each other into one image (ASF, Generate a Mosaic of Two Sentinel-1 Products in Adjacent Paths, 2018). SAR mosaic was used to merge the sentinel-1 data and performed some parameters such as resampling method of bilinear interpolations, weight average of overlap active during the processing of mosaicking, define the pixel size.

9. SAR subset

subsetting is the process of retrieving a portion of large files which are used for a specific purpose or area of interest. It is also used to reduce the size of the satellite image by the area of interest, restrict and classify the time of range, exclude particular observations, select the cross-section of data, and select a particular kind of time-series data (ASF, How to Create a Subset of a Sentinel-1 Product, 2018). In this section was performed the subset and mask of preprocessing sentinel-1 data.

10. Conversionsion to dB

- Conversion to dB the backscatter coefficient is converted to decibel using logarithmic transformation like **σ0 (dB) = 10*log10 (abs (σ0))** **(3.2)**

  Where, σ0 (dB) – backscattering image in dB

  σ0 – Sigma naught image

3.4.4 Processing of digital elevation model (DEM)data

A digital elevation model (DEM) is a digital imagery representation of earth terrain in which the matrix point has a value corresponding to its altitude above a sea level derived by digitizing elevation data from the topographic map or stereo imagery, interferometric synthetic aperture radar, or light detection and ranging (LIDAR) (oguchi, s,, & waklewicz, 2011). The DEM layer was added to ArcGIS 10.7.1 and merged the twelve layers to create the raster data set with the help of mosaic in data management and convert the suitable projection system of WGS 84 UTM zone 37N and masked the raster image based on the study area boundary. After that classifying the digital elevation model (DEM) value based on the elevation interval.

3.4.5 Processing Rainfall data

Rainfall is the one factor in increasing the desert locust breeding and infestation to distribute through the locust invasion area directly or indirectly provides ecological requirements for breading and maturation (WMO, 2020).

The following step is a method of processing the rainfall data

- The precipitation layers were added to ArcGIS using the multi-dimensional tool to the make NetCDF file converted into raster layer in ArcGIS to explore and extract information about the precipitation.
- Adjust the projection system to coincide with the ground ancillary historical data of desert locust observation and clipped the study area using extraction by mask.
- Convert the raster data to point using a conversion tool and apply the Inverse Distance Weighted interpolation (IDW) method by masking based on the study area and reclassifying the monthly data millimeter per month, to interpret the value of precipitation and the desert locust movement with the area of interest. Interpolation is a geostatistical analysis used to convert point observations to the continuous surface and

fill the gap between measured values, in addition, to comparing the spatial pattern by measurement and the spatial pattern of other spatial entities.

3.5 Ground survey data overlay with environmental variables

The environmental variables used to investigate the distribution of desert locusts and interpret which weather conditions are favorable to outbreed and formation of swarms, devastating agricultural products, and pasturelands. In this section, the ground survey data on desert locust infestation were overlaid into preprocessed and arranged rainfall data of monthly layers with the similar month of ground survey data to investigate factors of rainfall amount in the distribution of desert locust and rainfall amount within each month. The total infestation site recorded in 2019 and 2020 is 90 site and 164 site respectively and non-infested site is 50 and 121 respectively. Green vegetation of EVI layers also improved the movement of desert locusts similar to rainfall layers, The ground survey data overlaid the monthly combined EVI layers used to analyze in which month green vegetation is suitable for desert locust development, determine widely distributed and spread infestation area and in order to assess which area is favorable and suitable to desert locust used as food and shelter.

DEM data was applied to determine the movement of the desert locusts in order to identify the elevation level of densely distributed desert locusts. according to (Dutta et al., 2003) the distribution of locusts in high elevation/mountainous areas with dense vegetation settled over a longer time, this is because the desert locust's maximum flight height is 1700 m. in this section the total ground survey infestation points data of three months overlaid the DEM layers and investigate the distribution and movement of the desert locust in a given area of interest. The spatial join of ground survey data and converted raster data of elevation into point data was also performed to interpret the elevation level in meters and infestation area by hectares analysis in an excel spreadsheet.

3.6 Damage assessment of desert locust using sentinel-1 SAR data and EVI data

In vegetation damage assessment/detection, attacked by desert locust infestation used as input to analyses and interpretation process of data from ground survey data. The ground survey data were the fundamental data to detect the infestation area and non-infestation area. These data contain attribute information of position, greens, located area, and necessary information about desert locusts. The zonal analysis is a method used to create the output raster in which the desired function is computed in cell value from the input value raster that intersects or falls within each zone of the specified input zone data set (ESRI, An overview of the Zonal toolset, 2021). The zonal analysis is one of the most important tools of arc GIS spatial analyst extensions applied in this study. The most common activity of GIS studies performed in zonal analysis such as environmental monitoring of soil erosion, damage detection, suitability analysis, and land management (Soysal et al., 2012). The common zonal tools available in arc GIS tabulate area, zonal geometry, zonal fil, and zonal statistics as a table. zonal statistics as a table of spatial analysis tool function was applied to compute the basic statistical parameter for the area of interest. The input data of zonal statistics were used as the raster data of preprocessed, ordered, and arranged data of sentinel-1dual-poll frequency of two bands (VH and VV), and the EVI layers of MODIS data and the feature of desert locust infestation area represented by point vector data of ground survey data to compute the pixel value of each point in the tabulated area of mean, standard deviation, and the sum of each statistic reflecting the individual district zones were computed.

3.7 Predicting desert locust infestation by geostatistical analysis

Geo-statistics is a GIS tool used to develop the statistical analysis data measured at any location in space available in a limited number of sampled points converted to continuous data and interpolate the optimal surface(ESRI, 2001). The purpose of the geostatistical analysis is to predict value where the survey team doesn’t cover the area during the data collected (Woldewahid, 2003). Geostatistical analysts applied several applications like geology, agricultural purpose, archeology, metrology, mining, etc. It is also used to assess the potential environmental hazards by interpolating the possible flow and direction of radiation and predicting the optimal condition for efficient and more optimal conditions(ESRI, 2001). spatial dependency is detected in several tools available in geostatistical analyst exploratory spatial data analyst (ESDA) and geostatistical wizard. Spatial interpolation is very important in various context estimating rainfall, groundwater pollution, temperature, and infested area of desert locusts helps to fill the gap of using known point data for an unknown area. Geostatistical analysis verifies the data features by using ESDA to perform the task with information on dependency, stationarity, and distribution (ESRI, Exploratory Spatial Data Analysis (ESDA), 2021). Interpolation is a geostatistical analysis procedure used to predict the lack of sample points using known points to find out the unknown point by measuring the near and distance point value to convert continuous surface based on the principle of spatial autocorrelation or spatial dependency (Childs, 2004).

The most flexible and suitable method in modeling spatial dependency and semi variogram modeling of the geostatistical analyst is kriging interpolation. Kriging interpolation is a powerful interpolation method for different applications spatially correlated in distance and directionally from known point predicted values derived from measuring the sophisticated weight average technique (Woldewahid, 2003). In this section, the Ordinary kriging method was used to predict the infested area by desert locusts typically modeling the local mean values in higher and quadratic regression analysis.

Sampling

During the period 2019 in the spring season, the desert locust infested were counted from September 2019 to November 2019. Similar methods in the 2020 spring season were applied to infested desert locusts sampled from September 2020 to November 2020 for three months. The sampling point of desert locust infestation data can be used to measure by the survey team anywhere in the given study area creating point density raster continuous data to answer the question and distinguish in which area the movement and risk of desert locust density is high and in which area is low movement.

Creating the semi variogram

A semi variogram is a description of the spatial continuity of data and discreet function calculated using a measure of variability between pairs of points at various distances (Deutsch & Journel, 1998). Lags are the distance between pairs at which the variogram is calculated. Fit the model (create surface) after examining the data in the ESDA the geostatistical wizard simply interpolates the data available for creating a surface. Geostatistical analysis of infested area sampled point data was performed in two stages of progress. The first method applied in this study with a degree of correlation used to sample site various distances was characterizing to coincide with the variogram. The second method was to build up the map using kriging interpolation (Woldewahid, 2003). The spatial distribution of desert locusts was determined using the historical locust occurrence in 2019 and 2020 of spring seasons 90 and 164 respectively.

Cross-validation

To check the accuracy of the interpolation method using cross-validation is the main step used to quantify the data reliability performed in geostatistical analysis. Cross-validation is one of the appropriate methods for testing the interpolation suitability methods (Rabie & Moustafa, 2011). It also removes the data from one or more point data locations at a time and predicts their associated data using the data on the remaining observation. in this case, simply compares the relationship between the predicted value and measured value to obtain desired information about the quality of the kriging model. The output surface in the geostatistical analysis is prediction, prediction standard error, quantile probability, and standard error of indicator

3.8 Statistical analysis

During vegetation damage assessment of desert locust applied the infested ground survey point and non-infested point using zonal statistics as a table in ArcGIS and statistical analysis in Microsoft office excel sheet. in this stage compute the mean, standard deviation, and P-value to analyze the damaged and non-damaged vegetation by desert locusts. Extract the mean value using zonal statistics as a table in spatial analysis tools in ArcGIS by adding the ground survey point data into the MODIS EVI and the sentinel-1 SAR preprocessed data. Extract the individual mean value of each point in table format and import it into a Microsoft Excel spreadsheet and calculate the average mean of each point data, standard deviation using the mean in Excel, and p-value of significant level (Eltoum, 2014). The t-test is a method used to determine a probability distribution of two mean samples tested hypothesis to quantify the significant level of applied data in a given area of interest and it is also a statistical measurement utilized to a comparison of observed data and tests the hypothesis based on obtained results (jargons, 2022). The two T-tests statistical analysis of unequal variance is were applied in this study to compare the mean of infestation present and non-infestation present of sentinel-1 SAR data and EVI MODIS data in an Excel spreadsheet. The general methodology work flow listed in (Figure 3.2) below from data source to achieve the goal of research

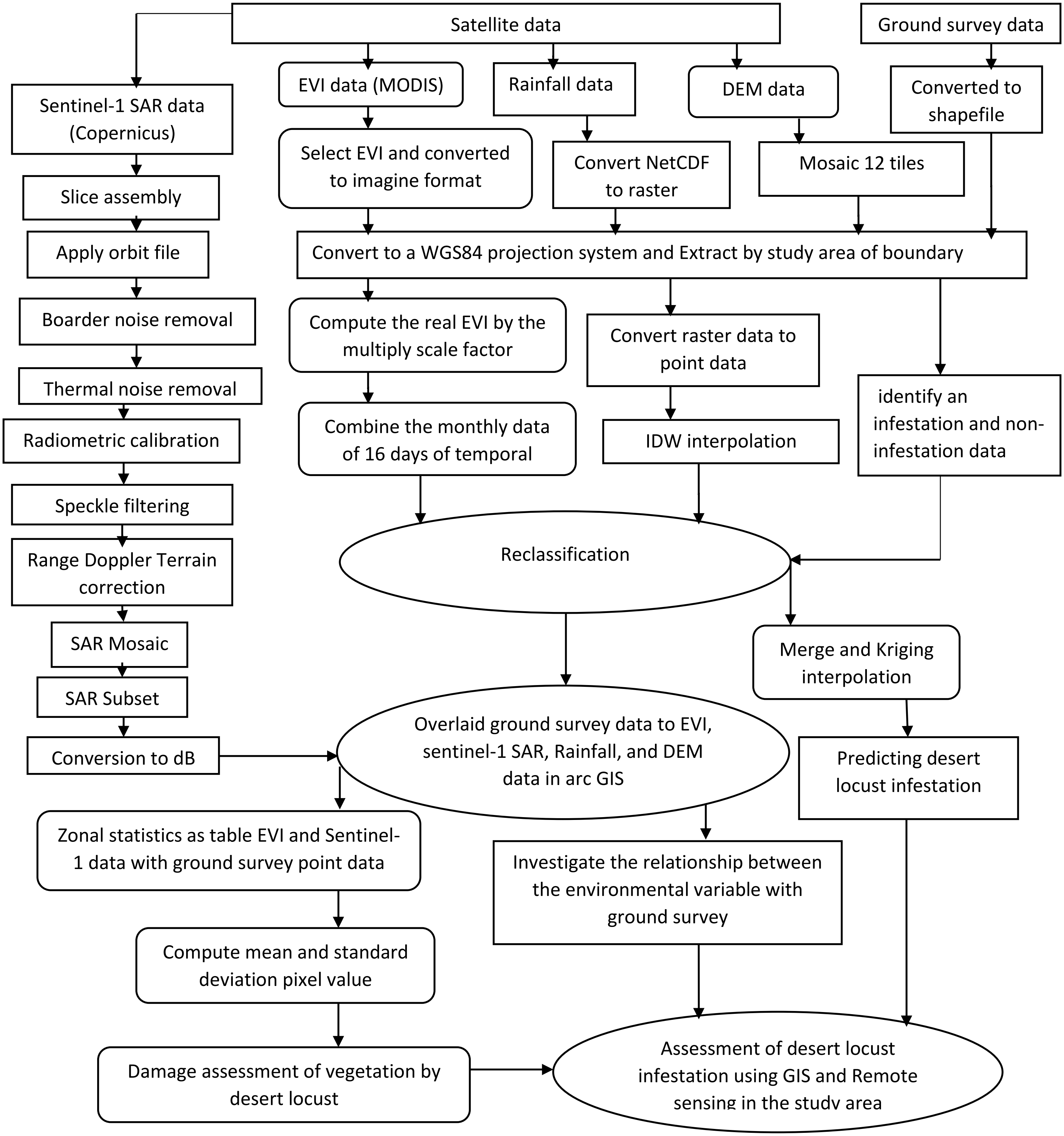

Figure 3.2 flow chart of methodology

Chapter four

4. Results

4.1 The Environmental variables of Rainfall, EVI, and DEM

The two years of 2019 and 2020 used in this study the same month from September to November the desert locust occurs consequently two years in dire Dawa and some parts of Somalia regions. Mostly spring season is the time of collecting and harvesting agricultural products accomplish from September to November when planting in the last season in Ethiopia. The survey team collected the ground survey data on both the desert locust that occurred and does not occur in study area. Symbols used in this study to represent the locust condition and the rainfall and DEM measurement unit. Null- the data does not occur or no infestation of desert locust occurrence, Present- the desert locust infestation any type of infestation occurred. the environmental factors were applied to green vegetation of EVI, rainfall and DEM data by integration of ground survey data in the spring season

4.1.1 Ground survey data vs rainfall data.

The precipitation of 2019 in the spring “tseday” season within September to November monthly series data shows the rainfall amount decrease and the infestation of desert locust recorded increase from September to November. This is due to locust infestation movement growing in Ethiopia since 2019 reveal in September and the survey team did not address the observation of ground survey. Based on the map of September 2019 precipitation results, the locust movement in September 2019 infestation occurred in three ranges of rainfall from33.8 mm - 60.4 mm, 60.5 mm - 86.4 mm, and 86.5 mm - 114 mm in different zones of the Somali region but a high range of rainfall the desert locust infestation has not occurred with the range of 115 mm – 147 mm and 148 mm - 191 mm of Somali regions and Dire Dawa administration is not infestation occurred (Figure 4.1). This leads to the locust movement being supported by precipitation to the next month suitable soil moisture content for breeding of locusts and the vegetation used as a food

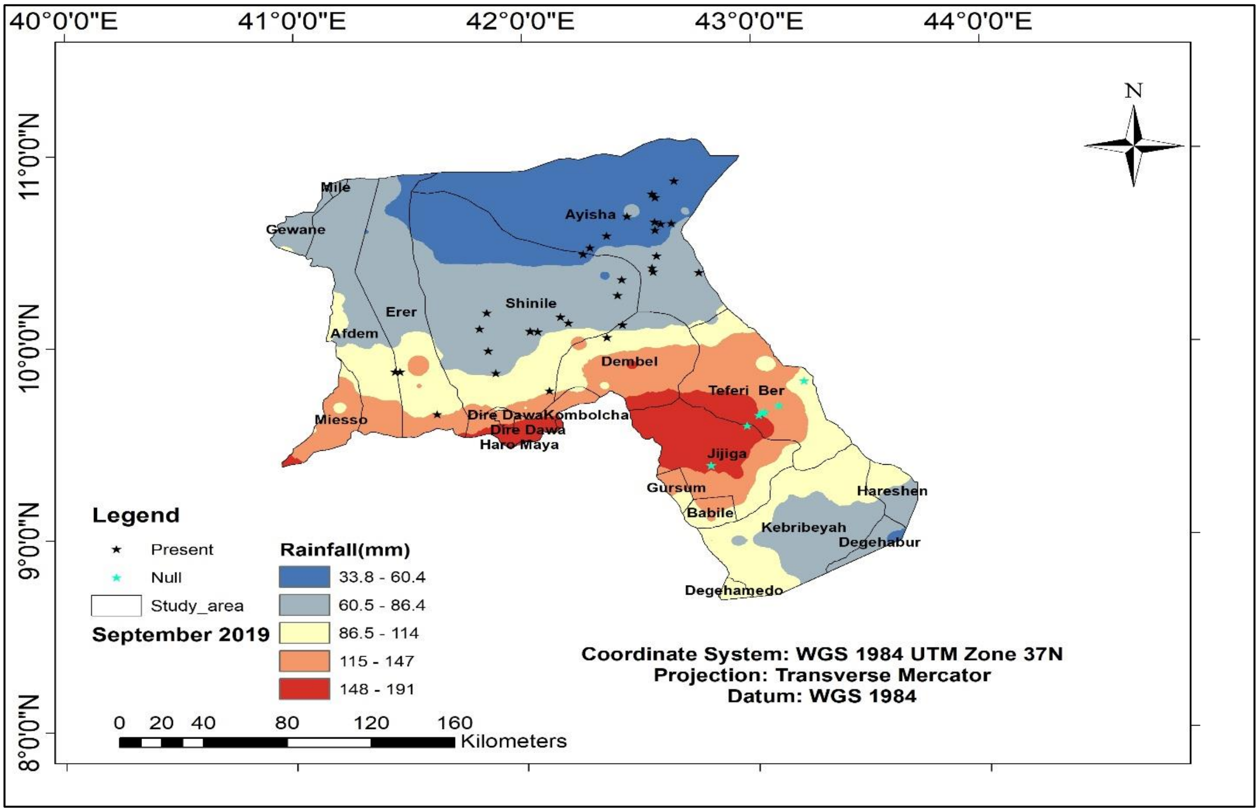

Figure 4.1 Desert locust infestation and rainfall amount September 2019

In October 2019 the rainfall amount reduces compared to September by some value of rainfall range in mm but the large area covered by 16.5 mm – 34 mm and the desert locust infestation recorded in this range of rainfall (mm) of Somali region and some area of Dire Dawa zones record in value of 34.1 mm – 52.1 mm (Figure 4.2) The coverage area of heavy rainfall in this month reduction in the Somali region and Dire Dawa administration in October and the infestation of the desert locust is a relatively very low movement with related of the amount of rainfall is light in large area coverage of study area.

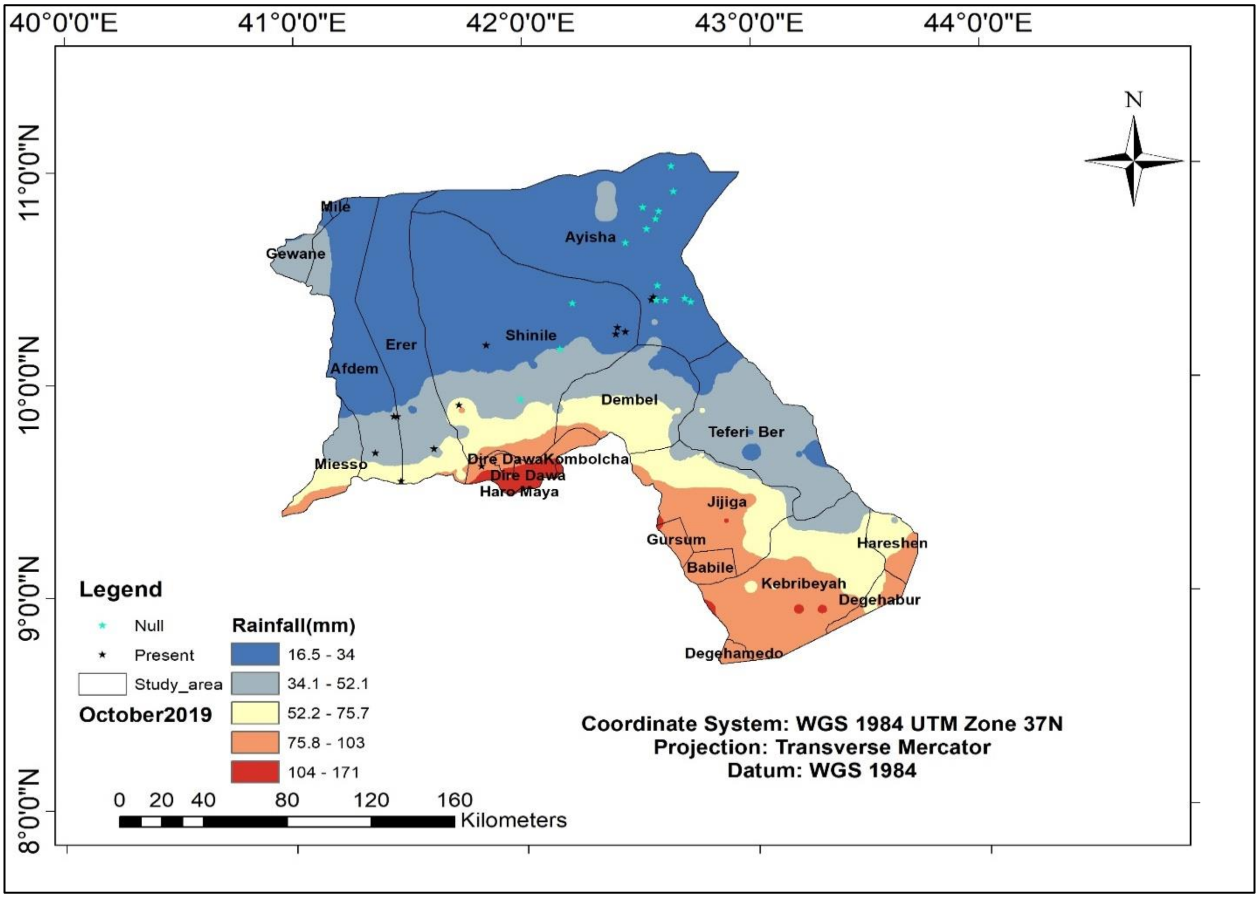

Figure 4.2 Desert locust infestation and rainfall in October 2019

The rainfall amount in November 2019 is very light compared to the two months of the previous spring season of two months and the desert locust infestation increased and distributed in all rainfall value ranges of covered all parts of the study area. This is because the heavy rainfall amount in the previous month leads to the breeding of desert locusts and simply moved from place to place to obtain suitable habitat for desert locusts and food. From (Figure 4.3) the movement of desert locusts shows from lowland area invasion and covered a large area of highland area migrate to the croplands and pasturelands with the help of the high amount of rainfall in 2019 spring season and covered all zones from time to time with the expansion of other parts of the country.

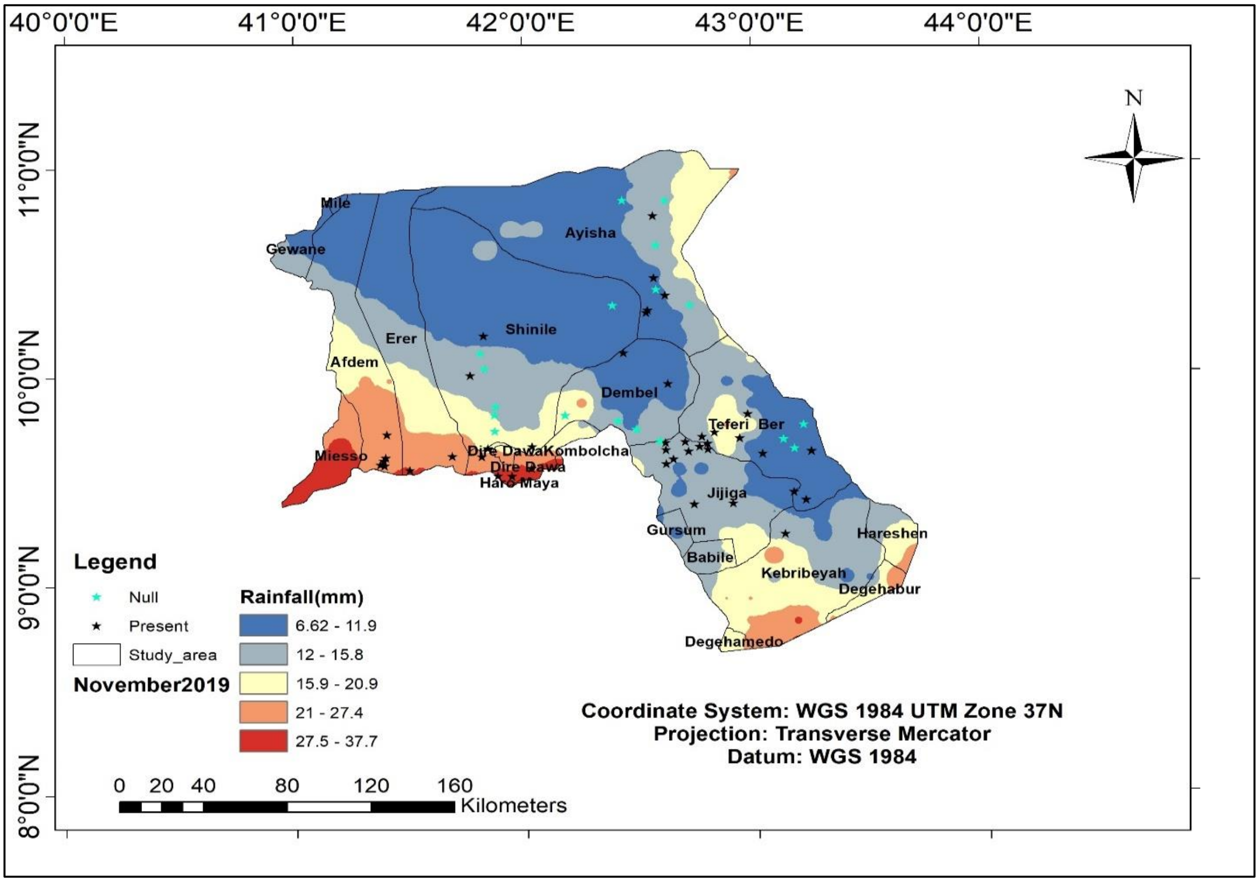

Figure 4.3 Desert locust infestation and rainfall in November 2019

In general, the spring season had good rainfall, and very important to develop locust factor that leads to invasion. The factor supported the growth of green vegetation using locusts as food and shelter and also used the soil moisture content is suitable for the breeding of locusts. the amount of rainfall varied in three months and decreased from September to November on the other hand, the movement of the desert locust covered a large area of interest in November 2019 in contrast to the two months of September and October 2019.

The precipitation of the 2020 spring season of rainfall was very high in September and medium in October and low in November of rainfall.

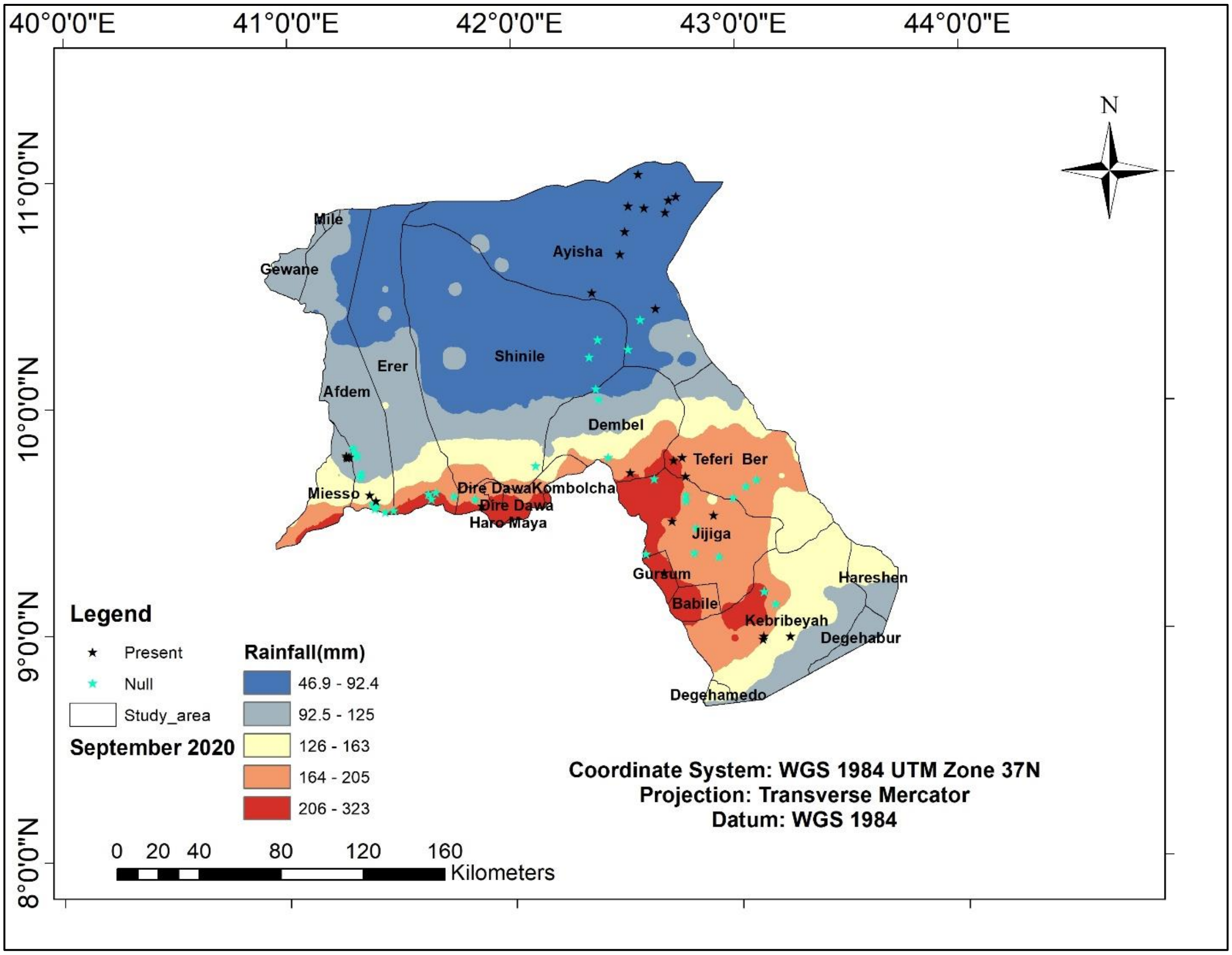

Figure 4.4 Desert locust infestation and rainfall in September 2020

In September 2020, (Figure 4.4) the rainfall amount reached 206 mm - 323 mm, and infestation observed in light rainfall from 46.9 mm - 92 mm covered a large area of desert locust infestation 164 mm - 205 mm also covered areas locust observed and some infestation also occurred in 92.5 mm -125 mm. In heavy rainfall amount from 206 mm to 323 mm and high rainfall ranges almost no infestation observed in September 2020.

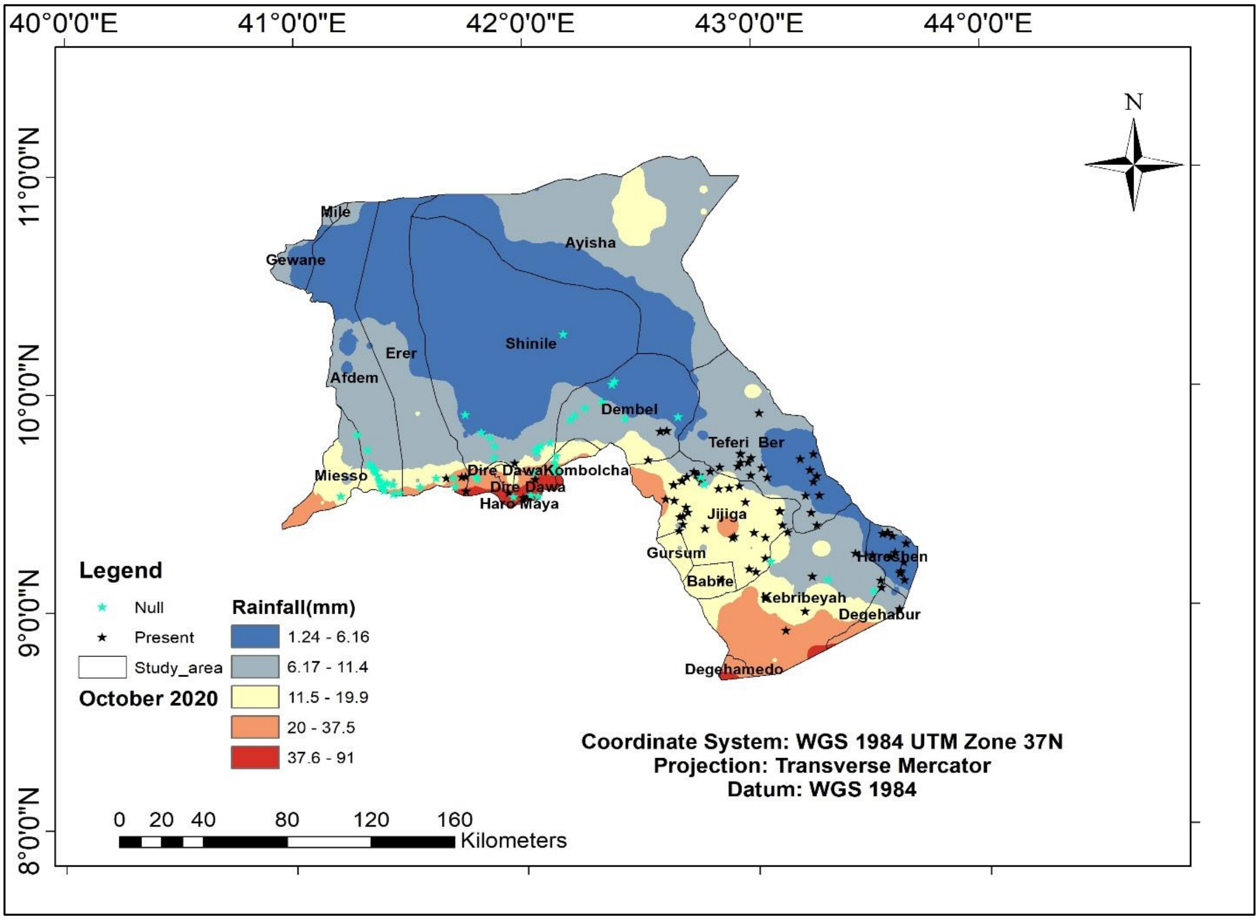

Figure 4.5 Desert locust infestation and rainfall in October 2020

In October 2020 the rainfall reached to37.6 mm - 91 mm and the light rainfall covered the large study area the observation of desert locust records from 1.24 mm to 6.16 mm (Figure 4.5) when compared to September the amount of rainfall in October has a great difference and reduced but the movement of desert locust infestation increases. In this season the distribution of desert, locust observation was found in all range rainfall values with different infestation amounts and the locust occurrence migrate to the southern part of the Somali region and Dire Dawa administration from the northern part of the study area.

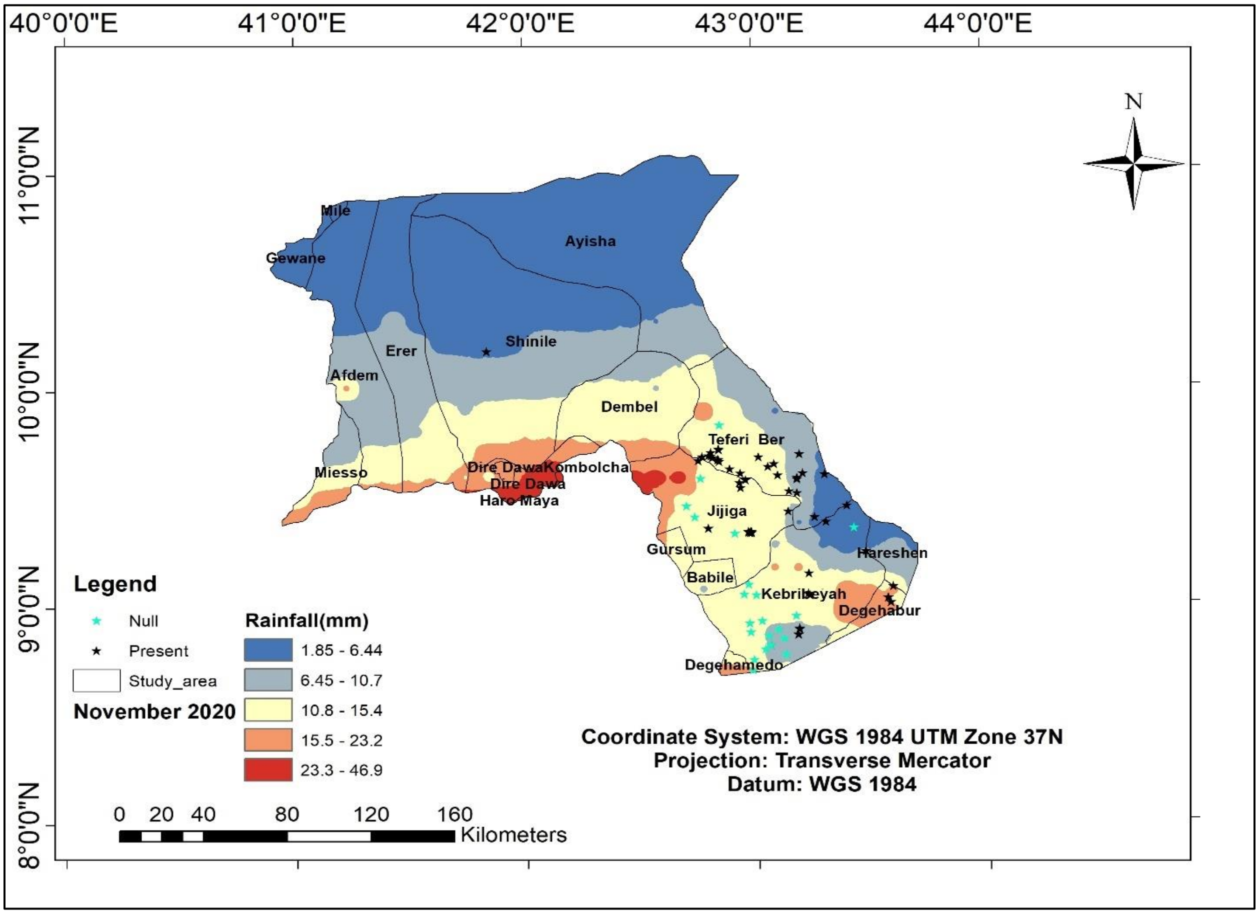

Figure 4.6 Desert locust infestation and rainfall in November 2020

In November 2020 (Figure 4.6), the amount of rainfall is lower compared to the above two months exploring the rainfall distribution and infestation of desert locust observation. During this month large area was covered by very low rainfall ranges of 1.85 mm – 6.44 mm and the locust observation of infestation occurred to some extent and the major desert locust infestation was observed in area coverage of 10.8 mm to 15.4 mm. the other range rainfall values, not infestation observed in heavy rainfall recorded in this season from 23.3 mm to 46.9 mm of the study area.

In general, the spring season of rainfall 2020 is very high in September and reduce to October and November and the desert locust infestation observed in October was light rainfall covered almost all of the area of interest and the recorded locust infestation area also higher number compared to September and November 2020.

4.1.2 EVI vs Ground survey data

vegetation cover is the most important factor to derive and develop desert locust movements like behavioral changes, color, shape, and the locust population density increase and formation of swarm and hopper bands (Meir Paul Pener, Stephen J, & Simpson, 2009).

The condition of green vegetation in the spring season was classified on the months of the season values with the invasion of desert locust distribution based on ground survey data of locust infestation present and not present. The green vegetation coverage area of EVI had good values used to locusts as a food, shelter and suitable for nutrition and development of desert locust with widespread the occupation area. The infestation observation appeared in the early season and at the end of the season but in the mid-season, the observed infestation is relatively very low infestation occurrence.

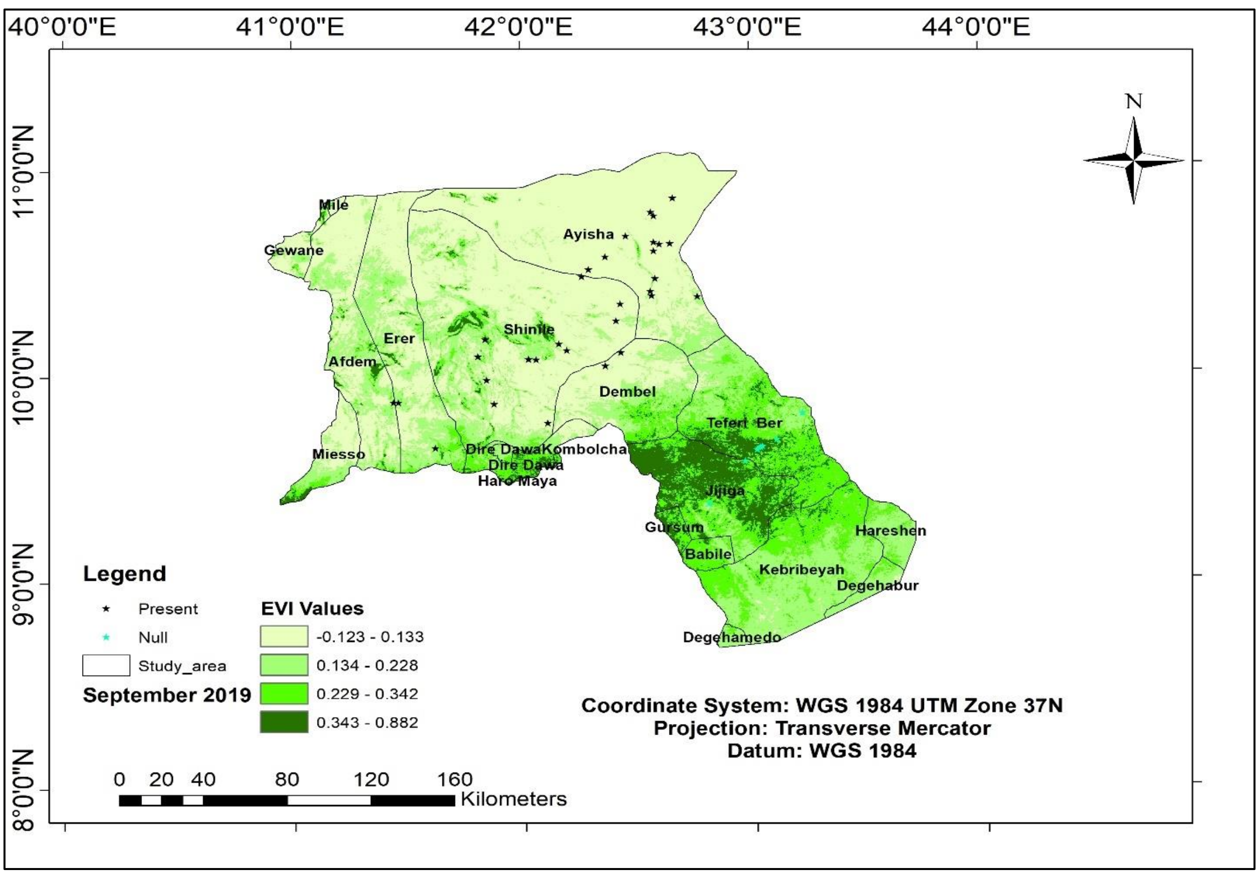

Figure 4.7 Green vegetation and desert locust infestation in September 2019

(Figure 4.7) September 2019 shows, the green vegetation values improved ranging from 0.343 – 0.882. But the infestation of desert locusts occurred in very low green vegetation areas with the range of - 0.123 – 0.133 and low range values of 0.134 – 0.228. The most area of interest is covered by the two ranges values and the distribution, and movement of desert locusts in this area based on the ground survey data of locust infestation. The highest value of green vegetation covered a small area of interest and no infestation was observed at 0.229 – 0.342 and 0.343 – 0.882. The movement of the desert locust in this season doesn't widely distribute and begging time to migrate and expand the southern part of the study area.

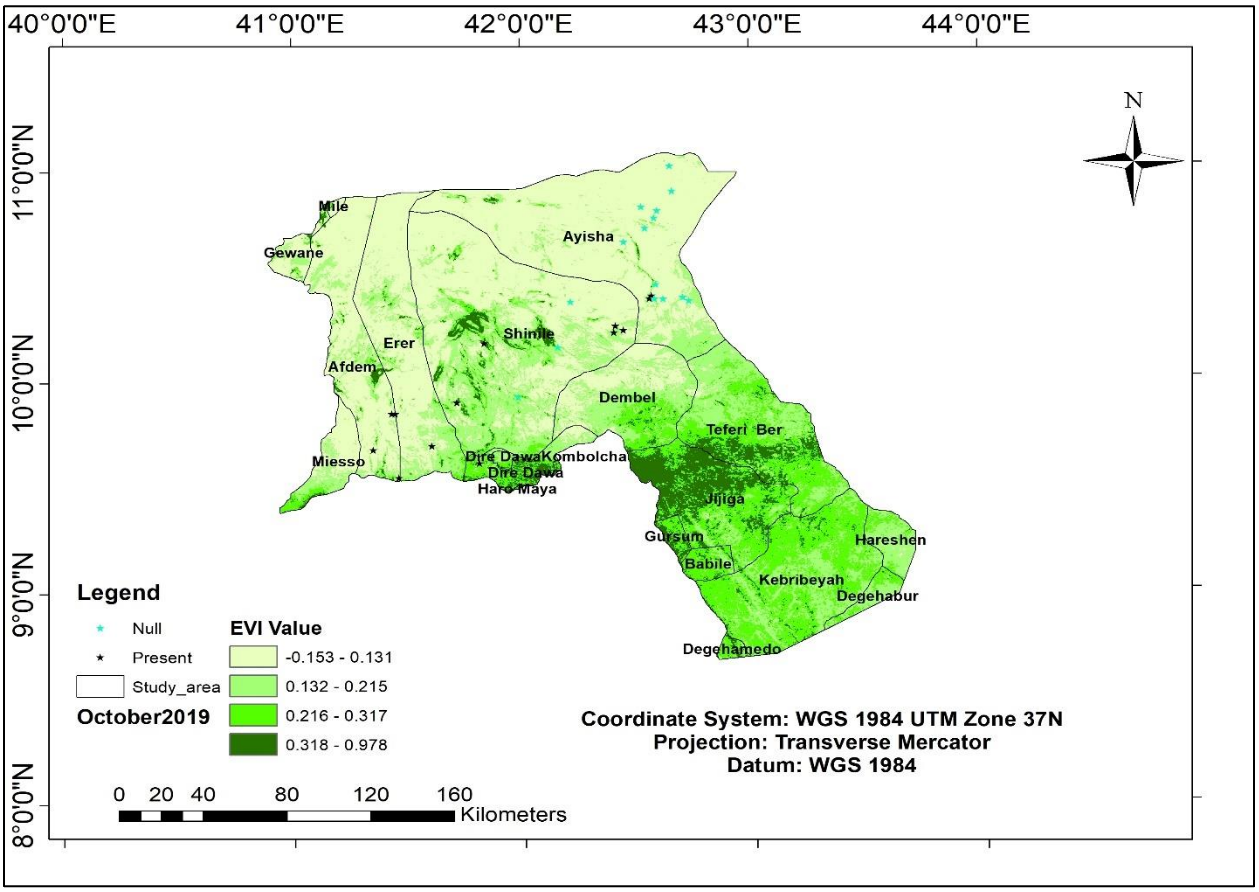

figure 4.8 vegetation and desert locust infestation in October 2019

The EVI values reached 0.318 – 0.978 but, the area of interest is covered in low vegetation and the infestation occurred within this season of EVI ranging from - 0.153 - 0.131 and 0.132 - 0.215 there was locust infestation recorded but the EVI values 0.318 - 0.978 covered high vegetation area and there is no infestation observed in this ranges of the study area (Figure 4.8). The movement of desert locust infestation in this season compared to September and November the recorded data is very small and the green vegetation high ranges in October season.

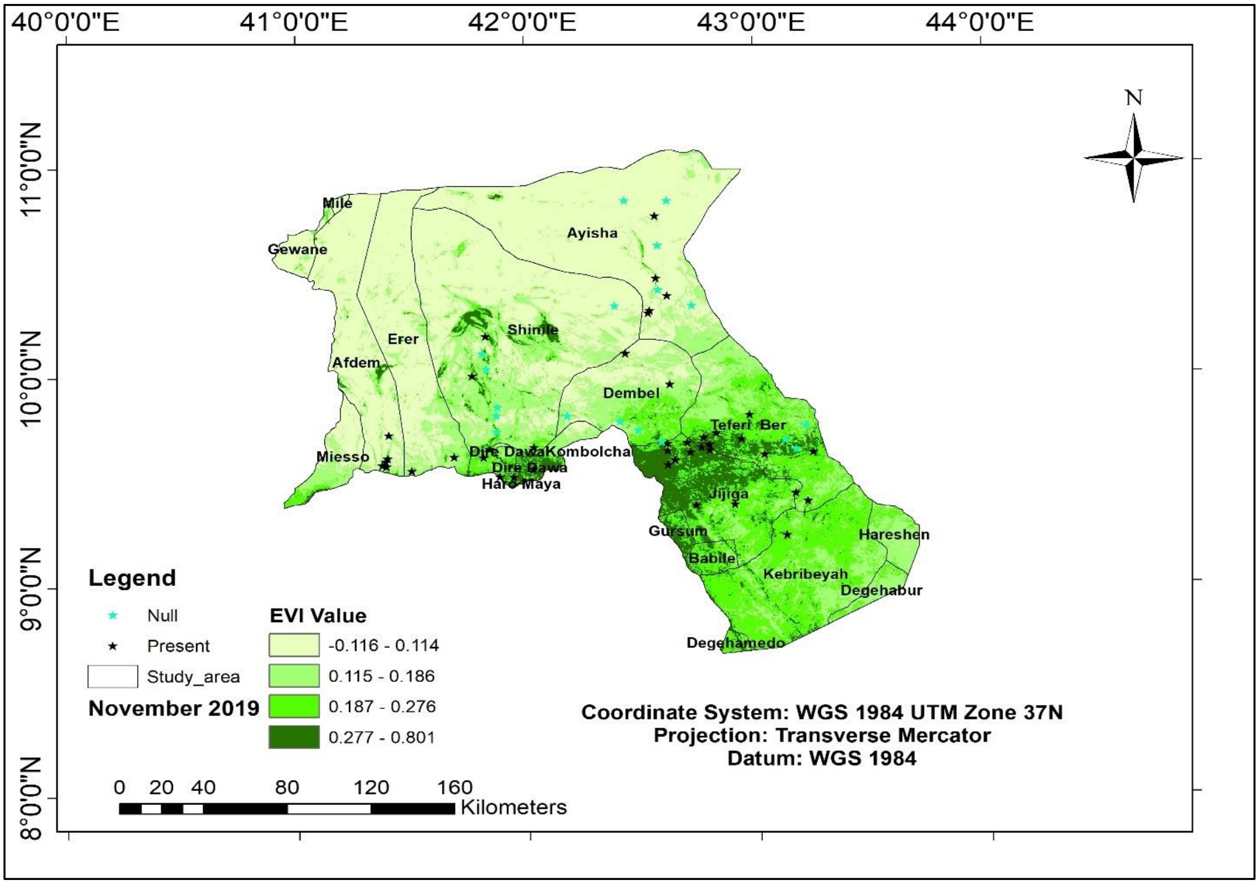

Figure 4.9 Vegetation and desert locust infestation in November 2019

In the spring season, the locust infestation occurred in all ranges of EVI values in November 2019 (Figure 4.9). The EVI values improved from 0.277 – 0.801 and there were high infestations recorded in this range and 0.187 – 0.276 infestation also recorded and distributed in all ranges of the given study area. In this season the large area was covered with EVI value ranges of -0.116 – 0.114 and 0.115 – 0.186 but the recorded value infestation level in the two ranges was lower than compared with high and very high vegetation index value ranges of 0.187 – 0.276 and 0.277 - 0.801 respectively.

In general, the spring season of green vegetation area reduce and locust infestation distribution expand from September to November in 2019 but in October 2019 the green vegetation improved reach in high vegetation value with a low coverage area of the infestation there was not enough survey data infestation occurred in this season or not infestation occurred.

In 2020, the spring season and distribution of locust infestation within the area of interest migrate to the southern part of a study area, and the number of infestation records increases and large area of coverage in the study area. The green vegetation values also reduce early season from September 2020, mid-season octobr2020, and end season November 2020 contrary with the locust infestations were increased.

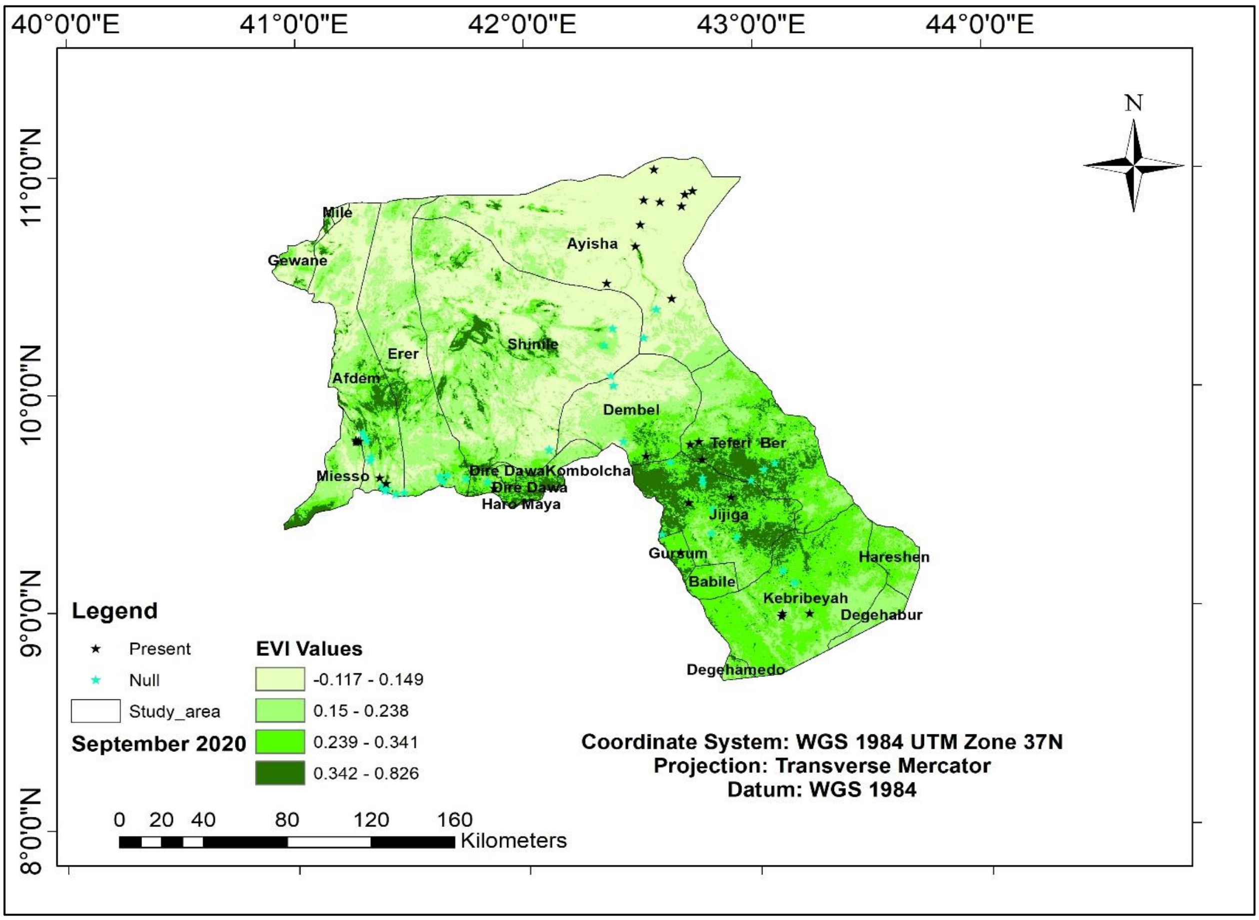

Figure 4.10 Vegetation and desert locust infestation in September 2020

In September 2020, the green vegetation had high values between 0.342 – 0.826, and the locust infestation was also observed in high vegetation values. The larger area was covered with the EVI value ranges of 0.15 – 0.238 and there were infestations in this range (figure 4.10). The infestation record in September 2020 in all EVI range values but there was a different number of records and area coverage in the given study area. The green vegetation of higher value and covers a large area compared to October and November in the spring season of 2020.

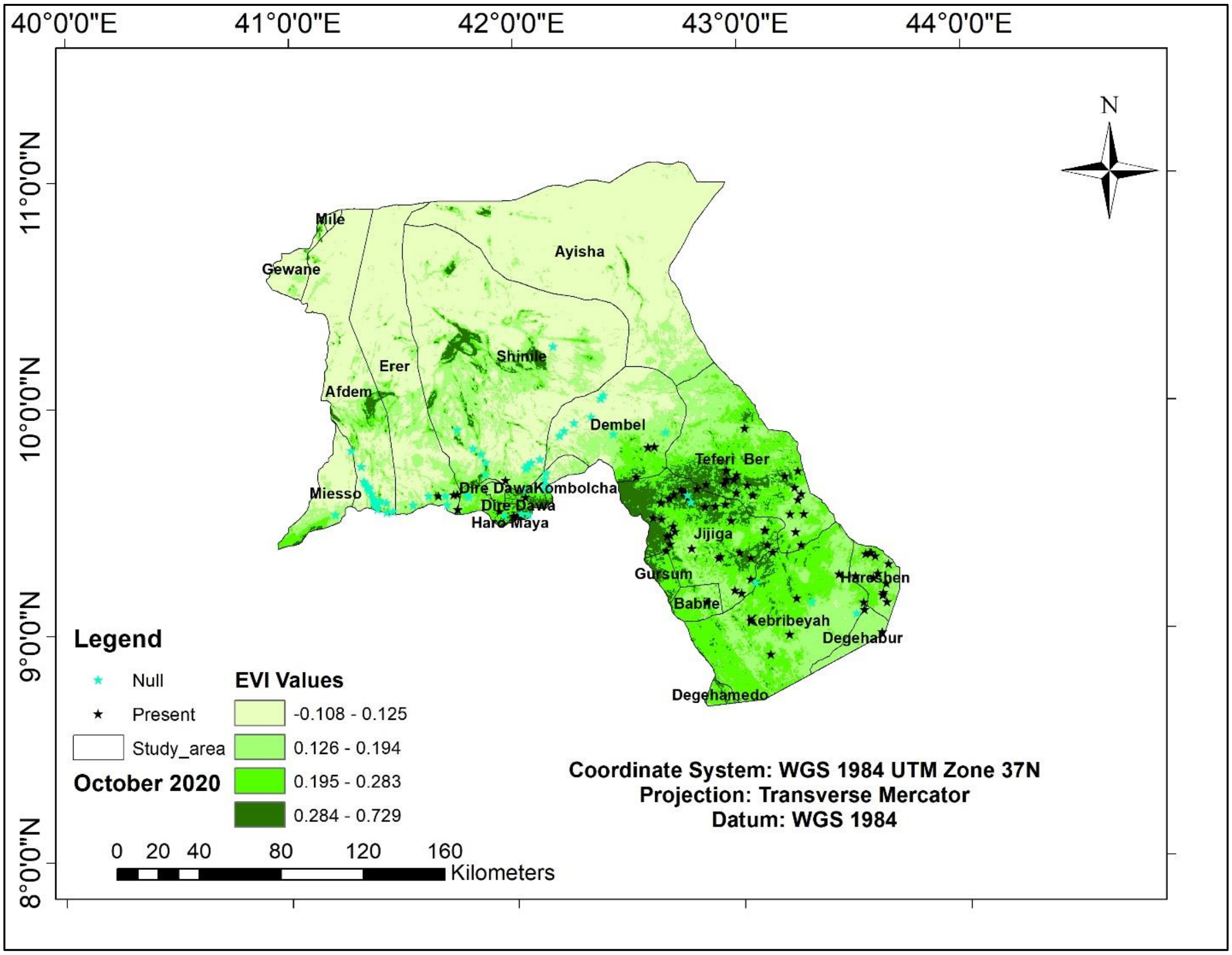

Figure 4.11 Vegetation and desert locust infestation in October 2020

In October 2020 (Figure 4.11) shows, The EVI reached 0.284 - 0.729 is a higher green vegetation index. The recorded locust infestation occurred and was distributed range values from 0.284 – 0.729 and covered high values of green vegetation because provides favorable for desert locust movement in habitat, food, shelter, and nutrition for a long period. the distribution of locust infestation recorded in October 2020 green vegetation range values from 0.195 – 0.125. The lowest vegetation value in October 2020 infestation type was not recorded in EVI range values of -0.108 - 0.125 and 0.126 - 0.194. the area of interest is largely covered by the range value of EVI in these two ranges of low vegetation. The movement of desert locusts also migrates to the southern part of the study area and in highland regions.

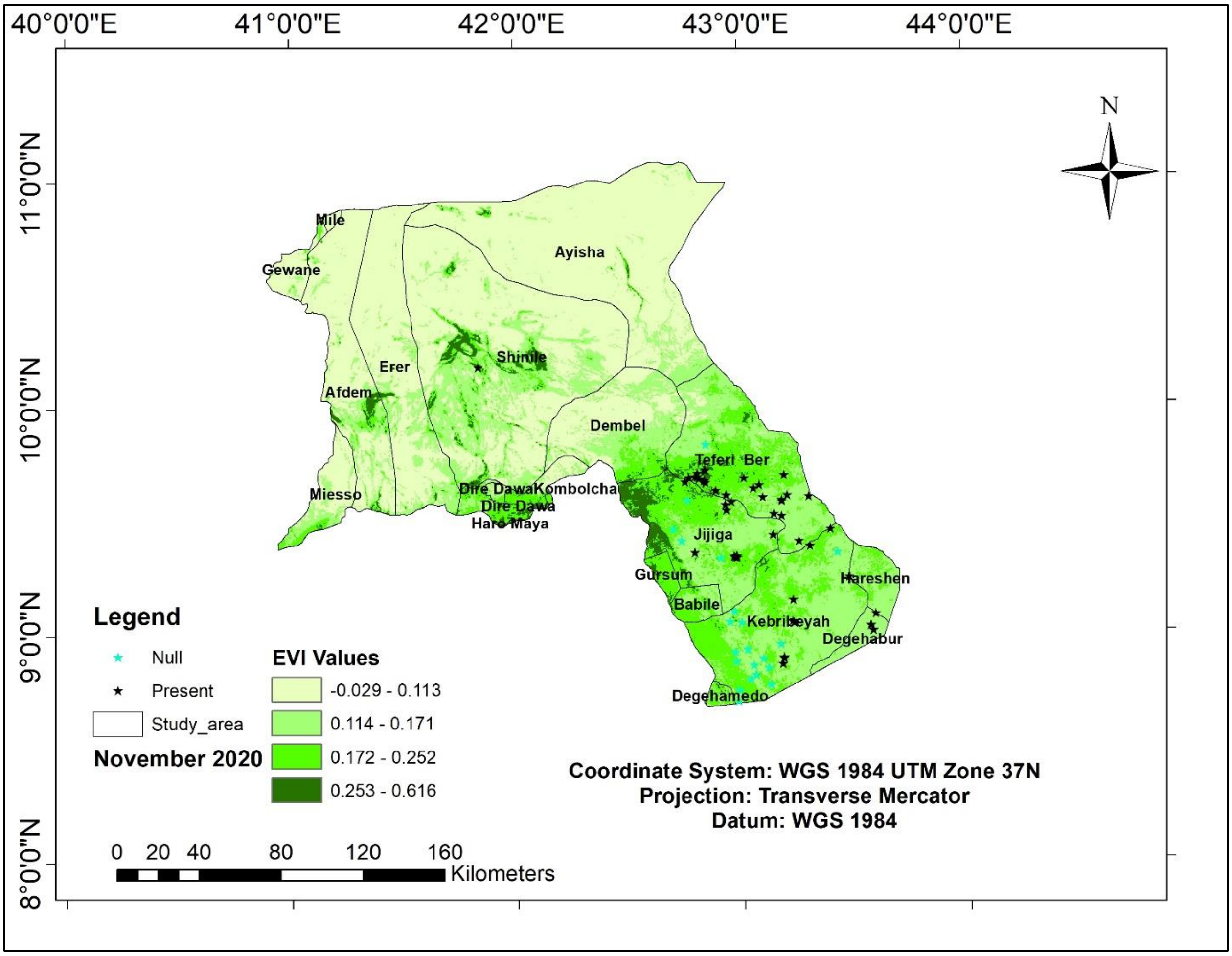

Figure 4.12 Vegetation and desert locust infestation in November 2020

In November 2020, the green vegetation reached 0.253-0.616. the infestation occurred in EVI range values of 0.172 – 0.252 and some infestation records in the EVI range of 0.114 – 0.171. the green vegetation index value was reduced and covered the area of interest with very low vegetation index values like-0.029-0.113 (figure 4.12).

In general, the spring season of 2020 Indicates the value of green vegetation gradually reduced. The green vegetation reduces caused by the rainfall amount reduction from September to November in the two years. The desert locust also migrates to survive and obtained the food and shelter of vegetation environments and suitable areas for breeding and invasion to expand the area of infestation.

4.1.3 DEM vs desert locust infestation area

Topographic is one factor of desert locust movement, habitat for breeding, and infestation related to weather conditions in various seasons. Mostly desert locust occurs in lowland area and hot weather condition because the rainfall in lowland area occur suddenly and green vegetation amount increase simply. In this case, locusts are used as food and shelter in green vegetation, and also the soil type of the lowland area approaches sandy soil with having a moisture content is suitable for the breeding of locusts simply. The following (Figure 4.13, Figure 4.14) shows, that the desert locust infestation occurred in different topographic areas like lowland and highland. the major desert locust infestation area occurred greeter than 600 m. Based on this observation the Elevation less than 600m is not a suitable area for locust movement and habitat of breeding. Ground survey observation and elevation, the desert locust suited area in the elevation of three classes, 692 – 931 m, 932 -1280 m, and 1,290 – 2650 m.

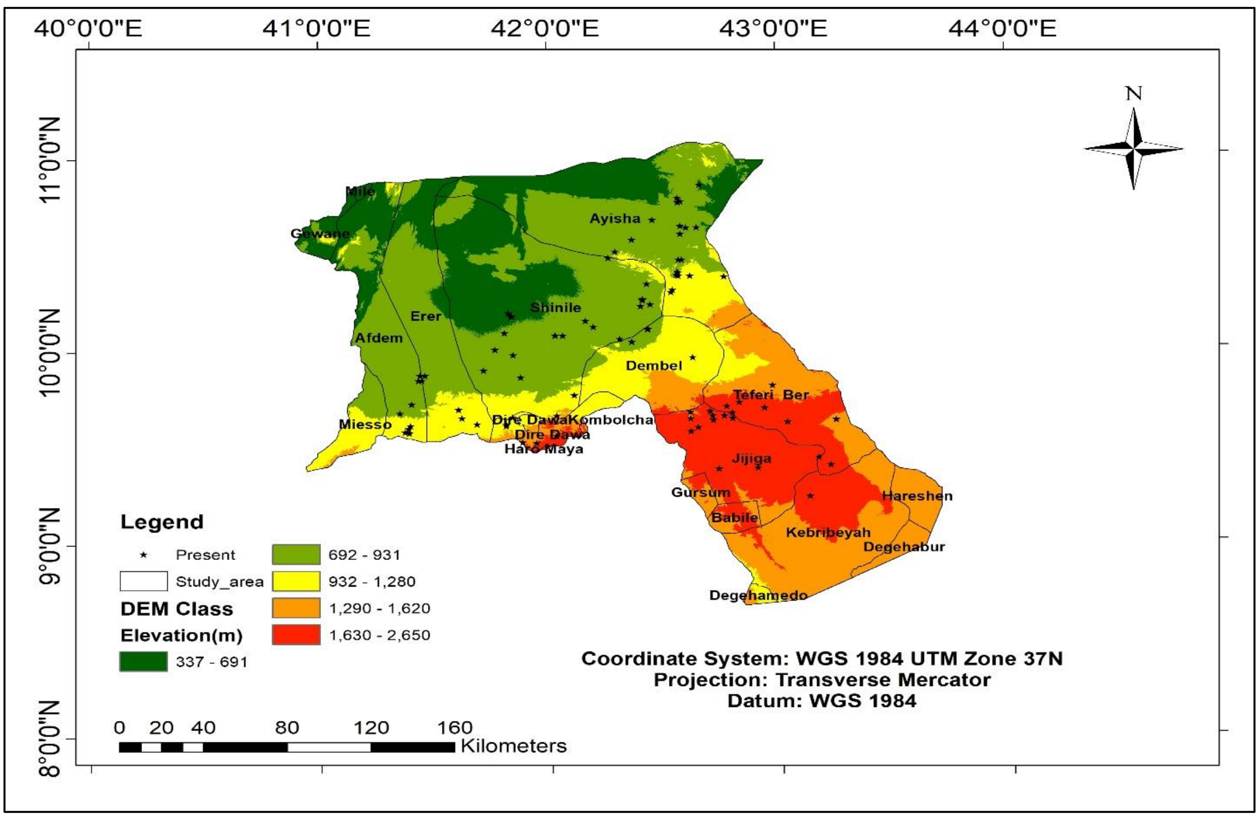

Figure 4.13 Desert locust infestation and Elevation levels 2019

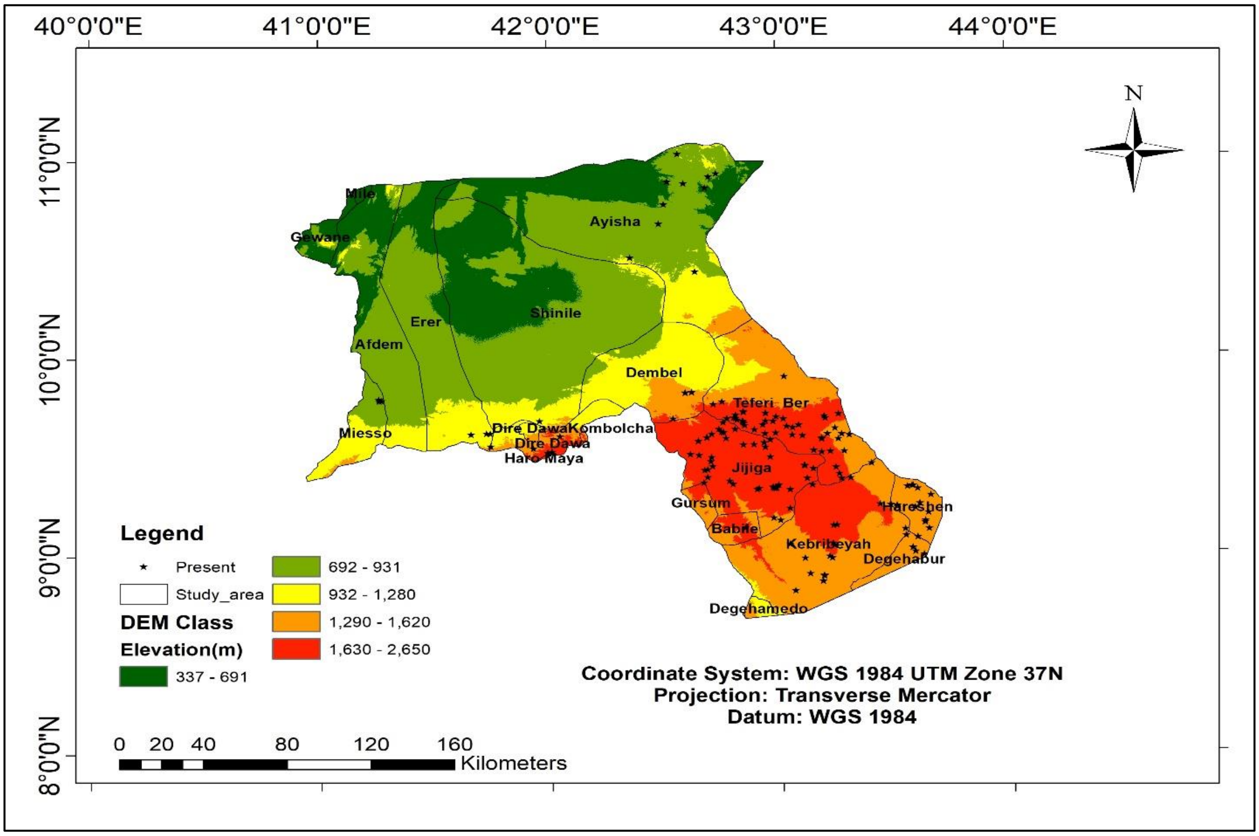

Figure 4.14 Desert Locust infestation and elevation level of 2020

When comparing the locust infestation between 2019 and 2020 in the same area the movement and infestation level increased from lowland areas to highland areas due to the expansion of agricultural places and the number of record desert locust occurrences spread to higher elevation levels. Based on the survey record infestation occurred at elevation levels from 337 to 644 record points in 2019 is 5 sites while in 2020 there are no record points in this elevation range. However, in higher elevation levels from 1675 to 2649 in 2020 is a 92-point record and in 2019 is a 20-point record and the area infested in 2019 maximum covered is 500 hectares whereas in 2020 infested to 20000 hectares record in one place of high elevation level. To confirm this observation spatial relationships were performed on the elevation and desert locust infestation sites by converting the raster DEM data to vector in meters and infestation ground survey in hectares (Ha) in both 2019 and 2020 respectively using scatter plot in excel sheet.

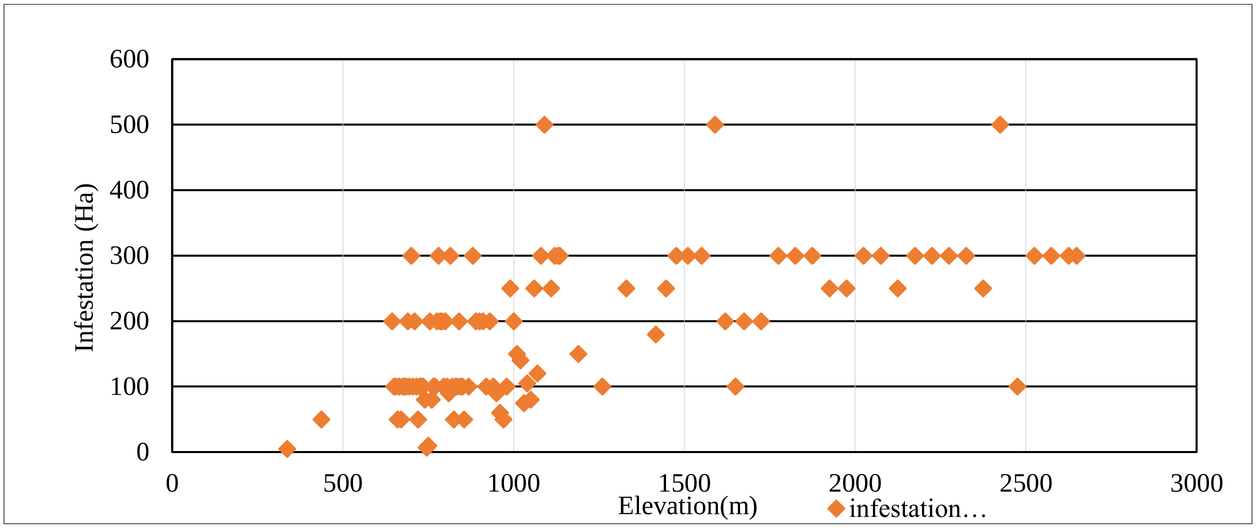

Figure 4.15 Scatter plot of Elevation level and infestation size in 2019

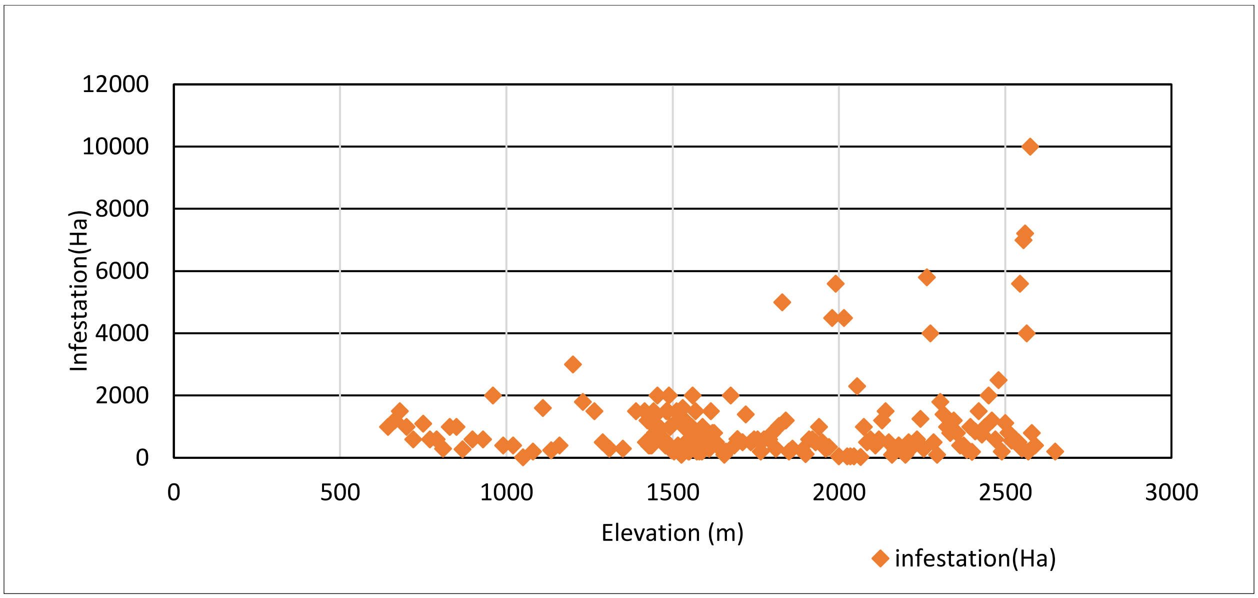

Figure 4.16 Scatter plot of elevation level and infestation size in 2020

The above (Figure 4.15, 4.16) shows, the movement of desert locust infestation and elevation level in scatter plots with area-covered hectares. the scatter plot shows the density of locust invasion increase from low elevation level to high elevation level in 2019 and 2020. The lowland area of the study area does not have enough amount of green vegetation used as food and shelter for desert locusts due to this the locust occur and migrate from the lowland area of the study area to the highland area mostly high vegetation-covered areas like pasture, crops, and agricultural product in high-level elevation.

4.2 Vegetation damage assessment of locust infestation of sentinel-1 data& EVI data

4.2.1 Vegetation damage assessment of MODIS EVI time-series data

The infested and non-infested area vegetation of Modis data mean value in the year of 2019 and 2020 spring seasons computed and presented in (Table 4.1). The infested area mean value is (0.107, 0.149, 0.209) and the non-infested mean value is (0.345, 0.11,0.172) in 2019 and the infested mean value is (0.219, 0.229, 0.19) and the non-infested mean value is (0.273, 0.165, 0.164) in 2020. the damaged vegetation in September of the two years mean value is lower than the non-infested mean value of EVI and the non-infested mean value greater than the infested area. on the other hand, the mean value of the infested areas in the two years of October and November mean value is greater than the mean value of the non-infested area.

In General, the mean value of the damaged pixel in the spring season is 0.465, non-damaged by desert locust is 0.627 in 2019, and the infested mean pixel value is 0.638 and the non-infested mean pixel value is 0.602 in 2020.

Table 4.1 Mean, Standard deviation, and P-value of MODIS data

Modis date	Infested mean	Infested std	Non-infested mean	Non-infested std	P-value
2019/09	0.107	0.039	0.345	0.111	0.002
2019/10	0.149	0.043	0.111	0.034	0.151
2019/11	0.209	0.061	0.172	0.047	0.303
2020/09	0.219	0.092	0.273	0.079	0.08
2020/10	0.229	0.047	0.165	0.062	0.003
2020/11	0.19	0.037	0.164	0.026	0.0203

The infested mean of a time series data in the spring season of 2019 increased their mean EVI values data acquisition of MODIS from September 2019 to November 2019 and similar to October 2020 in (Figure 4.17 and Table4.1).

The statistically significant infested and non-infested values in 2019 EVI MODIS data from the above (Table 4.1) accepted the null hypothesis September 2019, October 2020 and November 2020 satisfied the statistically significant at 0.05 threshold. While the mean EVI values statistical difference of sampled infested and non-infested vegetations were not significant results shows, October 2019, November 2019, and September 2020 rejects the null hypothesis and there is a difference between the infested and non-infested vegetation data statistically accepted the alternative hypothesis p-value >0.05.

The standard deviation of the infested/damaged area recorded in September 2020 was greater than other data acquisition of EVI data leading to varying degrees of healthy vegetation in damaged areas by desert locusts.

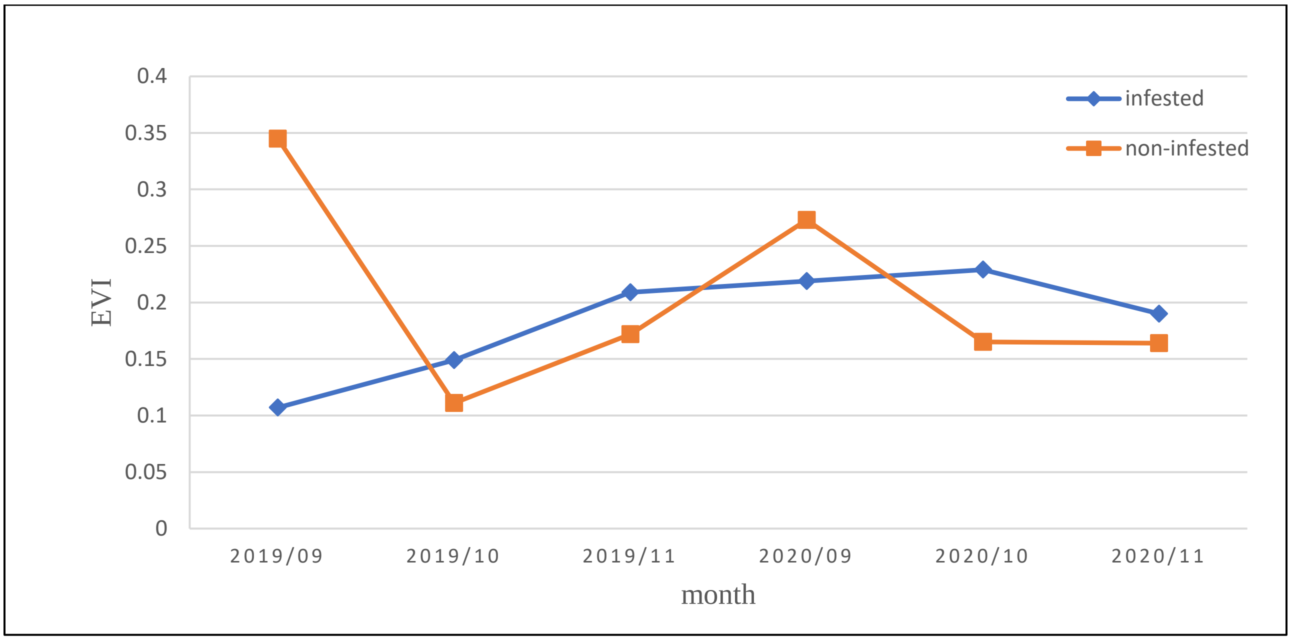

Figure 4.17 MODIS EVI data of infested and non-infested mean values of vegetation

(Figure 4.17) shows, the infested mean value increased from September 2019 to November 2020 in the spring season while the non-infested mean value was initially at a high level and downward and upward to some extent and decrease.

4.2.2 Vegetation damage assessment of sentinel-1 SAR data analysis

In sentinel-1 SAR data of desert locust damage, the cross-polarized backscatter signal is dominated by vegetation cover and more sensitive to identifying the desert locust effect compare to the co-polarized backscatter and damaged area by DL is lower backscatter power due to loss of vegetation cover(Adams et al., 2021)

Sentinel-1 VH and VV backscatter images acquired used for damage assessment of vegetation by desert locust due to high spatial resolution and cloud-free access data with a higher temporal resolution by computing the mean and standard deviation of damage/infested area and non-infested area of ground survey data of desert locust invasion area.

Table 4.2 Mean, standard deviation, and p-value of sentinel-1 SAR data of band VH

date	Infested mean	Infested stdv	Non-infested mean	Non-infested stdv	P-value
2019/09	-19.876	1.756	-18.218	0.324	0.06
2019/10	-20.864	1.504	-19.593	1.185	0.16
2019/11	-17.996	1.509	-17.06	3.91	0.72
2020/09	-17.775	2.022	-17.257	1.93	0.50
2020/10	-18.13	3.06	-18.06	2.537	0.82
2020/11	-19.727	3.066	-17.54	2.07	0.02

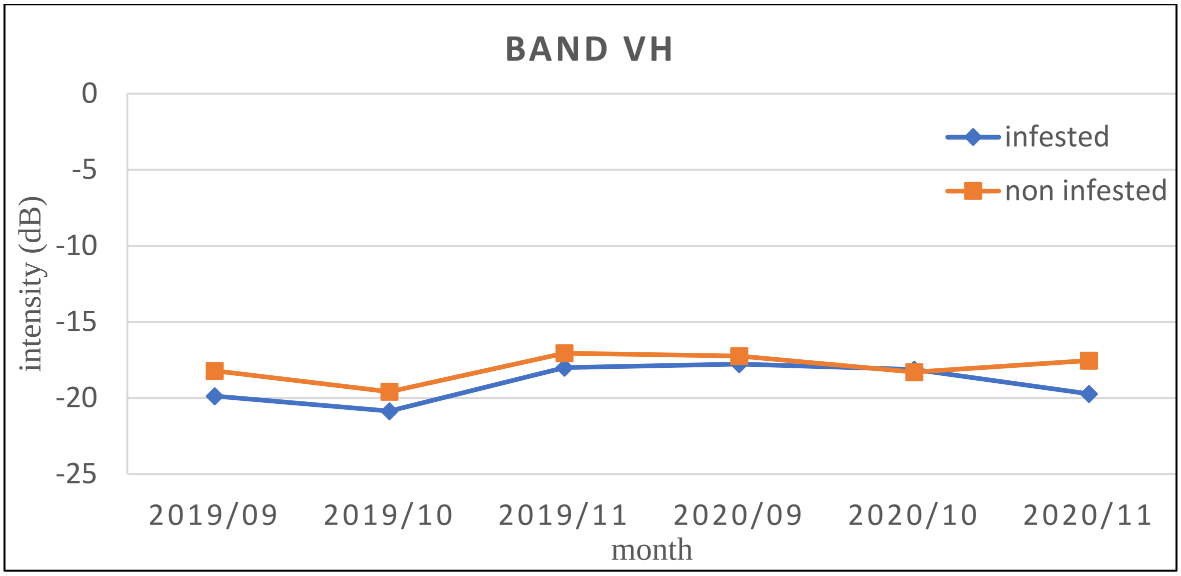

Figure 4.18 Sentinel-1 SAR data mean value of infested and non-infested vegetation band VH

Table 4.3 Mean, standard deviation, and p-value of sentinel-1 SAR data of band VV

Date	Infested mean	Infested stdv	Non-infested mean	Non-infested stdv	P-value
2019/09	-12.01	2.275	-11.486	0.303	0.6
2019/10	-14.254	2.233	-12.645	1.279	0.19
2019/11	-11.692	1.77	-10.116	4.814	0.62
2020/09	-11.469	2.122	-11.239	2.492	0.79
2020/10	-12.17	3.132	-12.126	2.421	0.93
2020/11	-13.859	2.765	-10.915	1.704	0.001

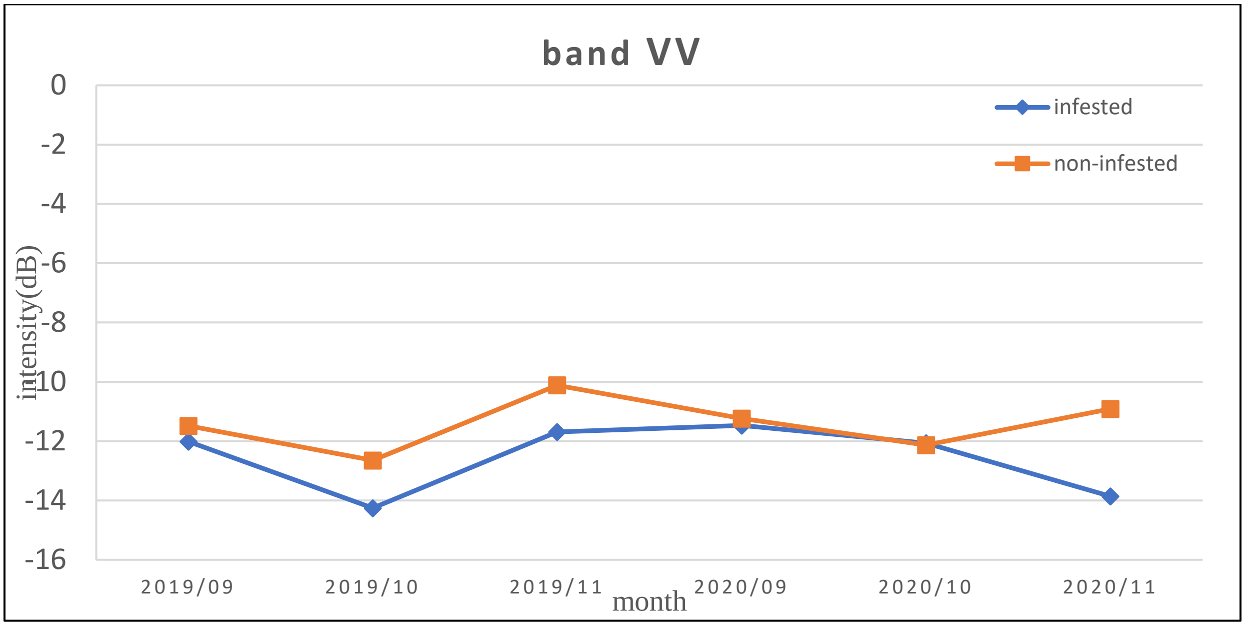

Figure 4.19 Sentinel-1 SAR data mean value of infested and non-infested vegetation band VV

In (Figure 4.18, 4.19 and Table 4.2, 4.3) shows the higher mean value in cross-polarization (VH) and co-polarization of (VV) backscatter recorded in September 2020 with an infested area of sentinel-1 data by desert locust with a mean value of -17.775 dB and -11.469 dB respectively. Similarly, the low mean value of the cross-polarization (VH) and co-polarization (VV) were extracted in October 2019 mean values of -20.864 dB and -11.469 dB of vegetation infested with desert locusts due to the desert locust invasion increase and the vegetation of greenness decrease with several factors like rainfall amount reduction.

The mean value of cross-polarization VH backscatter difference between the infested and non-infested areas by desert locust for the acquisition of September 2019, October 2019, November 2019, September 2020, October 2020, and November 2020 is 1.658 dB, 1.271 dB,0.936 dB, 0.518 dB, 0.176 dB, and 2.187 dB mean values respectively. From September 2019 to October 2020 during the spring season between the infested and non-infested areas, there is a reduction. but in November the difference between infested and non-infested difference increases.

The change of magnitude higher difference between the infested and non-infested area based on the mean pixel value of cross-polarization VH backscatter of sentinel data occurred in November 2020 with 2.187 dB and in co-polarization, the greater change occurred in similar to cross-polarization backscatter in November 2020 with a mean value of 2.94 dB.

The co-polarization of backscatter value difference Backscatter means value between infested and non-infested in September 2019 is 0.524 dB and increased in October 2019 and November 2019 by the mean value of 1.609 dB and 1.576 dB respectively. But in September and October 2020 mean value difference declined by 0.23 dB and 0.056 dB respectively. At the end of the spring season in November 2020, the difference between infested and non-infested mean values increased by 2.94 dB.

From the above figures and table, there were no statistically significant differences between the infested and non-infested areas at the 0.05 threshold in September 2019, October 2019, November 2019, September 2020, and October 2020. Whereas November 2020 is statistically significant at a threshold of 0.02 at cross-polarization (VH) and 0.001 at co-polarization (VV) in sentinel-1 SAR data.

In general, this study extracted the mean value of the infested and non-infested area of sentinel -1 SAR data backscatter of cross-polarization and co polarization and the difference of VH and VV backscatter between the infested and non-infested areas different based on the acquisition date related to the signal results of returned to the sensor and several factors change the results varied. the magnitude of the mean pixel value in cross-polarization and co-polarization ranges varies from -16 dB to -21 dB and -10 dB to -15 dB.

4.3 Predicting desert locust infestation using kriging interpolation.

The most familiar and adopted interpolation method in a GIS environment used for pests and insects have widely utilized kriging interpolation. To get accurate results during the prediction, the referenced control point of sampled data and the number of samples based on area coverages should be well distributed within the area of interest (Al-kindi, n.d.). Kriging maps used to predict the unknown point of desert locust infestation, Identify the potential occurred area of desert locust distribution, the data collector or survey team doesn’t observe due to economy, time, weather conditions, the difficulty of topography, and different problems. In addition to kriging maps, the combined three months of average vegetation data were applied to investigate and compare the distribution of desert locusts in which area the vegetation range is high and low.

4.3.1. The frequency distribution of locust density

The frequency distribution of desert locust density in 2019 of three consecutive months of spring season locust infestation of all data were arranged with 36.6% of the33 sites having less than 100 locust/Ha 24.45% of 22 sites between 101-200 locust/Ha, 33.33% of 30 sites between 201-300 locust/Ha and 5.55% of 5 sites indicates greater than 300 locust/Ha (Table 4.4, Figure 4.20). In spring 2020 also applied a similar arrangement and classification was performed on the frequency distribution of locust infestation and obtained 12.19% having 20 sites of less than 200 locust/Ha, 19.51% or 32 sites between 201-400 locust/Ha, 21.95% of 36 sites record between 401-600 locust/Ha, 20.12% having 33 sites between 601-1000 locust/Ha and 26.23% having 43 sites above /greater than1000 locust/Ha (Table 4.5, Figure 4.21).

Table 4.4 Frequency distribution of 2019 locust density

Classification (Ha)	Number of recorded sites	Control point proportion (%)	Area (Ha)	Area proportions (%)
<= 100	33	36.67	2772	15.67
101 – 200	22	24.45	3970	22.45
201-300	30	33.33	8600	48.64
=>300	5	5.55	2340	13.24
Total	90	100	17682	100

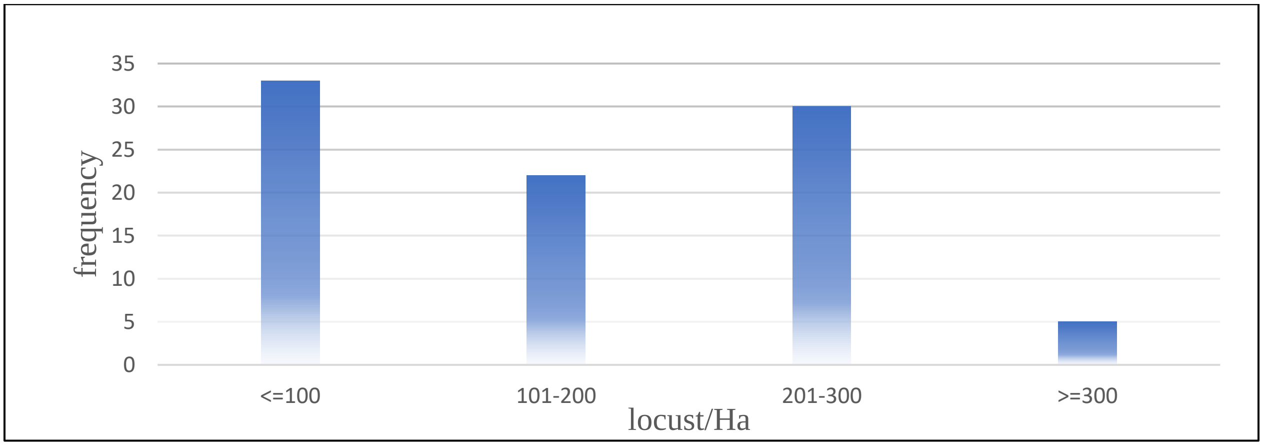

Figure 4.20 Graphically representation of frequency distribution locust density 2019

Table 4.5 Frequency distribution of 2020 locust density

Classification (Ha)	Number of recorded sites	Control point proportion (%)	Area (Ha)	Area proportions (%)
<=200	20	12.19	2830	1.52
201-400	32	19.51	10758	5.78
401-600	36	21.95	19570	10.52
601-100	33	20.12	29789	16.02
=>1000	43	26.23	123055	66.16
total	164	100	186002	100

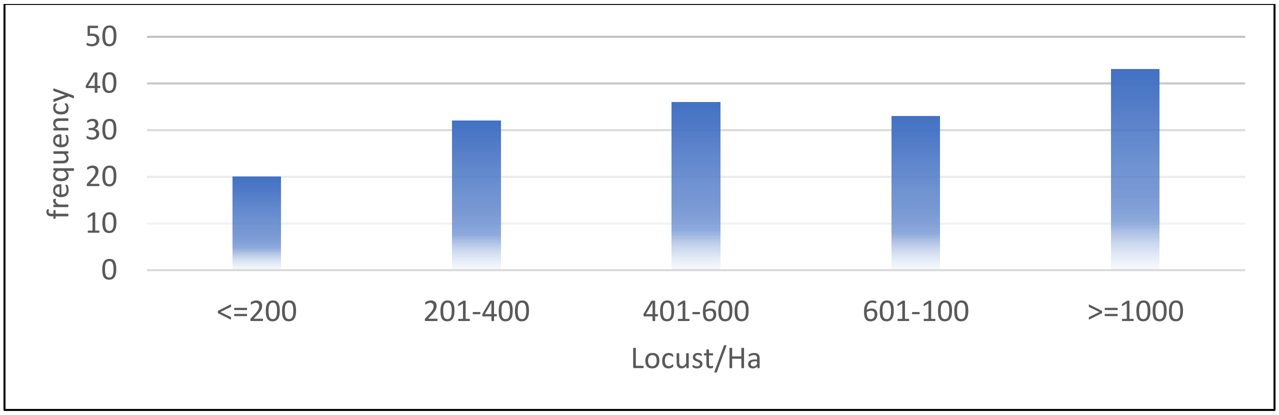

Figure 4.21 Graphically representation of frequency distribution locust density 2020

4.3.2 The spatial dependency of desert locust infestation.

The spherical model was utilized to describe spatial autocorrelation between the measured value locust's density distribution/locust infestation by using a semi-variogram graph in the area of interest of the spring season for two years. The spatial structure of /spatial pattern of desert locust density was weak and not significant for two years. The nugget effects in (Figure4.22, Figure 4.23) recorded high values indicate the spatial correlation very low value. the nugget effect of spring 2019 and 2020 is 0.36 and 0.77 values respectively. The correlation range for spring season 2019 was 0.49 in decimal degrees and the correlation range for spring 2020 was 0.19 in decimal degrees.

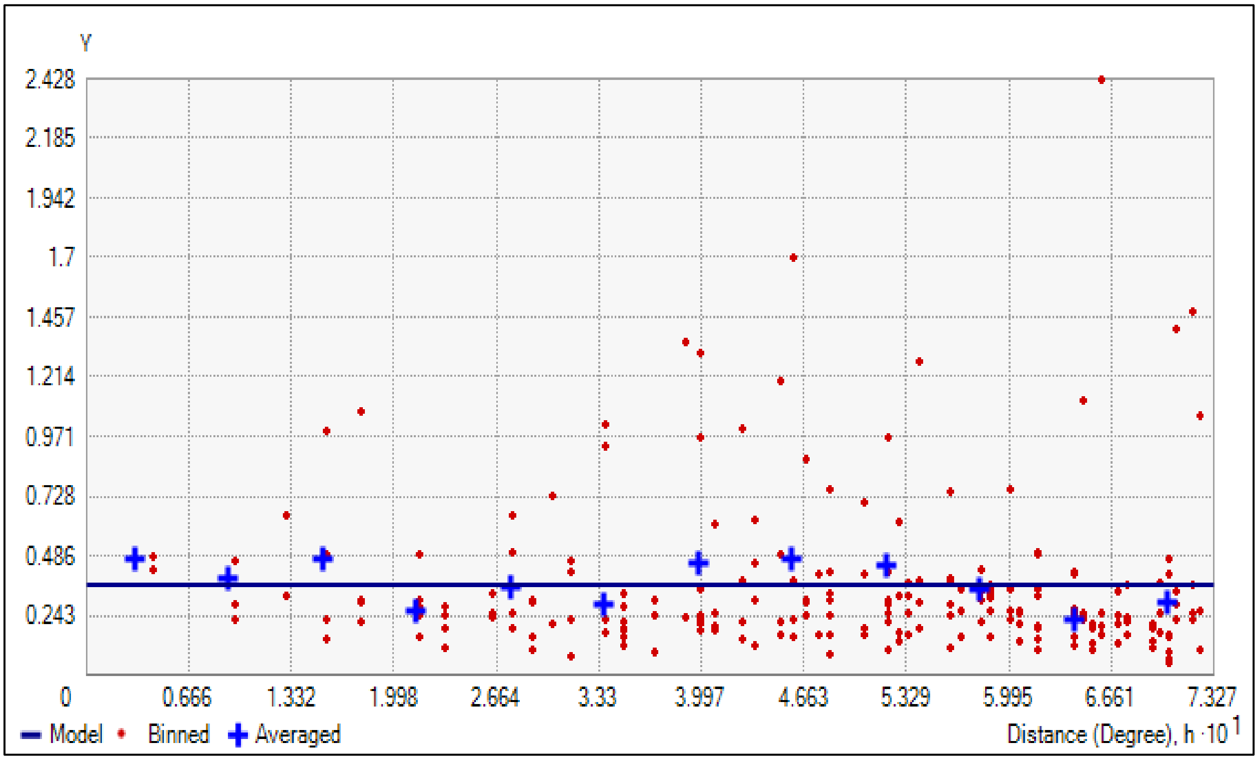

Figure 4.22 The semi variogram of desert locust infestation in the spring season of 2019

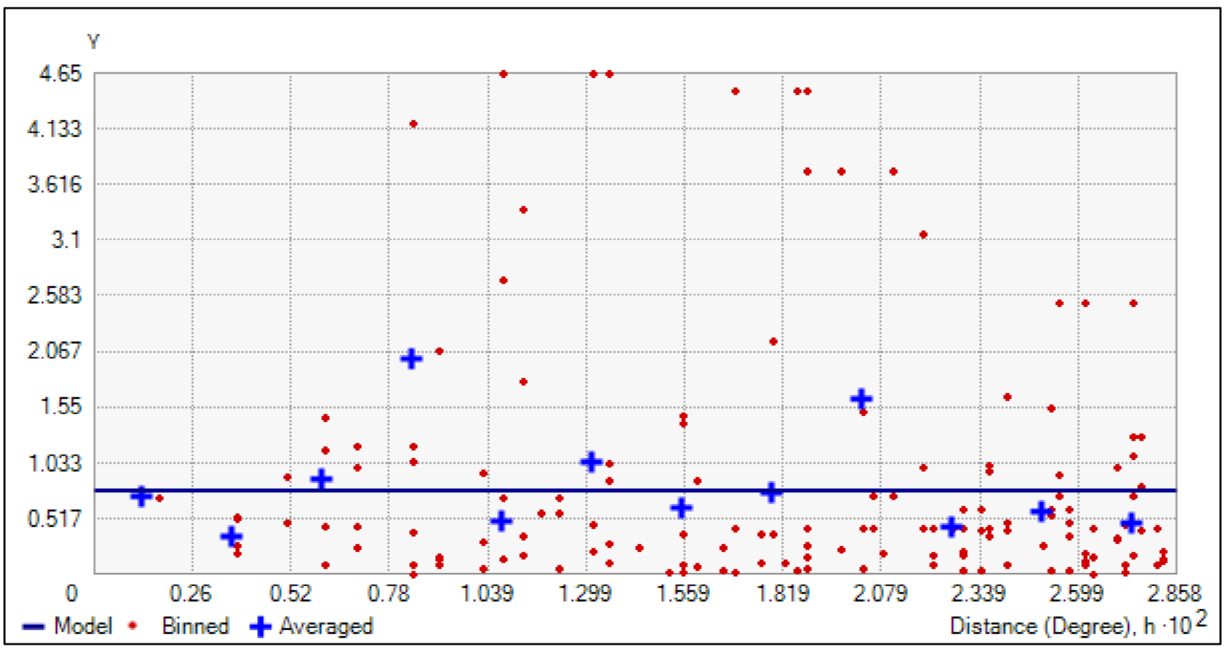

Figure 4.23 The semi variogram of desert locust infestation in the spring season of 2020

4.3.3 Prediction maps of kriging Locust density and vegetation cover map of 2019

The spring season of 2019 kriging predicted map of infested area and average vegetation cover map shows the distribution of locust density in each site and vegetation range. in (Figure 4.24) the largest area of kriging predicted map reached 284 - 410 hectares locust distribution occurred in high vegetation of the study area within the vegetation level 0.3-0.71 of highly vegetation cover and 0.215 – 0.311. The smallest value of predicted kriging map of desert locust infestation ranges from 0 - 74 hectares also occurred in low vegetation cover values of -0.127- 0.132 of unsuitable area for development of desert locust distribution and breeding. the kriging map shows the hot spot and most favorable area of desert locust distribution is the southern part of the study area indicates the vegetation cover and this area is more suitable to locust resistance of seeking problems used as food, shelter, habitat, and speed up reproduction system desert locust.

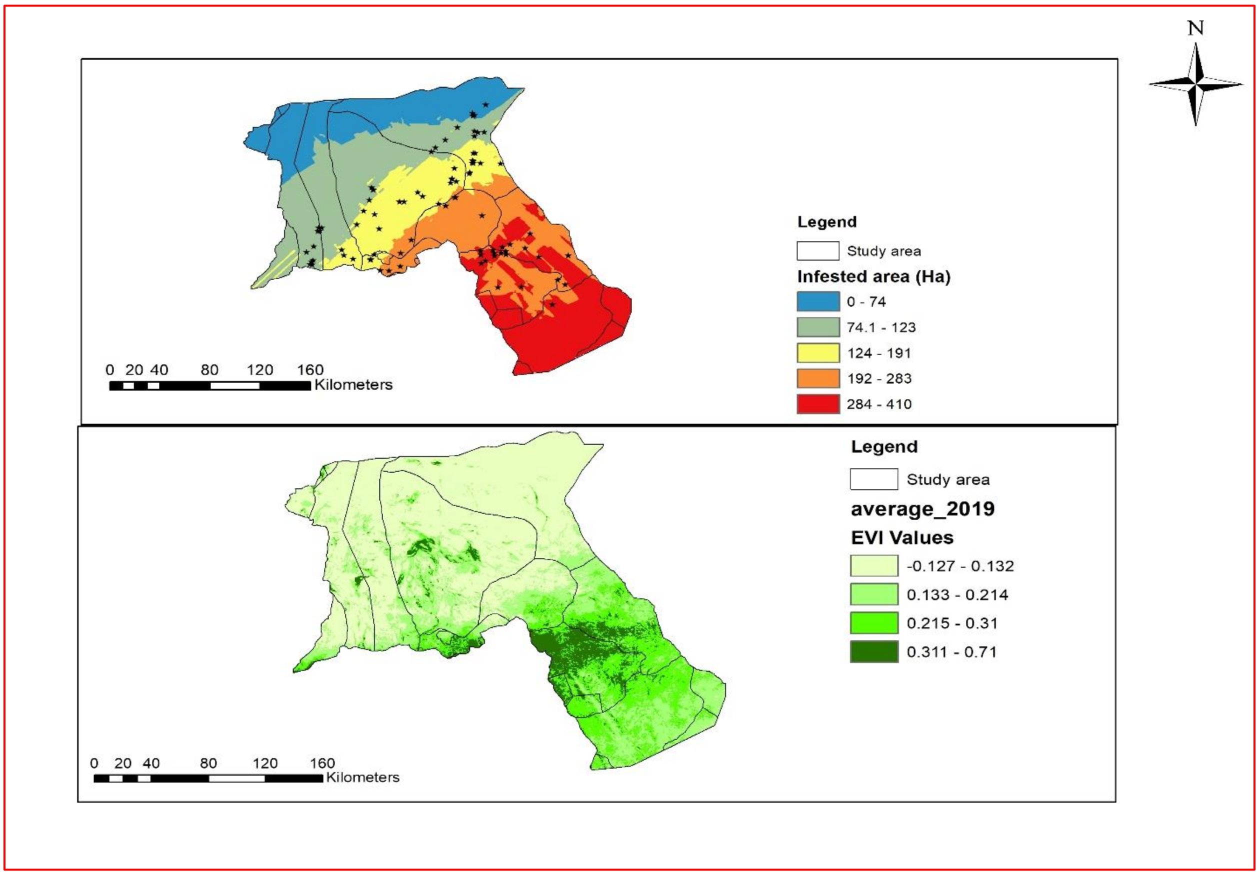

Figure 4.24 Kriging map of infestation size and vegetation cover in the spring season of 2019

4.3.4 Prediction maps of kriging Locust density and vegetation cover map of 2020

The kriging predicted map of spring season 2020 and average vegetation cover maps recorded high value in (Figure 4.27) infestation range reached 1400 – 2470 hectares. However, the area coverage indicated from the map is lower vegetation cover range from -0.076 - 0.126, and southeast part of the study area vegetation coverage medium range of 0.193 - 0.27. most areas indicate from the predicted map is not favorable for the development of desert locust. the area located in the eastern part of the study area border of Djibouti predicted high infestation area in a small area within (-0.076 – 0.126 and 0.127 – 0.66) the vegetation cover range. the major area covered from infestation range of 136 - 438 hectares compared to other range of infestation level.

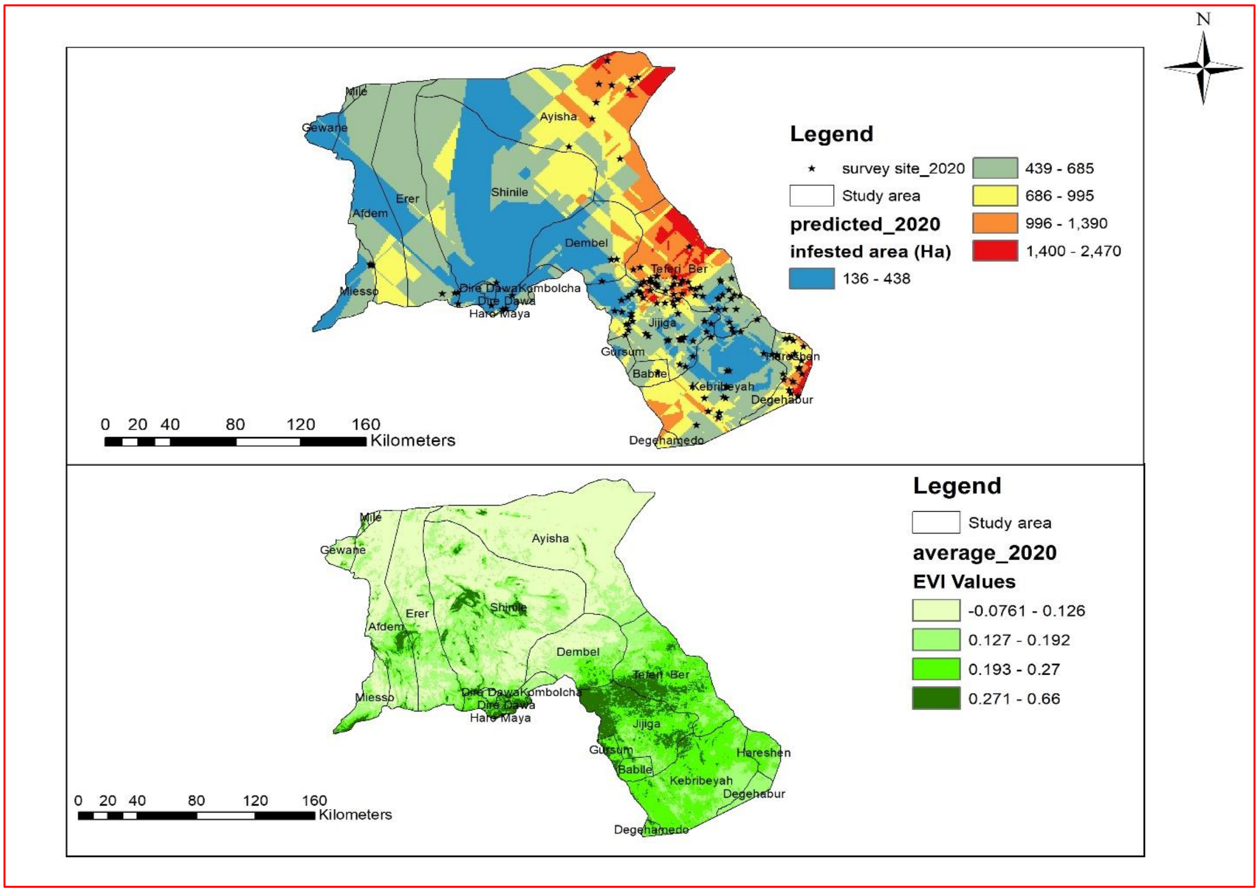

Figure 4.25 Kriging map of infestation size and vegetation cover in the spring season of 2020

The infestation level in the spring season of 2019 is smaller than compared to the spring season of 2020 based on predicted area hectares ranges. The maximum infestation in 2019 reached 284-

410 Ha, whereas, in 2020 the maximum reached 1400 - 2470 Ha. However, the vegetation-covered is hugely recorded and the distribution of locust density in the spring season of 2019.

In general, the infestation of predicted an average vegetation cover map shows the density of locusts presented and distributed in the study area. The predicted map is used for several purposes like taking decisions and support as guides to the survey team on which area is the next survey target, to investigating the conditions and environmental variables of potential areas of the desert locust, taking pest seeds when desert locust occurs, damage detection and so many purposes applied kriging interpolation.

4.3.5 Tasting kriging (Cross-validation)

Cross-validation is one of the appropriate methods for testing the interpolation suitability methods. It also removes the data from one or more point data locations at a time and predicts their associated data using the data at the rest of the location.in this case, simply compares the relationship between the predicted value and measured value to obtain desired information about the quality of the kriging model. The cross-validation value indicates the correspondence of the measured value and the predicted value is very weak infestation sizes. A regression analysis was applied to the measured and estimated locust infestation sites in both spring seasons for two years. the regression coefficient was not significantly different from one (the slope of 45 degrees) indicating the estimated locust density consistent with the measured value in spring 2019 which the regression value (square r = 0.237 and the significant value is probability p = 0.0003 which means the model performed fairly well in spring 2019. However, the regression coefficient was significantly different from one (the slope of 45 degrees line1:1) which means the estimated locust density is not consistent with a measured value of spring 2020 and the regression result indicates square r = 0.0084 and the significant value of probability p = 0.263 which means the probability value $p > 0.05$ reject the null hypothesis and the kriging model is not accepted based on the result indicating of regression value and the probability value.

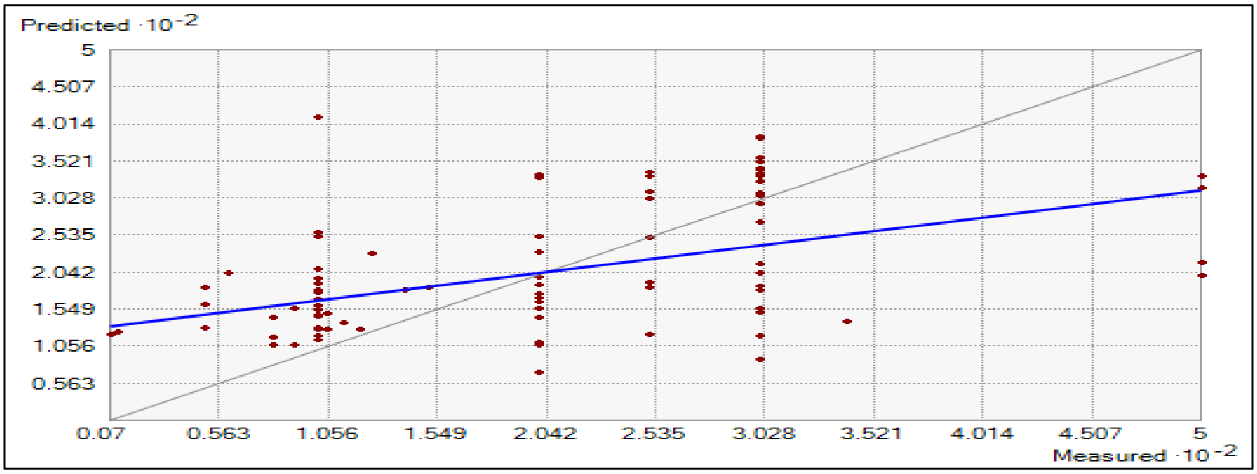

Figure 4.26 The observed and estimated locust density values 2019

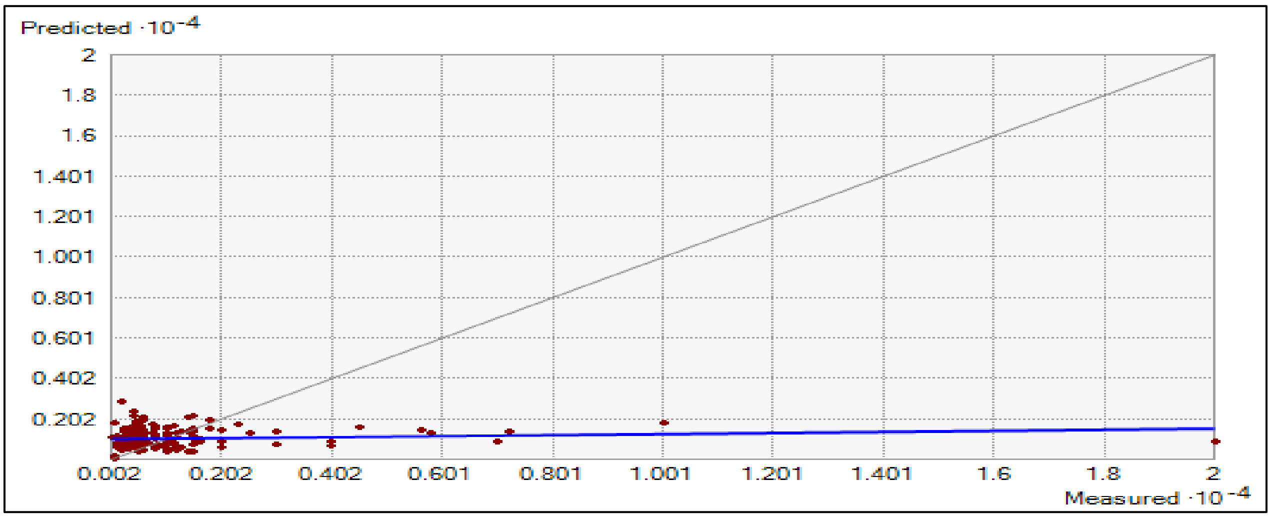

Figure 4.27 The observed and estimated locust density values 2020

The general overview of cross-validation results of desert locust infestation size indicates in two years of the spring season the random distribution of spring 2019 data was a little bit randomly distributed and accepted the kriging model to some extent, whereas, a spring season of 2020 data is not accurate and not randomly distributed. Based on this reason the kriging model was not accepted and an efficient method for predicting desert locust infestation in a given study area in spring 2020 data

Chapter Five

5. Discussion

The datasets used to find the research problem and develop the model were obtained from secondary sources like remote sensing data of optical and radar satellite images of green vegetation, rainfall data, DEM and ground survey data from the ministry of agriculture to assess desert locust infestation during 2019-2020 of the spring seasons. The open-source /freely available earth observation satellite data was used to investigate the distribution of desert locusts and map the effect of environmental variables related to ground survey data to explain the deriving factors of desert locust infestation. The environmental variables like precipitation, soil moisture, temperature, and vegetation coverage were undertaken many researchers applied in recent years to derive the potential areas of desert locust breeding habitat and invasion area were generated from long-term earth observation satellite data and significantly used to evaluate factors affecting the agricultural products and pastureland (Wang et al., 2021). The study applied a method of investigating the environmental variable of EVI and precipitation by overlaid ground survey data. The environmental variable showed that the amount of rainfall and EVI decreases from September to November each year, but the distribution of desert locust infestation increases and expands the area. These kinds of events happened to depend on the climatic condition leading to the winter season in Ethiopian weather situation, an infestation of locusts widely distributed and damaged vegetation, the time of crop harvesting, and the survey team observation capacity with addressed all infestation areas leads to EVI and rainfall decreased. In addition to this, the desert locust infestation migrates from lowland area to highland area from September to November in the spring season, because, In Ethiopia the summer season rainfall amount high and facilitates the growth of vegetation in all area and locust resistance simply. However, the amount of rainfall is reduced and green vegetation dry locust moves to the favorable area to obtain food and better habitat(Rabie & Moustafa, 2011). the rainfall and EVI ranges also varies from season to season and the infestation level increase and reduced based on the weather conditions take to account the data observer capacity covered infested areas of different seasons was performed during estimation of likely breeding and likely infested area using GIS and remote sensing. The environmental variables were interpreted in this section based on the range value of green vegetation and rainfall compared to the locust density distribution of ground survey data in each month of the spring season. In addition, rainfall and green vegetation DEM were taken as consideration and identifying which elevation levels are suitable for the desert locust infestation and determining maximum locust infestation occupied area above 337-2650 m. However, the elevation level of desert locust infestation distribute under 400 m in a recent study of Egypt likely breeding and likely infested area using GIS and remote sensing techniques (Rabie & Moustafa, 2011).

Earth observation remote sensing satellite open-source data having coarse spatial resolution and temporal resolution is difficult to detect desert locust vegetation damage. However, high spatial and temporal resolution commercial satellite data and the aerial photos taken during infestation time possibly detect the damaged area of vegetation by desert locusts (Adams et al., 2021). Several researchers used to detect damage to vegetation or loss of vegetation attacked by desert locusts determined by comparing the reflectance of healthy vegetation in optical data computed the vegetation index value like NDVI and EVI pre and posted desert locust outbreak of affected areas (Klein, Oppelt, and Kuenzer, 2021). The damage assessment of vegetation was performed using optical data of MODIS EVI and radar data of sentinel-1 SAR data computing the mean pixel value and standard deviation applied zonal statistics of ground survey data. Vegetation of desert locust damage detected computing the statistical measurements of mean pixel value, and standard deviation with a significantly confidence interval of 95%. The infested area means pixel value reduced in September and increase in October and November. This kind of result obtained may be the green vegetation and rainfall reduced from September to November and the desert locust infestation migrate to having good vegetation for resistance and the infested area covered by dense vegetation than non-infestation area. (Eltoum, 2014) the study agreed with this study of detection of vegetation cover by desert locusts in Sudan used of three years of ground survey locust data with MODIS EVI data. In addition to MODIS EVI data sentinel-1, SAR data of Copernicus with the high spatial and temporal resolution was applied to detect vegetation damage by desert locust computing the mean and standard deviation of the infested and non-infested area. The main advantage of SAR data of sentinel-1 is penetrating the cloud cover effects, fog, getting the top of dry soil, and being available in any weather conditions with high spatial resolution and temporal resolution accessed open-source data (Woodhouse, 2005). The radar data of sentinel-1 data was preprocessed in the SNAP toolbox used for all sentinel sensors and developed by Brockman Consult and available through the ESA website (brockmann-consult, 2019). The sentinel-1(SAR) data mean pixel value of the infested area of damage vegetation value reduced compared to the non-infestation area from September to November in each month of two years. unlike MODIS EVI data, Sentinel-SAR data provide the damaged area detected the difference correctly the mean pixel value of infestation is less than by some value to non-infestation area in cross and co polarization bands. This is due to the impact of spatial resolution, temporal resolution, and weather conditions affecting MODIS data (Bell et al., 2020) the study was similar result computed of the mean pixel value and standard deviation using sentinel-1 SAR data observation of hail damage Swaths to Agricultural Crops in the Central United States. Vegetation damage detection of the desert locust is limited in freely available satellite data due to spatial and temporal resolution to assess the sporadic event of the locust. This kind of analysis obtained good results in high spatial and temporal resolution of commercial satellite data such as planet data(Adams et al., 2021).

Finally, kriging interpolation was applied to on-ground survey data to predict desert locust infestation which observers didn’t address due to several problems and environmental factors. spherical semi variogram modeling was applied to analyze the spatial relationship of desert locusts geo-statistically (Woldewahid, 2003). The nugget effect of the high value indicates the spatial autocorrelation of desert locust infestation in the spherical model is very low value and un correlated with the range reduction of coverage area. The semi variogram result was not attractive to determine the spatial pattern of desert locust infestation in kriging interpolation. several limitations of kriging interpolation methods to predict the best infestation size of unobserved areas. Some of these limitations are different measurements taken in one area in the same month kriging interpolation considered as one or taking the mean value. this kind of measurement increase the prediction errors, the small infestation area is ignored by the data observer or filled by 0 but the infestation level is not null in reality, the survey sites are not randomly distributed over the study area and the distance between the survey site is not regular this kind of problem is not successfully run and obtained good result of prediction of un-surveyed data in kriging interpolation(Rabie & Moustafa, 2011) the statistical measurement of multiple regression was computed between observed infestation and estimated value. the result of 2019 accepted the kriging interpolation to some extent and 2020 was not accepted.

Chapter Six

6. Conclusion and Recommendations

6.1 Conclusion

Desert locust is a dangerous insect type damaging and distracting agricultural product and pasturelands migrate vastly from place to place in a swarm. This study focused on the assessment of desert locust infestation using GIS and remote sensing techniques utilizing freely available satellite data (MODIS EVI, sentinel-1 SAR data, DEM, precipitation) and ground survey data of desert locusts' infestation present and infestation absence. Furthermore, the proposed method applied to the investigation and analysis of environmental variables (green vegetation, precipitation, and DEM) was performed in order to identify the distribution of locusts and determine deriving factors, vegetation damage assessment was applied to the sentinel-1 SAR data and MODIS EVI data of different month of 2019 and 2020 in the spring season by overlaid monthly ground survey data, and kriging interpolation implemented on desert locust infestation of total ground survey data of spring season in each year of 2019 and 2020. The sentinel application platform (SNAP) toolbox was used in this study to pre-processed the sentinel-1 SAR data. arc GIS software was applied to reclassification based on the value of different layers, zonal statistics, interpolation (IDW and Kriging) were performed to assess desert locust infestation in the study area. Depending on the obtained result, it can be concluded that climate change of the rainfall amount increases without normally adopted condition leads to locust outbreaks, develop the growth of vegetation, create a favorable condition of soil moisture for locust breading, and expand the distribution of locust to severe damage rangelands and cropland area. In the spring season of 2019 and 2020 rainfall amount rained in September developed the movement of locusts in the next months of October and November and the distribution of locusts occurred in September migrates to vegetated areas next month and mostly infestation occurred above 400 m elevations. Vegetation damage assessment of desert locusts is impossible to detect area by using open-source satellite directly. However, the high spatial and temporal resolution of radar data with ground survey data detects the damaged area to some extent compared to the low spatial resolution of MODIS EVI data in this study.

Finally, the kriging interpolation of the geostatistical analysis method was performed to predict the desert locust infestation of un surveyed areas by the survey team. However, the method is not successfully predicted un surveyed areas especially the spring season of 2020 data. This is due to the accuracy of data and not being randomly distributed all over the study area.

6.2 Recommendations

GIS and remote sensing technique is interesting science for the management and monitoring of desert locust distribution pre-infestation and post-infestation in an area. The following suggestion and recommendations are forwarded to monitor the locust distribution.

- Predict and forecast the rainfall amount by the integration of the National metrology agency, FAO and MOA should be to take a measurement and monitor pre and post occurring desert locusts with a high spatial resolution of precipitation data.
- The responsible organization should be identifying the vegetation type that is suitable for desert locust distribution and simply attacked by desert locusts at the country level to take a fast response during infestation before the damage.
- Commercial satellite data having a high spatial and temporal resolution is used to investigate the vegetation damage by desert locust infestation at the country level.
- The survey team during collecting information about desert locusts conducts accurate data without carelessness and filing the exact value on the fields.
- Kriging interpolation of geostatistical analysis needs accurate and randomly distributed data. this kind of data correctly predicts un surveyed areas doesn’t survey due to several problems like weather conditions, the landscape of topography, economic issues, and so on.
- This research is used as guide for study about desert locust conditions in for damage assessment, ecological conditions and kriging interpolation by developing the time required technology and high spatial resolution data with correctly conducted survey data.

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Appendix:

1 FAO desert locust survey and control form

1	Survey stops	1	2	3	4	5	6
1.1 1.2 1.3 1.4 1.5 1.6	ID Observer name Location name Time Latitude longitude						
2	Ecology						
2.1 2.2	Area (Ha) survey Habitat (plain, pasture, wadi, crop, hills, dunes)						
2.3	Last date rain (light, moderate, heavy)	L M H	L M H	L M H	L M H	L M H	L M H
2.4	Vegetation (Green, Greening, dry, drying	G D	G D	G D	G D	G D	G D
2.5	Vegetation density (low, medium, high	L M H	L M H	L M H	L M H	L M H	L M H
2.6	Soil moisture (wet, dry)	W D	W D	W D	W D	W D	W D
3	Locust						
3.1 3.2	Present/ Absent Area infested (Ha)	P A	P A	P A	P A	P A	P A
4	Hopper						
4.1	Hopper stages(H12345FU)	H12345F	H12345F	H12345F	H12345F	H12345F	H12345F
4.2	Band density (low, medium, dense)	L M D	L M D	L M D	L M D	L M D	L M D
4.3 4.4	Appearance (solitary, transient, gregarious) Behavior (isolated, scattered, group)	S T G I S G	S T G I S G	S T G I S G	S T G I S G	S T G I S G	S T G I S G
5 5.1	Band Band stage(H12345F)	H12345F	H12345F	H12345F	H12345F	H12345F	H12345F

5.2 5.3 5.4	Band density (low, mid, dense) Band size Number of bands	L M D	L M D	L M D	L M D	L M D	L M D
6	Adults						
6.1 6.2 6.3 6.4 6.5	Appearance (solitary, transient, gregarious) Maturity (mature, immature) Behavior (isolated, scattered, group) Adult density (transect, site) Breeding (copulate, laying)	S T G M I I S G C L	S T G M I I S G C L	S T G M I I S G C L	S T G M I I S G C L	S T G M I I S G C L	S T G M I I S G C L
7	Swarm						
7.1 7.2 7.3 7.4 7.5 7.6 7.7	Maturity (mature, immature) Swarm density (low, medium, high) Swarm size Number of swarms Swarm breeding (copulating, laying) Flying (direction, time, height)	M I L M H C L	M I L M H C L	M I L M H C L	M I L M H C L	M I L M H C L	M I L M H C L
8	Control						
8.1 8.2 8.3 8.4 8.5	Pesticide Application rate Area treatment Instrument (Air, Ground) Estimated %kill	A G	A G	A G	A G	A G	A G
9	Comments (eL3, manual)	eL3 M	eL3 M	eL3 M	eL3 M	eL3 M	eL3 M

Was a GPS used to determine locations? Is a brief interpretation or analysis of result included?

yes No yes no

Country: ---------------------------------- Locust office: ------------------- date: -----------

Cleared by: ---------------- date: ---------