Assessment and Projection of Climate Change Impacts on Malaria Distribution in Ethiopia: Case of Combolcha and Debark Districts

By

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A Thesis submitted to

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS

MoFLNR	Ministry of Forest, Lands, and Natural Resource
WMO	World Meteorological organization
WHO	World Health organization
IPCC	Intergovernmental Panel on Climate Change
CIGI	Centre for International Governance Innovation
CC	Climate Change
UNFCCC	United Nations Framework Convention on Climate Change
GCMs	Global climate models
RCPs	Regional climate products
MARA	Malaria Atlas Risk in Africa
MIAC	Man- Induced Atmospheric Changes
RTH	Rainfall, temperature and humidity
NMA	National Meteorological Agency
ONDJ	October, Novenber, December and January
FMAM	February, March, April, and May
JJAS	June, July, August and September
GPCP	Global precipitation climatology project
N-W, N-E	North West, North East
ENACTS	Enhanced National Climate Service
NGO's	Non-governmental organizations
NASA	National Aeronautics and Space Administration

ABSTRACT

The dynamics of Earth's climate system have been affecting human life. In particular, climate change has a significant impact on the environment, socio-economic as well as on public health, especially on the transmission of malaria disease. Some sources of facts display that while no precisely defined limit exists beyond which malaria will not be found, recently a malaria distribution case has been seen in high land areas of Ethiopian. Thus, the objective of this research is to assess the impact of climate change on elevation-dependent malaria distribution temporally over Combolcha and Debark districts which are high lands of Ethiopia where there was no the case in history. The method applied for assessment and projection of climate variability is statistical approach, in general. And for assessment and projection of climate driven malaria distribution, the method used was based on the intersection of the favorable climate parameters (RTH) with the suitable threshold values. Thus, gradual malaria expansion to higher altitudes is justified in association to climate change and variability. In the result, we determine that the change and variability in precipitation was more significant (0.64 correlation) in controlling malaria transmission than the temperature over relative lower elevation areas (Combolcha). On the reverse, the change and variability in temperature (0.53 correlation) takes the first place in controlling malaria transmission over Debark. Moreover, the result indicates that the climate change and variability allowed malaria transmission site potentially tending to elevate/upraise to the high lands of Ethiopia like Debark district, recently. In this climate malaria suitability assessment, the altitude 2,800 meter above mean sea level was determined to be the demarcation point-level above which the disease malaria could not existed in Debark woreda for the period (1986-2016). Finally, this assessment result (2,800m) better demonstrated malaria transmission site with respect to elevation as compared with the result obtained using MARA13 malaria projection model output (2,500 m), for 2015. And, due to the present and future climate change malaria occurred on recent-time over new places of Ethiopia, in particular over high lands of Debark district; and in future, there is an indication to malaria persist over 2,800m elevation and incident on beyond this topographical height. Generally, we conclude that in the face of climate change malaria is climbing above the theoretical limit that nearly 2,000 m was the elevation beyond which malaria was believed unlikely to exist.

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

The application of physics with its branches becomes wider and diversified; and put the figure print on several socio-economic spectra. In line to this, its use is involved to serve on different occupations and professions of developmental sectors, research institutes and service offering agencies like: power generation and telecommunication (electricity and magnetism), medical application (Laser Physics), development of new materials (Nano-scale physics), satellite and remote sensing (space and astronomy physics), the issue of climate and its dynamics (atmospheric physics) and etc.

In general, physics has helped shape the industries and service centers in making work easier, P.F. Glaser et al, 1993; J.D Cutnell & K.W. Jonhson, 2001. In particular, the exciting application of physics for Meteorological science and climate studies has been recognized and practicable widely by the 20^{th} century. The nature of Earth's atmosphere and its climate was introduced by the science physics; and hence the role of physics is reflected indirectly through the application of climate studies. For instance, in atmospheric physics the nature and dynamics of climate has been formulated with the basic laws of physics. Once the basic physical equations are fixed, it becomes familiar and common job to predict the state and characteristics of the climate. In this regard, to understand the impressing application of atmospheric physics and Meteorology Science, here after, the issue of climate studies and its impacts is presented in this paper.

The dynamics of Earth's climate system have been affecting human life. Climate along with its variability and change had been observed laying impressive impacts on different socio-economic activities such as: agricultural, power generation, water supply, public health, social and political issues, (IPCC, 2015). An increase in greenhouse gases leads to increased warming of the atmosphere, ocean and the Earth's surface. As a result, climate change become familiar in the past, present and future time, C. McSweeney et al 2006, Z. T. Segel et al 2008 & USAID 2015. Beside to this, H. F. DAIZ and R. S. BRADLEY, 1997 found evidence for appreciable differences in mean temperature changes with elevation during the last several decades. And, according to I. Rangwala & J. R. Miller, January 2012 the sensitivity of climate changes to surface elevations, is remarkable just like to the climate changes identified at a horizontal surface with fixed altitudes. Existing literature suggests that global warming or inter-annual/decadal climate variability have a direct influence on the epidemiology of vector-borne diseases. As WMO & WHO, Sept. 2015 of the Intergovernmental Panel on Climate Change (IPCC), anticipated changes in temperature and rainfall will affect the natural habitats of mosquitoes, changing the prevalence of the vector or prolonging transmission seasons or both in some areas, and potentially exposing new regions and populations to malaria and result in negative impact on developmental gains. In the face of climate change, Author 's Guide, 2014 malaria ranges are quickly expanding, though it is a complex relationship that is still being researched. Parts of Ethiopia that have never been affected by malaria are now seeing their populations infected by this disease due to climate change. In this study we have a plan to assess the impact of climate change on malaria distribution in temporal and spatial bases over North and North-East regions of Amhara, in Ethiopia, where now there is a new case of malaria incidence than before.

1.2 STATEMENT OF THE PROBLEM

While no precisely defined limit exists beyond which malaria will not be found, researches deal with that 2,000 meters was the elevation beyond which malaria was believed unlikely to exist. That limit, however, has been identified at a much lower level for some countries and at much higher levels for others. Such limitations are based on climate suitability that enable how far up mountains and highlands mosquitoes are able to go in particular localities and not on any other. In general, an elevation of 1,500 meters above sea level is used to define the limit above which the likelihood of finding malaria will be rare. This puts up Eastern Africa's various highlands above that limit; but again, the disease has been found in some areas of Ethiopia above 2,000 meters. In line with this, in different occasions, while the meetings made for seasonal forecasting hosted by National Meteorology Agency of Ethiopia, stakeholders put their fundamental feedback regarding to the information provided for health sectors. In their response they said that "The data collected from NMA have been giving a good indicator for occurrence of malaria in different regions of the country. However, recently a malaria distribution case has been seen in high land areas of Ethiopian (such as Combolcha and Debark woredas health center). But, the information gathered from NMA did not reveal this special case of incidence of malaria over those places. This is where the problem comes and gaps are seen in the service of NMA for health sector. Definitely, the gap is due to shortage in frequent studies in assessing of malaria distribution considering the influence of climate change. This leads us to limited understanding of the relationship between climate and the disease as a result we are unable to observe the actual facts over local places. For this reason, our knowledge of climate impact on malaria distribution for higher elevations needs to be updated. Besides, the main and the primary problem is lack of high-resolution data that can represent each specific area with different altitude, even within a single district.

1.3 BENEFITS AND BENEFICIARIES OF THE STUDY

Meteorological and climatological data (information) has many applications in different developmental and service providing sectors of both governmental and NGOs. One of the services offered though with these applications is health-climate information. This service would potentially assist the government, health centers and NGOs (donors) in planning, budgeting and decision-making activities so that they can be able to succeed their mission according to their plan and goal. In other words, the befit of climate-malaria data will be to save life in the society in timely and cost minimized manner (economic wise that centralized all rounded sustainable development and stable economic growth). After all, the final result of this investigation is to add value for advancing the NMA service such that the agency enables to provide the most applicable information about malaria occurrence and distribution for clients. Moreover, the result of this paper will, potentially, contribute in serving as a reference for educational institutes, research centers, students and researchers who intend to study in related topics.

1.4 SIGNIFICANCE OF THE STUDY

Decision makers in health sectors are looking toward the scientific based information. Thus, the result of this study will help to equip accurate and timely information essential to their decision. In other words, the study can benefit to the improvement of early warning and preparedness in the Heath sector. So, primarily the result of the study will enable concerned units (NMA) in providing accurate information for users, on time. Hence, this study will help health offices and concerned governmental and/or NGO’s officials in succeeding their plan and decision-making activities in view of health and socio-economic risk minimization. Generally, the end user, in one or the other way around, is the community. Hence, mainly the significance of this study, therefore, is associated in strengthen the communities' health care task and save life.

1.5 OBJECTIVES OF THE STUDY

1.5.1 General Objective

The general objective of the study was:-

- To evaluate the impact of climate change on malaria distribution in temporal and spatial bases with respect to elevation over the particular local areas such as: Combolcha and Debark districts.

1.5.2 Specific Objectives

The specific objectives of the study were:-

- To perform characterization, assessment of climate and show the change and variability (the trend) of climate variables which are conducive for malaria prevalence.

- To determine climate suitability for malaria distribution with two data sets (gauge measurement and ENACTS data set) and identify the variable that significantly control the suitability of climate change for malaria transmission with elevation.

- To valid the result obtained in climate suitability assessment of malaria in this study with results observed from malaria model projections, over the areas under study.

1.6 SCOPE OF THE STUDY

This research study is limited to the temporal and spatial assessment and projection of elevation-dependent malaria distribution based on only climate conditions. Again, our scope of study sites is limited to two woredas, focusing on only the areas where climate-health data could not screen out the actual incidence of malaria.

CHAPTER TWO

LITERATURE REVIEW

2.1 APPLICATION OF PHYSICS FOR CLIMATE DYNAMICS

The application of physics with its branches becomes wider and diversified; and put the figure print on several socio-economic spectra. In line to this, its use is involved to serve on different occupations, and developmental sectors like: power generation and telecommunication (electricity and magnetism), medical application (Laser Physics), development of new materials (Nano-scale physics), satellite and remote sensing (space and astronomy physics), the issue of climate and its dynamics (atmospheric physics) and etc. In general, physics has helped shape the industries and service centers in making work easier, P.F. Glaser et al, 1993; J.D Cutnell & K.W. Jonhson, 2001. For instance, in atmospheric physics the nature and dynamics of climate has been formulated with the basic laws of physics.

Once the basic physical equations are fixed, it becomes familiar and common job to predict the state and characteristics of the climate. In further elaboration, H. E. de Swart, 2016 the basic principle of physics has many applications in our everyday life. For instant, the energy we consume in our home, offices vacation places are the product of physics in its electricity and magnetism branch. The car we drive, the aero plane, the satellites floated on the space are made possible and real through the study of physics in its kinematics and dynamics branch. The study of atmosphere and climate weather forecasting and climate prediction has been actualized with the study of thermodynamics, kinematics and dynamics of fluids with statistical physics (stochastic theory of climate: probabilistic in nature) and atmospheric physics applications, (J.B. Marston and P. D. Williams,2016), (J. Demaeyer and S. Vannitsem, 2017) and (A. Tantet, 2015)]. In journal of physics, the governing equations and the dominant balances of flow in the atmosphere and ocean is described in detail by H. E. de Swart, 2016. In his paper, the basic concepts of the thermodynamic principles and the governing equations of motion of the atmosphere enable us only to know the average state of the atmosphere since the solution of the equations have inexact solution, in nature.

2.1.1 Climate Modeling and Projection

At present time the science and technological development equipped us, basically, with two climate modelling methods, S. Vannitsem and V. Lucarini 2016. The one is statistical model, and the other is dynamical climate model.

What is a climate model? In general terms, a climate model could be defined as a mathematical representation of the climate system based on physical, biological and chemical principles. Even for models with the highest resolution, V. Lucarini et al.92017 the numerical grid is still much too coarse to represent small scale processes such as turbulence in the atmospheric and oceanic boundary layers, the interactions of the circulation with small scale topography features, thunderstorms, cloud microphysics processes, etc.

Types of climate models: In order to make climate predictions such as the Earth's future temperature, scientists use these types of global climate models: Earth Balance Models (EBMs), Earth Models of Intermediate Complexity (EMICs), and General Climate Models (GCMs). A way of differentiating between models is related to the complexity of the processes that are included. The term GCM was introduced because one of the first goals of these models is to simulate the three-dimensional structure of winds and currents realistically. They have classically been divided into Atmospheric General Circulation Models (AGCMs) and Ocean General Circulation Models (OGCMs). For climate studies using interactive atmospheric and oceanic components, the acronyms AOGCM (Atmosphere Ocean General Circulation Model) and the broader CGCM (Coupled General Circulation Model) are generally chosen.

When employed correctly, all the model types can produce useful information on the behavior of the climate system. There is no perfect model, suitable for all purposes. This is why a wide range of climate models exists, forming what is called the spectrum or the hierarchy of models. Depending on the objective or the question, one type of models could be selected. The best type of model to use depends on the objective or the question. On the other hand, combining the results from various types of models is often the best way to gain a deep understanding of the dominant processes in action.

2.1.3 Down Scaling Climate Change Scenarios on Local Level

In this study, the selection of regional climate models is based on the results obtained from literature reviews that have been done to assess the strength of the models on regional and local levels. The other significant principle that should not be forgotten in selecting climate models is the data source types they are using like: surface in-situ observation, satellite observation and blended data. Based on this concept, we tried to present the available models used to assess climate changes and future projection over Eastern Africa regions. Some of these GCM for example are K. F Ahmed et al. November, 2012 CCSM, GFDL, PCM, CGCM, MPI and MIROC. And, the regional models, for the analysis of temperature extremes, are the RCM–GCM combinations are RCM–CGCM, CRCM–CGCM, CRCM–CCSM and WRFG–CCSM. In the case of precipitation extremes, RCM–GFDL replaced CRCM–CCSM. According to (ICPAC, March 2016), some other GCM and RCM may also be selected as far as the model can depict the climate situations well in Eastern Africa regions. In addition, results obtained from published research journals can be used as a secondary source of data for local area climate changes and projections. For instant, the result obtained from B. Lyon et al., 15 June, 2017 shows us the change of temperature for 18^{o}c, over our study areas, an altitude of 31.2-meter per decade. In this basis, we can, as optional, possibly use this source of data instead of wasting time for downscaling climate models in the process of producing climate change visual information and its future projection. Thus, we are lucky in having these options. In addition, we have (ICPAC, March 2016) secondary source of data which provide us 'Projected changes in rainfall and temperature over Greater Horn of Africa (GHA) in different scenarios'. With these data, we aim to roughly display the future prospect of malaria transmission over the study areas in particular. Again, (Cicsnc.org and ncsu.edu) illustrates that some type of downscaling is usually required to transform global climate model simulation data into something that can be applied to impacts assessments.

The comparison in climate assessment and prediction models is performed by comparing the output of the models against observations for present climate. From the article discussed in (phys.org, 2008) models look good when predicting climate change.

So far in the thesis by M. Andreas, October 2012 no attempt has been made to distinguish between LAMs (local area climate models) for the purpose of numerical weather prediction and for the purpose of regional climate downscaling.

An advantage of GCMs (ciesin.edu) is their ability to perform multiple simulation experiments using different greenhouse gas emissions scenarios.

2.1.4 Climate Variability, Change and its Impacts

The impacts of climate and variability and its change is introduced in the industrial period, and persisted on present-day and continue in the future, (IPCC, 2012). Its impact is different socio-economic spectra like: agriculture, health, political and economic growth, (IPCC, 2015). An increase in greenhouse gases leads to increased warming of the atmosphere, ocean and the Earth's surface, so then climate change introduced, in the near past, present and future time C. McSweeney et al 2006, Z. T. Segel et al 2008, USAID 2015. Beside to this, H. F. DAIZ and R. S. BRADLEY, 1997 found evidence for appreciable differences in mean temperature changes with elevation during the last several decades. And the sensitivity of climate changes to surface elevations, I. angwala & J. R. Miller, 2012 is remarkable just like to the climate changes identified at a horizontal surface with fixed altitudes. Several existing literatures Arab et al. (2014), Be´guin et al. 2011, Leonard 2015, A.J. McMichael et al. 2003, Bosello et al. 13 2005, K. L. Ebi et al. 2012 suggests that global warming or inter-annual/decadal climate variability have a direct influence on the epidemiology of vector-borne diseases. As WMO & WHO, Sept. 2015 refers to the conclusion of the Intergovernmental Panel on Climate Change [IPCC, 2015], anticipated changes in temperature and rainfall will affect the natural habitats of mosquitoes, changing the prevalence of the vector or prolonging transmission seasons/or both in some areas, and potentially exposing new regions and populations to malaria and result in negative impact on developmental gains.

Air temperature has increased more steadily, compared to relative humidity. Scientists assumed that the RH of the atmosphere will stay, more of the time, with little change regardless of how the climate changes, (earth.nasa.gov). As air warms it becomes capable of holding more and more water vapor letting the RH increased. RH is the percentage ratio of actual water vapor to saturated water vapor; it has a meaning that RH: the percentage of water in the air relative to the amount of water the air can hold. According to I. R. Orimoloye et al., 2018, the change of RH is governed by the change in temperature and RF. Thus, the variability of the RH is somewhat complex in nature, as it is affected by RF, temperature and wind. However, qualitative interpretation can be done to determine the magnitude of the change in RH. For instance, if both RF and temperature increase, strong change of RH is expected, both decreased will result in high decrease of RH, the one decreases the other increase RH will increase very slightly or in moderate range etc. The RF will be more significant factor on RH on dry seasons; in turn the temperature takes the place on rainy season. Again, S. C Sherwood et al., 2010 the change of RH is determined seasonally by convention expressed as 30% for ONDJ, 40% for FMAM and 30% on JJAS if the RH is assumed to increase in very high magnitude. The range of change is starts from 10% for slight change, 15% for moderate, 30% for high and 40% for very high change; and the seasonal dependence is considered as in the previous sentence.

2.2 CLIMATE AND HEALTH RELATIONSHIP

2.2.1 Impact of Climate Change on Malaria

In some studies, the effect of climate change on malaria is described directly. Higher temperatures reduce the development time of pathogens in vectors and increase potential transmission to humans. Vector species require specific climatic conditions (temperature, humidity) to be sufficiently abundant to maintain transmission of malaria, S. Kovats & R. Akhtar, 2008. Climate-induced effects are more consistent with the observed changes over a few regions of Africa and South America.

A recently published articles have estimated the potential impact on the global distribution of dengue fever, M. van Lieshouta et al., 2004; but the potential impact of climate change on other species of malaria have been neglected due the lack of appropriate models and reliable high-resolution surveillance data with which to refine and validate them. The minimum temperature threshold incorporated in many of malaria models was 16^{0}C. But recently, the minimum mean temperature was increased to 17 ^{0}C to ensure that the development cycle of the parasite could be finished within a month, the smallest time scale of the assessment. This condition is the major gap/difference seen in all malaria models. So, a closure study at local level shall be done for the assessment of the malaria distribution and display the facts that cannot be identified by the models. Further, the study by M. Lunde1 et al., 2013 inform that the relationship between sporozoite development and the survival of infectious mosquitoes at different temperatures is poorly understood; therefore, any model projections relating the two should be interpreted with care. Some models suggest different value of temperature. For instance, Bayoh-Lunde suggests that transmission is most efficient at around $25°C$. However, none of the models, except Bayoh-Lunde, capture all of the characteristics of the reference data. But, according to E. T. Ngarakana-Gwasira et al., 23 February 2016 results from the model suggest that the optimum temperature window for peak falciparum malaria transmission is 30–32∘C. All the models provide different results for efficient transmission of the malaria species. This might be explored at particular location and a specific value of temperature along with other climate variable should be determined that can trigger efficient transmission of the disease.

Considering climate information for malaria risk management in Syrilanka, WMO & WHO, Sept. 2015, the analysis results clearly showed evidence of climatic influence on malaria, both spatially and temporally. As discussed for instance in Author‘s Guide, 2014 malaria can now survive at higher elevations and higher latitudes than ever before. This means that malaria is becoming a threat in places that have never had problems with it historically.

Several methods have been used to estimate changes in the worldwide distribution of malaria in scenarios of global climate change. As discussed in F. C. Tanser et al., 2003, one approach relies on a biological model that predicts a large increase in global malaria potential. Some have criticized biological models on the basis that crucial parameters and their relations with environmental factors have not yet been quantified. Generic disadvantages of worldwide or continent-wide statistically-driven models are that data sets used to statistically develop the models are often of uncertain accuracy, models are not easily reproducible (i.e. results vary with training data and methods used), and the results are often applicable only to national or sub regional scales. We use a set of parasite surveys done on local study areas to produce a spatiotemporally validated climate impact assessment on malaria transmission.

The other approach adopted for assessment of climate change impacts on malaria transmission, A. Arab et al., 2014, is spatiotemporal hierarchical model. The goal is to develop a statistical model that utilizes data on the number of cases of malaria and potential variables that may be correlated with the spatial and/or temporal variability of the number of malaria cases. The result showed that two most important climate factors were found to be average annual temperature and total annual precipitation, and they show negative associations with malaria incidence. Thus, one can put in mind and basically identify that which climate variable has effects on malaria transmission to assess the relations over time in areas of interest. A special and simple study made by T. Ikeda et al., 29 May, 2017 using composite analysis found a high incidence of malaria during the pre-peak season (Sep-Nov) was associated with the climate phenomenon La Niña and cool air temperatures over southern Africa. Thus, we can develop temporal relationship between La-Nina and El-Nino episodes and malaria distribution in an area of interests.

2.2.2 Malaria Transmission Information Map

According to, G. Kopec et al., 11 May, 2006 in the absence of good epidemiological data on malaria distribution in Africa, climate information has long been used to develop malaria risk maps that illustrate the boundaries of climatic suitability for endemic transmission. To this analogue, FDRE MoWIE, NMA, Feb., 2017, a map that displays malaria prone areas is prepared under NMA. This data gives at least an indication for malaria survival on national level. But, it is difficult to exactly identify from the map that which zones and/or woredas are associated with the case. Therefore, it is better to supplement this map information with tabular data such that one can easily identify particular areas which fulfill the favorable condition for malaria distribution. This is one limitation. Again, this bulletin emphasis on malaria outbreak (sudden increase beyond the normal endemicity which means epidemic). But, users reported that "recently few places, even highland areas, are recording a new malaria case nevertheless the information forwarded did not figure out this case". The question is that, what about the incidence or the existence of malaria and expansion over new areas which has no record before? In this research we want to explore in depth and identify that the method applied for assessing malaria out break and investigating/inspecting malaria incidence does or not mean the same.

2.2.3 Multi-Model Malaria Model Approach

According to C. Caminade et al., 2012 recall the study by Gething et al., 2010, the contradicting observations of increase in global temperature and but global decline, mainly over Europe and Northern America, in malaria endemicity is due to intervention. Whereas, the contraction/decline of the distribution coverage is irrespective of global warming is not a matter of intervention and measures to control malaria. As evidence, look at sub Saharan regions, most of Southern Africa countries and Western half of Ethiopia where intervention is poor. Here is the answer by the author; change in malaria endemicity over Africa and to less extent over South America is strongly driven by climate. This means that extreme climate event also plays a positive role in reducing malaria distribution. Further, the study by C. Caminade et al., 2012 approves that climate suitability map of malaria distribution based on observation of climate data one for 1980-2009 and the other for 1999-2010. The multi-malaria model agreement is poor over areas like: central and northern pocket areas of Ethiopia, Southern parts of South Africa, Angola and Sahel belt including Somalia and Kenya. This tells us the condition over these places is yet well known by these models. So, what other method better display the situation over these areas? The answer may be a closure/case study should be projected in order to depict the actual on the ground in relation to malaria distribution. To this end, ensemble of climate driven malaria models was used to increase the precision of the five malaria models (MARA, MAISMA, LMO, UMU and VECTRI) such that the ensemble model demonstrates the malaria transmission with the most increased high spatial resolution. However, these five malaria models have shortcomings over localities even if they were aggregated in an ensemble model approach.

2.2.4 A Closure Look at Malaria-Climate Relations

Climatic factors associated with increases in temperature, rainfall and humidity are primary factors. They induce the emergence of mosquito vectors in abundance. The secondary factors, such as drug resistance, agricultural development, population growth, migration, conflicts, land reclamation and so on, only accelerate a process put in motion by climatic factors. In the study called ‘temperature suitability for malaria climbing the Ethiopian highlands, B. Lyon et al. 2017, temperature is widely accepted as a fundamentally important environmental factor constraining its malaria transmission. Air temperatures below approximately 18 °C and 15 °C, respectively, prohibit the development of the Plasmodium falciparum and P. vivax parasites. While locations of sufficiently high elevation have temperatures below these transmission thresholds, a fundamental question is how such temperature ‘threshold elevations’ are changing with time.

The threshold temperature (18 °C) was recorded e.g, at 2300 m elevation, B. Lyon et al., 15 June, 2017 then after a decade this value can be exhibited at 2300+31.5= 2331.5 m. Similarly, for a couple and triple of decades the change will be 63 and 94.5 m respectively (See Annex C).

Using a newly developed national temperature dataset for Ethiopia that combines numerous in-situ surface observations with downscaled reanalysis data, B. Lyon et al., 15 June, 2017, we here identify statistically significant increases in elevation for both the 18 °C and 15 °C thresholds in highland areas between1986–2016. This product (Annex C), will help to estimate future climate prospect and its change per elevation and per time (Annex B).

Map of seven strata of malaria risk used in the 2010-2015 national malaria strategy (FMoH, 2009) and used by President's Malaria Initiative (PMI) in their strategic funding plans (PMI, 2011). The climate suitability maps are based on the likelihood of stable transmission using a rules-based, fuzzy logic approach based on long-term rainfall and temperature data Hutchinson et al., 1995 that affect transmission Craig et al., 1999. This result indicates that our study area (Debark district) which is greater than 2500 m high is thought as malaria free region.

The investigation results fix that the elevation above 2500 m is suggested to be free from malaria (see the map under Annex C). Later in this paper, we compare this fact with our results.

2.3 CLIMATE DATA ANALYSIS WITH COMPUTATIONAL STATISTICS

Statistical computational application for climate study is a fundamental tool. Therefore, in climate study a basic statistical analyzing theories and formulas are designed in the book called ‘Statistical Analysis in Climate Research’ written by Hans and Francis, 2003. The following sub sections are sorted from different chapters of the above book and presented as climate data analysis tool. The most common statistical calculations in climate studies are like mean, standard deviation and standardized climate anomalies, time series analysis, trend of climate and its variabilities, correlation coefficients and coefficient of climate variations. These give meaning full results in view of the climate nature in reality observation.

2.3.1 Missing Data and Quality Control

Initially, data arrangement was carried out by substituting missing station data with ENACTS reanalysis data by the nearest latitude and longitude spatial reference location.

The other technical method applied for filling missing data is using weighted mean formula:

$$X = \sum_{i=1}^{n}(xi * wi) \,/\, \sum_{i=1}^{n} wi \qquad [2.3.1]$$

Where W_i the percent weight given to each record is called a weighting factor.

The other essential data processing unit was data quality control which is determinant for the quality of the research result. This was performed by visualization of extremum values within data and compare with the observations of neighboring stations. And then, in place of low quality data the above equation [2.3.1] is used to correct and substitute the data with low quality.

2.3.2 Characterization and Assessment the Climate

2.3.2.1 Climate Variability

With time series (to be more specific standardized deviation in precipitation, temperature anomaly) will be applied to understand the intensity of climatic variabilities over the period of 1988-2017 over the study areas was done using coefficient of variation as follows.

$$CV = \frac{\delta}{\mu} * 100\% \qquad [2.3.2.1.1]$$

Where μ is the average RF or Temperature, δ standard deviation of the population. CV< 20% implies low variability within the climate parameter over time, 20%<CV<30 implies moderate variability, >30% implies high variability, >40% v. high variability and >70 extreme variability.

2.3.2.2 Climate Trend Analysis

If the data distribution has symmetry (normal distribution) Linear regression trend analysis will be applied to understand the intensity and tendency of climatic trends over the period of 1988-2017 over the study areas.

$$Y = mXi + b \qquad [2.3.2.2.1]$$

Where Y is dependent variable representing precipitation and temperature magnitude; X_i represents the year of climate observation and m and b represents the slop and the intercept of the graph. The +ve value of the slope indicates increasing trend of the climate characteristics and decreasing with the opposite sign. Higher magnitude of slop shows strong increasing or decreasing trend depending on the sign of the magnitude.

But, if the data distribution is skewed, we shall be using Mann-Kendall trend analysis written as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} Sgn(xj - xi) \qquad [2.3.2.2.2]$$

where, S is the Mann-Kendall's test statistics; xi and xj are the sequential rainfall or temperature values in the year i and j (j > i), and n is the length of the time series. The Sgn (xj − xi) is an indicator function that results in the values −1, 0, or 1, where j > i and it is calculated as:

$$Sgn(xj - xi) = \begin{pmatrix} +1 & if & xj - xi & > 0 \\ 0 & if & xj - xi & = 0 \\ -1 & if & xj - xi & < 0 \end{pmatrix} \quad [2.3.2.2.3]$$

The Sen's estimator of slope: The test is applied where the trend is assumed to be non-linear (Gebre et al. 2013). Then, the slope (change per unit time) is calculated as:

$$Q = \frac{Xj - Xi}{i - j} \; for \; i = 1 \ldots n \quad [2.3.2.2.4]$$

where, xi and xj are data values at times i and j (j > i), respectively. The median of these n values of Q is Sen's estimator of slope. Based on the above equations, trends of current climate elements (rainfall,temperature) will be determined.

In addition, standardized rain fall and temperature anomaly were computed using the following statistical equation

$$(S)^* = \frac{(\eta - \tilde{\eta})}{S} \quad [2.3.2.2.5]$$

Where (S)*, S, ƞ and ῆ represents standardized anomaly of the climate parameter, standard deviation, the magnitude of precipitation or temperature measure for a given year or season and the mean measure of the climate variables over a season or year. Positive values of (S)* indicates positive deviation (increase) from the climatic mean and decrease on the opposite episode with time frame. These statistical analyses can be applied both in comparing and determining the climate change between two consecutive climate episode and climate changes per each decade.

2.3.2.3 The Advantage of Mann-Kendall Test over Linear Regression

The linear regression trend tells us about how the data population on average tends increase/decrease compared to the difference of the data within each consecutive year. Whereas Mann-Kendall test tells us about the tendency of the trend by averaging the difference between a given year and all the remaining years. In this test, the estimation of the slope is smooth and corrected. But, in linear regression trend the estimation of the slope is rough since it gives more weight for the maximum difference value between two consecutive years. Hence, this results in bias. In general, for non-normal distribution of data the non-parametric tests like Mann-Kendall take the advantage over the linear regression trend. But, if the data has symmetrical distribution, the linear trend regression and the non-parametric tests have approximately the same result in calculation of trends and changes over a period. Statistical meaning of Z-test tells us that the trend/or change is significantly strong or less relatively. For instant a 50 mm increase on May rain fall (100mm) and July RF (300mm), the increase /or change is more significant virtually by 50% on May than July which is only 16.3% increase is less significant change, comparatively.

2.3.2.4 Decadal Climate Change and Variability

Under this section we to manipulate the change of climate variables over a decadal period. We did this simply by subtracting the average precipitation of the 1st decade (1986-1995) from the 2nd decade (1996-2005), and the 2nd decade from the 3rd decade (2006-2015). The same is done for temperature. To do this we use the following formula.

$$D1 = x2 - x1; \qquad D2 = x3 - x2 \qquad [2.3.2.4.1]$$

Where D1 and D2 are differences of each decadal climatology and x1, x2, and x3 are mean of rain fall or temperature on the corresponding decadal period.

2.3.3 Composite Analysis of Climate Variability Versus Malaria Incidence Frequency

This method is used to compare the effect of climate variability in relation to malaria existence likelihood per year. This is conducted through time series analysis of RT and compare with the fraction of malaria incidence per year.

$$\mathrm{I} = \frac{n}{12} \qquad [2.3.3.1]$$

Where letter 'I' represents unit-less fraction indicating the intensity of persisting malaria per year; and n represents number of months that climate was suitable for malaria occurrence possibility. 'I' ranges from 0 to 1, in magnitude; where 0 indicates no chance of malaria incidence and 1 indicates strong expectancy of malaria prevalence throughout the year. In addition, coefficient of variation (r) tells us about the strength of the relation between two variables, in our case: malaria occurrence frequency with temperature variability and rain fall variability on different seasons. As a result, we can also calculate the correlation coefficient as

$$ruy = \frac{\sum_{i=1}^{n} uiyi - n\bar{u}\bar{y}}{\sqrt{(\sum_{i=1}^{n}(ui)^2 - n(\bar{u})^\wedge 2)(\sum_{i=1}^{n} yi^2 - n\bar{y}^\wedge 2)}} \qquad [2.3.3.2]$$

2.3.4 Procedure of Displaying Climate Malaria Suitability

As per (Grover-Kopek et al. 2006), the conducive climate condition for malaria transmission in Africa are when the monthly precipitation accumulation is at least 80 mm, the monthly mean temperature is between 18°C and 32°C and the monthly mean relative humidity is at least 60%. When these conditions occur simultaneously the malaria transmission is assumed to happen. This is based on the intersection of the climate conditions as shown on the next figure.

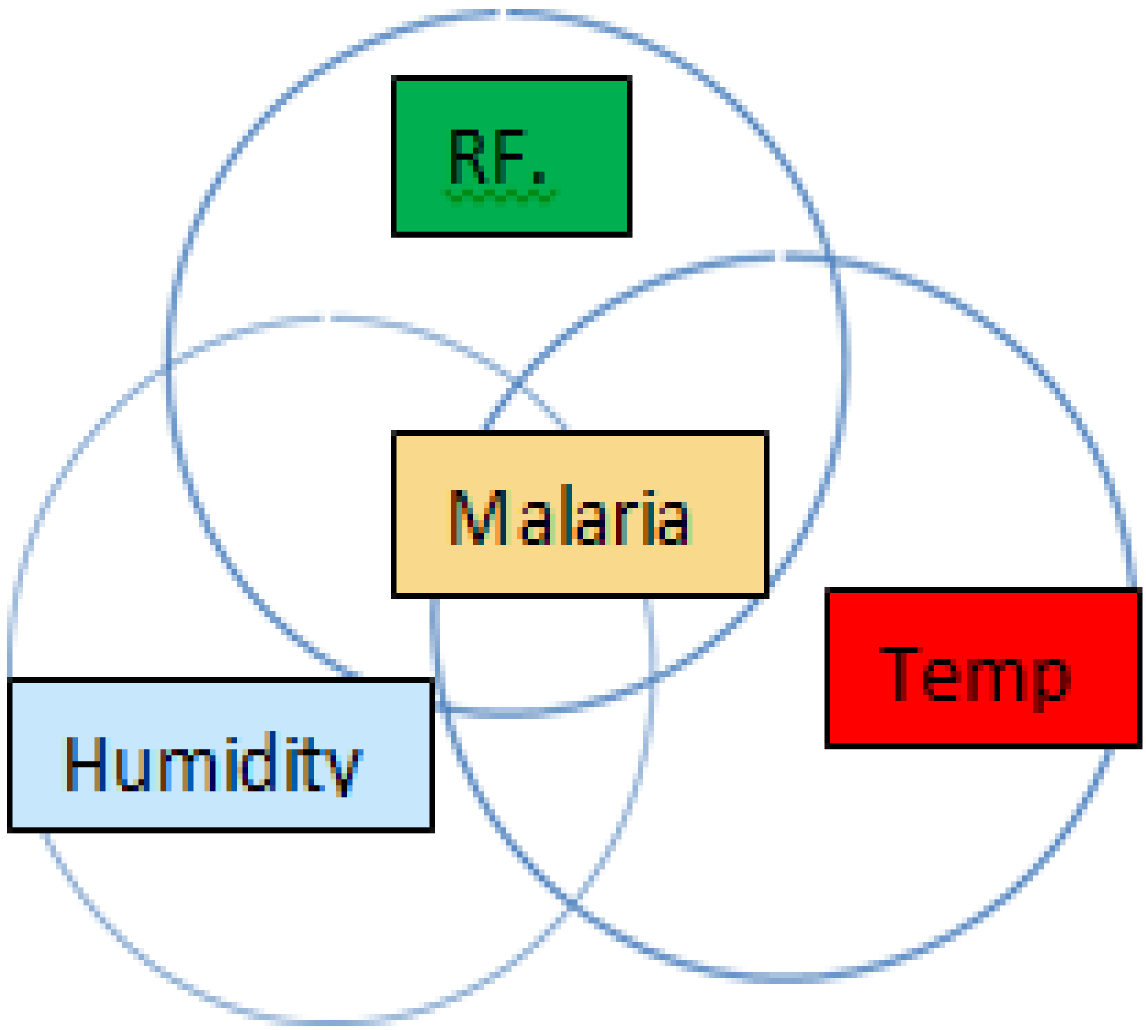

Figure 2.3.4: Principle of climate driven malaria assessment

The following procedure represents logical algorithm intersecting-method of climate parameters which are conducive for malaria transmission:

1. Open Instat$_+$ v3.37 and call the data from the directory of the file saved
2. Select the column of the month for which filtering process is going to be performed
3. Click on the sort & filter tool; Click filter menu
4. Go back to the selected column and click on the arrow found at the first cell of the column
5. Tick mark all the values > 80 for precipitation, the rest with untick mark
6. Repeat the same steps for all the months
7. Record the filtered data if available and the corresponding years for each month
8. Shade the cells with the values that satisfy the condition at step 5 with blue color RF,
9. Repeat the same procedure for temperature ($18<T<32\ ^{o}c$) and relative humidity (>60%) and shade the cells with red and grey color respectively.
10. Using the following simple algorithm, match the values that fulfill the three conditions (based on the result of step 8 and 9) simultaneously and record the month; and repeat this step for each year. The following algorithm was deigned to intersect the climate variables which fulfilled the criteria for malaria incidence on a given month and year.

The next paragraph provides the algorithm designed for this study purpose. It gives remarkable picture the required climate malaria information. And it is intended to solve the problem associated with lack of demonstrating the exact places under malaria occurrence when usually the interpretation of climate malaria information is produced with maps. This approach was used here for the first time after it had been demonstrated on the seminar courses and found equally advantageous when compared to using maps.

> Algorithm: Using Logical Operator ‘AND’:-
> AND (logic1, logic2, logic3.......)
> Logical operator ‘AND’ Checks whether all arguments are TRUE; and returns True if all arguments are TRUE otherwise FALSE.
> If RF >80mm AND $18<T<32\ ^{o}c$ AND RH>60% TRUE otherwise FALSE

11. Based on the above logical operator select the month and the year that returns TRUE and record the values with three columnar cells, side by side, with their prescribed colors,

12. Else mark all the cells with ‘X’ symbol that returns FALSE for those months and years.
13. Finally, make detail interpretation on the result obtained with tabular data.

CHAPTER THREE

MATERIALS, PROCEDURES AND METHODS

3.1 DESCRIPTION OF THE STUDY AREA

This study was carried out in Northern and North-Eastern Ethiopia. Particularly, Combolcha and Debark woredas are found around Eastern and Northern Amhara region, with in the Weyna-Dega and Dega agro-ecological zone, respectively. Combolcha is located 08^{0}45’0’’ N, 38^{0} 58’ 59’’ E, which is 367 km at North-Eastern direction from Addis Ababa capital city of Ethiopia; and Debark is located at 822 km Northern direction, from Addis Ababa, with latitude and longitude of 9.6^{o} N and 37.9^{o} E, respectively. The altitude at the sites is an elevation 1915 and 2850 meters above sea level for Combolcha and Debark respectively.

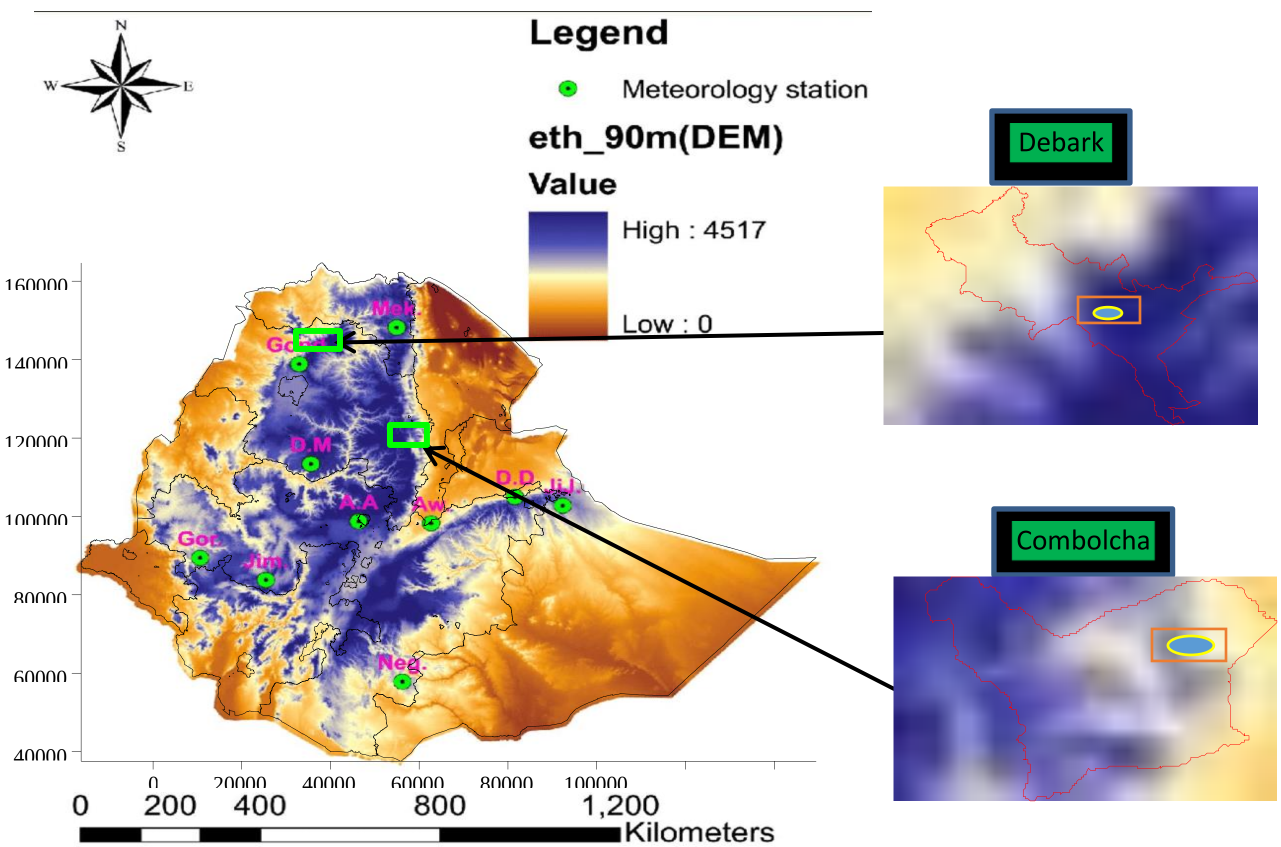

Figure 3.1 Meteorological Station Distribution and Topography Map of the Study Area, the rectangular boxes and circles represent the study areas & the corresponding towns in the woredas.

3.2 MATERIALS

3.2.1 Data

Data/Materials used for the research work was climatological data collected from NMA, ENACTS and IRI Websites of world data set etc. ENACTS data set is a high-resolution climate data with area coverage of four by four km for a single grid cell. In Amhara region, there are different classes of meteorological stations, based on quality and quantity of products. Combolcha and Debark Meteorological stations are categorized first and second-class meteorological stations respectively. In this study, monthly total precipitation, monthly mean of daily average of maximum & minimum temperature and monthly mean relative humidity was used for the period of 1986-2016.

3.2.2 Data Processing and Analyzing Tools

One of the Starting points of this study was to assess the Climate characteristics of the study areas and demonstrate climate variabilities over the areas under investigation. For such objective we used Instat+V 3.37 software, Mann-Kendall program software, XLSTAT, excel spreadsheet, and Surfer version8/ GIS for the statistical analysis of both climate characteristics and generating climate-based malaria distribution information.

3.2.3 Quality Control and Missing Data

Initially, missing station data was substituted with ENACTS reanalysis data by the nearest latitude and longitude spatial reference location. The other technical method applied for filling missing data is using weighted mean formula [equation 2.3.1]. The other essential data processing unit was data quality control which is determinant for the quality of the research result. And then, in place of low quality data the above equation [2.3.1] is used here again to correct and substitute the data with low quality.

3.3 METHODS AND PROCEDURES

3.3.1 Schematic Diagram of Methodology and Flow Processes

The following sketch diagram represents the flow processes along with the necessary methods and the research target. It traces out basically three units: the processes, methods and targets/termination. The target includes identify climate parameter affect malaria transmission.

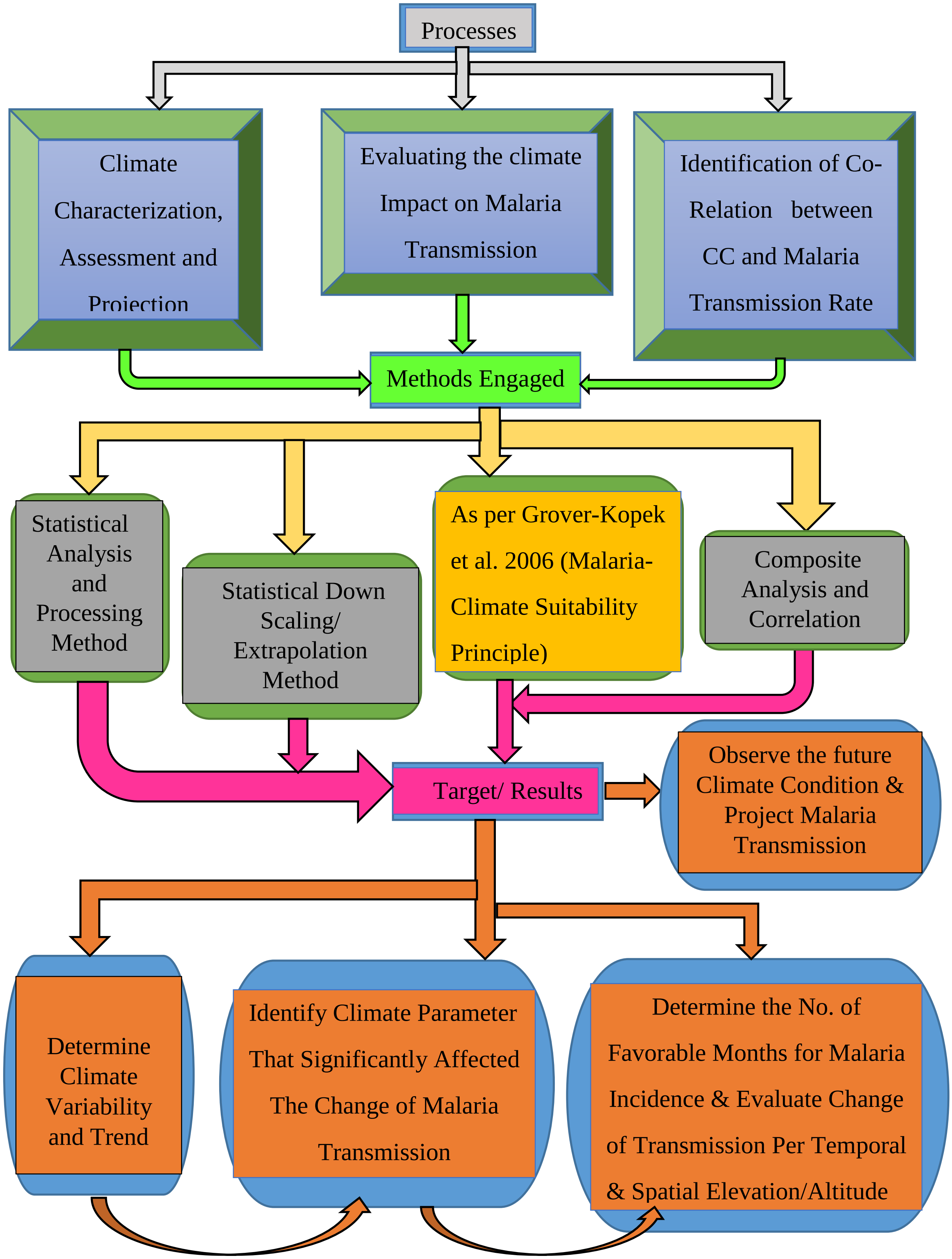

Figure 3.3.1: Schematic diagram representing the study design and structure of processes

3.4 DESCRIPTION OF THE METHODS

To identify the relationship between climate variability/change and malaria characteristics we applied similar statistical methods with Grover-Kopek et al. 2006. The detail is presented under the next sub sections.

3.4.1 Assessment and Characterization of Climate of the Study Areas (1986-2016)

I. **Climate variability:** To understand the intensity of climatic variabilities and deviations from the climate mean, coefficient of variation and standardized deviation anomaly of statistical analysis was applied on precipitation and temperature over the period of 1988-2017 [detail description in section 2.3.2.1].

II. **Climate Trend Analysis and Decadal Changes:** If the data has normal distribution, linear regression trend is applied to understand the intensity and tendency of climatic trends [equation 2.3.2.2.1]. But, since the data distribution is skewed, Mann-Kendall trend analysis was used based on [equation 2.3.2.2.2 to 2.3.2.2.5]. The changes of climate variables from consecutive decades was done using [equation 2.3.2.4.1] to observe the climate change. The process of downscaling and extrapolating for estimating the future climate condition over our study areas was performed using the description presented under (section 2.1.5 and 2.2.4).

3.4.2 Assessment of Malaria Distribution Based on the Observed Climate (1986-2016)

The favorable climatic conditions for transmission of malaria over the study areas are adopted from Grover-Kopek et al. 2006, which satisfies the following conditions.

1. monthly precipitation accumulation is at least 80 mm
2. monthly mean temperature is between 18°C and 32°C and
3. monthly mean relative humidity is at least 60%.

On the basis of the above principle, the assessment of climate caused malaria distribution was demonstrated on two data sets.

3.4.3 Procedure for Producing Climate-Malaria Information on Tabular Form

In this research design, we undergone a certain processes and procedures to evaluate the climate suitability for malaria incidence over areas under the study. Here, tabular form of information displaying approach is selected to show the assessment of malaria distribution, for point location and for a few numbers of very far apart located weather stations, rather than displaying the assessment results on maps. This was carried out through the procedure presented under [section 2.3.4].

3.4.4 Composite Analysis of Climate Variability Versus Malaria Incidence Intensity

This method is used to compare the effect of climate variability in relation to malaria existence likelihood per year. This is conducted through comparing time series analysis/trend of Rainfall and temperature with the trend of fraction of malaria incidence per year [calculated using equation 2.3.3.1]. In addition, correlation coefficient (r) tells us about the strength of the relation between two variables., in our case: we calculated the correlation between malaria occurrence frequency with temperature and rainfall variability on different seasons (equation 2.3.3.2).

3.4.5 Future Prospect of Malaria Transmission over the Study Areas

To carry out future prospect of malaria transmission, we modified our data based on the estimate of climate projections for different scenarios, extracted from published papers, as a secondary data source. Then the difference obtained in extracting the future climate change has been added upon the current climate mean data found on hands. This, even then, enable us to observe the future climate condition roughly with respect to change of time and spatial elevation. Next, we follow the same method as shown under [section 3.4.2 and 3.4.3], to demonstrate the future malaria distribution based on climate suitability logic, such that future prospect of malaria appearance likelihood was potentially indicated, over higher altitude places.

CHHAPTER FOUR

RESULT AND DISCUSSION

4.1 CLIMATE ASSESSMENT AND CHARACTERIZATION FOR STUDY AREAS

4.1.1 CLIMATE CHARACTERSTICS OF COMBOLCHA

Annual Precipitation Characteristics of Combolcha (1986-2016)

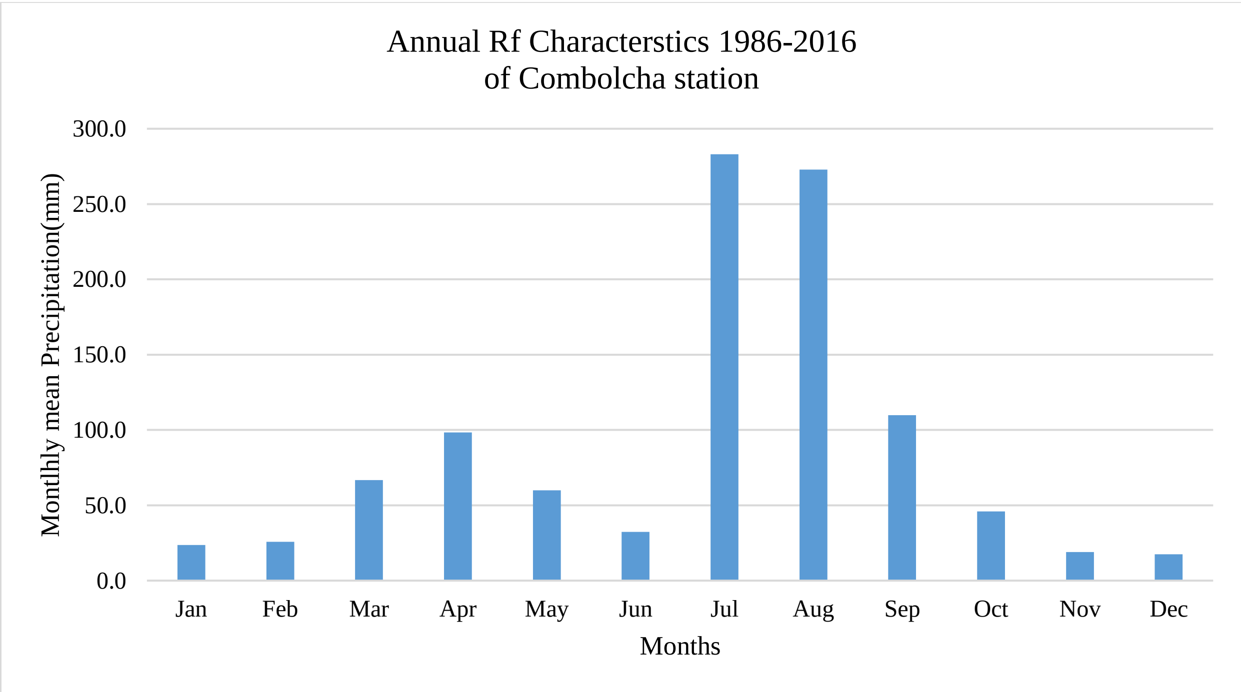

Figure 4.1.1.a: Annual Precipitation characteristics of Combolcha (1986-2016)

As shown on fig.4.1.1.a, Combolcha weather station exhibited bi-modal type of rain fall characteristics for the year 1986-2016. That means, there have been two rainy seasons per year. The first rainy season starts from March and prevails up to May with the pick on April with mean value equal to 99.0 mm. The second rainy season starts on June and extends up to September with peak values observed on July and August. With this climatic mean, mainly months of April, July, August and September recorded rain fall amount greater than 80.0 mm which has appositive impact for transmission of malaria disease.

Long-Range Mean Monthly Temperature Profile During 1986-2016 over Combolcha

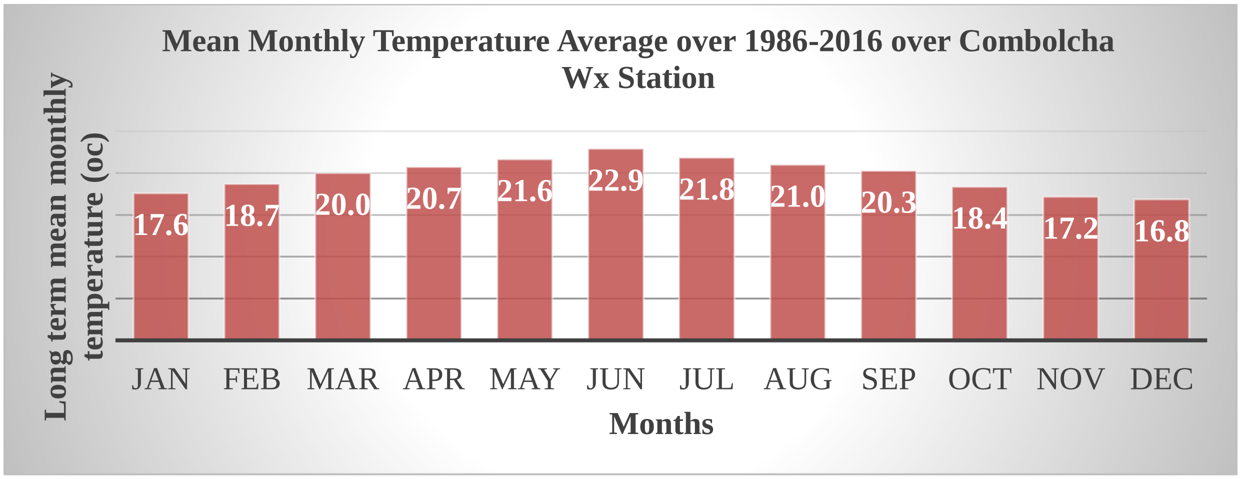

Figure 4.1.1.b. Long Range Mean Monthly Temperature Profile over 1986-2016 over Combolcha

The above figure represents the long-range temperature of monthly mean averaged over 31 years. The peak is recorded on June with value 22.9 ^{o}c and the smallest is on December, 16.8 ^{o}c. From the malaria occurrence perspective, months of FMAM and JJASO favor the conducive condition based on the principle (>18 ^{o}c). The rest of the months, NDJ do not satisfy the condition.

Seasonal Rain Fall Anomaly for Combolcha (1986-2016)

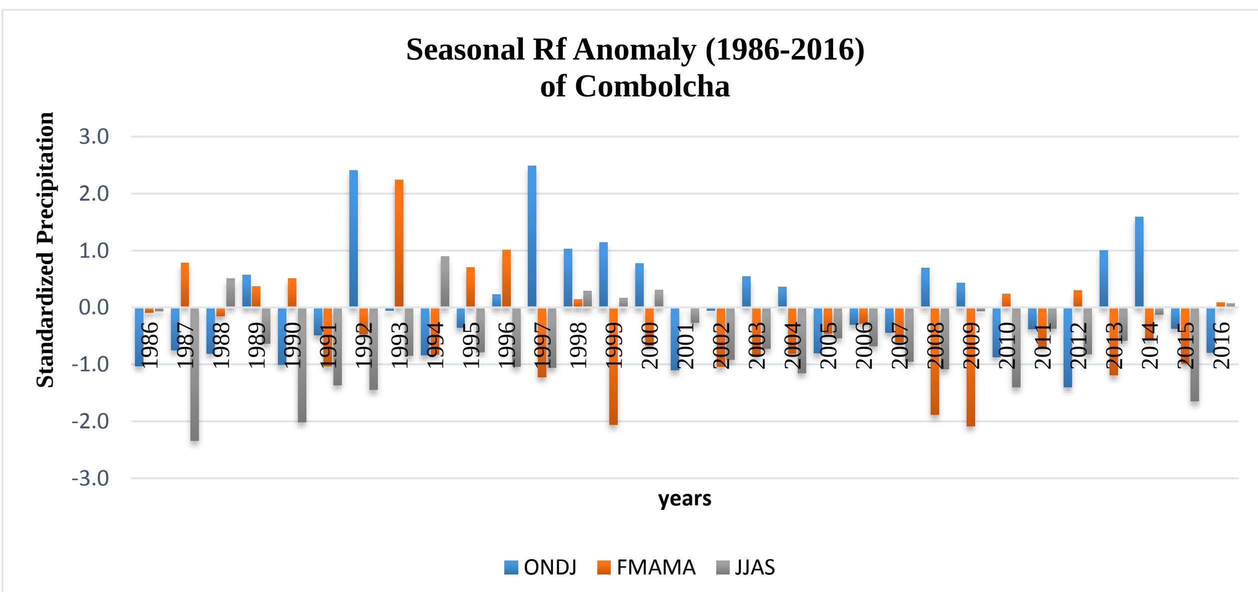

Figure 4.1.1.c: Seasonal Rain Fall Standardized Anomaly for Combolcha (1986-2016)

The above figure 4.1.1.c depicts variation of standardized precipitation anomalies from the mean climatic condition for three seasons ONDJ (Bega), FMAM(Belg) and JJAS (Kiremit).

For several years out of the 30 climatic years (1986-2016) ONDJ showed a negative deviation from the mean with value approximately from -0.5 to -1.5 in the year of 2012. In contrast, the number of years with the positive deviation is less than half though the standardized deviation magnitude is strong (+2.2) in 1992, 1997 and 2014 which is virtually greater than the negative deviation. Therefore. On this season (ONDJ) the positive impact of climate is very limited except for the years associated with extreme positive deviation. Whereas, FMAM and JJAS mostly exhibited a negative deviation from the mean condition starting from the year 1997 up to 2009. Thus, negative impact is expected over these particular years.

Annual and Seasonal Precipitation Trend for Combolcha

The following figure shows the overall trend of annual and seasonal precipitation over Combolcha from 1986-2016.

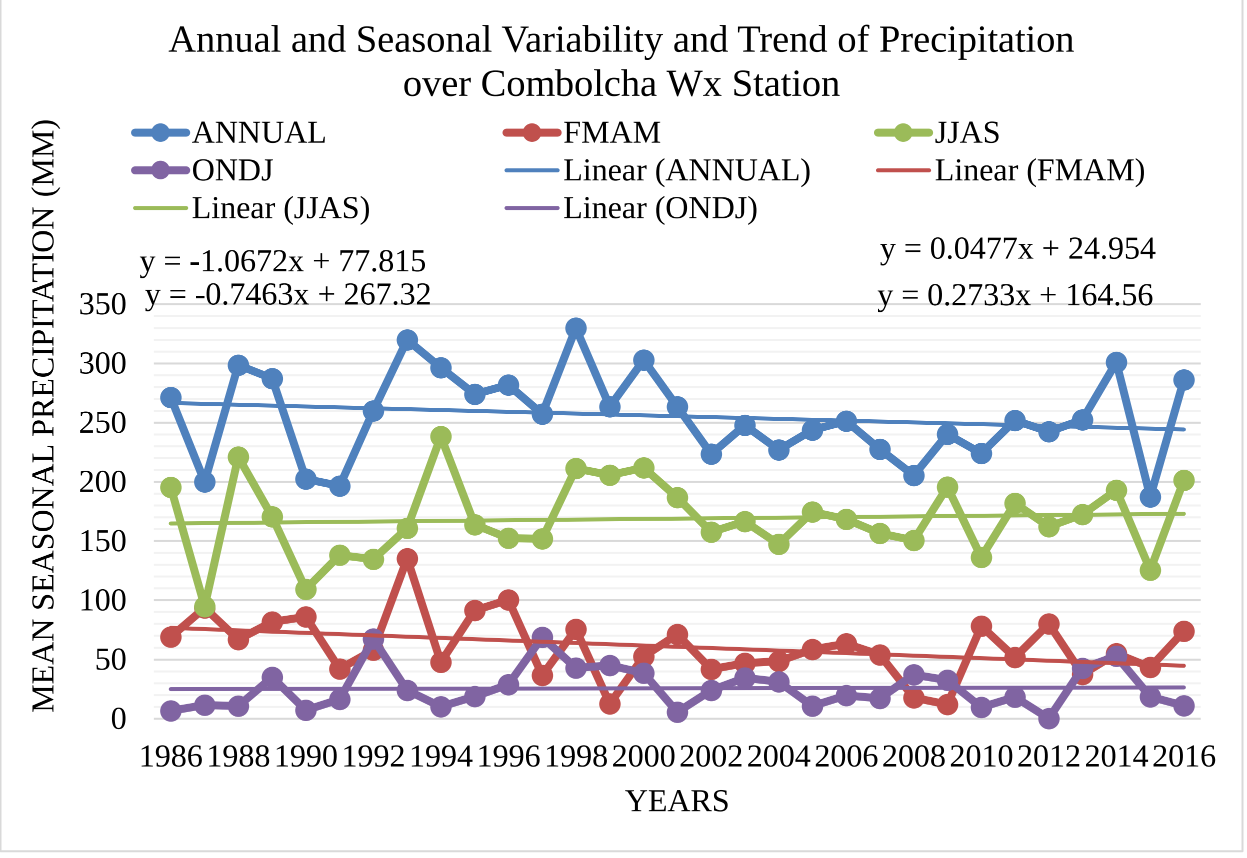

Figure 4.1.1.d: Annual seasonal Precipitation Trend and variability for Combolcha (1986-2016)

Virtually, a decreasing trend in precipitation is observed on annual base. However, this may or may not affect the occurrence of malaria since monthly cumulative rain fall may or may not significantly decrease bellow 80 mm. So, we shall see the impact of precipitation on malaria in detail on seasonal and monthly base as provided in the next paragraphs.

On ONDJ (Bega) season for Comblocha, one can see from the sketch, the variability is drawn with time series graph. With a period of five years, the graph crosses the mean condition one time up and the other time down. This shows there existed a five-year rain fall variability for ONDJ over Combolcha. In addition, there were a slight increase in precipitation trend on this season. This fact may have a positive impact on malaria transmission such that extension of malaria season apart from the usual period/months is expected.

On FMAM (Belg) season, unlike ONDJ, the variability had irregular pattern on this season. Once the rain fall performance increased from the mean, it takes longer time to decrease again; until that there is moderate variation (with small amplitude) without intercepting the mean value. The same is true on the decreasing rain fall performance. Apart from this a sharp increasing and decreasing variability with shorter period is observed with extreme values. On the other hand, a significant decreasing trend is observed starting from the year 2010 and onwards. This could result in negative impact for malaria distribution on particularly on FMAM season.

On JJAS (Kiremt) season, the rain fall variability, in general, had regular pattern with period of five years on average. Despite a slight increasing trend in precipitation from 1986-2016, there was prolonged decrease for the period starting from 2002 up to 2008. This situation could rise unfavorable condition for malaria distribution on this season for the prescribed period (2000-2008).

Seasonal Temperature Anomaly and Trend for Combolcha

The figure provided next tell us information about how frequently the temperature deviates from the mean and its trend on seasonal base. This graph (figure 4.1.1.e) shows seasonal temperature deviation from the seasonal mean and trend of each season for temperature for Combolcha station. As can be seen from the graph the temperature trend showed increasing though out the whole seasons. But, the increase was pronounced on FMAM season for Combolcha. Especially strong positive deviation is started from 2000 and persisted to 2016. Further the years2013, 2015 and

2016 recorded extreme event in temperature for the stations. This event could favor a suitable condition for malaria transmission following the rainy seasons, FMAM and JJAS.

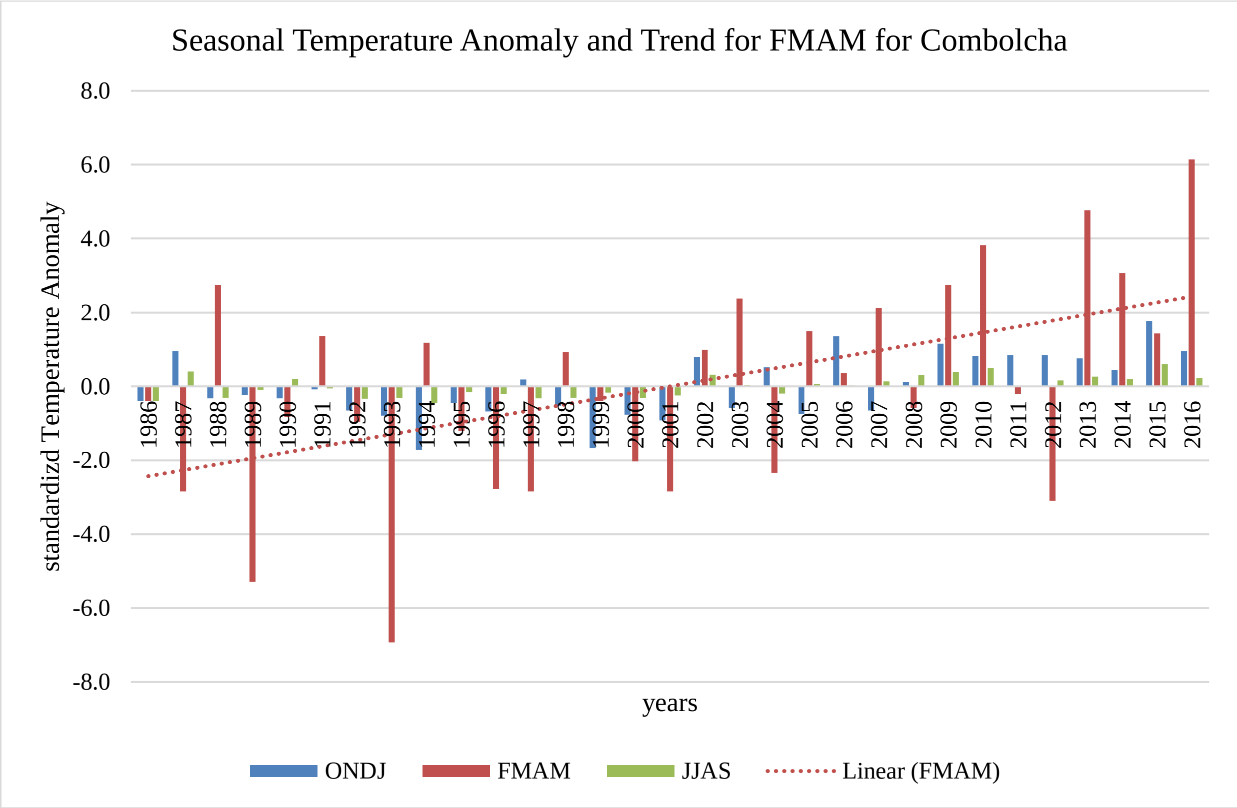

Figure 4.1.1.e: Seasonal Temperature Anomaly for Combolcha (1986-2016)

On the other hand, before the year 2000 there, mostly, was a temperature record below the mean for FMAM and JJAS for Combolcha. This had a negative impact on malaria distribution on the respective years. However, there were some numbers of years which showed a positive deviation that could favor malaria prevalence on Combolcha on the season of FMAM (Belg), before 2000. In similar, 2009, 2010, 2013 and 2016 were the years exhibited as a suitable year for malaria occurrence on the Belg season (FMAM), on basis of temperature suitability.

. Summary of Climate Variability and Trend over Combolcha

The following table provides the summary of climate variability and trend over Combolcha station with seasonal and annual base, for precipitation and temperature. The coefficient of variation with rank of variability strength and the trend with Z-test and the slope are given in the table. The Z-test tells us the significance of the trend on the range (-1.96 <= Z-test <= 1.96 with 5% uncertainty).

Table 4.1.1.1: Summary of Coefficient of variation and Trend for RF and Temperature over Combolcha Station

Station	Element	Season	Coefficient of Variation		Z-test	S.slope
				Rank		
Combolcha	RF	ONDJ	75.0%	Extremely high	0.816	0.088
		FMAM	53.7%	V. high	-1.462	-0.227
		JJAS	25.8%	Moderate	1.428	0.334
		Annual	23.6%	Moderate	-1.258	-0.195
	Temp.	ONDJ	17.5%	Low	2.414	0.110
		FMAM	17.6%	Low	2.636	0.138
		JJAS	17.8%	Low	3.502	0.140
		Annual	17.5%	Low	3.773	0.378

As seen on the above table, the result shows that the variability of precipitation is extremely high on ONDJ with 75.0 % and relatively small slope magnitude implies less effect on malaria transmission on this season. Again, on FMAM very high variability, 53.7 %, in precipitation together with moderate slope implies medium effect on malaria distribution on this season. FMAM variability. The slope is low on ONDJ, moderate on FMAM and strong on JJAS, relatively. This implies the impact of precipitation on malaria prevalence is rare on dry season (ONDJ) due to low slope of trend; and but there may be a chance of favorable precipitation condition for malaria occurrence due to extremely high variability. And on the small rainy season (FMAM), the fluctuation of malaria prevalence could highly be influenced by medium-strong increasing /decreasing trend and very high rain fall variability. On the other hand, on JJAS and Annual base the fluctuation of malaria transmission remains stable (slightly affected) due to moderate variability and low rain fall trend. However, on JJAS there was a strong increasing trend on precipitation that could rise significant increase in malaria incidence if and only if the temperature is supportive. In case of the temperature, the variability is low implies that it is stable. And the slope is increasing for all the seasons and the annual base. The positive slope along with low variability implies stabile increasing trend of temperature on all seasons. This condition could rise a strong positive impact on malaria transmission if the rain fall is supportive for all seasons. Otherwise the effect remains pronounced primarily on JJAS and secondly on FMAM since these were the seasons usually thought to have adequate rainfall for malaria prevention/anticipation.

Table 4.1.1.2: Semi-Decadal rain fall differences over Combolcha weather station on average and cumulative change in mm.

Every 5-Years/Inter-Decadal Changes of Rain Fall over Kombolcha Station					
Total and Average changes	Change Order	Seasons			
		Annual	FMAM	JJAS	ONDJ
Average change	x2-x1	69.74	-18.3	35.72	52.32
Average change	x3-x2	70.72	-77.56	78.16	70.12
Average change	x4-x3	-183.78	-8.62	-80.5	-94.66
Average change	x5-x4	-45.38	-33.22	-20.18	8.02
Average change	x6-x5	68.9	33.86	21.92	13.12

On five years variation, X2-X1, X3-X2, X4-X3, X5-X4, X6-X5 represents the differences of rain fall over the period of 1990-1986, 1995-1991, 2000-1996, 2005-2001, 2010-2006, 2016-2011, respectively.

The five years differences describe the variability and the trend well than the decadal variation. Thus, the favorable condition for malaria transmission explained on five years base. As one can see from the table, the rain fall has significantly decreased on the period x4-x3 and x5-x4 (2001-2005 and 2006-2010) on FMAM season. Similarly, on the period x4-x3 (2001-2005) on JJAS. This condition could put an unfavorable factor for malaria transmission on the prescribed periods and seasons. In contrast, the re-increasing face in rain fall on the period of x6-x5 (2011-2016) is expected to affect the malaria transmission in positive way on the three seasons.

Table 4.1.1.3 shows that unlike the precipitation, the temperature had increased during periods such as: x4-x3 and x5-x4 (2001-2005 and 2006-2010) on FMAM, ONDJ and JJAS seasons. This could influence the transmission of malaria in positive situation, if and only if the rain fall is supportive. Whereas, a slight decrease in temperature is observed on the period x6-x5 (2011-2016) on FMAM and JJAS.

Table 4.1.1.3: Decadal temperature differences over Combolcha weather station

Every 5-Years/Inter-Decadal Variations of Temperature at Combolcha Wx Station					
Total and Average changes	Change Order	Seasons			
		Annual	FMAM	JJAS	ONDJ
Average change	x2-x1	-2.96	0.01	-1.44	-1.53
Average change	x3-x2	0.03	-0.09	0.01	0.11
Average change	x4-x3	3.83	1.08	1.61	1.14
Average change	x5-x4	4.82	1.4	1.73	1.69
Average change	x6-x5	0.3	-0.4	-0.15	0.85

This could decrease the transmission of malaria on these seasons if and only if the rain fall has a decreasing trend. And, on ONDJ the period x6-x5 (2010-2016) recorded an increasing trend; such that the malaria transmission is expected to prevail over this season as far as the rain fall is found to favor malaria incidence.

4.1.2 CLIMATE CHARACTERSTICS OF DEBARK

Annual Precipitation Characteristics of Debark

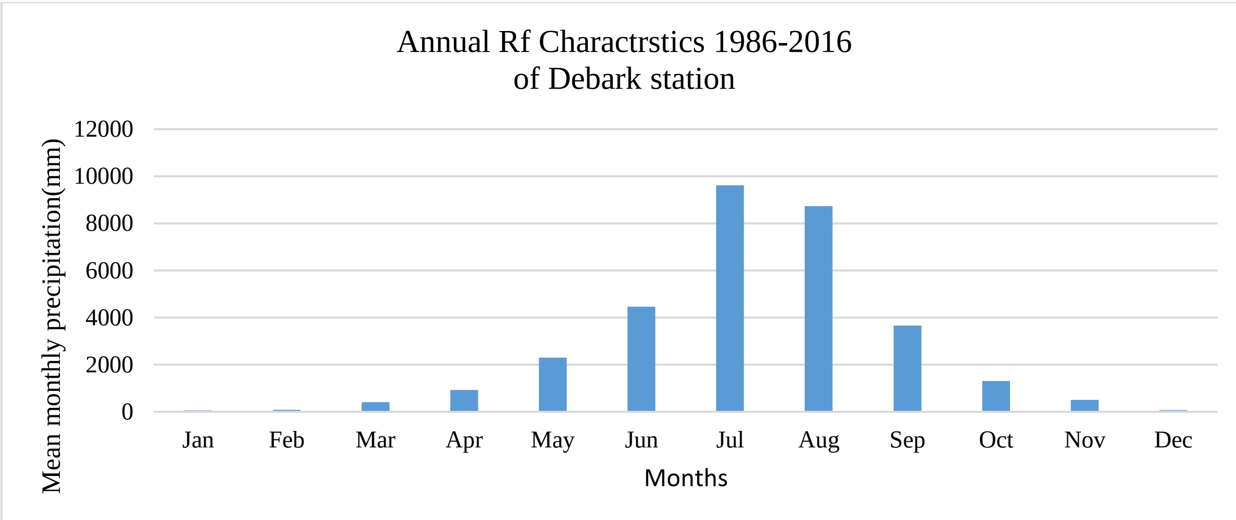

Figure 4.1.2.a: Annual Precipitation characteristics of Debark (1986-2016)

As shown on fig.4.1.2.a, Debark weather station exhibited mono-modal type of rain fall characteristics for the year 1986-2016. That means, there have been one rainy season per year. The rainy season starts from June and persists up to September with the picks observed on July and August. With this climatic mean, mainly months of July, August and September recorded rain fall amount greater than 80.0 mm which has appositive impact for transmission of malaria disease.

Long Range Mean Monthly Temperature Profile over Debark

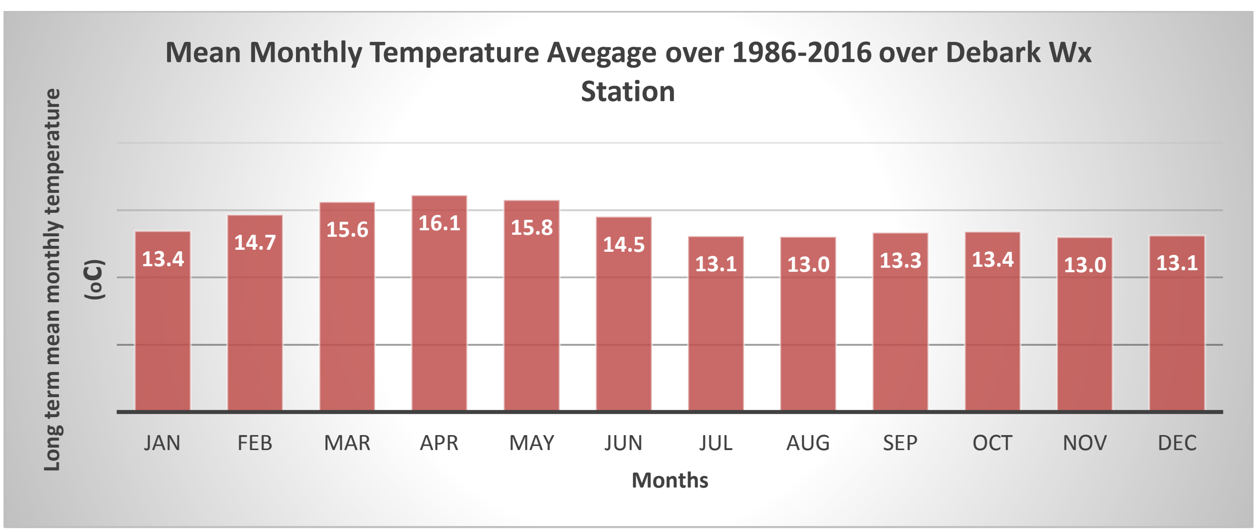

Figure 4.1.2.b: Long Range Mean Monthly Temperature Profile over 1986-2016 over Debark

As shown on the above graph, the mean monthly temperature reaches peak on April. The second peak is observed on may. The smallest record is exhibited on November and December. Based on this mean record in temperature average over 1986-2016, no one month could full fill the criteria for malaria transmission. But, on the former two months the condition might probably be favorable for malaria transmission based on separate years (1986-2016). In contrast, the temperature, on the latter two months could lead to a strong negative impact on malaria transmission throughout the year 1986-2016.

Seasonal Rain Fall Anomaly for Debark (1986-2016)

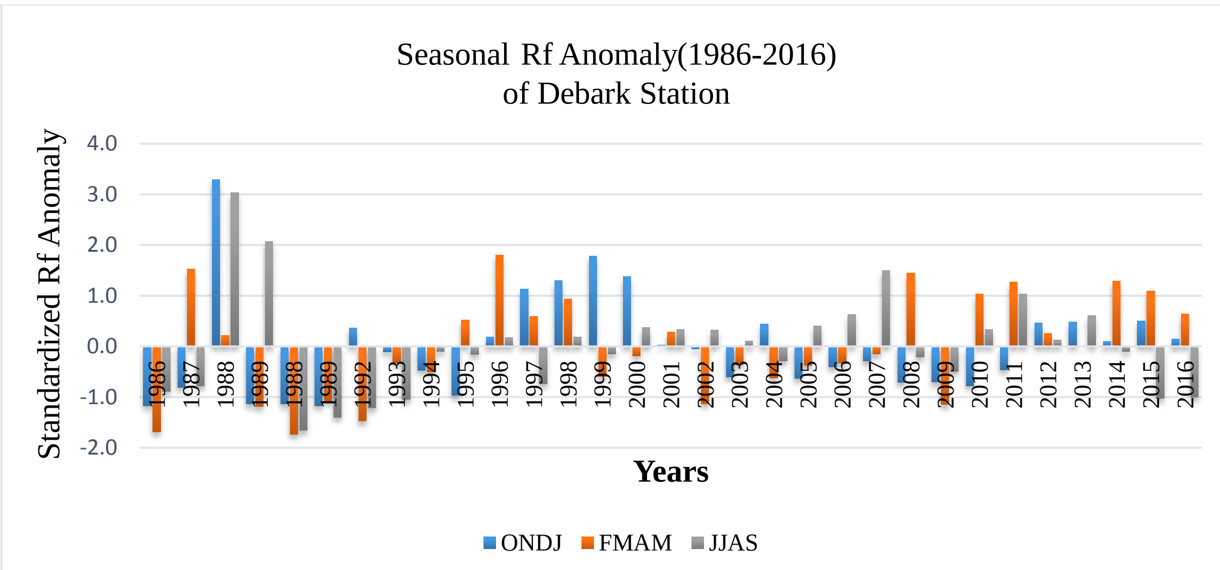

Figure 4.1.2.c: Seasonal Rain Fall Anomaly for Debark (1986-2016)

The above figure 4.1.2.c depicts variation of standardized precipitation anomalies from the mean climatic condition for three seasons ONDJ (Bega), FMAM(Belg) and JJAS (Kiremit).

For more than half number of years out of the 31 climatic years (1986-2016) ONDJ showed a negative deviation for several years. But 1988,1997, 1998, 1999, 2000, 2015 and 2016 exhibited a positive deviation. On the other hand, FMAM showed negative deviation on 1988-1994 and 2002-2007; and positive deviation on 1995-2001 and 2010-2016. For the aforementioned periods precipitation have favored negatively and positively for malaria distribution, respectively. But, JJAS have showed a negative deviation for several years except few years like: 1988, 1989, 2007, 2011, 2015 and 2016. Since, the amplitude of the negative deviation is relatively small the chance of malaria occurrence is only slightly affected. Except this fact, the precipitation performance had a positive impact on malaria occurrence.

Annual and Seasonal Precipitation Trend for Debark (1986-2016)

The following figure shows the overall trend of precipitation over Debark station from 1986 to 2016. Virtually, an increasing trend in precipitation is observed, on annual base. However, this may or may not affect the occurrence of malaria since epidemiology of malaria is primarily rainy season dependent. Thus, the seasonal variations and seasonal trends in precipitation performance need to be treated separately, as in the next paragraphs.

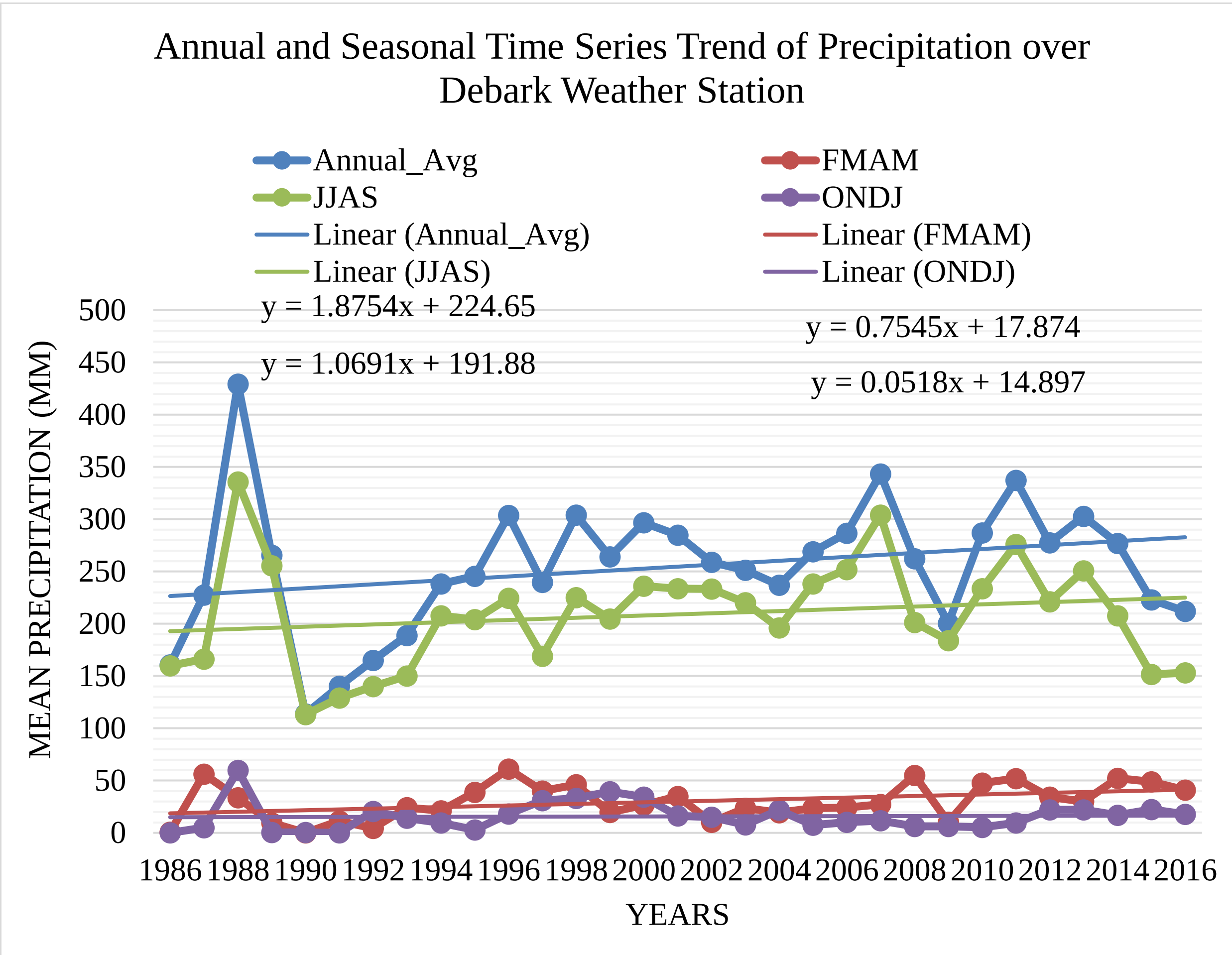

Figure 4.1.2.d: Seasonal and Annual rain Fall Variability and Trend of Combolcha (1986-2016)

The variability in rain fall performance had a regular pattern on average, but the amplitude of variation decreases from the year of 2000 and onwards 2016. In line with this, there were a slight increase in precipitation trend on this season starting from 2000. This fact may have a positive impact on malaria transmission such that a chance of incidence of malaria is expected as far as the temperature and humidity conditions are fulfilled; otherwise not expected.

In similar fashion to Combolcha, Debark also showed irregular rain fall variability over FMAM. Once the rain fall performance increased from the mean, it takes longer time to decrease again; until that there is moderate variation without intercepting the mean interval. The same is true on the decreasing rain fall performance. Apart from this a sharp increasing and decreasing variability with shorter period is observed with extreme values. On the other hand, a moderate increasing trend is observed starting from the year 20005 and onwards. This could result in positive impact for malaria distribution on FMAM season over the recent years.

As one can see from the sketch, the rain fall variability over JJAS, in general, had regular pattern with period of five years on average. But, at the beginning of the first two five years (1986-1990 and 1991-1995) the variation amplitude was strong as compared to next two five years (1996-2000 and 2001-2005). Again, the amplitude of variation rises moderately for the last two five years (2006-2010 and 2011-2016). for the period starting from 2002 up to 2008 the decrease was prolonged. On the other hand, a slight increasing trend is observed starting from 2005 and onwards. This situation could rise favorable condition for malaria distribution on this season for the prescribed period (2005-2016).

Seasonal Temperature Anomaly and Trend for Debark

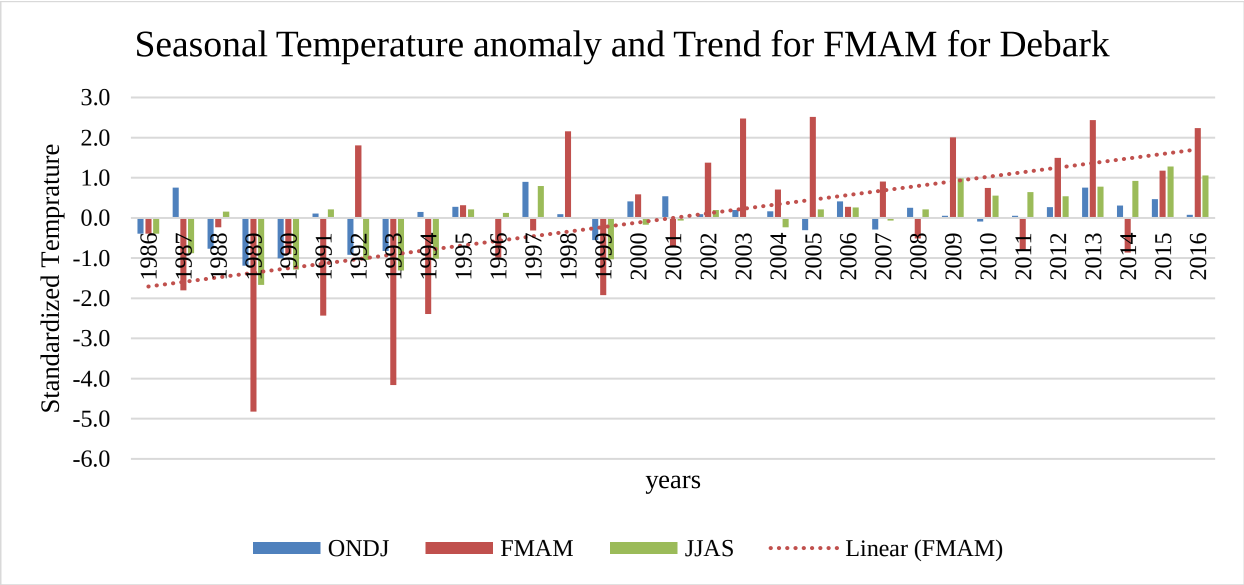

Figure 4.1.2.e: Seasonal Temperature Anomaly for Combolcha and Debark (1986-2016)

The preceding graph provides seasonal temperature deviation from the seasonal mean and trend of each season for temperature on Debark station. As can be seen from the graph the temperature trend showed increasing though out the whole seasons. But, the increase was pronounced on FMAM season as well. Especially strong positive deviation is started from 2000 and persisted to 2016. Further the years 2015 and 2016 recorded extreme event in temperature. This favored a suitable condition for malaria transmission following the rainy seasons, FMAM and JJAS. On the other hand, before the year 2000 there was a temperature record below the mean for FMAM and JJAS season. This had a negative impact on malaria distribution on the respective years.

. Summary of Climate Trend and Variability over Debark

The following table provides the summary of climate variability and trend over Debark station.

Table 4.1.2.1: Summary of Coefficient of variation and Trend for RF and Temperature on Debark

Station	Element	Season	Coefficient of Variation		Z-test	S.slope
				Rank		
Debark	RF	ONDJ	96.4%	Extremely high	1.360	1.062
		FMAM	45.6%	V. high	2.312	3.500
		JJAS	27.5%	Moderate	1.428	6.652
		Annual	27.6%	Moderate	1.360	8.282
	Temp.	ONDJ	17.7%	Low	2.414	0.110
		FMAM	17.9%	Low	2.636	0.138
		JJAS	17.9%	Low	3.502	0.140
		Annual	17.7%	Low	3.773	0.378

Table 4.1.2.1 shows the coefficient of variation with rank of variability strength and the trend with Z-test and the slope. The Z-test tells us the significance of the trend on the range (-1.96 <= Z-test <= 1.96). Thus, this result shows that the variability of precipitation is extremely high on ONDJ

with 96.4 % and FMAM very high on FMAM 45.6 % variability. The slope is low on ONDJ, moderate on FMAM and strong on JJAS, relatively. This implies the impact of precipitation on malaria prevalence on these seasons is rare on dry season (ONDJ) due to low slope of trend and extremely high variability. And on the small rainy season (FMAM), malaria prevalence is highly influenced by medium-strong increasing trend and very high rain fall variability. On the other hand, on JJAS and Annual base the fluctuation of malaria transmission remains stable (slightly affected) due to moderate variability and low rain fall trend. However, on JJAS there was a strong increasing trend on precipitation that could rise significant increase in malaria incidence if and only if the temperature is supportive. In case of the temperature, the variability is low implies that it is stable. And the slope is increasing for all the seasons and the annual base. The positive slope along with low variability implies stabile increasing trend of temperature on all seasons. This condition could rise a strong positive impact on malaria transmission if the temperature at the weather station height is suitable for existence of malaria.

Otherwise the effect remains pronounced primarily on JJAS and secondly on FMAM since these were the seasons usually thought to have adequate rainfall for malaria anticipation. In addition, the temperature with low variability implies that there was no or very little fluctuation in malaria transmission on the area where the condition is met.

Table 4.1.2.2: Semi-Decadal rain fall differences over Debark weather station

Every 5-Years/Inter-Decadal Variations of Rain Fall over Debark Station					
Total and Average changes	Change Order	Seasons			
		Annual	FMAM	JJAS	ONDJ
Average change	x2-x1	-175.14	0.02	-160.2	-14.96
Average change	x3-x2	344.56	74.78	182.7	87.08
Average change	x4-x3	-86.3	-65.74	49.88	-70.44
Average change	x5-x4	62.92	42.34	42.78	-22.2
Average change	x6-x5	30.4	42.12	-54.22	42.5

On the above table one can see that, on five years variation, X2-X1, X3-X2, X4-X3, X5-X4, X6-X5 represents the differences of rain fall over the period of 1990-1986, 1995-1991, 2000-1996, 2005-2001, 2010-2006, 2016-2011, respectively.

The five years differences describe the variability and the trend well than the decadal variation. Thus, the favorable condition for malaria transmission variability was explained on five years base. As one can see from the table, the rain fall has significantly increased on FMAM season for the whole terms except for the period x4-x3 (2001-2005). Similarly, the had increasing performance on the middle terms except for the first and the last term x6-x5 (2011-2016) on JJAS. This condition could put a favorable factor for malaria transmission on the prescribed periods and seasons although there are exceptional periods with a slight decrease precipitation. Apart from this, the re-increasing face in rain fall on the period of x6-x5 (2011-2016) is expected to affect the malaria transmission in positive way on FMAM and ONDJ seasons, as far as the temperature is found satisfactory.

Table 4.1.2.3: Semi-Decadal temperature differences over Debark weather station

Every 5-Years/Inter-Decadal Variations of Temperature for Debark wx station						
Total and Average changes	Change Order	Seasons				
		Annual	FMAM	JJAS	ONDJ
Average change	x2-x1	1.96	0.33	0.65	0.98
Average change	x3-x2	4.59	1.63	1.53	1.43
Average change	x4-x3	1.87	1.74	0.24	-0.11
Average change	x5-x4	0.07	-0.75	1.07	-0.25
Average change	x6-x5	2.35	0.01	1.28	1.06

The temperature had increased on the whole periods except for x5-x4 (2006-2010) on FMAM and JJAS seasons. This could influence the transmission of malaria in positively, if and only if the rain fall is supportive. In case of ONDJ there were very slight decrease at the middle terms; and during the rest of the periods the change had a significant positive sign. This could contribute to a positive impact for the transmission of malaria on this season if and only if the rain fall had an increasing trend over the corresponding periods.

4.2 ASSESSMENT OF CLIMATE IMPACT ON MALARIA TRANSMISSION OVER STUDY AREAS

In this section, we discuss the climate variables that are conducive for malaria transmission with the minimum threshold values. These are when cumulative monthly precipitation is greater than 80mm, the mean monthly average temperature ranging from 18 to 32 ^{o}c the monthly average relative humidity greater than 60%. Based on this, number of months that consolidate these conditions, simultaneously, have been assessed and identified for the years 1986-2016 for both Combolcha and Debark districts with two data sets.

4.2.1 ASSESSMENT OF CLIMATE IMPACT ON MALARIA TRANSMISSION OVER COMBOLCHA WOREDA

Monthly Precipitation Cumulative (1986-2016) for Combolcha Station

The monthly cumulative precipitation information that obey the principle of malaria epidemiology is presented bellow in table 4.2.1.a for Combolcha station from 1986-2016.

Table 4.2.1.a: Monthly Precipitation cumulative (1986-2016) for Combolcha station

Combolcha St	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Years	RF>=80n	RF>=80n	RF>=80n	RF>=80n	RF>=80n	RF>=80n	RF>=80n	RF>=80n	RF>=80n	RF>=80n	RF>=80n	RF>=80mm
1986	x	x	x	138.7	x	118.2	254.3	336.1	x	x	x	x
1987	x	x	115.3	x	144.8	x	x	289.8	x	x	x	x
1988	x	96.8	x	100.6	x	x	397.2	271.3	170.5	x	x	x
1989	x	x	116.3	165.2	x	x	240	249.5	174.1	x	x	104.1
1990	x	99	123.4	116.4	x	x	x	115.2	211.6	x	x	x
1991	x	x	95.6	x	x	x	175.6	204.7	116	x	x	x
1992	82.8	x	x	137.3	x	x	174.6	208.2	149.3	82.6	x	x
1993	x	83	x	239.9	181	x	256.8	155.3	226.6	x	x	x
1994	x	x	x	x	x	x	436.6	331.6	154.4	x	x	x
1995	x	x	x	209	x	x	284.2	260.5	80.5	x	x	x
1996	x	x	139.7	133.4	124.8	x	164.4	346.9	x	x	x	x
1997	x	x	x	x	x	104.2	234.8	216.3	x	154.6	87	x
1998	95.4	91.5	x	124.6	x	x	480.2	248.2	114.5	x	x	x
1999	x	x	x	x	x	x	374.3	328.4	109.1	121.8	x	x
2000	x	x	x	132.8	x	x	326.6	359.3	119.3	x	x	x
2001	x	x	139.9	99	x	x	349.4	235.4	115.3	x	x	x
2002	x	x	x	82.1	x	x	278.5	254.8	86.8	x	x	x
2003	x	x	x	80.9	x	x	208.9	269.4	149.3	x	x	x
2004	x	x	x	127.5	x	x	239.6	239.4	82.5	x	x	x
2005	x	x	x	x	86.4	x	342.7	293.9	x	x	x	x
2006	x	x	121.8	87.1	x	x	237.5	277.2	144.6	x	x	x
2007	x	x	x	115	x	x	320.7	175.5	92.3	x	x	x
2008	x	x	x	x	x	x	294.9	209.1	x	x	x	x
2009	x	x	x	x	x	x	370.1	320.4	x	x	x	x
2010	x	x	x	102.7	107.6	x	363.9	107.6	x	x	x	x
2011	x	x	x	x	130.9	x	278	338.6	90.5	x	x	x
2012	x	x	109	177.1	x	x	284	261.6	x	x	x	x
2013	x	x	x	x	x	x	336.3	284.9	x	x	x	x
2014	x	x	x	x	90.9	x	307.5	319.5	135.2	x	x	x
2015	x	x	x	x	102.2	x	x	332.8	107.9	132.7	x	x
2016	x	x	x	155.8	107.7	x	276.1	346	119.2	192.3	x	x

In the table 4.2.1.a the cells with precipitation cumulative which have value equal to and greater than 80 mm per month are shaded with blue color. The rest are marked with 'X' symbol which means their monthly sum were below 80mm. Based on the above table, for most of the years

(1985-2016) July, August and September satisfies the condition for malaria transmission precipitation suitability. Secondly, March, April and May also satisfy the condition over some years (1986-2016).

Monthly Mean Temperature (1986-2016) for Combolcha Station

The monthly mean temperature information is presented bellow in the table 4.2.1.b for Combolcha station from 1986-2016.

Table 4.2.1.b: Monthly Mean Temperature (1986-2016) for Combolcha station

Combolcha St	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Years	18<=T<=32	18<=T<=	18<=T<=	18<=T<=	18<=T<=	18<=T<=	18<=T<=	18<=T<=	18<=T<=	18<=T<=	18<=T<=	18<=T<=32
1986	x	19.7	19.7	19.9	21.6	22.3	21.3	20.5	19.5	18	x	x
1987	x	18.8	19.9	19.8	20.4	22.8	23.5	21.3	21.0	19.2	x	18
1988	18.9	19.8	20.4	21.0	22.1	23.1	21.3	20.0	19.7	18.05	x	x
1989	x	18.0	19.2	18.9	20.8	22.7	22.1	20.9	19.8	18.2	x	x
1990	x	18.8	19.5	19.9	22.3	23.5	21.8	21.7	20.3	18.1	x	x
1991	18.7	19.3	20.1	20.9	21.9	22.7	21.8	21.1	20.1	x	x	x
1992	x	18.6	20.0	20.5	21.2	23.0	21.8	20.1	19.0	x	x	x
1993	x	x	19.0	19.3	20.0	21.7	21.5	20.9	19.9	18.4	x	x
1994	x	18.8	20.5	21.3	21.5	23.6	20.6	19.9	19.1	x	x	x
1995	x	19.1	19.8	20.3	21.0	22.8	21.4	20.9	20.0	x	x	x
1996	x	18.8	19.7	20.1	20.3	21.8	21.6	20.8	20.5	x	x	x
1997	x	x	20.3	20.2	21.2	21.8	21.5	20.6	20.1	18.6	x	x
1998	18.4	19.2	20.0	21.5	21.2	22.1	21.3	20.6	20.1	18.75	x	x
1999	x	x	19.7	20.8	22.4	23.2	21.1	20.6	20.1	18.1	x	x
2000	x	x	19.7	20.9	21.4	22.8	21.4	20.2	19.7	18.45	x	x
2001	x	x	19.2	20.3	21.8	23.1	21.1	20.8	19.5	18.8	x	x
2002	x	18.7	20.2	20.7	22.4	23.3	23.0	21.5	20.2	18.55	x	18.35
2003	x	19.5	20.4	20.9	22.2	22.9	21.9	20.9	20.5	x	x	x
2004	19.1	18.0	19.4	20.4	21.5	21.8	21.8	21.1	20.1	x	x	x
2005	18	19.2	20.7	21.0	21.5	22.9	21.5	21.3	20.7	x	x	x
2006	x	19.9	20.0	20.1	21.5	23.1	21.6	21.2	20.2	19.25	x	18.4
2007	x	19.4	20.1	20.8	22.5	23.5	21.3	21.2	20.9	18	x	x
2008	x	x	19.1	21.0	22.8	23.4	22.5	21.2	20.8	18.8	x	x
2009	x	19.1	20.4	21.4	22.4	24.1	21.8	21.5	21.0	18.85	x	18.45
2010	18	20.1	19.9	21.8	22.4	23.8	22.2	22.4	20.8	19.3	x	x
2011	x	18.5	19.1	21.7	21.8	22.8	21.9	21.0	20.4	18.6	18.3	x
2012	x	x	19.4	20.4	21.3	22.7	21.8	21.4	21.1	18.25	18.25	x
2013	18.2	18.8	21.4	22.3	22.5	23.8	22.1	20.9	20.8	19.05	18.25	x
2014	x	19.7	20.8	21.5	21.6	23.1	22.7	21.0	20.4	18.6	18.2	x
2015	x	18.8	20.2	20.9	22.4	22.9	23.7	21.9	21.2	19.7	18.7	18.6
2016	19	19.5	22.6	22.0	21.9	22.9	22.1	21.3	21.0	19.2	x	x

Based on the temperature data presented in table 4.2.1.b, during the months starting from February up October the temperature was found to be favorable for malaria transmission almost for the whole years (1986-2016). But, only for few years November, December and January satisfies the condition, especially on recent years.

Monthly Mean Relative Humidity for Combolcha Station

The monthly mean relative humidity information is presented bellow in table 4.2.1.c for Combolcha station from 1986-2016.

Table 4.2.1.c: Monthly Mean Relative Humidity (1986-2016) for Combolcha station

Combolch	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Years	RH>=60%	RH>=60%	RH>=60%	RH>=60%	RH>=60%	RH>=60%	RH>=60%	RH>=60%	RH>=60%	RH>=60%	RH>=60%	RH>=60%
1986	x	x	x	x	x	x	x	x	x	x	x	x
1987	x	x	61	x	x	x	x	x	x	x	x	x
1988	x	x	x	x	x	x	x	62	61	x	x	x
1989	x	x	x	60	x	x	x	x	60	x	x	74
1990	x	72	x	x	x	x	x	x	x	x	x	x
1991	x	x	61	x	x	x	x	x	x	x	x	x
1992	65	69	x	x	x	x	x	x	x	x	x	x
1993	64	66	x	65	x	x	x	63	x	x	x	x
1994	x	x	x	x	x	x	61	60	x	x	x	x
1995	x	63	x	63	x	x	x	x	x	x	x	x
1996	66	x	62	x	x	x	x	x	x	x	x	x
1997	61	x	x	x	x	x	x	x	x	x	x	x
1998	66	64	x	x	x	x	x	64	61	x	x	x
1999	x	x	x	x	x	x	x	x	x	x	x	x
2000	x	x	x	x	x	x	x	x	x	x	x	x
2001	x	x	x	x	x	x	x	63	x	x	x	x
2002	x	x	x	x	x	x	x	x	x	x	x	x
2003	x	x	x	x	x	x	x	x	x	x	x	x
2004	x	x	x	x	x	x	x	x	x	x	x	x
2005	x	x	x	x	x	x	x	x	x	x	x	x
2006	x	x	x	x	x	x	x	x	x	x	x	x
2007	65	x	x	x	x	x	x	x	x	x	x	x
2008	x	x	x	x	x	x	x	x	x	x	x	x
2009	x	x	x	x	x	x	x	x	x	x	x	x
2010	x	x	x	x	x	x	x	63	x	x	x	x
2011	x	x	x	x	x	x	x	60	x	x	x	x
2012	x	x	x	x	x	x	x	x	x	x	x	x
2013	x	x	x	x	x	x	x	63	x	x	x	x
2014	x	x	x	x	x	x	x	x	x	68	x	x
2015	x	x	x	x	x	x	x	x	x	65	x	x
2016	64	x	x	66	x	x	x	x	x	61	x	x

As seen from table 4.2.1.c, the relative humidity measure was favorable from January to April and August to September for the years 1986-1998. After this period the suitable condition of relative humidity was limited to August and September with the exception of years 2007 and 2017. Apart from this, the conducive relative humidity amount, for malaria transmission, exhibited extension in duration up to the month of October, in 2014-2016. On the other hand, months of November, May, June and December with exception of 1986 the whole climatic years (1986-2016) showed a negative impact for malaria prevalence.

Malaria Climatic Suitability (1986-2016) for Combolcha

As shown on the following table 4.2.1.d, the climate variables which are determinant for malaria transmission are brought with the necessary threshold values. These are monthly precipitation cumulative (with blue color), mean monthly temperature threshold 18-32 ^{o}c (with red color) and

Table 4.2.1.d: Malaria Conducive Climate Condition (1986-2016) for Combolcha

Combolch	Jan				Feb			Mar			Apr		May	Jun		Jul			Aug			Sep			Oct		Nov	Dec
Years	RF	T	RH	RF	T	RH	RF	T	RH	RF	T	RH	RF	T	RH	RF	T	RH	RF	T	RH	RF	T	RH	RF	T	RH	RF
1986	95	18	66																									
1987							115	19.9	61																			
1988																		271	20.0	62	171	19.7	61					
1989										165	18.9	60									174	19.8	60					
1990				99	18.8	72																						
1991							95.6	20.1	61																			
1992																												
1993										240	19.3	65						155	20.9	63								
1994															437	20.6	61	332	19.9	60								
1995										209	20.3	63																
1996							140	19.7	62																			
1997																												
1998				92	19.2	64												248	20.6	64	115	20.1	61					
1999																												
2000																												
2001																		235	20.8	63								
2002																												
2003																												
2004																												
2005																												
2006																												
2007																												
2008																												
2009																		108	22.4	63								
2010																		339	21.0	60								
2011																												
2012																												
2013																		285	20.9	63								
2014																												
2015																								133	20	65		
2016										156	22.0	66												192	19	61		

monthly average relative humidity greater than 60% (with grey color). Based on this principle, the year before 1998 there was a possibility of malaria transmission twice per year. These months were mainly February to April. The second malaria transmission months were August and September. Generally, the malaria transmission season was seen following the first rainy season (February to April) and the second rainy season (August and September). Meanwhile, the month of May to June and November to December were observed transition periods or malaria free months for the whole years. Besides, January and July rarely exhibited the favorable condition for malaria transmission as far as the onset of the rainy seasons started early, see 1986 and 1994 respectively. On the other hand, after the year of 1998, the conducive conditions for malaria prone months are limited only to the second rainy season (August and September). Apart from this, the malaria transmission season was elongated to the first month of the next season (October), in the year 2015 and 2016.

4.2.2 ASSESSMENT OF CLIMATE IMPACT ON MALARIA TRANSMISSION OVER DEBARK WOREDA

4.2.2.1 Climate Impact on Malaria over Debark Using Station Data

Here, we first used station data collected from Debark weather station for similar interval of time (1986-2016). Secondly, we also assessed climate impact on malaria with gridded/ ENACTS data set with similar time interval to station data. And observe the difference of the results obtained by using these two data sets. To the same manner we did for Combolcha, the cumulative monthly precipitation, the mean monthly temperature and the monthly average of relative humidity were evaluated whether the recorded values met the threshold level or not, as per the principle.

Monthly Precipitation Cumulative (1986-2016) for Debark Station

The monthly cumulative precipitation information is presented bellow in table 4.2.2.1 for Debark station from 1986-2016.

Table 4.2.2.1: Monthly Precipitation cumulative (1986-2016) for Debark station

Debark Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Years	RF>=80mm	RF>=80m	RF>=80m	RF>=80m	RF>=80m	RF>=80m	RF>=80m	RF>=80m	RF>=80m	RF>=80m	RF>=80m	RF>=80m
1986	x	x	x	x	x	89	225	201	125	x	x	x
1987	x	x	x	x	225	220.4	95.4	300.1	x	x	x	x
1988	x	x	x	x	x	142.9	752.7	575	117.7	239	x	x
1989	x	x	x	x	x	214.3	732.3	308.1	99.2	x	x	x
1990	x	x	x	x	x	x	163	152	126	x	x	x
1991	x	x	x	x	x	x	168	210	x	x	x	x
1992	x	x	x	x	x	x	200.4	238	x	x	x	x
1993	x	x	x	x	83.3	96.6	165	162.7	176.4	x	x	x
1994	x	x	x	x	x	160.7	255.1	313.8	100.9	x	x	x
1995	x	x	x	x	131.3	113.4	280.2	308	114.4	x	x	x
1996	x	x	x	94.9	125.9	319.1	242.5	224.7	111.8	x	x	x
1997	x	x	x	x	112.8	97.8	225	297.4	x	90.9	x	x
1998	x	x	x	x	171.7	162.7	317.9	226.9	192.4	118.8	x	x
1999	x	x	x	x	x	91.1	334.4	252.8	141	106.6	x	x
2000	x	x	x	89.3	x	167.1	303.8	284.2	189.1	113.5	x	x
2001	x	x	x	x	x	154.4	347.6	383	x	x	x	x
2002	x	x	x	x	x	155	375.7	295	108.2	x	x	x
2003	x	x	x	x	x	217.5	190.4	314.2	158.3	x	x	x
2004	x	x	x	x	x	174.3	280	264.1	x	x	x	x
2005	x	x	x	x	x	130.1	456.6	242.1	124.4	x	x	x
2006	x	x	x	x	x	122.1	275	482.6	128.4	x	x	x
2007	x	x	x	x	x	359.7	456.8	269.7	130.3	x	x	x
2008	x	x	x	91.3	128.3	120.4	201.1	319.8	163.8	x	x	x
2009	x	x	x	x	x	89.2	365.6	191	89.7	x	x	x
2010	x	x	x	94.6	x	181.4	385.1	262.6	106.1	x	x	x
2011	x	x	x	x	153.9	95.8	532	358.8	117.6	x	x	x
2012	x	x	x	x	133.7	149.8	330.4	280.4	124	x	x	x
2013	x	x	x	x	x	146.7	473	286.3	96.5	88.8	x	x
2014	x	x	x	x	83.7	108.5	231.5	290.5	201	x	x	x
2015	x	x	x	x	120.4	84.2	103.5	272.9	145.9	x	x	x
2016	x	x	x	x	110.6	170	157.7	169	116.5	x	x	x

In the table 4.2.2.1 the cells with precipitation cumulative which have value equal to and greater than 80 mm per month are shaded with blue color. The rest are marked with ‘X’ symbol which means their monthly sum were below 80mm. Based on the above table, for most of the years (1985-2016) June, July, August and September satisfies the condition for malaria transmission precipitation suitability. Secondly, March, April and May also satisfy the condition over some years (1986-2016). For few numbers of years May and October months also favored a positive impact for malaria transmission.

Monthly Mean Relative Humidity for Debark Station

The monthly mean relative humidity information is presented bellow in table 4.2.2.2 for Debark station from 1986-2016.

Table 4.2.2.2: Monthly Mean Relative Humidity (1986-2016) for Debark station

Debark	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Years	RH>=60%	RH>=60%	RH>=60%	RH>=60%	RH>=60%	RH>=60%	RH>=60%	RH>=60%	RH>=60%	RH>=60%	RH>=60%	RH>=60%
1986	x	x	x	x	62	67	83	76	74	x	x	x
1987	x	x	x	x	x	70	86.5	86.5	72.5	x	x	x
1988	x	x	x	x	x	68	82.5	85	74.5	60.5	x	x
1989	x	x	x	x	69.5	74	79	85.5	73	x	x	x
1990	x	x	x	x	63	70	82	79	68.5	66.5	64.5	x
1991	x	x	x	x	x	70	81	84.5	76.5	74.5	x	x
1992	x	x	x	x	x	67	76	77	78	62	65	x
1993	x	x	x	x	60	72	80	75	79	63	60	x
1994	x	x	x	x	x	71	81	79	77	62	x	x
1995	x	x	x	x	x	65	80	83	69	x	x	x
1996	x	x	x	x	68	74	77	83	71	x	x	x
1997	x	x	x	x	x	67	79	74	62	x	x	x
1998	x	x	x	x	60	70	78	79	67	60	x	x
1999	x	x	x	x	x	70	83	82	74	71	x	x
2000	x	x	x	x	x	70	79	82	75	69	x	x
2001	x	x	x	x	x	67	77	81	68	64	x	x
2002	x	x	x	x	x	60	74	77	68	x	x	x
2003	x	x	x	x	x	62	77	80	74	x	x	x
2004	x	x	x	x	x	60	75	75	69	x	x	x
2005	x	x	x	x	x	x	80	76	71	x	x	x
2006	x	x	x	x	x	60	72	79	71	x	x	x
2007	x	x	x	x	x	66	80	78	70	x	x	x
2008	x	x	x	x	x	70	86.5	86.5	72.5	x	x	x
2009	x	x	x	x	x	68	82.5	85	74.5	60.5	x	x
2010	x	x	x	x	69.5	74	79	85.5	73	x	x	x
2011	x	x	x	x	63	70	82	79	68.5	66.5	64.5	x
2012	x	x	x	x	x	70	81	84.5	76.5	74.5	x	x
2013	x	x	x	x	x	67	76	77	78	62	65	x
2014	x	x	x	x	x	x	74	80	72	x	x	x
2015	x	x	x	x	x	x	61	76	70	x	x	x
2016	x	x	x	x	62	64	80	78	70	x	x	x

As seen from table 4.2.2.2, the relative humidity measure was favorable from January to April and June to September for the whole years. And May, October and November are months observed as fulfilling the principle RH threshold for malaria transmission, for some number of years. The rest of the months are considered to affect malaria distribution negatively.

Monthly Mean Temperature (1986-2016) for Debark Station

The monthly mean temperature information is presented bellow in the table 4.2.2.3 for Debark station from 1986-2016.

Table 4.2.2.3: Monthly Mean Temperature (1986-2016) for Debark station

Debark St	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Years	18<=T<=	18<=T<=	18<=T<=	18<=T<=	18<=T<=	18<=T<=	18<=T<=	18<=T<=	18<=T<=	18<=T<=	18<=T<=	18<=T<=
1986	x	x	x	x	x	x	x	x	x	x	x	x
1987	x	x	x	x	x	x	x	x	x	x	x	x
1988	x	x	x	x	x	x	x	x	x	x	x	x
1989	x	x	x	x	x	x	x	x	x	x	x	x
1990	x	x	x	x	x	x	x	x	x	x	x	x
1991	x	x	x	x	x	x	x	x	x	x	x	x
1992	x	x	x	x	x	x	x	x	x	x	x	x
1993	x	x	x	x	x	x	x	x	x	x	x	x
1994	x	x	x	x	x	x	x	x	x	x	x	x
1995	x	x	x	x	x	x	x	x	x	x	x	x
1996	x	x	x	x	x	x	x	x	x	x	x	x
1997	x	x	x	x	x	x	x	x	x	x	x	x
1998	x	x	x	18.6	x	x	x	x	x	x	x	x
1999	x	x	x	x	x	x	x	x	x	x	x	x
2000	x	x	x	x	x	x	x	x	x	x	x	x
2001	x	x	x	x	x	x	x	x	x	x	x	x
2002	x	x	x	x	x	x	x	x	x	x	x	x
2003	x	x	x	x	x	x	x	x	x	x	x	x
2004	x	x	x	x	x	x	x	x	x	x	x	x
2005	x	x	x	x	x	x	x	x	x	x	x	x
2006	x	x	x	x	x	x	x	x	x	x	x	x
2007	x	x	x	x	x	x	x	x	x	x	x	x
2008	x	x	x	x	x	x	x	x	x	x	x	x
2009	x	x	x	x	x	x	x	x	x	x	x	x
2010	x	x	x	x	x	x	x	x	x	x	x	x
2011	x	x	x	x	x	x	x	x	x	x	x	x
2012	x	x	x	x	x	x	x	x	x	x	x	x
2013	x	x	x	x	x	x	x	x	x	x	x	x
2014	x	x	x	x	x	x	x	x	x	x	x	x
2015	x	x	x	x	x	x	x	x	x	x	x	x
2016	x	x	x	x	x	x	x	x	x	x	x	x

Based on the temperature data presented in table 4.2.2.3, only the year 1998 on the month of April with amount 18.6 c^{o} satisfied the conducive condition. And, the rest of the years and the whole months could not exhibit temperature suitability for malaria incidence, ever in the given climate period (1985-2016), based on Debark weather station.

Malaria Climatic Suitability (1986-2016) for Debark Station

As shown on the following table 4.2.2.4, the climate variables which are determinant for malaria transmission are brought with the necessary threshold values. These are monthly precipitation cumulative (with blue color), mean monthly temperature threshold 18-32 ^{o}c (with red color) and relative humidity greater than 60 %.

Table 4.2.2.4: Climate Conducive Malaria Occurrence (1986-2016) for Debark

Debark St	Jan			Feb			Mar			Apr			Ma	Jun	Jul			Aug			Sep			Oct			No	Dec
Years	RF	T	RH	RI	T	RH	RF	T	RH	RF	T	RH	RF	T	RH	RF	T	RH	RF	T	RH	RF	T	RH	RI	T	RH	RF
1986	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
1987	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
1988	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
1989	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
1990	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
1991	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
1992	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
1993	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
1994	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
1995	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
1996	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
1997	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
1998	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
1999	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
2000	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
2001	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
2002	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
2003	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
2004	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
2005	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
2006	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
2007	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
2008	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
2009	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
2010	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
2011	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
2012	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
2013	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
2014	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
2015	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
2016	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

The above table provides assessment of climate suitability for malaria prevalence and distribution based on Debark station climate data. Unfortunately, none of the months and years given above were identified to satisfy the climate conducive condition for malaria epidemiology. This is due the fact that when we get higher and higher in altitude the temperature measure decreases with elevation. So, the main reason for the existence of unfavorable climate condition for malaria transmission over Debark 'town' (2836.0 m elevation) was due to the temperature found to be below the minimum threshold value (<18c^o) for the whole years, as shown on table 4.2.2.3.

Using station data, it is found difficult and insufficient to assess the impact of climate variability on malaria distribution for woreda level. Therefore, high resolution data used to study the condition for the entire woreda based on the ensemble of gridded data cell available. Thus, using high resolution gridded data, in the next sub sections the climate malaria suitability is studied and the results are discussed, for Debark district with 24 grid areas near to the station.

4.2.2.2 Climatic Suitability for Malaria Using Gridded Data for Debark woreda

The following table presents six selected grid cells with their georeferenced locations, altitudes and distance and direction of meteorological station that found at Debark town.

Table 4.2.2.2.a: Georeferenced location of grid cells along with altitude, distance and direction

Latitude	Longitude	Altitude (m)	Lat., Long. & Altitude (m) of Debark Station	Distance from Debark Station(km)	Direction from Debark Station
13.18175	37.81875	1941.0	13.14213, 37.8979, 2836	9.6	N-W
13.21875	37.81875	2175.8	13.14213, 37.8979, 2836	12.1	N-W
13.21875	37.85625	2143.5	13.14213, 37.8979, 2836	9.6	N-W
13.21875	37.89375	2069.2	13.14213, 37.8979, 2836	8.5	N-W
13.21875	37.93125	1922.8	13.14213, 37.8979, 2836	9.3	N-E
13.21875	37.96875	2803.4	13.14213, 37.8979, 2836	11.5	N-E

Each grid cell represents four by four km area coverage which is equal to 16 km^2. Initially, 24 grid cells which have 384 km^2 in area coverage, debark station location being at the center. This area had a distance of 12.0 km East and West of Debark station and 8.0 km North and South of the station, on average. Out of 24 grid locations, the result of assessment showed that only on the aforementioned six locations was the climate driven malaria transmission have been found to exist (see table 5.2.2.1).

Malaria Climatic suitability for 13.18125 Latitude and 37.81875 Longitude ocation

As shown on the following table 5.2.2.2, the climate variables which are determinant for malaria transmission are brought with the necessary threshold values. These are monthly precipitation cumulative (with blue color), mean monthly temperature threshold 18-32 ^{o}c (with red color) and relative humidity greater than 60 %.

Table 4.2.2.2.b: Malaria Climatic Suitability for 13.18125 latitude and 37.81875 longitude location

13.1813	37.8188																					
	Jan	Feb	Mar	Apr	May				Jun			Jul			Aug			Sep		Oct	Nov	Dec
Years	RF,T,RH	RF,'	RF,'	RF,T,	RF	T	RH	RF	T	RH	RF	T	RH	RF	T	RH	RF	T	RH	RF,T,RH	RF,T,	RF,T,F
1986																						
1987																						
1988								98	18	68												
1989																						
1990																						
1991																						
1992																						
1993																						
1994																						
1995								93	19	65												
1996																						
1997																						
1998					116	18.4	60															
1999																						
2000																						
2001																						
2002																						
2003																						
2004								156	19	70												
2005								178	18	60												
2006								115	19	72												
2007								90	19	60												
2008								81	19	70												
2009																						
2010								82	20	74							81	18	73			
2011					134	19.3	63	90	19	70							85	18	69			
2012								125	19	70												
2013																						
2014																						
2015											102	21	61	270	18	76	144	18	70			
2016					115	20.6	62	189	20	64	284	21	80	355	19	78						

The grid cell location represented with 13.18125 latitude and 37.81875 longitude is found 9.6 km away from Debark weather station in North West direction at altitude of 1941.0 m. The elevation is lower than Debark weather station which is equal to 2836 m.

Regarding to climate malaria relation, this location had a better malaria distribution as compared to the location round the Debark weather station. In line with this, the month of June takes the first place for the percent of malaria distribution. Sometimes, the month of May also contributes for malaria distribution as far as the onset of rainy season starts early. Whereas, on 2015 and 2016 there were prolonged malaria transmission climate factor starting from May to September. This resulted from the late secession of the rainy season and gradual temperature increase over time. The temperature increasing trend is discussed under section 4.1.2 which is stated to favor malaria distribution under Debark Woreda, in general.

Malaria Climatic Suitability for 13.21875 Latitude and 37.81875 Longitude Location

As shown on the following table, the climate variables which are determinant for malaria transmission are brought with the necessary threshold values. These are monthly precipitation cumulative (with blue color), mean monthly temperature threshold 18-32 ^{o}c (with red color) and relative humidity greater than 60 %.

Table 4.2.2.2.c: Malaria Climatic Suitability for 13.21875 latitude and 37.81875 longitude location

13.2188	37.8188																			
	Jan	Feb	Mar	Apr		May			Jun			Jul		Aug			Sep	Oct	Nov	Dec
Years	RF,T,RH	RF,T,	RF,T	RF,'	RF	T	RH	RF	T	RH	RF	T	RH	RF	T	RH	RF,T,	RF,T	RF,T	RF,T,
1986																				
1987																				
1988																				
1989																				
1990																				
1991																				
1992																				
1993																				
1994																				
1995																				
1996																				
1997																				
1998								95	19.3	70										
1999																				
2000								165	18	70										
2001																				
2002																				
2003																				
2004																				
2005																				
2006								122	18.5	60										
2007								268	18	66										
2008																				
2009								87	19.4	68										
2010																				
2011					140	19	63													
2012								118	18.2	70										
2013								126	18.5	67										
2014																				
2015																				
2016								102	19.6	64	190	18.3	80	298	19	78				

The grid cell location represented with 13.21875 latitude and 37.81875 longitude is found 12.1 km away from Debark weather station in North West direction at altitude of 2175.8 m. The elevation is lower than Debark weather station which is equal to 2836 m.

Regarding to climate malaria relation, this location also revealed a better malaria distribution as compared to the location round the Debark weather station. In this case, the month of June is found to be a major malaria transmission season stating from 1998 and onwards. This result is due to an increasing in precipitation on JJAS season, (sea fig. 4.1.2.d). While the month of May, July and

August favored a positive impact on malaria distribute as a result of increasing temperature trend (section 4.1.2) and prolonged rainy season in 2016.

Malaria Mlimatic Suitability for 13.21875 Latitude and 37.85625 Longitude Location

As shown on the following table, the climate variables which are determinant for malaria transmission are brought with the necessary threshold values. These are monthly precipitation cumulative (with blue color), mean monthly temperature threshold 18-32 ^{o}c (with red color) and relative humidity greater than 60 %.

Table 4.2.2.2.d: Malaria Climatic Suitability for 13.21875 latitude and 37.85625 longitude location

13.2188	37.8563																			
	Jan	Feb	Mar	Apr	May		Jun			Jul			Aug			Sep		Oct	Nov	Dec
Years	RF,T,RH	RF,T	RF,T	RF,T	RF,T	RF	T	RH	RF	T	RH	RF	T	RH	RF	T	RH	RF,T	RF,	RF,T
1986																				
1987																				
1988																				
1989																				
1990																				
1991																				
1992																				
1993																				
1994																				
1995						87	18	65												
1996																				
1997																				
1998																				
1999																				
2000																				
2001																				
2002						140	18	60												
2003																				
2004																				
2005																				
2006						119	18	60												
2007																				
2008																				
2009																				
2010																				
2011						90	18	70												
2012						111	18	70												
2013						139	18	67												
2014																				
2015																				
2016						102	19	64	190	18	80	298	19	78	271	19	70			

The grid area location represented with 13.21875 latitude and 37.85625 longitude is found 9.6 km away from Debark weather station in North West direction at altitude of 2143.5 m. The elevation is lower than Debark weather station which is equal to 2836 m.

Regarding to climate malaria relation, this location also revealed a better malaria distribution as compared to the location round the Debark weather station. In line with this, the month of June is found to be a major malaria transmission season starting from 1995 and onwards. This result is due to an increasing in precipitation on JJAS season, sea fig. 4.1.2.d. While the month of July, August and September favored a positive impact on malaria distribution as a result of a significant increasing temperature trend (section 4.1.2.) and late secession of the rainy season in 2016.

Malaria Climatic Suitability for 13.21875 Latitude and 37.89325 Longitude Location

As shown on the following table, the climate variables which are determinant for malaria transmission are brought with the necessary threshold values. These are monthly precipitation cumulative (with blue color), mean monthly temperature threshold 18-32 °c (with red color) and relative humidity greater than 60 %.

Table 4.2.2.2.e: Malaria Climatic Suitability for 13.21875 latitude and 37.89375 longitude location

13.2188	37.8938																	
Combolch	Jan	Feb	Mar	Apr	May		Jun			Jul		Aug		Sep		Oct	Nov	Dec
Years	RF,T,RH	RF,T	RF,T	RF,T	RF,T	RF	T	RH	RF	T	RH	RF,T,R	RF	T	RH	RF,T,	RF,T	RF,T,
1986																		
1987																		
1988																		
1989																		
1990																		
1991																		
1992																		
1993																		
1994																		
1995						85	19	65										
1996																		
1997																		
1998									311	19	78							
1999																		
2000																		
2001																		
2002																		
2003																		
2004																		
2005																		
2006						104	18	60										
2007																		
2008						118	19	70										
2009																		
2010																		
2011																		
2012																		
2013																		
2014																		
2015													283	19	70			
2016						106	19	64	194	18	80							

The grid area location represented with 13.21875 latitude and 37.89375 longitude is found 8.5 km away from Debark weather station in North West direction at altitude of 2069.2 m. The elevation is lower than Debark weather station which is equal to 2836 m.

Regarding to climate malaria relation, this location also revealed a better malaria distribution as compared to the location round the Debark weather station. Similar to over the prescribed locations, this location also exhibited the incidence and prevalence of malaria on the month of June, starting from 1995 and onwards. Again 2015 and 2016 are the years which become a remarkable malaria transmission period for more than two months. This result is due to an increasing in precipitation on JJAS season, sea fig. 4.1.2.d. While the month of July, August and September favored a positive impact on malaria distribution as a result of a significant increasing temperature trend (section 4.1.2) and late secession of the rainy season in 2015.

Malaria Climatic Suitability for 13.21875 Latitude and 37.93125 Longitude Location

As shown on the following table, the climate variables which are determinant for malaria transmission are brought with the necessary threshold values. These are monthly precipitation cumulative (with blue color), mean monthly temperature threshold 18-32 °c (with red color) and relative humidity greater than 60 %.

Table 4.2.2.2.f: Malaria Climatic Suitability for 13.21875 latitude and 37.93125 longitude location

13.21875	37.93125																					
Combolcha	Jan	Feb	Mar	Apr		May			Jun			Jul		Aug			Sep			Oct	Nov	Dec
Years	RF,T,RH	RF,T	RF,T	RF,T	RF	T	RH	RF	T	RH	RF	T	RH	RF	T	RH	RF	T	RH	RF,T	RF,T	RF,T
1986								100	19	67	228	19	83									
1987																						
1988																						
1989																						
1990																						
1991											97	19	81									
1992																						
1993																						
1994																						
1995																						
1996								178	18	74												
1997								94	19	67												
1998																						
1999																						
2000																						
2001																						
2002																						
2003																	126	18	80			
2004																						
2005																						
2006														285	18	79						
2007																						
2008								85	20	70												
2009																	102	19	85			
2010																						
2011					139	21	63	85	20	70				339	19	79						
2012								107	20	70												
2013								139	20	67												
2014																						
2015														116	20	76	277	21	76			
2016								112	22	64	193	22	80	288	21	78	350	18	78			

The grid cell location represented with 13.21875 latitude and 37.93125 longitude is found 9.3 km away from Debark weather station in North East direction at altitude of 1922.8 m. The elevation is lower than Debark weather station which is equal to 2836 m.

Regarding to climate malaria relation, this location also revealed a better malaria distribution as compared to the location round the Debark weather station. Similar to over the prescribed locations, this location also exhibited the incidence and prevalence of malaria on the month of

June, starting from 1995 and onwards. Again 2015 and 2016 are the years which become a remarkable malaria transmission period for more than three months per year. This result is due to an increasing in precipitation on JJAS season, sea fig. 4.1.2.d. While the month of July, August and September favored a positive impact on malaria distribution as a result of a significant increasing temperature trend (section 4.1.2) and late secession of the rainy season in 2015. Apart from this, 1986 and 1990 had showed climate suitability for malaria prevalence over this location. This event resulted from a slight positive deviation in temperature from the mean (see again section 4.1.2). Moreover, starting from the 2002 the months of September and August fulfills the climate condition conducive for malaria outbreak in consequence to an increasing trend (fig.4.1.2. d) in precipitation and late secession of the kiremt rainy season.

Malaria Climatic Suitability for 13.21875 Latitude and 37.96875 Longitude Location

As shown on the following table, the climate variables which are determinant for malaria transmission are brought with the necessary threshold values. These are monthly precipitation cumulative (with blue color), mean monthly temperature threshold 18-32 ^{o}c (with red color) and relative humidity greater than 60 %.

Table 5.2.2.2.h: Malaria Climatic Suitability for 13.21875 latitude and 37.96875 longitude location

13.21875	37.96875	T average >= 18 centigrade, RF>=80mm & RH>=60%												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep			Oct	Nov	Dec
Years	RF,T,RH	RF,T	RF,T	RF,T	RF,T	RF,T	RF,T	RF,T	RF	T	RH	RF,T,	RF,T,	RF,T,
1986														
1987														
1988														
1989														
1990														
1991														
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2003														
2004														
2005														
2006														
2007														
2008														
2009														
2010														
2011														
2012														
2013														
2014														
2015									280	19	70			
2016														

The grid cell location represented with 13.21875 latitude and 37.96875 longitude is found 11.5 km away from Debark weather station in North East direction at altitude of 2803.8 m. The elevation is approximately near to Debark weather station which is equal to 2836 m.

Regarding to climate malaria relation, this location also revealed a little bit a better malaria distribution as compared to the location round the Debark weather station. Unlike to Debark station location, this place has showed the incidence of malaria based on climate suitability criteria for the month of September, in 2015. This result is due to an increase in precipitation on JJAS season (see fig. 4.1.2.e) and a remarkable increased temperature trend to higher altitudes, gradually (see section 4.1.2).

The ENACTS data set shows the details of malaria transmission since it is a high-resolution data that can depict the actual fact happened on the ground. So, we could observe that malaria existed at different altitudes (1922.8 to 2803.4 m) and very near distance from Debark town (9.6 to12.1 km) where the weather station is located, 2836.0 m altitude. A study done before by International travel advisories (IAMAT, 2013) specify that Addis Ababa is malaria free. However, malaria cases are diagnosed within the city limits as a result of infections acquired outside the city or within its growing periphery Woyessa & Ali, 2003; Woyessa et al. 2004. Analogues to this, the result obtained in table 4.2.2.2.h showed that the climate suitability which was experienced in recent years (2015) is the cause for the detection of malaria near to Debark or with its periphery area, just at 11.5 km distant from the 'center' (referring to weather station location) and at approximately 2803.4m altitude above mean sea level.

With these analyses, our result displayed the malaria transmission in a better manner compared to the result obtained by MARA13 (Source: Ethiopia-Epi-report-020520) malaria projection model forecasted for the recent year 2015, (see the map under Annex C.2). The model used the same logic as we used in malaria climate suitability in this paper. The product of the model, issued for the year 2015, showed that the malaria incidence elevation was expected be 2,500 m, where areas above this height are supposed to be malaria free regions. However, in our assessment result we have seen that the climate became conducive for malaria incidence just at elevation of 2803.8m, recently (on 2015, table 5.2.2.7).

4.3 CLIMATE VARIABILITY VERSUS MALARIA EXPECTATION PATTERN

The following results showed malaria expectation pattern in relation to the variability of climate parameters time series over Combolcha and Debark Woredas.

4.3.1 CLIMATE VARIABILITY VERSUS MALARIA EXPECTATION PATTERN OVER COMBOLCHA

The following results showed malaria expectation pattern in relation to the variability of climate parameters time series over Combolcha.

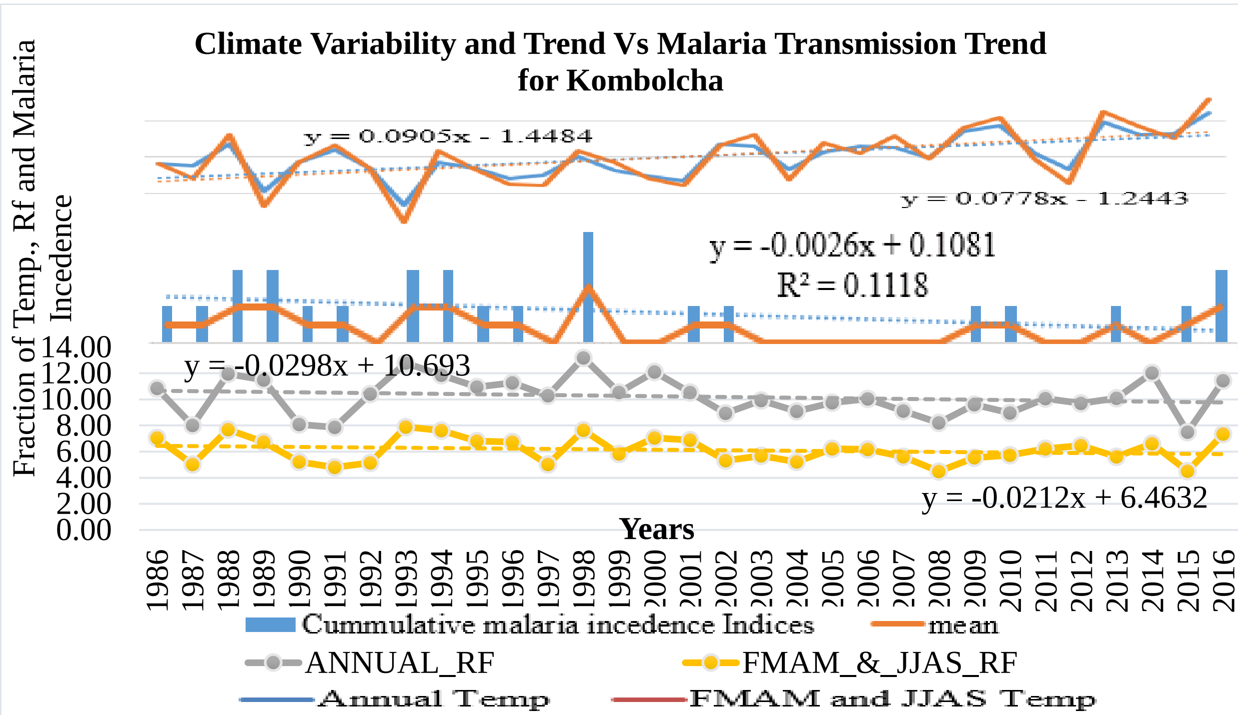

Figure 4.3.1. Trend and variability of precipitation on FMAM_JJAS and ANNUAL, Malaria Expectation Tend and Time series for Kombolcha Woreda and Trend variability of Temperature on FMAM_JJAS and ANNUAL

Clearly, a slight decreasing trend in malaria occurrence is observed similar to the precipitation trend regardless of the increase in temperature, during 1986-2016 over Combolcha. In similar speaking, on FMAM and JJAS seasons there were a significant decrease in precipitation, from 2001 up to 2008. This condition collapsed malaria transmission on FMAM during the indicated years. In the next two years, the temperature increases along with the increase in precipitation allow the disease re-emerging. Again, the increase and decrease of temperature and precipitation directly affects malaria transmission in positive and negative face during the years 2009-2011 and 2011-2014, respectively. In addition, the increase of malaria transmission in 1988,1989, 1993,1994 and 1998 is due to the effect of the temperature and precipitation increase; the reverse is true on the rest of the years. In general, the increase and decrease of the malaria transmission was the direct result of the increasing and decreasing periods in precipitation and rain fall. From table 4.3.1 one can see that RF strongly correlated on FMAM and JJAS with 0.64 and 0.49 than the temperature, over Combolcha woreda. The lower temperature correlation with negative sign (-0.14 and -0.29) indicates that the influence of increasing or decreasing temperature in reducing or advancing malaria transmission was less significant since the temperature measure could already exceed the threshold on FMAM and JJAS over Combolcha. Again, this indirectly tell us that the precipitation was primarily responsible for malaria transmission-fluctuation than the temperature. But, when we compare the two seasons independently an increase in temperature on JJAS is relatively significant to favor malaria transmission than on FMAM. The same is true for the decreasing of malaria. In other words, the variability of temperature is slightly correlated to malaria transmission-fluctuation on JJAS than FMAM, relatively.

Table 4.3.1: Coefficient of correlation that shows the malaria occurrence fluctuation and trend in response to climate trend and variability of weather parameters on seasonal time scale.

Station	Corr. Coeff. (r) between Variability of Climate and Malaria Occurrence Trend				
Debark	Climate Variables	Seasons			
		Annual	JJAS	FMAM	ONDJ
	RF	0.12	0.01	0.37	Null
	Temp.	0.45	0.53	0.13	Null
Kombolcha	RF	0.43	0.49	0.64	-0.199
	Temp.	-0.09	-0.14	-0.29	-0.083

The above table reminds us that the change and temporal variability in malaria transmission is related to the change in temperature and rain fall performance. The correlation value with +1 indicates a strong direct relation, -1 a strong relation on the contrary, near to Zero magnitude indicates slight relation and 'Null' is insignificant (very poor relation).

4.3.2 CLIMATE VARIABILITY VERSUS MALARIA EXPECTATION PATTERN OVER DEBARK

The following results showed malaria expectation pattern in relation to the variability of climate parameters time series over Debark.

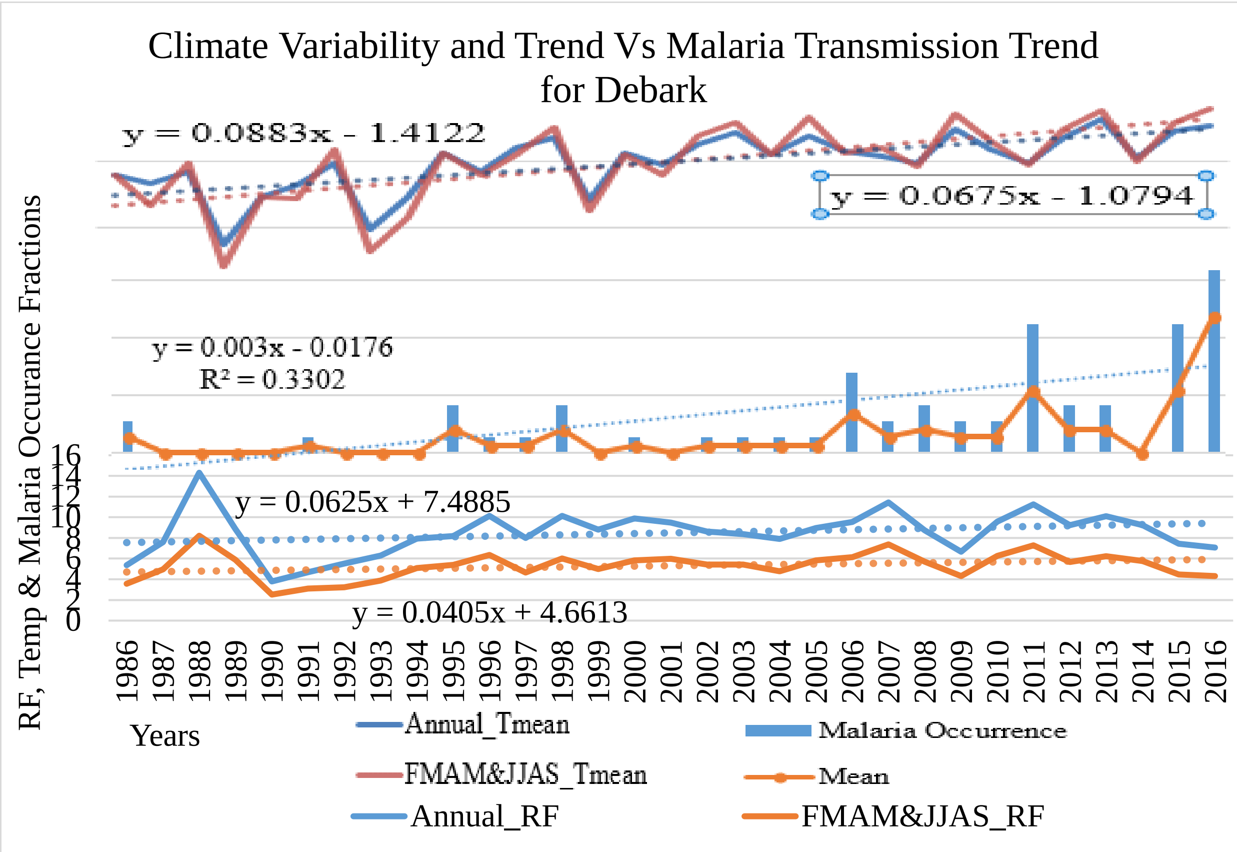

Figure 4.3.2: Trend and variability of precipitation on FMAM_JJAS and ANNUAL, Malaria Expectation Tend and Time series for Debark Woreda and Trend variability of Temperature on FMAM_JJAS and ANNUAL

Unlike to Combolcha woreda, the temperature plays the principal role than the precipitation in controlling the malaria transmission variability and trends, over Debark woreda. As shown on the above graph, the malaria occurrence had strong increasing trend just as the temperature trend pattern. However, the precipitation also had a moderate positive relation and slight increasing trend on FMAM; and a slight correlation and increasing trend on JJAS was identified. In general, over this woreda the temperature is strongly correlated (0.53, on JJAS) and the precipitation is correlated moderately (0.37, on FMAM) in response to malaria occurrence and variability.

4.4 PROJECTION OF CLIMATE IMPACT ON MALARIA TRANSMISSION

In this chapter, first we see the climate projection changes for temperature and precipitation over Great Horn of Africa, extracted from IGAD Climate Prediction and Application Center (ICPAC) for our study areas. Apart from this we also considered the rate of temperature increase with elevation, based on the results obtained from recently published paper, B. Lyon et al., 15 June, 2017. Next, we projected the malaria transmission prospect on the future, over our study areas, based on the climate suitability in view of the future climate scenarios.

4.4.1 PROJECTION OF CLIMATE FOR DIFFERENT SCENARIOS AND DIFFERENT ALTITUDES

The projection of climate change was performed with rough estimate as it was extracted from the secondary data source like ICPAC (IGAD CLIMATE PREDICTION AND APPLICATION CENTER) publications and website and from results of different published papers.

Projection of Climate for Different Scenarios as Extracted From ICPAC

Projection of Climate for different Scenarios were extracted from ICPAC with different regional climate models along with their ensemble average. For both Combolcha and Debark woredas, the mean temperature and rainfall were projected for the scenarios like: 2020, 2030 and 2050. The regional climate models used for this projection were RCM2.6, RCM4.5, and RCM8.5. Finally, for our purpose, the ensemble average was taken which is supposed to minimize an error (Annex B). The same was done for relative humidity qualitatively based on the temperature and precipitation changes expected in future (refer to section 2.1.4 last paragraph).

Elevation-Dependent Temperature Projection on Temporal Base

Here, elevation dependent temperature projection is done for Debark district. This is performed depending on the result obtained from B. Lyon et al., 15 June, 2017. This result brought us with the secondary data (Annex C) which infer the temperature rate with respect to elevation. According to this outcome, for a fixed temperature value (18 ^{o}c) a 31.2meter increase in elevation per decade (10 years) was observed. Based on this, we deduced and extrapolated the height, on future scenarios, over where this fixed temperature value potentially reach at (table 4.4.1). In case of Combolcha woreda, the elevation dependent temperature forecast did not give a sense since the elevation is relatively low and the temperature value under consideration (18 ^{o}c) is already exhibited on previous period (1986-2016) over this altitude. Therefore, we perform this temperature estimate only for Debark woreda.

Table 4.4.1: Elevation dependent temperature projection over Debark woreda

Station	Climate Periods	Elevation Dependent Temperature Projection	
		Altitude	Temperature
Debark	Previous term (1986-2016)	2803.8 meter	18 degree centigrade
	Current mid-term (2020)	2836.3 meter	18 degree centigrade
	Near-term (2030)	2867.6 meter	18 degree centigrade
	middle-term (2050)	2930.0 meter	18 degree centigrade

The fixed, 18.0 ^{o}c, temperature increases with 31.2m height per each decade. Under section 4.2.2.2 (see table 4.2.2.2.h), the mean temperature was detected to reach 2803.8m with magnitude greater than 18.0 ^{o}c. Thus, using this result together with the following evidences the future prospect of malaria transmission was introduced in the next paragraph as follows.

On the upcoming climate periods the temperature just reach at the corresponding heights shown in the table 4.4.1. Thus, starting from the period 2020 the temperature becomes suitable for malaria transmission just at elevation of Debark weather station which is about 2836.0-meter-high above the ground. Again, under section 4.2.2.2 (4.2.2.2.a and 4.2.2.2.4) the precipitation and relative humidity measures already full fill the favorable condition for malaria transmission for several months, most frequently on June, July, August and September. So, with the justification of these data (table 4.4.1, section 4.2.2.2.a and 4.2.2.2.b) there will be incidence of malaria starting from 2020 and afterwards, over such high ground, in Debark woreda. More probably, the months that will be experienced by malaria incidence are anticipated to be June, May and July, in order, since these months contribute to the principal rain fall amount with little variability, even under future climate change in precipitation (Annex B). Again, the temperature is expected to favor malaria occurrence due to the change in air temperature in future on the aforementioned months (see table 4.4.2.1).

4.4.2 FUTURE PROSPECT OF MALARIA TRANSMISSION

The introduction of the future prospect of malaria distribution discussed in the previous section 4.4.1 was based on the data extracted from elevation dependent temperature projection. In addition to the above introduction, in this section again, a tabular demonstration is conducted below to display the future malaria transmission prospect based on another data source generated through the task of future climate change projection. And, this data was gained by extracting from ICPAC climate information sources. Then, similarities and differences of the results obtained by these two approaches about malaria distribution prospect (section 4.4.1 and 4.4.2) are discussed next under this section.

Future Prospect of Malaria Transmission over Debark

Table 4.4.2.1 Future prospect in Malaria Transmission over Debark Woreda

Station	Debark (Altitude=2836.0 m)											
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
T_Forcast_2020	16.4	18.2	19.1	19.6	19.3	18.9	17.4	17.4	17.7	17.3	16.9	17.0
T_Forcast_2030	15.6	17.2	18.1	18.6	18.3	18.2	15.7	15.7	16.0	15.6	15.2	15.3
T_Forcast_2050	15.9	18.3	19.3	19.8	19.4	18.5	18.1	17.6	17.3	15.9	15.5	15.6
RF_Forcast_2020	0.5	1.5	20.0	32.6	110.2	169.6	157.3	168.6	116.1	66.6	3.6	0.5
RF_Forcast_2030	0.7	2.0	21.1	33.7	111.3	170.7	158.4	169.7	117.2	67.7	4.7	0.7
RF_Forcast_2050	1.0	5.5	14.9	27.5	105.1	164.5	152.2	163.5	111.0	77.3	14.3	10.3
RH_Average	41.0	40.8	42.5	48.6	54.0	73.7	86.7	88.3	79.4	62.6	56.5	48.9
RH_Average	50.7	44.9	46.8	53.4	61.0	73.7	86.7	88.3	79.4	77.5	69.9	60.6
RH_Average	50.7	49.4	51.5	60.0	66.0	70.3	86.7	92.7	83.3	77.5	69.9	60.6
	Favorable months for malaria under future prospect of climate change scenarios											
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Previous term(1986-2016	Nil	Nil	Nil	Nil	x	x	x	Nil	Nil	Nil	Nil	Nil
	Nil	Nil	Nil	Nil	x	x	x	Nil	Nil	Nil	Nil	Nil
	Nil	Nil	Nil	Nil	x	x	x	Nil	Nil	Nil	Nil	Nil
Current mid-term(2020)	Nil	Nil	Nil	Nil	x	18.9	x	Nil	Nil	Nil	Nil	Nil
	Nil	Nil	Nil	Nil	x	169.6	x	Nil	Nil	Nil	Nil	Nil
	Nil	Nil	Nil	Nil	x	73.6645	x	Nil	Nil	Nil	Nil	Nil
Near-term(2030)	Nil	Nil	Nil	Nil	18.2	18.2	x	Nil	Nil	Nil	Nil	Nil
	Nil	Nil	Nil	Nil	111.3	170.7	x	Nil	Nil	Nil	Nil	Nil
	Nil	Nil	Nil	Nil	61.0	73.7	x	Nil	Nil	Nil	Nil	Nil
middle-term(2050)	Nil	Nil	Nil	Nil	18.5	18.5	18.1	Nil	Nil	Nil	Nil	Nil
	Nil	Nil	Nil	Nil	105.1	164.5	152.2	Nil	Nil	Nil	Nil	Nil
	Nil	Nil	Nil	Nil	66.0	70.3	86.7	Nil	Nil	Nil	Nil	Nil

The above table 4.4.2.1 denotes Malaria Transmission Prospect over Debark Station; ‘x’ symbol indicates that there is no observation of malaria transmission; the symbol ‘Nil’ represents there was no expectation of a suitable condition for malaria occurrence on the previous period(1986-2016) and no change anticipated in the future; and the table cells with colors and the respective temperature, precipitation and RH values represents the future expectation of malaria incidence event along with the corresponding starting climate period and months.

Thus, as one can observe from the above table that in consequence of the climate change the temperature becomes suitable for malaria transmission on months like February to July. Regarding to the precipitation the monthly amount is greater than 80 mm during the months of May to September, regardless of the climate change effect. Therefore, the transmission of malaria is anticipated to incident on the month of June starting from the near future (2020), over such high altitude where there was no a case before. This result was similar to the one described in the previous section 4.4.1, that tells us about the starting period (2020) of the malaria incidence in Debark woreda at elevation of 2836.0 meter, due to elevation dependent temperature increase.

Next, the number of months favoring for malaria transmission increased by one month (May) just on the period 2030. Once again, the increase of temperature along with the other climate variables let the number of months to increase again by one month (July) on the period 2050. On the other hand, the rest of the months remained unfavorable, for future, for malaria transmission as before. In general, the future climate condition will be suitable for malaria to inhabit over higher and higher elevation in Debark woreda with increased number of months, gradually.

Future Prospect of Malaria Transmission over Combolcha

Similar to Debark woreda, tabular demonstration of future malaria assessment was carried out based on climate factors, as provided in the next table. For the whole climate scenarios (2020, 2030 and 2050) the temperature was found to have a positive impact on future malaria transmission. Whereas, the precipitation is observed in decreasing manner decade to decade in the future on FMAM (Belg season); and it increases on the Bega season (ONDJ), extending number of months, decade to decade. As one can see from the table provided next, earlier to 2016 there were malaria transmission seasons experienced following the rainy seasons (FMAM and JJAS). The most common months associated with malaria occurrence were March, April, August and September; rarely in February, very rarely in July and October months, before the year 2016. And, the months denoted by 'Nil' are those on which the climate totally did not seen to encourage for malaria transmission.

Table 6.2.2: Future prospect in Malaria Transmission over Combolcha Woreda

Station	Combolcha											
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
T_Forcast_2020	19.7	20.8	22.1	22.8	23.7	25.0	23.9	23.1	22.3	20.5	19.3	18.9
T_Forcast_2030	19.4	20.8	22.1	22.8	23.7	24.9	23.8	23.0	22.2	20.2	19.0	18.6
T_Forcast_2050	21.7	23.0	24.3	25.0	25.9	26.9	25.8	25.0	24.2	22.5	21.3	20.9
RF_Forcast_2020	27.9	9.9	49.7	80.3	43.1	29.4	271.9	262.1	104.4	49.6	23.3	22.0
RF_Forcast_2030	55.9	4.9	44.7	75.3	38.1	31.4	273.9	264.1	106.4	81.6	67.0	50.0
RF_Forcast_2050	83.4	9.9	49.7	71.0	43.1	19.4	261.9	252.1	94.4	93.6	80.7	66.0
RH_Average	65	55	55	60	47	37	60	60	60	61	57	61
RH_Average	65	61	61	61	51	40	60	66	63	61	57	61
RH_Average	71	67	67	67	57	46	67	76	72	63	61	66
	Favorable months for malaria under future prospect of climate change scenarios											
	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec
Previous term(1986-2016)	x	rare	>18	>18	Nil	Nil	V.rare	>18	>18	V.rare	x	Nil
	x	rare	>80	>80	Nil	Nil	V.rare	>80	>80	V.rare	x	Nil
	x	rare	>60%	>60%	Nil	Nil	V.rare	>60%	>60%	V.rare	x	Nil
Current mid-term(2020)	x	x	x	22.8	Nil	Nil	23.9	23.1	22.3	V.rare	x	Nil
	x	x	x	80.3	Nil	Nil	271.9	262.1	104.4	V.rare	x	Nil
	x	x	x	60.0	Nil	Nil	60	60	60	V.rare	x	Nil
Near-term(2030)	x	x	x	x	Nil	Nil	23.8	23.0	22.2	20.2	x	Nil
	x	x	x	x	Nil	Nil	273.9	264.1	106.4	81.6	x	Nil
	x	x	x	x	Nil	Nil	60	66	63	61	x	Nil
middle-term(2050)	21.7	x	x	x	Nil	Nil	25.8	25.0	24.2	22.5	19.3	Nil
	83.4	x	x	x	Nil	Nil	261.9	252.1	94.4	93.6	80.7	Nil
	71	x	x	x	Nil	Nil	67	76	60	63	61	Nil

When we see the future condition, the transmission of malaria tends to decrease from the Belg season (FMAM) just after the near future term (2020). This is due to the future forecast for precipitation shows a significant decrease over the indicated season. Whereas on July, the occurrence of the disease transforms from very rare to permanent chance of malaria occurrence starting from the period 2020 to 2050. The same is true on October month except that the incidence of malaria is expected to start on period 2030. Further, on the month of November and January the climate condition will be suitable for malaria transmission such that the disease will incur (experience) these months on the last term (2050). These was due sufficient increase of both the temperature and precipitation on these season (ONDJ), in the future. This climate effect will allow malaria to exist over elongated duration of months over this season; and there will be a seasonal shift in malaria transmission, in consequence. And, during August and September the transmission continuous in future as it was before. The rest of the months persisted in negative impact for malaria transmission. In general, these opposite effects of temperature and rain fall could, in future, rise a decrease (in number of months from FMAM), an increase (on JJAS) and a seasonal shift in malaria transmission (on ONDJ), in Combolcha woreda.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The assessment of the climate showed that the precipitation was suitable for malaria transmission on two seasons (from FMAM to JJAS) in Combolcha woreda, totally. Whereas, in Dekark (below 2,800 m) the precipitation favors for malaria incidence on two seasons (May and JJAS) while only on one season (JJAS) in Debark woreda (>2,800 m). The temperature also was suitable for malaria transmission for several months ranging from February up to October. Whereas, in Debark the temperature was suitable for malaria transmission over lower altitudes (< 2,800 m) on May to September and it was opposing against above this elevation, generally during (1986-2016).

The malaria transmission was common in Combolcha in two seasons before 2001. But, in the period 2002-2008 there was a breakdown/discontinuity in the occurrence of malaria. After, 2008 it re-emerges with lower rate of recurrence on FMAM than JJAS. Apart from this, the malaria transmission season was elongated to the first month of the next season (October), in the year 2015 and 2016. Regarding the relation between climate variability and Semi-Decadal differences, the precipitation found to be the leading factor for the decreasing trend/re-emerging event in malaria transmission on FMAM (0.64 correlation value in climate malaria relationship) and on JJAS (0.49). As a result of the above climate factors the malaria transmission showed a decreasing trend during the period (1986-2016), in Combolcha woreda.

In contrast, in Debark woreda (with elevation below 2,800 m) malaria transmission observed with an increasing trend in consequence of the temperature increase, as a major factor, in general. The temperature was directly related with malaria transmission variability and trend with correlation value 0.53 (JJAS) and 0.37 (FMAM). But, just above the height about 2,800 meter the temperature could not exceed the favorable threshold value (18 ^{o}c) for malaria incidence. Finally, in this climate malaria suitability assessment the altitude (2,800 meter) was determined to be the demarcation point-level above which the disease malaria could not existed in Debark woreda for the period (1986-2016). This result agreed to the feed-back mentioned by the health officials of the woreda on the occasion/juncture of NMA's seasonal climate forecasting meeting held in 2016. Moreover, this result was compared with the results obtained by other similar studies [MARA13 malaria model (Source: Ethiopia-Epi-report-020520)] which used the same logic and method as done in this thesis. Thus, this result could screen out the incidence of malaria just at 2,800 m while it is anticipated at 2,500 m high based on the projection made by the model for the year 2015.

In short, we conclude that the change and variability in temperature of the surrounding was more significant in controlling malaria transmission than the rainfall over relative high grounds (Debark). In another way, the change and variability in precipitation takes the first place in controlling malaria transmission over relative lower elevation areas (Combolcha).

Regarding the future prospect of malaria, the overall effects of temperature and rain fall changes could cause a decrease (in number of months from FMAM), an increase (on JJAS) and a seasonal shift in malaria transmission (on ONDJ), in Combolcha woreda. In the same case, the future climate condition particularly the increasing temperature will be suitable for malaria to inhabit over higher and higher elevation in Debark woreda with increased number of months, gradually.

Generally, we conclude that in the face of climate change malaria is pushing upwards the roof of the theoretical limit that nearly 2,000 m was the elevation beyond which malaria was believed unlikely to exist.

5.2 RECOMMENDATIONS

For relatively higher elevated places, over shorter range of spatial coverage and with complex topography (like in Debark woreda) the gridded data was able to show the actual conditions with high spatial resolution over a given small locality. Therefore, it is recommended to use this data option when and where there is a lack of ability to display the actual facts on the ground due to using the station data for large area coverage.

The procedure developed in a new way in this study and tested for the first time to display the climate malaria suitability information in a tabular form is appropriate for point location than on a map which is better form for the whole of the country. Therefore, this technique is recommended also to be used as supplementary for both small area coverage as well as for the country wide.

Apart from this, the relationship between climate and health (particularly like malaria) can be regarded and used as a climate monitoring tool. Climate monitoring in a sense is that if the nature of the malaria transmission is changed over a certain place one can think that there is a sign of climate change over that place.

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APPENDICES

ANNEX A: STATION DATA

Name	Elevatior	Geogr1	Geogr2	Element	Year	Time	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Combolcl	1857	39.7176	11.0839	PRECIP	1986	09:00	0	32.7	54.9	138.7	49.5	118.2	254.3	336.1	73.5	6.9	0	20.2
Combolcl	1857	39.7176	11.0839	PRECIP	1987	09:00	0	74.8	115.3	39.5	144.8	0	50.1	289.8	39.3	36.2	0	10.4
Combolcl	1857	39.7176	11.0839	PRECIP	1988	09:00	7.3	96.8	32.4	100.6	38.2	45.1	397.2	271.3	170.5	29.7	0	5.6
Combolcl	1857	39.7176	11.0839	PRECIP	1989	09:00	11.8	43.7	116.3	165.2	2.2	18.5	240	249.5	174.1	23.8	0	104.1
Combolcl	1857	39.7176	11.0839	PRECIP	1990	09:00	20.9	99	123.4	116.4	5.1	0	109.9	115.2	211.6	7.9	0	0
Combolcl	1857	39.7176	11.0839	PRECIP	1991	09:00	4	35	95.6	15.4	22	56.4	175.6	204.7	116	26.7	0	34.6
Combolcl	1857	39.7176	11.0839	PRECIP	1992	09:00	82.8	18.4	49.3	137.3	27.2	6.1	174.6	208.2	149.3	82.6	55.3	49
Combolcl	1857	39.7176	11.0839	PRECIP	1993	09:00	46.2	83	37.1	239.9	181	4.7	256.8	155.3	226.6	41.8	0	7.6
Combolcl	1857	39.7176	11.0839	PRECIP	1994	09:00	0	0	53.9	51	86	30.7	436.6	331.6	154.4	2.2	36.8	1.9
Combolcl	1857	39.7176	11.0839	PRECIP	1995	09:00	0	29.5	48	209	79.4	30	284.2	260.5	80.5	30.3	0	44.6
Combolcl	1857	39.7176	11.0839	PRECIP	1996	09:00	48.4	3.4	139.7	133.4	124.8	61.8	164.4	346.9	37.3	8.3	57.2	1.9
Combolcl	1857	39.7176	11.0839	PRECIP	1997	09:00	33.6	0	64	69	13.6	104.2	234.8	216.3	52	154.6	87	0
Combolcl	1857	39.7176	11.0839	PRECIP	1998	09:00	95.4	91.5	36.3	124.6	49.2	2.9	480.2	248.2	114.5	76.5	0	0
Combolcl	1857	39.7176	11.0839	PRECIP	1999	09:00	54.4	3.8	22.7	19	5.4	10.8	374.3	328.4	109.1	121.8	1.7	2
Combolcl	1857	39.7176	11.0839	PRECIP	2000	09:00	0	0	6.2	132.8	70.8	42.3	326.6	359.3	119.3	57.4	58.5	38.3
Combolcl	1857	39.7176	11.0839	PRECIP	2001	09:00	5.1	2.7	139.9	99	42.9	46.8	349.4	235.4	115.3	7.1	0.8	8.9
Combolcl	1857	39.7176	11.0839	PRECIP	2002	09:00	18.1	5.8	58.9	82.1	20.7	10.6	278.5	254.8	86.8	15.4	0	62.2
Combolcl	1857	39.7176	11.0839	PRECIP	2003	09:00	64.7	26	75	80.9	5.8	38.1	208.9	269.4	149.3	0.2	12.9	60.2
Combolcl	1857	39.7176	11.0839	PRECIP	2004	09:00	12.6	11.7	39.7	127.5	14.8	28	239.6	239.4	82.5	66.8	40.1	5.5
Combolcl	1857	39.7176	11.0839	PRECIP	2005	09:00	18.7	4.5	75.8	67	86.4	20.9	342.7	293.9	40.8	17.7	6.7	0
Combolcl	1857	39.7176	11.0839	PRECIP	2006	09:00	8.8	0	121.8	87.1	44.3	14.7	237.5	277.2	144.6	61.9	1.2	6.4
Combolcl	1857	39.7176	11.0839	PRECIP	2007	09:00	40.5	34	52.3	115	14.9	37.1	320.7	175.5	92.3	21.6	6.6	0
Combolcl	1857	39.7176	11.0839	PRECIP	2008	09:00	25.5	0	0	18.1	52.7	29.4	294.9	209.1	68.7	47.3	75.6	0
Combolcl	1857	39.7176	11.0839	PRECIP	2009	09:00	23.6	11.4	17	13.4	6.4	34.6	370.1	320.4	58.1	63.2	11.5	31.6
Combolcl	1857	39.7176	11.0839	PRECIP	2010	09:00	0	31.6	70.7	102.7	107.6	15.9	363.9	107.6	57.9	11.7	15.2	11.6
Combolcl	1857	39.7176	11.0839	PRECIP	2011	09:00	15	0	50.4	25.5	130.9	20.4	278	338.6	90.5	16.6	41.4	0
Combolcl	1857	39.7176	11.0839	PRECIP	2012	09:00	0.3	0	109	177.1	34	50.1	284	261.6	52.9	0.5	0	0.2
Combolcl	1857	39.7176	11.0839	PRECIP	2013	09:00	36.8	0.3	54.2	55.2	40	1.8	336.3	284.9	67.2	132.7	0.6	0
Combolcl	1857	39.7176	11.0839	PRECIP	2014	09:00	1.8	21.7	52.7	55.1	90.9	9.3	307.5	319.5	135.2	192.3	11.4	6
Combolcl	1857	39.7176	11.0839	PRECIP	2015	09:00	13	0	71.1	0	102.2	18.6	42.7	332.8	107.9	12.2	34	14.6
Combolcl	1857	39.7176	11.0839	PRECIP	2016	09:00	21.6	11.3	20.7	155.8	107.7	64.2	276.1	346	119.2	7.6	14	0.6

Name	Elevatior	Geogr1	Geogr2	Element	Year	Time	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Debark	2836	37.8979	13.1421	PRECIP	1986	09:00	0.0	0.0	0.0	0.0	3.0	89.0	225.0	201.0	125.0	0.0	0.0	0.0
Debark	2836	37.8979	13.1421	PRECIP	1987	09:00	0.0	0.0	0.0	0.0	225.0	220.4	95.4	300.1	49.5	18.4	1.3	0.0
Debark	2836	37.8979	13.1421	PRECIP	1988	09:00	0.0	43.6	10.0	49.4	31.9	142.9	752.7	575.0	117.7	239.0	0.2	0.0
Debark	2836	37.8979	13.1421	PRECIP	1989	09:00	0.0	0.0	1.0	0.0	37.0	214.3	732.3	308.1	99.2	0.0	1.0	1.0
Debark	2836	37.8979	13.1421	PRECIP	1988	09:00	2	0	0	0	0	12	163	152	126	0	0	0
Debark	2836	37.8979	13.1421	PRECIP	1989	09:00	0	0	0	12	33	74	168	210	64	0	0.0	0.0
Debark	2836	37.8979	13.1421	PRECIP	1992	09:00	0	0	0	0	18	49	200.4	238	73	26	55.3	1.1
Debark	2836	37.8979	13.1421	PRECIP	1993	09:00	0.7	0.0	5.0	9.0	83.3	96.6	165.0	162.7	176.4	56.2	0.0	0.0
Debark	2836	37.8979	13.1421	PRECIP	1994	09:00	0.0	0.5	0.5	16.3	67.9	160.7	255.1	313.8	100.9	22.5	15.2	0.0
Debark	2836	37.8979	13.1421	PRECIP	1995	09:00	0.0	1.1	19.4	3.7	131.3	113.4	280.2	308.0	114.4	4.0	5.0	2.1
Debark	2836	37.8979	13.1421	PRECIP	1996	09:00	0.0	0.0	23.7	94.9	125.9	319.1	242.5	224.7	111.8	11.5	56.5	4.9
Debark	2836	37.8979	13.1421	PRECIP	1997	09:00	0.0	0.0	14.3	33.2	112.8	97.8	225.0	297.4	55.4	90.9	32.0	0.7
Debark	2836	37.8979	13.1421	PRECIP	1998	09:00	0.2	0.0	9.6	2.9	171.7	162.7	317.9	226.9	192.4	118.8	13.4	0.0
Debark	2836	37.8979	13.1421	PRECIP	1999	09:00	12.7	0.0	0.0	26.3	52.8	91.1	334.4	252.8	141.0	106.6	20.8	18.0
Debark	2836	37.8979	13.1421	PRECIP	2000	09:00	0.0	0.0	0.0	89.3	17.5	167.1	303.8	284.2	189.1	113.5	23.0	0.0
Debark	2836	37.8979	13.1421	PRECIP	2001	09:00	0.0	0.0	20.1	53.8	65.5	154.4	347.6	383.0	50.0	55.9	5.2	3.5
Debark	2836	37.8979	13.1421	PRECIP	2002	09:00	0.0	0.0	15.1	9.4	16.7	155.0	375.7	295.0	108.2	41.0	0.2	19.0
Debark	2836	37.8979	13.1421	PRECIP	2003	09:00	0.0	26.3	2.0	6.0	60.3	217.5	190.4	314.2	158.3	9.1	21.6	0.0
Debark	2836	37.8979	13.1421	PRECIP	2004	09:00	19.2	12.7	6.1	47.0	11.3	174.3	280.0	264.1	65.6	40.5	26.9	0.0
Debark	2836	37.8979	13.1421	PRECIP	2005	09:00	0.0	0.0	35.3	28.0	30.6	130.1	456.6	242.1	124.4	22.2	7.0	0.0
Debark	2836	37.8979	13.1421	PRECIP	2006	09:00	0.8	0.0	7.0	30.3	59.8	122.1	275.0	482.6	128.4	36.0	3.1	1.3
Debark	2836	37.8979	13.1421	PRECIP	2007	09:00	4.1	0.0	1.6	47.0	60.7	359.7	456.8	269.7	130.3	12.2	31.1	0.0
Debark	2836	37.8979	13.1421	PRECIP	2008	09:00	2.6	0.0	0.0	91.3	128.3	120.4	201.1	319.8	163.8	16.4	5.9	0.0
Debark	2836	37.8979	13.1421	PRECIP	2009	09:00	0.0	2.0	22.9	5.8	10.0	89.2	365.6	191.0	89.7	4.0	16.2	5.2
Debark	2836	37.8979	13.1421	PRECIP	2010	09:00	13.7	0.0	22.9	94.6	73.7	181.4	385.1	262.6	106.1	5.7	2.0	0.0
Debark	2836	37.8979	13.1421	PRECIP	2011	09:00	2.5	0.0	31.8	21.7	153.9	95.8	532.0	358.8	117.6	5.0	30.7	0.0
Debark	2836	37.8979	13.1421	PRECIP	2012	09:00	0.0	0.0	1.8	2.0	133.7	149.8	330.4	280.4	124.0	25.2	51.4	11.3
Debark	2836	37.8979	13.1421	PRECIP	2013	09:00	0.0	0.0	29.5	20.5	69.8	146.7	473.0	286.3	96.5	88.8	0.0	0.0
Debark	2836	37.8979	13.1421	PRECIP	2014	09:00	0.0	0.1	78.9	46.1	83.7	108.5	231.5	290.5	201.0	44.1	23.8	0.0
Debark	2836	37.8979	13.1421	PRECIP	2015	09:00	0.0	0.0	25.5	49.1	120.4	84.2	103.5	272.9	145.9	33.8	50.6	5.6
Debark	2843	37.8978	13.1418	PRECIP	2016	09:00	0.0	0.0	20.4	33.0	110.6	170.0	157.7	169.0	116.5	67.0	4.0	0.0

Station	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Debark	**1986**	13.2	14.2	15.5	16.0	16.0	14.2	13.4	12.7	12.6	12.9	12.8	12.8
Debark	**1987**	13.1	14.3	15.3	16.1	14.3	13.2	13.1	12.2	13.0	14.2	13.5	14.9
Debark	**1988**	14.1	13.9	16.0	16.4	15.7	14.3	12.6	13.9	13.7	13.7	10.1	12.5
Debark	**1989**	12.6	13.9	13.9	14.2	14.1	13.1	12.0	12.0	12.1	12.0	12.4	11.9
Debark	**1990**	12.7	13.6	15.3	16.0	16.2	13.8	12.6	12.0	11.9	12.8	11.9	12.1
Debark	**1991**	12.6	13.2	15.2	15.4	15.4	14.3	13.4	12.9	14.0	14.1	13.0	13.8
Debark	**1992**	13.4	14.8	16.6	16.6	16.6	15.0	11.3	12.4	12.3	12.5	11.8	12.2
Debark	**1993**	12.2	13.1	14.1	14.6	15.2	13.9	11.0	12.8	12.6	12.6	12.7	12.7
Debark	**1994**	13.2	13.6	14.6	15.9	15.1	14.0	12.2	12.2	12.7	13.2	13.7	13.5
Debark	**1995**	13.7	14.9	15.3	16.5	16.0	15.2	13.1	13.2	13.2	13.4	13.4	13.5
Debark	**1996**	13.3	15.2	15.4	15.8	14.6	14.2	13.4	13.2	13.5	13.6	13.1	13.1
Debark	**1997**	13.5	14.9	16.0	16.0	14.9	14.6	13.4	13.6	14.8	14.1	14.2	14.3
Debark	**1998**	14.4	15.0	16.4	18.6	15.0	15.7	12.3	12.7	13.2	13.5	12.8	12.7
Debark	**1999**	13.7	15.1	14.9	15.5	14.3	13.1	12.2	12.6	13.1	12.6	12.3	12.5
Debark	**2000**	14.0	14.8	16.9	15.4	15.9	14.4	12.9	13.2	13.0	13.3	13.2	14.0
Debark	**2001**	12.8	13.9	14.7	16.5	16.2	14.0	13.5	12.9	13.4	14.6	13.7	13.9
Debark	**2002**	13.2	15.0	15.4	16.3	17.2	14.8	13.3	12.8	13.7	13.5	13.6	13.1
Debark	**2003**	14.0	15.2	16.3	16.9	17.1	14.1	13.4	13.3	13.3	13.2	13.4	13.1
Debark	**2004**	14.2	14.8	16.0	15.9	16.4	14.1	13.0	13.0	13.3	12.9	13.4	13.1
Debark	**2005**	13.3	16.3	16.0	16.6	16.5	15.0	13.0	13.3	13.4	13.0	12.7	13.0
Debark	**2006**	14.0	15.7	15.6	15.9	15.4	14.8	13.5	13.1	13.4	14.1	13.2	13.2
Debark	**2007**	13.2	15.0	16.4	15.4	16.6	14.2	13.3	13.2	13.1	13.1	13.0	12.8
Debark	**2008**	14.2	14.6	16.3	15.3	15.4	14.6	13.5	13.1	13.4	13.6	13.0	13.2
Debark	**2009**	13.4	15.1	16.0	16.9	16.8	16.2	13.1	13.8	13.8	13.6	13.3	12.9
Debark	**2010**	13.3	14.9	15.5	16.0	16.8	15.2	13.2	13.5	13.8	13.5	13.0	12.9
Debark	**2011**	13.5	14.2	14.7	16.6	15.8	15.2	13.7	13.4	13.6	13.4	13.2	13.2
Debark	**2012**	13.7	15.4	15.8	16.8	16.1	15.0	13.6	13.2	13.8	13.7	13.8	12.8
Debark	**2013**	14.2	15.8	16.1	16.7	16.7	15.2	13.5	13.0	14.6	14.6	14.1	12.9
Debark	**2014**	14.1	14.3	15.1	15.9	15.8	15.1	14.2	13.6	13.8	13.8	13.2	13.0
Debark	**2015**	13.3	15.4	16.1	16.5	15.7	15.0	14.4	13.9	14.4	14.4	13.7	13.3
Debark	**2016**	13.3	15.3	17.4	16.8	15.5	15.1	14.8	14.0	13.3	12.8	12.7	14.6

Station	Element	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Combolc	T_mean|-mo	**1986**	16.85	19.7	19.65	19.85	21.55	22.25	21.25	20.5	19.45	18	17.3	16.9
Combolc	T_mean|-mo	**1987**	17.05	18.75	19.9	19.8	20.35	22.75	23.45	21.3	20.95	19.2	17.85	18
Combolc	T_mean|-mo	**1988**	18.9	19.75	20.4	21	22.1	23.05	21.25	20	19.7	18.05	15.95	16.3
Combolc	T_mean|-mo	**1989**	16.6	18	19.2	18.9	20.75	22.65	22.1	20.85	19.75	18.2	16.9	17.7
Combolc	T_mean|-mo	**1990**	17.2	18.75	19.5	19.9	22.25	23.5	21.75	21.7	20.25	18.1	17.5	16.4
Combolc	T_mean|-mo	**1991**	18.7	19.3	20.1	20.9	21.85	22.7	21.75	21.05	20.05	17.75	16.35	16.95
Combolc	T_mean|-mo	**1992**	17.5	18.6	20	20.5	21.2	22.95	21.75	20.1	19	17.1	16.4	17.45
Combolc	T_mean|-mo	**1993**	17.05	17.35	18.95	19.25	20	21.7	21.5	20.85	19.9	18.4	16.75	15.95
Combolc	T_mean|-mo	**1994**	17	18.75	20.5	21.25	21.5	23.55	20.6	19.85	19.05	16.8	16.5	15.75
Combolc	T_mean|-mo	**1995**	16.75	19.1	19.8	20.25	20.95	22.75	21.35	20.85	19.95	17.75	17	17.4
Combolc	T_mean|-mo	**1996**	17.8	18.8	19.65	20.1	20.3	21.8	21.6	20.75	20.45	17.85	16.55	16.2
Combolc	T_mean|-mo	**1997**	17.3	17.25	20.25	20.15	21.15	21.8	21.45	20.55	20.1	18.6	17.9	16.55
Combolc	T_mean|-mo	**1998**	18.4	19.15	20	21.5	21.15	22.05	21.25	20.6	20.1	18.75	16.15	15.45
Combolc	T_mean|-mo	**1999**	16.75	17.9	19.7	20.75	22.4	23.15	21.05	20.6	20.05	18.1	15.55	15.75
Combolc	T_mean|-mo	**2000**	17	17.5	19.7	20.9	21.35	22.8	21.35	20.15	19.65	18.45	16.6	16.15
Combolc	T_mean|-mo	**2001**	15.75	17.55	19.2	20.25	21.8	23.05	21.05	20.75	19.5	18.8	16.55	16.75
Combolc	T_mean|-mo	**2002**	17.7	18.65	20.15	20.65	22.4	23.3	22.95	21.45	20.2	18.55	17.15	18.35
Combolc	T_mean|-mo	**2003**	17.4	19.5	20.35	20.9	22.2	22.85	21.9	20.9	20.45	17.8	17.15	16.25
Combolc	T_mean|-mo	**2004**	19.1	18	19.35	20.4	21.45	21.8	21.8	21.05	20.05	17.35	17.05	17.6
Combolc	T_mean|-mo	**2005**	18	19.15	20.7	20.95	21.45	22.9	21.5	21.25	20.65	17.8	16.9	15.55
Combolc	T_mean|-mo	**2006**	17.6	19.85	19.95	20.1	21.45	23.1	21.6	21.15	20.2	19.25	17.75	18.4
Combolc	T_mean|-mo	**2007**	17.5	19.4	20.1	20.8	22.45	23.45	21.25	21.2	20.85	18	16.95	16
Combolc	T_mean|-mo	**2008**	17.75	17.75	19.1	20.95	22.8	23.4	22.5	21.2	20.75	18.8	17.1	16.55
Combolc	T_mean|-mo	**2009**	17.6	19.05	20.4	21.4	22.4	24.1	21.8	21.45	21	18.85	17.65	18.45
Combolc	T_mean|-mo	**2010**	18	20.05	19.9	21.8	22.35	23.75	22.15	22.35	20.75	19.3	17.6	16.9
Combolc	T_mean|-mo	**2011**	17.9	18.45	19.05	21.65	21.75	22.75	21.85	21	20.4	18.6	18.3	17.05
Combolc	T_mean|-mo	**2012**	17.6	17.6	19.4	20.35	21.25	22.7	21.8	21.35	21.05	18.25	18.25	17.75
Combolc	T_mean|-mo	**2013**	18.2	18.75	21.35	22.25	22.5	23.8	22.1	20.9	20.75	19.05	18.25	16.15
Combolc	T_mean|-mo	**2014**	17.8	19.65	20.75	21.5	21.6	23.1	22.7	21	20.35	18.6	18.2	16.35
Combolc	T_mean|-mo	**2015**	16.95	18.8	20.15	20.9	22.35	22.9	23.65	21.9	21.2	19.7	18.7	18.6
Combolc	T_mean|-mo	**2016**	19	19.5	22.6	21.95	21.9	22.9	22.1	21.3	21	19.2	17.4	16.5

Name	Elevation	Geogr1	Geogr2	Element	Year	Time	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Debark	2836	37.8979	13.14213	RELHUM	1986	12:00	47	46	35	58	62	67	83	76	74	56	56	44
Debark	2836	37.8979	13.14213	RELHUM	1987	12:00	42.5	44	36.5	42	57	70	86.5	86.5	72.5	58.5	59	47
Debark	2836	37.8979	13.14213	RELHUM	1988	12:00	39	37	45	46.5	57.5	68	82.5	85	74.5	60.5	51	53
Debark	2836	37.8979	13.14213	RELHUM	1989	12	42	39	48	54.5	69.5	74	79	85.5	73	57.5	58.5	52
Debark	2836	37.8979	13.14213	RELHUM	1990	12	42	53.5	46	45.5	63	70	82	79	68.5	66.5	64.5	53
Debark	2836	37.8979	13.14213	RELHUM	1991	12	41	37	38	56	50.5	70	81	84.5	76.5	74.5	59	51
Debark	2836	37.8979	13.14213	RELHUM	1992	12	40	36	39	45	55	67	76	77	78	62	65	53
Debark	2836	37.8979	13.14213	RELHUM	1993	12:00	43	37	31	56	60	72	80	75	79	63	60	39
Debark	2836	37.8979	13.14213	RELHUM	1994	15:00	35	31	40	39	58	71	81	79	77	62	50	50
Debark	2836	37.8979	13.14213	RELHUM	1995	12:00	33	35	41	43	53	65	80	83	69	51	45	45
Debark	2836	37.8979	13.14213	RELHUM	1996	12:00	38	38	44	49	68	74	77	83	71	52	52	46
Debark	2836	37.8979	13.14213	RELHUM	1997	12:00	38	49	39	42	57	67	79	74	62	56	56	44
Debark	2836	37.8979	13.14213	RELHUM	1998	12:00	39	30	42	33	60	70	78	79	67	60	54	45
Debark	2836	37.8979	13.14213	RELHUM	1999	12:00	38	31	39	42	55	70	83	82	74	71	46	51
Debark	2836	37.8979	13.14213	RELHUM	2000	12:00	37	31	35	51	49	70	79	82	75	69	57	43
Debark	2836	37.8979	13.14213	RELHUM	2001	12:00	36	37	40	39	47	67	77	81	68	64	47	40
Debark	2836	37.8979	13.14213	RELHUM	2002	12:00	42	36	39	35	37	60	74	77	68	53	46	45
Debark	2836	37.8979	13.14213	RELHUM	2003	12:00	33	35	34	33	37	62	77	80	74	49	42	38
Debark	2836	37.8979	13.14213	RELHUM	2004	12:00	35	33	31	42	34	60	75	75	69	52	49	43
Debark	2836	37.8979	13.14213	RELHUM	2005	12:00	36	29	39	37	37	58	80	76	71	55	45	33
Debark	2836	37.8979	13.14213	RELHUM	2006	12:00	30	31	33	39	57	60	72	79	71	58	51	48
Debark	2836	37.8979	13.14213	RELHUM	2007	12:00	42	34	34	44	45	66	80	78	70	49	45	31
Debark	2836	37.8979	13.14213	RELHUM	2008	12	42.5	44	36.5	42	57	70	86.5	86.5	72.5	58.5	59	47
Debark	2836	37.8979	13.14213	RELHUM	2009	12	39	37	45	46.5	57.5	68	82.5	85	74.5	60.5	51	53
Debark	2836	37.8979	13.14213	RELHUM	2010	12	42	39	48	54.5	69.5	74	79	85.5	73	57.5	58.5	52
Debark	2836	37.8979	13.14213	RELHUM	2011	12	42	53.5	46	45.5	63	70	82	79	68.5	66.5	64.5	53
Debark	2836	37.8979	13.14213	RELHUM	2012	12	41	37	38	56	50.5	70	81	84.5	76.5	74.5	59	51
Debark	2836	37.8979	13.14213	RELHUM	2013	12	40	36	39	45	55	67	76	77	78	62	65	53
Debark	2843	37.89775	13.14175	RELHUM	2014	12:00	41	34	38	43	52	59	74	80	72	57	49	38
Debark	2843	37.89775	13.14175	RELHUM	2015	12:00	30	23	30	32	53	56	61	76	70	54	51	53
Debark	2836	37.8979	13.14213	RELHUM	2016	12:00	43	38	30	33	62	64	80	78	70	58	53	50

Name	**Elevation**	**Geogr1**	**Geogr2**	**Element**	**Year**	**Time**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Combolch	1857	39.71763	11.0839	RELHUM	1986	12:00	40	55		55	42	44	50	57	54	50	42	51
Combolch	1857	39.71763	11.0839	RELHUM	1987	12:00	51	42	61	55	54	34	36	53	49	49	38	44
Combolch	1857	39.71763	11.0839	RELHUM	1988	12:00	54	56	43	52	37	37	57	62	61	54	43	45
Combolch	1857	39.71763	11.0839	RELHUM	1989	12:00	54	54	55	60	37	31	44	53	60	49	42	74
Combolch	1857	39.71763	11.0839	RELHUM	1990	12:00	55	72	59	54	35	30	47	46	54	41	44	40
Combolch	1857	39.71763	11.0839	RELHUM	1991	12:00	51	59	61	45	40	34	55	54	52	48	42	48
Combolch	1857	39.71763	11.0839	RELHUM	1992	12:00	65	69	59	51	41	32	46	59	58	58	58	62
Combolch	1857	39.71763	11.0839	RELHUM	1993	12:00	64	66	45	65	57	37	49	50	56	54	46	45
Combolch	1857	39.71763	11.0839	RELHUM	1994	12:00	42	43	54	44	40	35	61	63	51	46	57	54
Combolch	1857	39.71763	11.0839	RELHUM	1995	12:00	50	63	59	63	50	43	53	60	57	51	48	59
Combolch	1857	39.71763	11.0839	RELHUM	1996	12:00	66	52	62	57	57	42	55	57	52	41	50	47
Combolch	1857	39.71763	11.0839	RELHUM	1997	12:00	61	42	53	51	38	46	49	52	49	52	57	49
Combolch	1857	39.71763	11.0839	RELHUM	1998	12:00	66	64	58	47	45	28	55	64	61	53	41	38
Combolch	1857	39.71763	11.0839	RELHUM	1999	12:00	50	36	52	37	33	30	53	56	58	57	44	50
Combolch	1857	39.71763	11.0839	RELHUM	2000	12:00	45	37	39	39	42	32	53	59	54	58	56	57
Combolch	1857	39.71763	11.0839	RELHUM	2001	12:00	58	46	57	41	41	32	53	63	53	49	43	44
Combolch	1857	39.71763	11.0839	RELHUM	2002	12:00	59	45	52	47	37	32	41	53	55	40	41	62
Combolch	1857	39.71763	11.0839	RELHUM	2003	12:00	58	48	50	52	31	34	51	59	56	44	46	50
Combolch	1857	39.71763	11.0839	RELHUM	2004	12:00	51	48	40	56	32	35	45	52	53	51	49	56
Combolch	1857	39.71763	11.0839	RELHUM	2005	12:00	55	41	53	46	50	36	54	55	53	49	45	40
Combolch	1857	39.71763	11.0839	RELHUM	2006	12:00	51	54	51	58	42	32	53	59	55	48	49	58
Combolch	1857	39.71763	11.0839	RELHUM	2007	12:00	65	54	46	52	39	38	56	55	56	47	49	45
Combolch	1857	39.71763	11.0839	RELHUM	2008	12:00	50	45	29	43	39	34	46	55	55	49	53	47
Combolch	1857	39.71763	11.0839	RELHUM	2009	12:00	52	45	43	40	31	31	54	56	49	48	40	59
Combolch	1857	39.71763	11.0839	RELHUM	2010	12:00	50	52	53	51	50	32	51	63	58	46	47	50
Combolch	1857	39.71763	11.0839	RELHUM	2011	12:00	56	40	47	43	48	31	52	60	51	45	59	48
Combolch	1857	39.71763	11.0839	RELHUM	2012	12:00	48	40	41	56	45	35	53	55	51	43	44	47
Combolch	1857	39.71763	11.0839	RELHUM	2013	12:00	50	43	47	47	40	34	54	63	51	53	53	47
Combolch	1857	39.71763	11.0839	RELHUM	2014	12:00	53	57	50	46	50	34	43	59	55	68	52	49
Combolch	1857	39.71763	11.0839	RELHUM	2015	12:00	51	42	40	34	46	37	34	56	56	65	59	60
Combolch	1857	39.71763	11.0839	RELHUM	2016	12:00	64	48	44	66	48	38	54	57	56	61	47	46

ANNEX B: FUTURE CLIMATE CHANGE PROJECTIONS OF TEMPERATURE AND RAIN FALL FOR DEBARK AND KOMBOLCHA STATIONS

Table B.1: Estimate of Climate change data extracted from ICPAC climate prediction

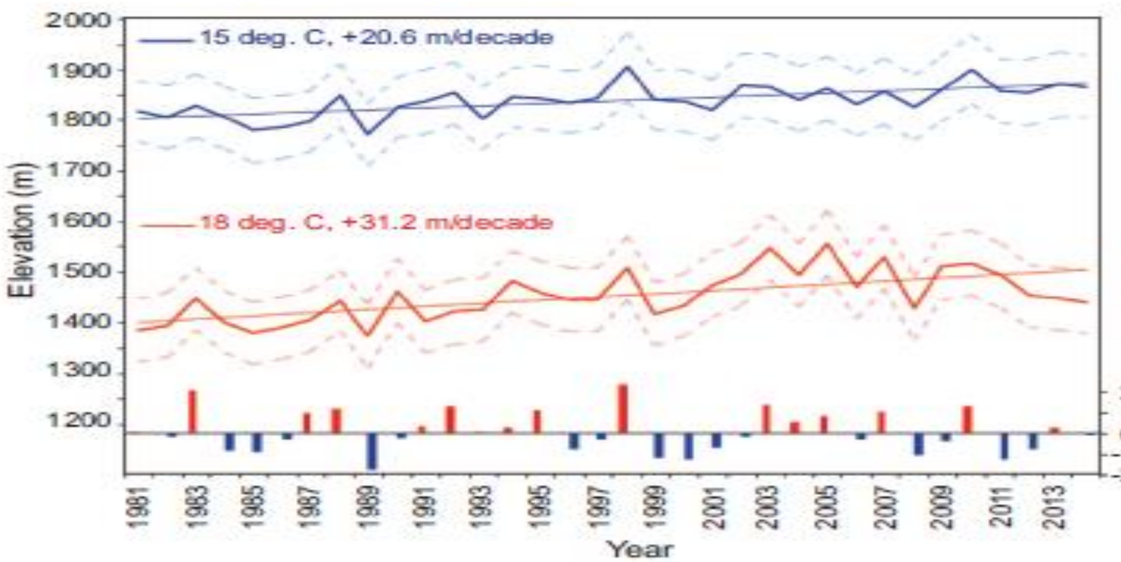
			Seasons											
Station	Climate parameters	Climate Models	Annual			FMAM			JJAS			ONDJ		
			Climate Scenarios			Climate Scenarios			Climate Scenarios			Climate Scenarios		
			1	2	3	1	2	3	1	2	3	1	2	3
Debark	RF (mm)	RCP2.6	0	-7	-17	-35	-35	-17	0	-7	-35	35	63	10
		RCP4.5	-17	-5	-17	-17	-5	-25	-17	-5	-17	-17	-5	50
		RCP8.5	-7	0	-5	-17	-50	-25	0	0	-5	-35	20	63
		Average	-8	-6	-13	-23	-30	-22	-6	-6	-22	-17	26	41
	Average Temp.(ºC)	RCP2.6	2.2	1.7	1.3	2.2	1.9	2.0	2.2	2.0	1.7	1.7	1.5	1.5
		RCP4.5	1.9	1.9	2.2	1.8	2.0	2.2	2.0	2.0	2.0	1.3	1.5	1.8
		RCP8.5	2.0	2.0	2.2	2.0	2.0	2.3	2.2	2.2	2.3	1.8	1.9	2.2
		Average	2.1	1.9	1.9	2.0	2.0	2.1	2.2	2.1	2.0	2.0	1.7	1.9
Kombolcha	RF (mm)	RCP2.6	0	-5	-10	-25	-25	-10	0	-5	-25	45	70	17
		RCP4.5	-10	0	-10	-10	0	-17	-10	-0	-10	-10	0	60
		RCP8.5	-5	5	0	-10	-35	-17	5	5	0	-20	30	70
		Average	-5	0	-6	-15	-20	-15	-2.0	0	-12	5	33	49
	Average Temp.	RCP2.6	2.2	1.7	1.3	2.2	1.9	2.0	2.2	2.0	1.7	1.7	1.5	1.5
		RCP4.5	1.9	1.9	2.2	1.8	2.0	2.2	2.0	2.0	2.0	1.3	1.5	1.8
		RCP8.5	2.0	2.0	2.2	2.0	2.0	2.3	2.2	2.2	2.3	1.8	1.9	2.2
		Average	2.0	1.9	1.9	2.1	2.1	2.2	2.1	2.0	1.9	2.1	1.8	2.0

The climate scenario 1, 2, and 3 represents scenarios of 2020, 2030, and 2050, respectively.

Table B.2: Elevation-Dependent Projection of Temperature on different Climate Scenarios

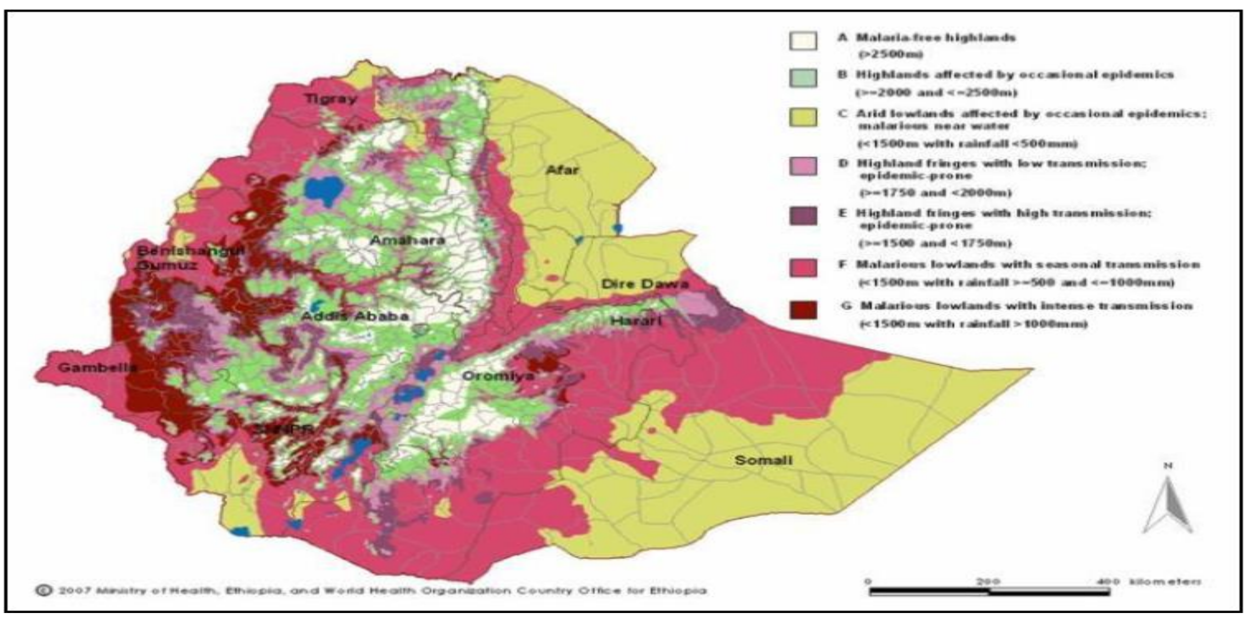
Temperature	18 ºC	18 ºC	18 ºC	18 ºC
Decades (yrs)	Past (2005-2014)	Present (2015-2019)	2020-2030	2030-2050
Elevations(m)	< 2803.8	>= 2803.8	>= 2836.0	>=2897.4

ANNEX C: SECONDARY DATA



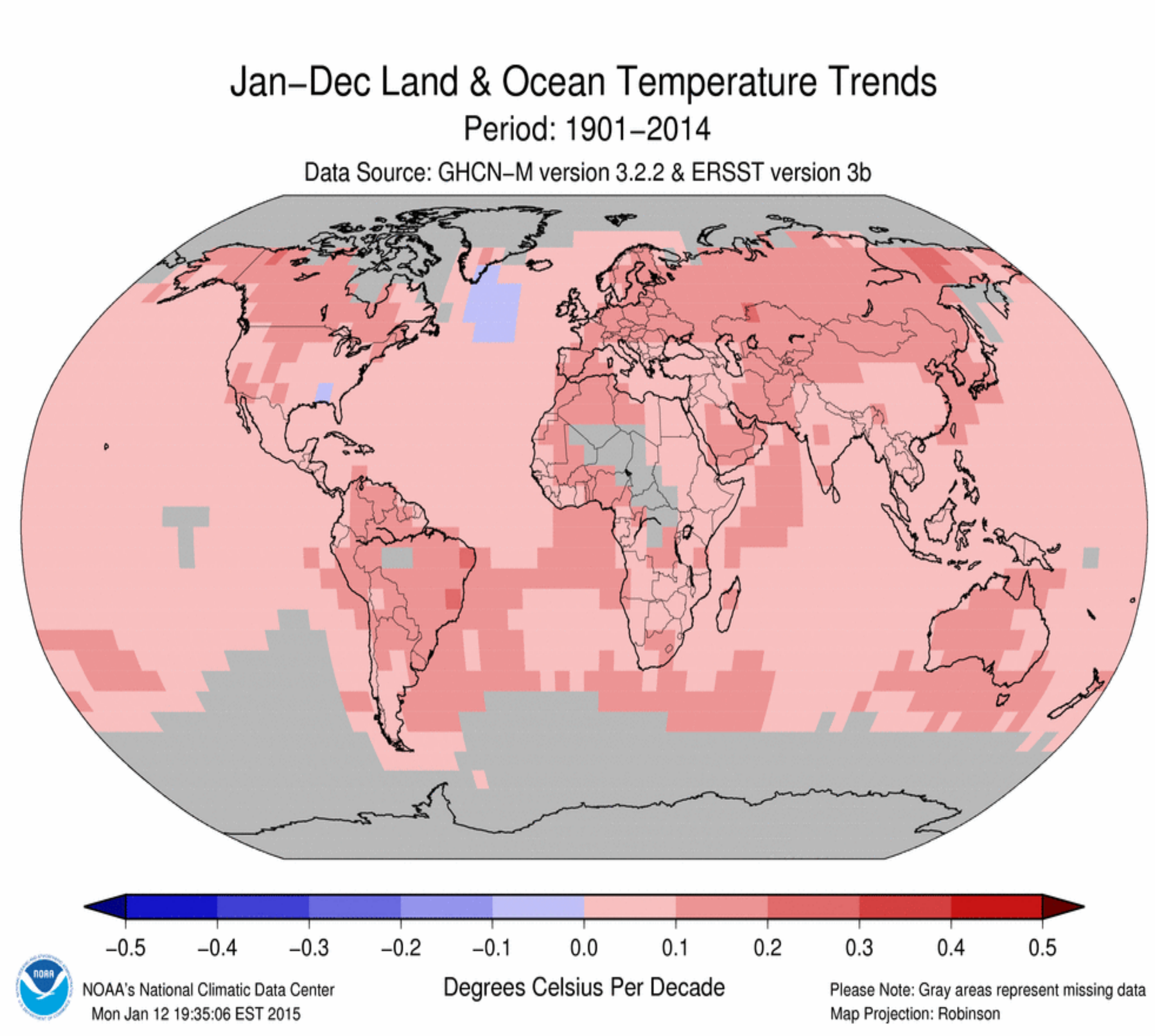
Source: Environ. Res. Lett. 12 (2017) 064015, [B. Lyon et al., 15 June, 2017]

Figure C.1: Time series (1981–2014) of the mean elevation above mean sea level (m) where the dekade (10 d) average temperature in a given calendar year never exceeds 18 °C (15 °C) is indicated by the solid red (blue) line.



Source: Ethiopia-Epi-report-020520

Figure C.2: Maps of malaria risk in Ethiopia: climate fuzzy suitability for stable malaria risk developed by MARA13; and predicted risks of malaria prevalence up to the year 2015.



Data Source: GHCN-M version 3.2.2 &ERSST VERSION 3B

Figure C.3: Jan-Dec Land and Ocean Temperature Trends During the Period 1901-2014